CREATIVE ENGINEERING DESIGN

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Abstract

Our time appreciates rationality and logic. We think that these qualities are the only functions in science, and together with carefully gathered knowledge those are the most powerful tools in our technical, economical and social progress. But in the case of design work we realize that these tools are quite dull and we have got into a tight place with them. All remarkable creative inventions are rational and logical, when we look at them afterwards, but in order to find something new in front of us more powerful tools are needed.

The tools are sensations and intuition. Because of their subconscious nature, we often do not take them seriously in our scientific work. All practical designers, however, are acquainted with those subconscious functions of the mind and they use them in those phases of work, when we have to go ahead of present knowledge. The rationality and logic of the new results are checked afterwards and, in a favourable case, a new piece of science is attained.

The first part of this book discusses the irrational functions of our mind. On the basis of the experience in engineering design it suggests some practical methods for controlling of them. All design work is based on knowledge of materials and components, but this knowledge must be alive especially in our subconscious mind.

The second part of this book gives some examples of the nature of knowledge usable in creative engineering design. (Only in printed version)

Keywords: creativity, creative engineering, intuition, subconscious activity

Preface

The idea of this book is based on two astonishments in my life. After finishing my studies in the Technical University of Helsinki in the late fifties I started working as an engineering designer in a big machine workshop in Southern Finland. My first astonishment was, that after two decades no one of my student comrades was drawing machines, except me. And still I loved that job in developing new structures.

In the beginning of eighties the systematic methods in engineering design were adopted with big enthusiasm by managers, teachers and engineers. My second astonishment was, that it was impossible for me to adopt those methods. I could not see any flaws in them, but the taste was bad. I simply hated them. Then I noticed, that no one of the engineering designers I knew liked them eather. Furthermore, the teachers of engineering design, who promoted these methods, did not have any practical experience in real design work. They had worked as leaders and managers in design work, but they had not drawn anything with their own hands for a very long time.

In 1982 I became a teacher of engineering design in University of Oulu. Since then I have been contemplating, what happened in the process of practical design work, when a new solution came up in my mind. I have noticed, that the process is completely irrational and subconscious, but there are means to promote it. These means are common to all practising designers and here I try to describe them.

I want to thank one of my students, *Cormac Power*, who turned my clumsy translation into English. I also have to thank my daughter, *Anu Tuomaala*. As a young practising engineering designer she has served as a guinea pig for my ideas. She has also helped me in problems of English language.

Oulu, 17th November, 1998
Jorma Tuomaala

1. Introduction

Motto I:

Pictura est laicorum literatura

Pictures are the literature of the laity
(Umberto Eco: Il nome della rosa)

Since the time of the antiquity the western man has appreciated logical thinking. Perhaps, just the adoption of this way of thinking developed human society, culture and sciences to the greatness we admire in the antiquity. The progress was not allowed to continue and the development stagnated in the "dark" Middle Ages. A desire towards the culture and the thinking of the antiquity continued to live in the protected world of the monasteries until it suddenly broke out in the form of the Renaissance in the 16th century.

The Latin sentence by Umberto Eco I used as the motto of this book, is based on his book describing monastery life at the end of the 14th century. Logical thinking revealed itself in sciences, but above all it was seen in the use of written words. People could not read, therefore they had to be undeveloped and nothing scientifically valuable was seen in their thinking. Only by looking at pictures did their thinking seem to get away from their everyday life.

A despising attitude towards pictures remained a prominent attitude. Science was still based on logical thinking described by words, and by admiring it, the preceding ideas and images were ignored. During the present century and even earlier the technique in the form of concrete machines has revolutionised our everyday life, and still we consider, that machine inventions are based barely on scientific mechanics and economical needs. According to this point of view we teach our future engineers and even engineering design we have described using strictly logical systematics. This way of teaching is producing successful engineering designers less frequently because the engineering design is essentially reading and producing pictures and images. The stressing of systematics and the lack of training in pictorial thinking have led to the fact that concrete design work, especially drafting, is carried out by designers having a lower technical education.

The enormous development of electronics and physics has further increased the appreciation of sharp logic. Because modern products based on this technology have brought the technical services nearer the man, these sciences have got admiration and value without criticism. At the same time there is a tendency to underestimate drafting and to think that engineering design has already reached its maturity and that its value is now in decline. The mechanical machines have been considered to represent the polluting chimney industry and they are attributed with all the disadvantages due to industry, whereas electronics and automation represent the new unpolluting communication society. It has not been realised that this is a false image without any basis.

It is true that electronics and automation have made good progress during the last decades with ever increasing speed. However, they represent only one part in techniques, which is able to act only together with other parts. We have invented fine automatic supervising systems, unoccupied manufacturing systems etc. but the basis of every function is still on a reliable machine. Even when choosing a new car the important point is not the amount of new technology in it, but the fact, that the car runs on its four wheels with reliability, comfort, and economy, as before.

The designers of automation have found such vast markets and plenty of applications that they do not find any need for developing engineering. On the contrary, because of their sophisticated component systems, they think all the mechanics needed is already available. It is easy to establish business in the electronics industry and the build-up time of products is short. This suits the economists perfectly well and they, on their part, think the whole progress of society in future is based on electronics and data processing. We speak about a new gallant data and service society that does not need stagnating lines of business. The universal depression and unemployment of the nineties prove the error of this view.

Manufacturing and engineering design are still needed. Only by using machines the inevitable work can be accomplished even in a communication society. New machines have to be designed to fulfil the needs of the customers, as before. In doing so we have to consider the influence of ever grow area, not only electronics and automation.

Motto II:

Omnes enim causae effectuum naturalium dantur per lineas, angulos et figuras. Aliter enim impossibile est scire propter quid in illis.

The ground for all natural effects is expressed in lines, angles and figures. Otherwise, you see, it is impossible to realise, why they exist.

(Umberto Eco: Il nome della rosa)

Machines are composed of physical structures determined by forms and dimensions. Only the simplest parts are determined exclusively by technical mechanics. In most cases a component has several forms organised in a way that when dimensioning one form it will effect all other forms. An engineering designer handles a large amount of dimensions when drafting a single detail. The whole machine is composed of several jointed and co-operating details. The machine, however, has to accomplish its clearly determined duty.

The engineering designer gathers plenty of experiences of several functional structures during his career. Those structures are frequently useful in many tasks, hence the design work is gaining efficiency and security. There are structures and their features in such huge amounts that it is impossible to manage them all in one's memory. There have been attempts to build selection systems based on functions, but their operation in the design of a new machine is often poor and also frequently misleading. The personally gathered knowledge of structures cannot be substituted by any data storage.

Creativity is needed in the creation of everything new. The design engineers try to intensify their work using logic and systematic methods. They are useful and even necessary, of course, but still the new solutions seem to pop up into mind out of something unknown. This pop up could be called **an intuitive flash.**

Artists often tend to underestimate logical and systematic thinking. Nevertheless, literature, to some extent, and especially music have attempted to profit from the use of systematics and different theories. As a result of this, music, to some extent, has developed into so-called modern music which is often hard to understand.

The ideas produced intuitively seem to be, despite all arguments, usually of the best quality. That arouses the question: should one mainly seek to use intuition along with the systematics in mechanical engineering and

a) *can one then still define the time needed to find a solution?*

b) *can one consider the intuitive solution as an optimum?*

c) *does the time used for solving a problem affect the quality?*

d) *is it possible to lead the intuitive process?*

First, I will discuss how one might use subconscious thinking together with conscious thinking in the process of designing. The approach is entirely fictive on the part of the subconscious mind but I have tried to make a hypothetical model of its presumed function that, I hope, will increase the understanding of the process and even to be of use in practical designing work.

In the following text I will attempt to handle the intuitive process and the possibilities of its controlled use based on my own experiences as a mechanical engineering designer. I will first talk about it from a drawing designer's point of view, not from the point of view of a design activity manager. My study is completely one-sided because there are plenty of texts available discussing the systematics of engineering design. In the first part of the book (in chapters 1...4) I will examine, in what ways one might use one's subconscious and conscious mind together in one's design work. The study is completely fictitious as far as the subconscious mind is concerned. But I have tried to develop a model of it, that I hope, will increase the understanding of the function and may even be useful in practice. I also have tried to expand the discussion to the area of literature and performing art, because I see engineering design, as well, as a deeply human activity giving one all the possibilities to grow as a person. I will try to build a generally applicable **method of intuitive creative work**.

In chapters 5..7 of the first part I will transfer the method of intuitive creative work into engineering design. By using some examples I will show the practical flow of the process. In one example I will analyse a work performed using a systematic design method and I will study it once again, using the intuitive method. I will also describe the gathering of and the function of design teams. Then I will discuss transferring knowledge using a diffuse process. The organisation of a company will be studied from the designer's point of view. In this connection, especially the use of knowledge diffusion is kept in mind as a tool of integrating a company's resources.

At the end of the first part (chapter 8) the designer's personal growth will be discussed. In some examples I will describe the formation of my own basic knowledge used in some inventions.

In the second part I will discuss the intuitive knowledge of a designer, concerning various structures. This knowledge is an essential basis for all engineering design. And when the designer understands the birth mechanism of knowledge in his mind it makes his growth as a designer faster. In this part I will concentrate only on some structures in order to define the techniques available.

The second part is included int the printed book, which can be ordered from University of Oulu.

2. Human Information Processing

Figure 2.1 shows the human body structure as a scheme. Uppermost is consciousness i.e. that part of our brain function where our conscious thinking and understanding is situated. Since it is the only area of our mind we recognise as being awake we often think it is all there is to it. The conscious memory seems to be limited in size and it's content is changed according to time and situation. When our conscious memory changes its content, the former content is forgotten. The lost content is very difficult to take up again but when the situation needs it, it suddenly appears!

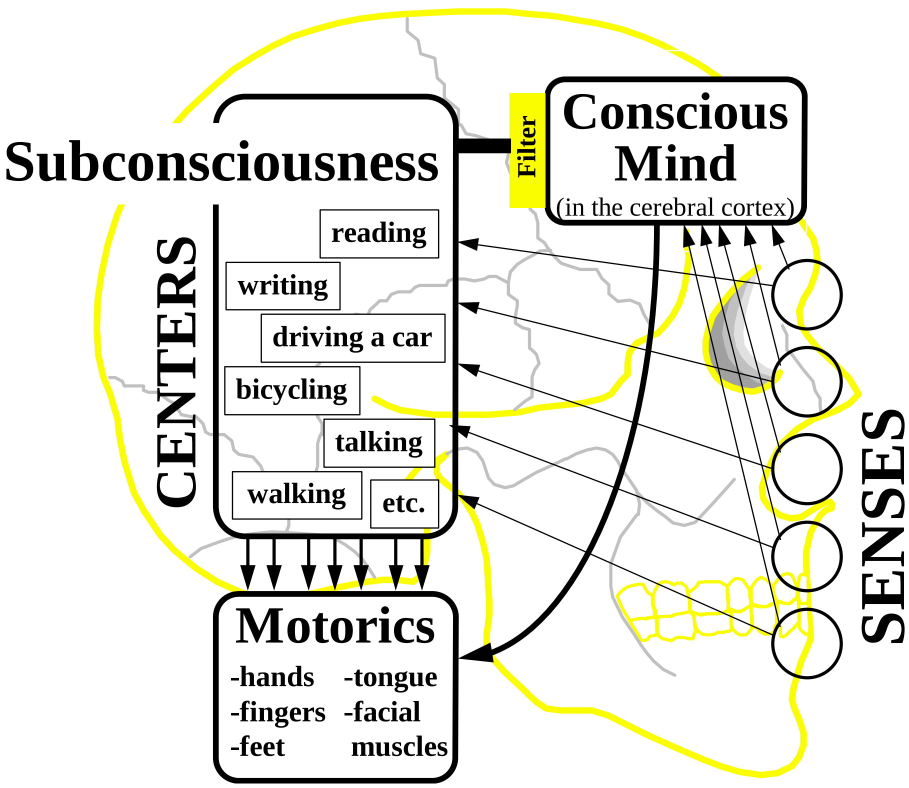

Figure 2.1 A system of human functions

Our conscious thinking is connected to our five senses and to the motorics of our body. The motorics consists of moving muscles and the linked support structure (skeleton) they use. With our senses we perceive events around us and also partly in ourselves, make a conscious decision in our mind and possibly order our motorics to act.

A closer look at the previous action shows that our senses also transfer information to our subconscious mind which also gives orders to the motorics. The subconscious mind can operate very actively when the reaction speed needed exceeds the capacity of the conscious mind. This happens for instance when we suddenly slip and still are able control our falling by changing our posture or grabbing a support, etc. From the action we have nothing in our conscious memory, so the action has had no connection with our conscious mind.

The conscious and subconscious minds are connected, through a filter. Thus we can't see the content of our subconscious mind and we can't read its memory. A man simply has no means to consciously puncture the filter. The filter is like a layer of sand; penetration is impossible from top to bottom, but from bottom to top it is easy. When the situation requires it, we are able to use the subconscious memory to its full extent, but only in relation to the specific problem. This phenomenon is extremely interesting and important. Its operation and our ability to control it might be one of the most important qualifications for creativity.

The structure of our subconscious mind is unknown. We can assume, that there are some kind of knowledge or operation centers, where everything, we ever have learned, is stored. Those centers are among other things, reading and writing, and perhaps all the operations we have learned by experience.

- *The conscious mind is the operative center of our thinking, but it's capacity and especially memory are limited. The subconscious mind has an unlimited memory and it's content we can benefit from like punching upwards through the layer of sand. The punching take place on the area of needed knowledge and the need triggers the punching. The essential matter in creative work is the ability to trigger that connection.*

2.1 Brains and the Conscious Mind

Brains hold the interpretation of the human mind, thinking and the senses. Their capacity in terms of the computer world is according to some estimates about 10^{14} bytes.[1] A computer this large has hardly been constructed. The senses can transfer information 10^9 bytes/sec which means that the brain would be filled with sensory perceptions in 10^5 seconds, i.e. in twenty-four hours. On the other hand the conscious mind can treat at most 100 bytes/sec. If our brain would work constantly and would use each information storing space only once, going through all of our brain would take about 30,000 years!

Human work in a group is considered to be very efficient. However, a group can treat information only about 3...4 bytes/sec. This is due to the slowness of our languages as a means of communication. If co-operation in the group is going on long enough, the major part of communication will be, however, wordless and it will result in an outstanding growth in efficiency .

One should give a few examples of the speed of information that exceeds that of communication with words. When we see a Greyhound bus, for instance, we know it is a Greyhound faster than anybody can say the word Greyhound. We recognise the colours and the shape we have perceived as visual information. But eventhough we recognise the bus, how many of us can tell its colours or describe the shape? The in-

[1] Based on Matti Bergström´s newspaper articles.

formation has been registered straight into our subconscious mind but not into our conscious mind, since it is not needed there.

In the 1940's the 0.5 W resistors used in electronics were identified with numbers. When the diameter of a resistor was about 3 mm and the length about 20 mm, it was very hard to find the right one from a group of different resistors, since one had to roll them around to see the numbers. In the next decade the resistors became smaller and they were identified with rings of different colours. The rings started from one end of the resistor, with brown symbolising the number one, red two, orange three, yellow four etc. A value was given with a precision of two numbers, so for example the first two rings indicated numbers 2 and 2 = 22. The third ring indicated the exponent of 10, so the combination of red+red+orange = 22000 ohms = $22 \cdot 10^3$ ohms. The fourth silver ring was wider than the others and indicated the precision of the value, 10%. Based on this, it was easy to see from which end to start reading the rings.

This code seems complicated but as a surprise to everybody it was extremely fast to read once one remembered the combination of colours and numbers. Even if in a heap of hundreds of resistors there were all the possible alternatives and only one 470 kilo-ohm resistor, it would only take a few seconds to find it!

It seems that eventhough we have developed a fine system of number identification into our subconscious mind, we do have even better pre-processors to identify colour combinations. If it is not of genetical inheritance an explanation may be that we can not separate the identification of numbers from the use of words and this process takes time. We interpret the resistor value first as a colour combination and search for this combination, not for the value. Exactly in the same way we identified the Greyhound bus as a familiar bus, not a Greyhound bus in particular.

When quartz watches became popular, many people thought that the digital displays would become common at the expense of hands. Nevertheless the popularity of digital watches sank and they are now sold at a discount. Almost all the watches still have hands although the movements are quartz operated. Only doormen prefer digital displays.

Looking at the time is a program deep down in our subconscious. When we are hurrying to catch a train and take a look at our watch, we do not look at what time it is. Just a quick look tells us whether we should go faster or not. If you ask a person who has just briefly looked at his watch what time is it ?, he shall have to look at it again in order to tell you the time. If the watch had had a digital display, one should have made a calculation to decide whether to go faster. A doorman makes constant notes of departure and arrival times. For him a digital display is of help, he does not need to figure out the time in numbers.

It's not possible to use the brain to its full capacity during a life time, at least not consciously. One can learn languages one after another and there is no problems to find space in our memory for them. On the other hand, the enormous power of our senses indicates, that we use only a very small part of the information produced by them. We must have some kind of pre-processing system for data being able to strike out all unnecessary information. With our sense of sight this pre-processing takes place on the retina of our eyes.

When we look at the scene of city life, we are only interested in certain architectural details, street life, traffic, etc. Women are normally interested in clothing. So, we program our senses to realise data for certain purposes and especially by looking at the scene we only realise a diminishing part of all the data which our eyes are really seeing. If we photograph the scene and look at the pictures later, we are going to see plenty of new interesting details, situations in groups of people, decoration in buildings etc. In so doing we make the tourist trip once again!

The conscious mind has a memory in which to store information and what to glance through. The memory can contain the plan for the day and the events in the past. The antique philosophers or actually the sophists began to play with the cause and the effect of making fun of the people listening to them. Using plain conscious arguments they guided people's thinking into situations completely opposite to common sense. This was the beginning of logical thinking.

Logical thinking means that in all our perceptions and thinking we attempt to see causal connections and use them in interpreting problems and in planning the future.

The whole western culture is significantly based on the tradition of logical thinking. Eventhough the Japanese are feared for their superiority in scientifical and economical planning, they themselves envy the western people for their logical abilities. One can not learn logical thinking in one or two generations.

The merit for the birth and growth of science can be given to logic. Perceptions become interpretations and further conclusions that lead to the search for new information. Everything that has been perceived as true is being compared to the previous knowledge and in case they are alike the new information is added to the old as a completion. A continuos concern for the world of science is to guard the validity of science. Logic thus has a very emphasised meaning.

Logical thinking further produces ever more complicated thinking structures, theories, hypotheses, various methods for handling information, etc. Science for the sake of science was first born in the form of geometry which gradually developed into mathematics, "the purest" of sciences.

The popularity of logic reached its peak during the age of enlightenment when everything that could not be proved logically or scientifically was abandoned. Eventhough they went too far in this, the effect was a purifying one. The century of romanticism that followed produced more valuable things than anything before or after. Still science continued its development faster and faster.

Logical thinking burdens our conscious mind. The logical processing of thoughts demands more and more space and our conscious mind has its limits. It is like a worktable from which things tend to fall down when it is overloaded. One has to rely more and more on registered information and to limit the information used in the logical processing. Sadly examples of this do exist in the scientific world. It is called empty research in Finnish and means that it is research that actually serves no purpose and brings nothing new or valuable.

On the other hand science can increase the handling capacity of our conscious mind. When we thoroughly understand the processes, we can omit the conscious thinking of it and use it as a **function**.

Mathematics is filled with these functions whose meaning we do not think about at all. We integrate, derive and calculate by inputting the results of complicated formulas into a calculator without thinking about their principals. When we add and subtract we still fully understand what we do. But when we calculate the bending of a beam we set aside the whole discussion. Then when we move on to more complicated statistic processes or processes concerning the strength of materials (e.g. FEM) and solve them with computers we are on such a high level that it can be dangerous.

The competence of a scientist is evaluated based on his critical view of sources. He should not use existing processes or functions without questioning their range of applicability and competence in that field. Also an ordinary engineer uses the same functions but can not or has not enough time to check the basis of these functions. How can we then rely on the results of his work?

This problem is becoming worse and worse all the time. When the requirements of work become greater we can not handle our work without treating it as if from a **higher level**, with the help of existing functions. This is due to the limitations of our conscious mind. Then the details deep down get dim and there may be some changes in their range of applicability that the highly developed process can not take into consideration. These changes can be in the use of materials, manufacturing processes, in the pollution regulations etc.[2]

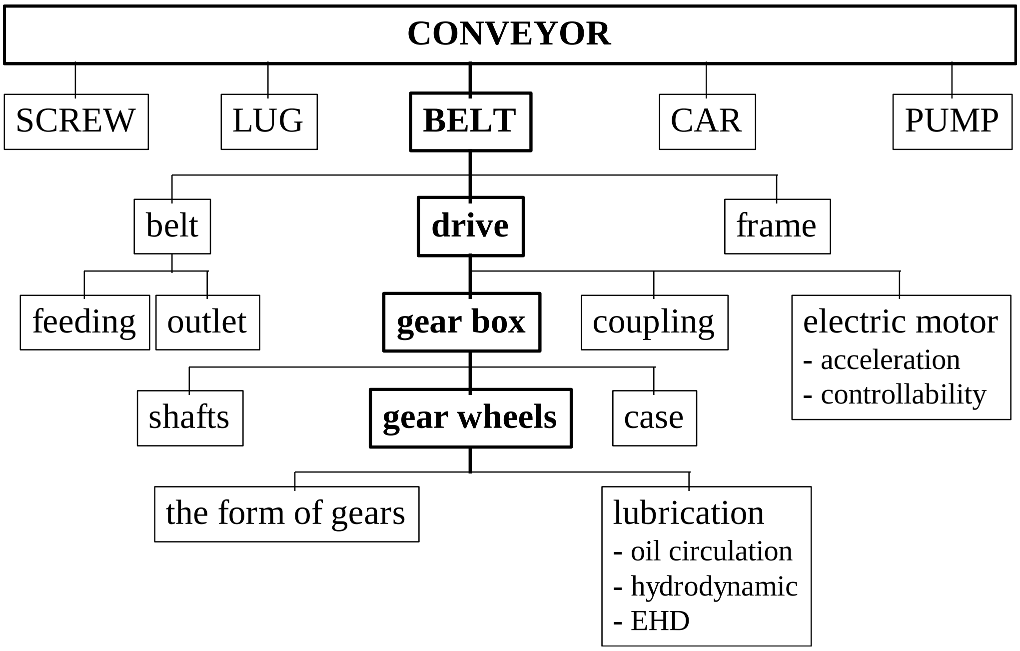

Figure 2.2 Example of the various layers of conscious thinking

Let us assume that figure 2.2 represents the design of a plant. We need a conveyor between different groups of machines. When we contemplate the entirety we only talk about the conveyor and maybe even draw it using a wide line. It may be that the project leader never thinks about it more precisely.

The designer, however, has to choose between different types of conveyors and the draftsman has to find a form for it. Still in most cases it is sufficient that we only work in these higher levels. If we nevertheless have to design the united action of these groups of machines under all possible circumstances, it may be required to descend deeper and deeper to the alternatives and also to think about the lubrication conditions of different types of gears to be sure of the complete suitability of the structure.

[2] The connection between a shaft and a hub requires an appropriate tightness. A standardized tolerance and fitting system has been created so that it would not be necessary to always calculate and think about the fitting. For each hub connection there are recommended fittings. The shaft for an electric motor is standardized to a tolerance of k6. Manufacturing technique has developed from manual lathes to machining centers. Of course these centers fulfil the given requirements but they do them so that the hub fittings are mostly too loose. Faults have been made for decades but the standard has not been corrected. The engineers do not even recognize the problem!

If we continuously forget the basic principles of structures we can not use them quickly when needed. Should any changes occur in the basis they escape our attention and we lose our ability to profit from them.

- *The interpretation of observations as a combination of colours or forms is much faster than via words or written marks. The transfer of observations into our consciousness is guided by an eliminating program, striking out the unessential part of the data.*
- *The limited capacity of the conscious mind compels us to use functions (formula of bending, for instance) instead of the details. It can use whole programs (like FEM) without paying attention to the internal structures of them. In creative work it is necessary to be able to wander in this hierarchy from the upper level (functions and formulas) down, even to the smallest details.*

2.2 The Subconscious Mind

In figure 2.1 we see a big box underneath our conscious mind; the subconscious mind. There is a passage there from the conscious mind, closed by a filter. The passages from the senses and motorics to the subconscious mind, on the other hand, are similar to the ones that lead to the conscious mind.

We can assume that the subconscious mind is a huge storage area of our brain capacity eventhough our conscious mind does not reach there unhindered. There is practically a limitless memory that can not be run through. What we forget from the conscious mind does not return. But in some appropriate connection it can pop up into our mind. The filter has let it through.

When we get old and our conscious mind has lots of blank moments we can remember some childhood events like yesterday. In between there has been decades of oblivion. It may yet be good that the filter is efficient in between. There is too much subconscious information for it to be treated consciously. Furthermore some of it may be traumatic and we could not bear having all the events of our life at hand. So the filter is like an intermediary information processor whose manoeuvring skill is one of the essential questions in creativity.

In order to understand the actions of the subconscious mind let us look at some ordinary events where the part of the subconscious mind is obvious.

2.2.1 Dreams

Eventhough we believe in science, logic and our own intelligence and believe that everything can be, in the end, explained rationally, there are some phenomena that does not work as they should. We see dreams that have no rational explanations.[3]

[3] Alex F.Osborne tells us that in his youth he once fainted on his way to the dinner table. However he had not reached the ground when he returned to consciousness. This fainting only lasted a few seconds but he saw a dream during it and it took a few thousand words to describe the dream.

It seems that the dreams rush into our minds as sporadic heaps very quickly but also vanish easily straight away. Usually we do not remember anything of our dreams next morning unless we wake up in the middle of them and go through them in our mind. If our conscious mind does not treat our dreams straight after we wake up and we fall asleep, it may be that we only have a vague feeling of what the dream was.

Our dreams are not completely accidental. They reflect the day's events and mentally intensive work especially, gives them content. Dreams have an importance in creative work since the solution to a long-term problem can come forth in a dream. Then it would be a pity to waste them. That explains why many people who do creative work have paper and pencil always next to there bed.

There are personal differences in the meanings of dreams. Some people never get mature solutions in them but then during the slow awakening in the morning the solution may easily flash into the conscious mind.

2.2.2 EUREKA!

When we concentrate on finding a solution to a problem we examine the available information critically and analytically. When this is not enough we make experiments and observations in the field of the problem and receive more information by analysing the results of these experiments. When we add this information to experience we should have a solution. Sometimes this works but often we have to continue working week after week with no solution in sight.

Then during a moment of relaxation, on a walk, in sauna, shaving - anywhere - the solution may flash clearly into our mind eventhough we were not contemplating it at that moment. This is called the **eureka** phenomenon.[4]

2.2.3 Subconscious Action

When we take a closer look at our own actions we notice that they are more or less automatic. Farthest from our control is probably the action of our heart that we can affect only with long-term physical exercising or unhealthy living habits. Another continuos automatic action is breathing that we can however control in many ways.

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[4] The king of Syracuse Hieron II had ordered a new golden crown from his court goldsmith. The crown was grand but the king heard a rumour that the goldsmith had cheated him and taken some of the gold and replaced it with cheaper silver. Archimedes, cousin of the king, a court scientist and army engineer was assigned to find out whether this rumour was truthful or not.

The task was simple in principle since Archimedes knew that the specific gravity of gold would be less if there were some silver in the alloy. The colour of the crown however did not show any signs of silver alloy. He thus needed to only determine the specific gravity of the metal used in the crown. The known weighing methods were precise enough to weigh the crown but since the crown was so complicated its volume was impossible to determine accurately enough.

Tired out by the hopelessness of the task Archimedes went to the public baths. Just as he stepped to the water he got an idea and shouted the famous EUREKA! He ran home without any clothing, through the city to check his idea by an experimentation. He had realized that if he weighed the crown also under the water he could calculate the exact volume and specific gravity of the crown from the difference of the weights.

Even to walk we have learned as a child. In the beginning we had to concentrate on it and the result was to say the least unstable. Later on it became a function to which we need not pay any attention. The action of walking is started from higher level as an objective to proceed in a certain direction. Even when we walk on rough terrain, where it is difficult to go, we can concentrate on other things and our feet still find their way. Thus the information from our sense of sight to the part of motorics called the feet goes through the subconscious mind without giving any information to the conscious mind.

Some subconscious actions are connected with both physical and mental processes. For a child it is hard to learn to speak. For an adult speaking is a deep subconscious process. Lowest is the formation of sounds which is difficult to change once it has been established. Especially those with defective speech know it well. They have no organic reason for this but it can take months to learn to pronounce the letter "s" correctly. On the other hand one should notice how the actors can amazingly control their speech both in the formation of sounds and even in the colour of their voice.

When we move to a higher level speech includes words. Words are symbols that have been assigned a meaning in general practice. Choosing the words does not, however, require any conscious control, only a certain need to express oneself is needed and the words come spontaneously.

Some people seem to talk all the time. One gets the impression that all the thinking they do while awake comes out immediately as talk. They can continue for hours!

Our tongue is very skilful in eating. When we chew our jaws develop a pressing force of tens of kilos which for the tongue would mean becoming handicapped if it were to get between the teeth. Yet it moves actively in the mouth pushing food between the teeth and hardly ever is bitten. We need not think about this action consciously at all. When one tooth is pulled away our tongue moves all the day feeling the empty space. We notice this consciously but do not notice that the tongue also learns to avoid this empty space in moving the food. Even just removing tartar makes the tongue restless for the rest of the day.

2.2.4 Subconscious Learning

From the subconscious actions we have already mentioned we can come to the following conclusions:

a) *Subconscious action is faster and more accurate than conscious action.*

b) *In subconscious actions the senses are read directly and the motorics are controlled directly without the help of conscious mind.*

c) *When it comes to the use of energy subconscious action is economical.*

d) *All subconscious action, has once been learned consciously. Learning has been difficult and changing once learned is very hard to do at an older age.*

Can one then learn subconscious actions as an adult and are they of any use? All the examples have described routines learned in early childhood. A good example is riding a bicycle. Let us assume that we have a talented grown-up person who has an academic technical education but has never seen a bicycle before. He reads a description of a bicycle and the instructions for the functions needed to use a bicycle for riding.[5]

Then when he tries to ride a bicycle he can't do it even if he had studied the description for days without being able to try it in use. It would probably take a grown-up days to learn how to ride sufficiently.

When you teach the same skill to a five-year-old boy it is useless to read him the description on which riding is based. He knows himself that he has to pedal but you have to say over and over again that he should turn the front wheel towards the side to which the bicycle tends to fall. Then you have to run for a long time keeping the bicycle upright.

It often becomes that you run with the boy (and the bicycle) a whole day and there are no signs of learning. The child is finally sad and tired - and then suddenly! When disappointment has dampened his determination and he gives up concentrating on steering he is suddenly upright. After this there is not enough road for him, the bicycle goes to all possible directions, but he does not fall down.

Sometimes the boy does not learn to ride during the first day and goes to bed sad and crying. In one case a little boy woke up early in the morning and howled at his father that now I know it, I saw a dream of how to do it. Then he rushed out, took his bicycle and rode without difficulties.[6]

From the foregone passage we can draw the following conclusions:

a) *The exact defining and description of a task to learn does not help learning. On the contrary, it may make it more difficult.*

b) *In some cases learning without physical contact to the task is impossible.*

c) *Learning occurs when we get the insight. This is purely a subconscious process.*

d) *A subconscious insight does not come when we consciously try to force it forward. It chooses, without exceptions, a moment when we have eased off our attention from the problem.*

e) *In difficult tasks a subconscious insight also takes time. In any case it takes a lot of foregoing conscious work. Without work done to solve the problem there will be no insight.*

f) *It can possibly be assumed that all learning requires a subconscious insight. It may be that we can not learn anything purely based on our conscious mind.*

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[5] A bicycle is a device that consists of two wheels on the same plane one behind the other. The wheels are connected to each other with a frame so that the front wheel can turn. On top of the frame is a seat and in the lower part there are pedals. The pedals rotate the sprocket which operates the back wheel. The front wheel is turned with a handle bar, on which the rider seated on the seat, can also lean.

When the rider sits on the seat and rides straight forward the gravity center formed by his own mass and the mass of the bicycle is situated on the vertical plane going through both contact points of the wheels on the ground. Riding is possible as long as the gravity center stays on that plane.

Since the condition is unstable the system tends to incline with an accelerating velocity. Then the rider turns the front wheel so that the movement gets a curved course. This curvature together with the velocity is regulated by a steering movement so that the transversal acceleration achieved can compensate the tilting moment and return to the state of equilibrium.

[6] Told by his father.

Riding a bicycle is learned at the age of 5 or 6. It can be said that, at that age we are children and these kinds of insights are possible only for children. In any case it has been seen that the best results in learning music and languages have been achieved when the children have been made to imitate their teachers with no specific rules, no grammar and no instructions on how to use one's hands (Suzuki and suggestopedic methods). There is time for them, too, but only after the basic insight has been achieved.

We learn to drive a car at the age of 17 or 18, i.e. we are more or less adults. In that, too, the beginning is hard and it takes an insight to use the steering wheel. On my behalf I remember my first attempt to drive a car at the age of 15. My brother and I were both allowed to drive about one kilometre. I started and it was really difficult to keep the car on the road. I grabbed the steering wheel and turned it back and forth fast. The same thing happened to my brother. After him I asked for a retry, i.e. after 5 minutes and now I could keep the car on the road with no difficulties. Of course I daren't drive fast, but the car reached 50 km/h for an instant.[7]

When we then get our driver's license it takes a long time before there are no shocks on the road. Especially on narrow crooked village roads somebody who comes toward us from over a hill can frighten us weak. Driving during a rush hour can stress us so much that we squeeze the steering wheel unnecessarily. Driving is real work! Then after thousands of kilometres there is no need to pay attention to how to drive and we do not even get shocked when we see an elk, we just react faster than we can think.

We are trained to drive a car in our youth when the learning is still easy. According to the commonly accepted opinion it will be more difficult to learn to drive the car after the middle age. It really seems to be, that our ability to learn has diminished. Totally, however, it has not vanished or this opinion even may be completely wrong. An older man is in almost every case used to having confidence in his subconscious processes. He doesn't remember, how much time and effort was needed for their maturing.

When a driver has past his first million kilometres in his late middle ages he certainly is in trouble, if he changes his car to a van. From drivers seat it is impossible to see backward on the right side. While entering the junction of a street and by turning to the right even the mirror does not help to see the cyclist entering the same junction on a track parallel to the van. To avoid an accident he has first to turn 90 degrees and then stop to look through the right window to see the path of cyclists. In one year he learns subconsciously to watch the cyclist's track in such an early phase that, if there is space available, he can turn to the right without stopping. He has not realised this checking at all! Only when no interval in the flow of cyclists is available, does his consciousness awake to act.

This necessary subconscious process for van and truck drivers, takes about one year to learn at the age of fifty. The time is the same needed for learning to drive in one's youth. Perhaps the only difference is, that the older man has lulled himself in the use of reliable subconscious processes. He will be disturbed, if there is not any to use. The new processes to learn will not come so often as in the youth. The temptation to use only old processes is big and learning new ones is a startling matter. Even today many old professors shrink away from working with computers. They are present everywhere, but even simple word processing is terrifying for

[7] The car was, by the way, Chevrolet Master de Luxe from 1938, six cylinders, 85 bhp. Funny how one still remembers the **important** things!

them. It's easy to give old age as the excuse, but the reason is more cowardice or comfortability.

Some people don't relax when driving. They don't like it and they will be tired after visiting a neighbouring town 100 km away. They never will be professional drivers, because for the professionals it is no problem to drive even 2000 km without rest. There really are big differences among people to base the action on the subconscious. The following will make a judgement by examples:

a) *It takes practical training to learn more complicated combinations of skills. An essential part of the effect of practical training is the insighted into the recording of movements into the subconscious mind.*

b) *The action under the control of the subconscious mind is, when needed, much faster and always more accurate than the one controlled by the conscious mind.*

c) *Having one insight is not enough, we have to get an insight of all the details separately.*

d) *When the whole idea is ready the action is started by a command from a higher level. Otherwise it is fully automatic and one can free oneself from it to think about other things. This wholeness only comes about after years of practice.*

e) *A fully automatic subconscious action uses the senses so that the conscious mind does not read them at all. In this way the action is faster and more accurate than the conscious one. It seems that supervising the use of time is more efficient sub-consciously than consciously.*

We can follow the subconscious reading of senses mentioned in paragraph e) by following the behaviour of a driver. He may look at the person next to him in the eyes for quite a long time without causing any danger. If he were told to close his eyes for the same time while driving, it would be much harder to succeed.

2.2.5 Solving a Problem in the Subconscious Mind

How then does an insight arise? According to the foregone discussion it is obvious that in all insights it is a question of an action in the subconscious mind. With the information we have now it is not possible to understand fully what takes place in the subconscious mind. It is not either easy to study it since we cannot glance through it. It might nevertheless be useful to introduce a model that can help to explain the phenomena as far as possible.

The information may be in the subconscious mind in the form of short element. The elements may be connected to each other and form nets. A net represents a more complicated active connection, an insight, figure 2.3.

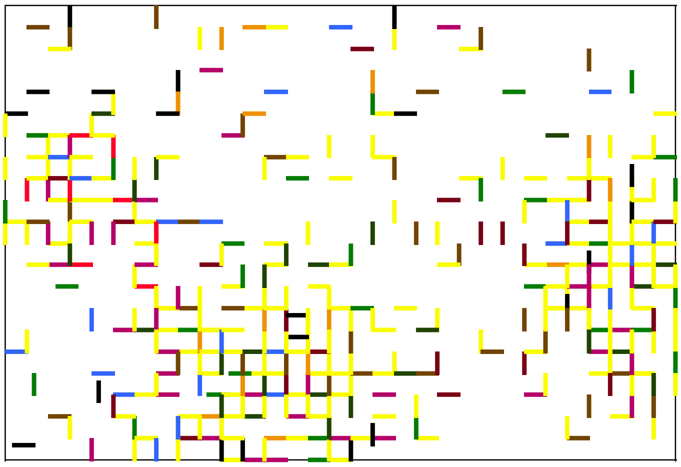

Figure 2.3 Partly chained elements of information in the subconscious mind

If we let the visible sides of the square matrix represent an information connection from one corner of a square to another one. Then these short parts of lines could represent a really "**short**" information cell, for instance about the tendency of a ball to roll on an inclined plane, that a stone is heavy or that water is mobile. These information elements connect easily to one another in different associations when an insight takes place. When we realise the inclination of a plane, already we have a small insight is that water can run downward on an inclined plane. The weight of a stone we realise, has a striking force when it comes to a sudden halt etc. An inclination is as easily connected with the rolling of a stone which also includes information about rotational movement. A sudden halt includes information about acceleration. This information comes, not as mathematical information, but as practical experience when throwing a stone or when it falls on our toes.

Hence, the joining of sides to one another produces an insight. The larger an entity the net is, the larger the insighted entity is. The nets are not, however, stiff and the elements used in them, i.e. insighted elements, can also be easily copied to another net in connection with other problems.

When we strive to solve a problem it is necessary to create a tension according to which the information elements tend to orientate themselves to form a net and thus form an insighted solution. The tension is formed by **defining an objective and developing a will** to achieve it. The more carefully an objective is defined and its necessity is accepted the stronger the tension will be.

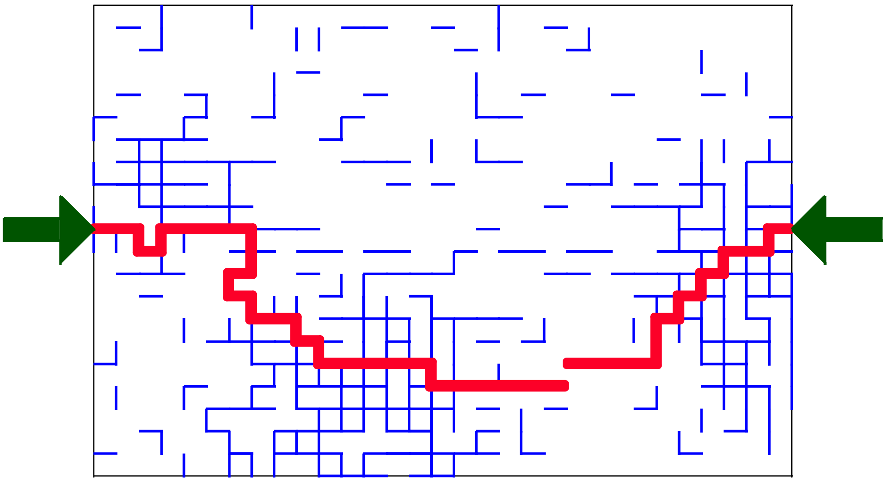

Figure 2.4 The necessity tension is directed at the subconscious mind

The arrows pointing at the sides of the set of squares describe the necessity tension. The tension interval is usually considerably longer than the existing chains in the subconscious mind. On the other hand experience forms long chains that can be used quickly.

The tension attempts to turn the elements towards its direction. It also tries to move them to empty spaces, find analogical connections from existing chains and copy them into appropriate places. In this way a connection between the endpoints of the tension starts to build up and the problem begins to be solved. When this connection is achieved there is a pleasant relaxation of the suspense, i.e. an insight. It is a very pleasing experience and always surprises when it comes at an unexpected moment.

The information elements exist in our subconscious normally and we are able to execute most of our duties based on them alone. Even experienced people, to say nothing of youngsters and kids, can not always find elements enough, or find those which are not completely suitable. In this case the tension, being too strong, will produce a forced and unmature solution. In the extreme case it may lead to panic as a result.[8]

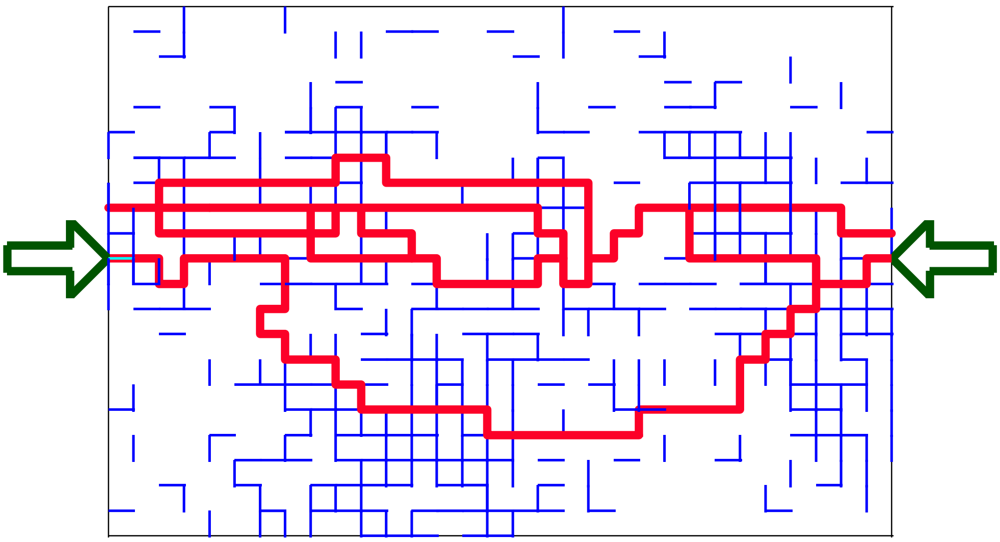

Figure 2.5 Insight is completed

We can complete our information matrix by introducing new knowledge into it. Doing so we must be aware, that the new knowledge must be learned deep in our subconscious. Otherwise it is not useful. This preconceives that we use a convenient handling of data, a conscious analysing and/or a testing in practice.

To form a connection, i.e. to get an insight, takes work and time. An energetic logical work however prevents the connection of information elements so a momentary relaxation of logic is needed. A low tension can not bring about a connection quickly and thus the net has to be completed by gathering and forming information. The results of this logical work is the transfer, via insights to the subconscious mind to build a connection. In demanding tasks many information thickets have to be built on the route, so called **heuristic points**.

[8] My brother told a story about a collision, where two cars driving in the same direction damaged each other mildly. They stopped and stopped the traffic on the street. A young (women) driver coming behind them should have braked strongly to stop her car in time, but instead of it she put her hands on her eyes and collided with the former cars.

- *A heuristic point is a thicket of information comprised by studying and drawing a detail, that possibly belongs to the whole insight. The point can be widened and tightened but it will never be combined deliberately to anything.*

A low tension requires more information gathering and with this gathering the work usually starts. The closer we come to a dead-line the higher the tension gets and thus, the probability of an insight. If it is an emergency situation the tension rises extremely high instantly. An insight takes place immediately using existing routes. This kind of a situation can take place for instance when we lose the control of a car on a slippery road. If there is no suitable route the result is panic and hard braking.

Maintaining a sufficiently low tension is thus useful. Nevertheless, there sometimes seems to be problems in creating it. Impatience can increase the tension, too high and the solution comes immaturely. We should also pay attention to the quality of the tension. A human ego tends to become too important and then creative work becomes useless, in Finnish we call it "carrying out oneself". We should then have a moment of relaxation at that point. Lots of columnists worry about the coming dead-lines and nevertheless the story is finished at the last moment. All the designers know that if the work has to be finished next week it will be finished on Friday evening of that last week. If there is half a year time to do it, it will be finished the evening of the due date.

Creating the suitable tension often encounters problems. If the task is completely new and it has no familiar details, the tension will not grow. In this case we can help it by starting the search for information in some casual point. In this way we establish the first heuristic point, which is able to awake the tension. If the experience in the area of the task is rich, then a solution can be found easily without any real progress. We must learn to identify situations like that and the tension can be suppress with new heuristic points or with a logical analysis.

In figure 2.5 lots of connections have already been formed. This represents a situation when the solution has been carried out in practice many times and enough experience has been achieved. A multiple route indicates the applicability of the solution to various demands. In use it could for instance mean that a young driver can start driving his car faster, he would not be scared numb in usually startling situations.

Using the subconscious mind as a main processor in solving problems is called **an intuitive solution of a problem**. It can quite reliably be timed to the right moment, since coming closer to the dead-line raises the necessity tension needed. Of course a design work does not get done only by waiting for an insight, a lot of routine work like making documents is also needed. It is also useless to wait for an insight if its premises are not there - one has to acquire enough information about the field concerned and analyse it.

It is typical of intuitive problem solving that the direction of the necessity tension is sensed well. With new information complete heuristic points can be built along this route at any place. When the time comes these points will touch each other. The **systematic problem solving** that has been considered as an opposite to the intuitive one presumes that the solving points are always constructed in a logical connection to one another, advancing in the right direction, of course. The points are being constructed fully before moving to the next one. When we then can not be sure of the quality of these partial solutions we try to build various parallel routes straight from the beginning and build the final route (=solution) by combining these partial routes in an optimal way.

- *The subconscious mind is living it's own life outside our conscious mind taking care of routine duties and using all of our senses. The conscious connection to the present activity in the subconscious mind is varying in width and depth. It also may be totally absent. In dreams the connection to our subconsciousness has no conscious guiding or interpretation.*
- *Subconscious action is more precise, faster and more economical than conscious action. Even very complicated knowledge and action centers are formed in the subconscious mind. The formation of centers also presumes learning through physical action. The learning takes time and tension provided by the conscious mind.*
- *The action of the subconscious knowledge center will be activated without a conscious order. The subconscious mind is also able to send information to the conscious mind activated by a situation.*

2.3 Two Sides of Human Thinking

The domination of the left hemisphere of the brain can be interpreted as the concentration of thinking to the conscious mind. When the right hemisphere dominates the subconscious mind is active. Which one then indicates a higher level of thinking? The answer is: neither one. When Freud defined the action of the logical side as a **secondary process** and the action of the subconscious side as a **primary process**, in creative work a simultaneous action of both sides is needed. This is called a **tertiary process**. [9]

Complete simultaneousness can not be reached since the action always concentrates to on one side or the other. What is important is that we can switch the concentration from one side to the other. By this alternating we create ideas and develop ideas into solutions.

Alternating is also familiar from elsewhere. It is what we do with analysis and synthesis but they are however logical processes. Creative work is a much more complicated process, than the plain alternating between divergent and convergent thinking. The present phases and situations are not easy to determine precisely, one must feel them with sense and fit in the thinking according to it.

2.3.1 Use of Presentiment

In figures 2.4 and 2.5 I have tried to outline the formation of an insight. We needed a tension that could build a connection between the information elements in the subconscious mind. Now we should make this model to work also in the conscious mind. We should also be able to present how existing subconscious

[9] Silvano Arieti: Creativity the Magic Synthesis

information chains can be used consciously. The problem is the difficult readability of the subconscious mind.

In figure 2.6 I have tried to present this. There are two separated levels, the higher one is the level of the conscious mind and the lower one is the level of subconscious mind. In both there is an information net with thickets, in the subconscious mind it is of course thicker and larger.

On the conscious level the logical information forms both connected and broken chains. Also the conscious objective appears as a tension between the sides of the plane. The missing connections are built by extrapolating logical cause and effect relationships. The conscious routes are based, however, on the subconscious information. Similarly the necessity tension is reflected towards the subconscious mind.

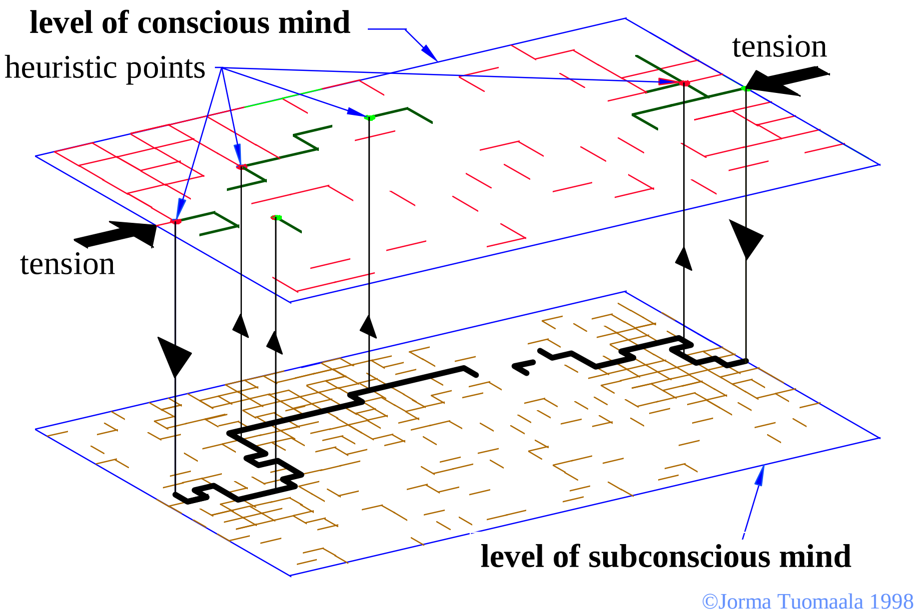

Figure 2.6 The formation of a presentiment

In the subconscious mind some relations gradually become activated and send signals to the loose chains of the conscious mind. They can not yet solve the entire problem but a sensitive researcher has a presentiment of what to study and in which parts it is necessary to add more information to both levels.

This sensitive perception of a presentiment in connection with logical work is a tertiary process at its best. It is not a question of guessing or any mystical phenomena but simply an ability to use one's subconscious information.

This sensing of the presentiment in logical work is the tertiary process as its best. It's not a question of guessing or any mystical phenomenon but solely an ability to benefit from knowledge in the subconscious mind. The "sand layer" is not completely impenetrable downwards and the creative man may sense possibilities through it even when the present situation does not presume the upward punching. By practising creativity this sensitivity will be clearly increased.[10]

The reflection of presentiment into the unchained parts of the conscious mind gives the hint to establish heuristic points. In the area of those points the

[10] The new Nobel prize winners were interviewed on Swedish television. A team awarded the prize for chemistry had a member of 80 years old. He was not present and so his younger colleges were asked if that old man was still able to work efficiently. The answer was straight. He does not work at all, but he has the best nose of all. He is attending the work of younger colleges and he has a fascinating ability to point out the most interesting and promising areas. In most cases he is right.

knowledge will be increased by gathering facts, analysis, calculation, logical interpretations etc. This gives us the possibility to see the meaning of logic in the creative work. Logical handling increases the quality of creative work. It produces holds for thoughts and produces material to fill the open areas. Logic is not a primary method in creativity, because this belongs to the subconscious mind. Logic is the tool box of creativity. With those tools it is possible to form and reinforce the elements to be fit and durable. Other than this logic has no value in creativity.

2.3.2 Loading the Subconscious Mind

In part 2.2.5 it was a question of the rise of the insight in the subconscious mind to the direction of necessity tension. There I already mentioned that when the information net is not dense enough we have to add also some subconscious information. Especially during a low tension period this is indispensable.

Increasing the subconscious information is possible only through the conscious mind. We thus need personal experience before an insight can take place. It is possible to load information in the heuristic points. This is called creating a net islet. If the information is gathered systematically it is usually done by widening the existing net islet.

Information is also gathered by studying. Then the insight may not be sufficient since hardly ever there are enough exercises giving practical experience. The subconscious information net created by studying is of necessity poorly constructed. Only after the students move to the working world they start reinforcing the net from those parts where the studied subjects fit in.

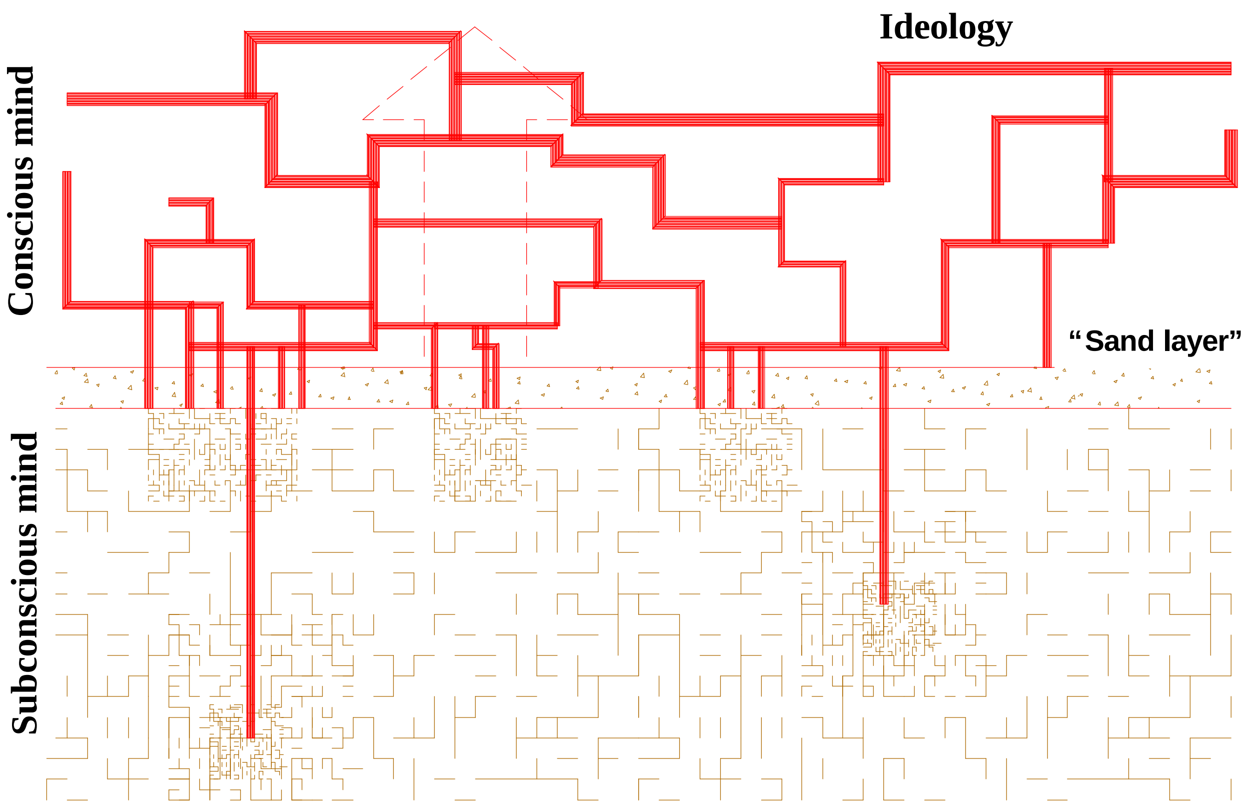

Figure 2.7 Loading the subconscious mind

Figure 2.7 attempts to give a model of loading the subconscious mind and of the co-operation between the conscious and the subconscious mind. Both minds are here one underneath the other, in between there is a boundary surface of the conscious mind. Above the boundary surface are the conscious actions and beneath is, as known, the subconscious mind with many information thickets.

In the upper edge of the conscious mind there is a simple main channel, the ideology. It attempts to direct all the conscious actions in the same direction. Eventhough it is unchanging, it never becomes subconscious, it always has to be kept in the conscious mind. When it comes to learning and other intellectual activities it is solely harmful.

When we acquire information about something we have to get an insight into it. Then the information penetrates laboriously through the surface boundary to the subconscious mind where it becomes attached to the existing information. The penetration is very difficult, if there is no practical action, good example in familiar context or something like that. In a positive case old knowledge pushes itself from the subconscious trough the "sand layer" and gives a familiar route for the new knowledge.[11] When the information increases also the connections increase and gradually a new center of knowledge, skills or actions, is formed, let it be a programming language, riding a bicycle or knitting etc. An existing action center, too, stays close to the surface boundary and abundant connections to the conscious mind imply that a lot of conscious information from the memory has been added to it. Finally we master the subject well and we can form it and give the finishing touches.

Giving names to the subconscious centers is a little problematic. If they are connected with movement we could call them action centers. When they are connected with knowing how to do something we could call them skill centers. But then a center to be formed when solving a problem is at least in the beginning an information center.

When an action center is finally completed and finished we can use it with very simple control commands and then only one channel is needed for the connection. At that time the action center starts to slowly descend deeper down to the subconscious mind. An example could be the earlier mentioned actions of the tongue in speaking or chewing. Both these actions have their own skill centers whose control from the conscious mind is very formal. The conscious moving of the tongue is controlled outside these action centers.

The action centers for speaking and chewing are examples of centers that have sunk to a level where the connection to the conscious control channels is very weak. Driving a car, for example, is a different kind of an action. It can be controlled in many ways eventhough it also functions perfectly as a subconscious action.

Every different languages each form their own skills center. When we speak English we connect ourselves directly to this action center and leave the center for our own language aside. In this way all the thinking happens in English and we can communicate fluently. If we have to do translations, especially simultaneous interpretation, we have to switch between the channels very quickly and it takes considerable effort. This is why the simultaneous interpreters take turns in

[11] When one starts learning a new language, the first words are very difficult to remember. Along the progress this will become easier. After some months use of this language the new words are caught painlessly, as if they were coming home.

congresses quite often due to getting tired. We can notice this even more clearly when we try to switch between more than two languages quickly.[12]

Playing the piano, like playing any instrument, forms a multi-layered and wide skill center. Interpreting the signatures of the notes form a part of this and act very independently. Usually we do not even notice these signatures when we start playing. But if the same tune is written to be played with different signatures changing to play it is slow.

The action center for forming speech and sounds is very deep in the subconscious mind for normal people. For actors it is closer to the surface boundary since they have to be able to create various ways of speaking according to the needs of a role.

In conclusion here is yet one interpretation where this model seems to fit well. When a pianist has thoroughly learned a piece of music he has formed his own skill center for it. When he knows it by heart and seldom plays it this center, also descends. When he then after years wants to make it a part of his next concert he can not play it with the sensitivity he wants to eventhough he still knows it by heart and his hands are in excellent shape.

He has to learn the piece over again. He has to play it slowly following the movements of fingers and their touch, as if he would learn it for the first time. Then the corresponding skills center rises again close to the surface boundary of the conscious mind and lots of connections build to the side of the conscious mind. The pianist can gradually start playing the tune in the way he wants to and the way the composer had intended. A sensitive connection from the subconscious mind of the composer through the conscious mind to something unknown, is being built (the arrow pointing upwards). Then when the performance begins and we add the sensitive expectancy of the audience, the player is in such a field of forces that even physical reactions are natural. He has stage fever. Then when the concert begins the connections start working and the fever disappears immediately. The audience experiences something very impressive.

- *The thickets of knowledge are able to send impulses into the conscious mind where they meet the tension. This may be called presentiment, because the conscious mind does not have the ability to solve the problem, yet.*
- *The presentiments point the convenient places out for heuristic points. By creating them the conscious logic can be used. The logic is the tool box for creative work, not the primary method.*
- *The subconscious knowledge centers tend to sink. In creative work one must be able to lift them back into touch with the surface boundary. The new knowledge centers are always created in touch of the surface boundary.*

[12] In 1977 I attended a congress of EEC Timber Committee in Geneva. I admired the action of simultaneous interpreters keeping all English, German, French and Russian members informed all the time. In the last afternoon we made an excursion to Bienne by train. I happened to enter the same cabin as our interpreters. When the train moved out, they fell immediately into sleep.

3. Intuitive Creative Work

A novel may be written systematically but also completely intuitively. A famous Finnish writer **Mika Waltari** did research on Egyptology for 10 years in various European museums. He found a story of a doctor called Sinuhe and became especially interested in his time, the time of the pharaoh Ekhnaton. In the summer of 1936 Waltari finished a play on this subject and it was performed in the Finnish national theatre. He did not, however, use all of the subject in this play and the idea was left to revolve.

Eventhough Waltari was busy during the following war many things seemed to relate to the time of Ekhnaton. Then in the summer of 1945 he withdrew himself into his room and wrote the novel called **Sinuhe the Egyptian**, over a thousand pages, in only a few weeks. He did not have any notes about the subject from the previous ten years.

Waltari followed in this, like in writing all of his novels, the complete technique of an intuitive creative work. We can distinguish some typical characteristics of it.

a) *There were no notes, all the material was concentrated in the subconscious mind.*

b) *The incubating period was long. He did at the same time other things, whose intensity was not continuos.*

c) *The thought was obviously in his mind during the war. The dramatic events of the war somehow related to this subject.*

d) *The realisation seems very easy. At least it was done in a very short time.*

What happened can be presented graphically:

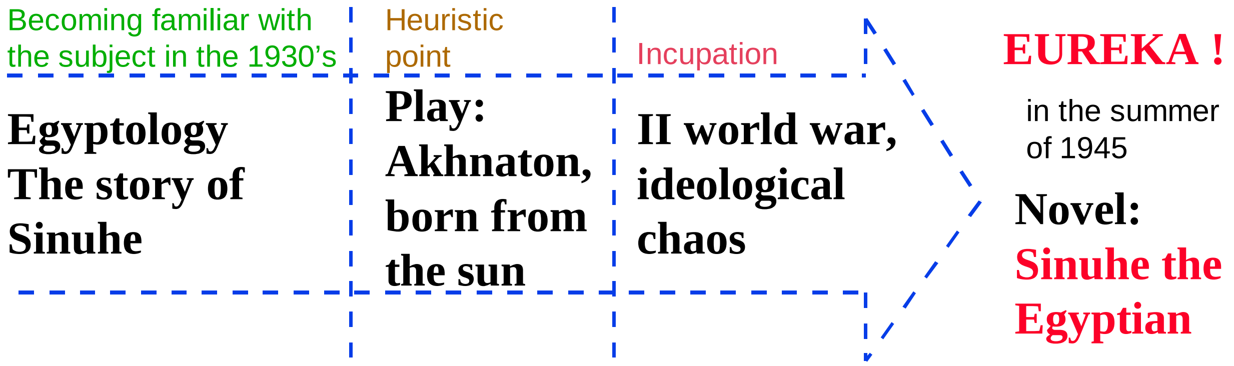

Figure 3.1 The intuitive development process of Sinuhe

The sketch adds some new points of view. Waltari was fascinated by the abundant amount of objects and literary information available in the museums about those remote times. The culture was not directly the basis of the western civilisation nor of any other culture. The Egyptians of today have very little inheritance from the ancient Egyptians. Still the culture was on a very high level even in medicine, not to mention construction work or the structure of the society.

This fascinated Waltari and created a strong tension to the interpretation of the subject.

The papyrus discovered, telling the story of Sinuhe, was a concrete beginning, a heuristic starting point. The analysis of it rose the tension to unwind a story about it.

Secondly the play was obviously a heuristic point. We can not be sure if Waltari had meant it to be that but it did become it when it turned out to be insufficient in discharging the tension. Waltari used a heuristic point later on consciously. He posted himself up on a theme called Johannes Angelos and in order to get acquainted with it he wrote a practising novel called Young Johannes which was published after his death. The numerous detective stories he wrote also served as heuristic points which were meant to train and develop style.

Incubation is a phase when the subconscious mind uses the time it needs or gets to produce the final insight, the eureka. Due to the war it became long and the war prevented and retarded efficiently the formation of an insight. Then when it broke out during the first peace time summer in favourable conditions, it was uncommonly ripe and final. Also the style was completely developed. It is the same style that Solomon the Preacher uses in the Bible. Hardly ever in Finnish literature has anybody written a novel of this quality in such a short time of only a few weeks.

We have already discussed the necessity of a tension in the subconscious process (2.2.5). We also talked about the subconscious mind needing time, incubation time to form a solution (2.2.4). There are allusions to heuristic points in many places. Now we should assemble these influencing factors into a conscious method of creative working which would abandon long-term logic as a dominating factor and would change it into a subconscious process that would be consciously directed with short-term logic, a necessity tension that reaches far and of course with the conscious building of heuristic points.

3.1 Tension

In the subconscious mind the information became an insight under the influence of necessity tension and time. To form an insight we needed sufficient subconscious information either completely based on existing information or based on existing information with the required parts added. The sensory perception of an insight is clear and pleasant but has no feeling for the events before an insight takes place. We can not then decide whether our subconscious mind uses logic, intelligence, stochastic (probable) means or something else. When a lot of time is sometimes needed the whole action might also be thought as a wholly stochastic action under the influence of tension.

However something anticipating an insight leaks into the conscious mind. Before the solution there may be a strong feeling of a presentiment. Likewise we can feel a growing inspiration. We usually feel these sensory perceptions only after a longer experience and sensitivity in intuitive work.

An insight often comes when we relax due to depression or exhaustion. I believe this is because a subconscious insight requires that the conscious mind loosens its control over the solution and inexperience in intuitive work leads to the need of this kind of situation (see footnote 4). A skilful and favourably advancing intuitive worker does not need these depressions but can loosen in the moment of solution and avoid the disturbance of an insight.

A subconscious tension does not arise without a conscious tension. We could think that the conscious tension acts after a long interval. Studying a profession often takes years and learning a form of art can take a lifetime. Subconscious tensions are of shorter duration but they come about continuously approximately to the same direction as the conscious tension. They reach from one insight to another. Together they could be called an *intuitive tension.*

- *An intuitive tension is a consciously and subconsciously sensed will to achieve an objective or to go in a certain direction. It is most effective when the conscious will creates ever more subconscious tensions toward the same direction, both parallel and in series. When the conscious action is directed at something else the intuitive tension keeps the subconscious action going. We must never focus the conscious tension at the point of a solution but must leave the solution completely to the subconscious mind to make.*

Does a human being then only have one intuitive tension or could there be more of them? Apparently there could be more but they should principally be more or less oriented in the same direction. Hobbies may be these intuitive sub-tensions and the profession i.e. work should definitely be one of these. If it is true that a human being has the possibility to have a balanced personality.

The coexistence of several tensions is important to the human creativity since it helps to loosen the conscious will even when it comes to an active objective and contributes to the forming of a subconscious solution.

Also the external factors have an influence on the formation of the tension. To a performing artist the mood of the audience and the reactions they show can have a tremendous effect and sometimes cause the performance to be either extraordinarily good or bad.

In team sport tension is built up and increased by shouting it aloud in a close group. Napoleon scared his front men with the cruelty and the recklessness of the enemy and thus increased the tension. To an individual athlete concentration before a performance is also intensifying the tension.

3.2 Heuristic Points

The eureka incident is an insight produced by the subconscious mind that breaks into our conscious mind unexpectedly. **Heuristics** is a method of creativity where we aim to get results with the help of the eureka phenomenon. It is a fundamental principle in intuitive creative work.

We can not control our subconscious mind directly and this has caused the heuristics to received a lot of negative judgement. It is considered utopic, mystic and unreliable. In modern times we can not wait for miracles to happen. Then we consciously try to deny the importance of the subconscious mind in building an insight and the fact that even in the tightest systematic control the insights are still formed as results of subconscious action, not as a logical solving of equations.

- *The method of intuitive creative working is that we consciously create favourable conditions for the eureka phenomenon. This is done by building a* *set of heuristic points and transferring information through them more efficiently than with words.*

An artist starts his painting from a detail. The rest of the painting is based on this, its environment, atmosphere etc. A machine designer examines the details by sketching them and developing them more precisely and extensively. He can look for a component he wants in the store, a bearing, a joint, a coupling, whatever, and he scrutinises it by touching, moving, placing it in different positions and on different surfaces. Holding it gives the weight, moving it the friction and acceleration and different positions tell something about how to connect it. Even the smell can vivify the conditions of installing.

Example 1

This is a personal experience, an incident which took place in the 1940's. After the war my mother had received from somewhere a cardboard box of thin blue cotton thread. All the spools had, however, become an indistinguishable entanglement. The thread was a treasure which was hard to get in that period of economic depression. My grandmother started the hopeless task of disentangling them and asked me to be mostly her companion. At first I was not allowed to touch this valuable treasure but than my grandmother had to give up with one spool since only small parts of thread came out at a time. I had my chance.

I placed the spool on the table and started spreading it out. I didn't try to pull out a thread, I just turned the mess around and loosened the knots to a wider area on the table. The tightest knots I opened with an awl. When there was nothing more to turn or loosen I gave an appropriate end of the thread to my grandmother and she started to wind. I made sure that the thread did not tighten new knots, I opened them immediately. In this way we were able to disentangle all the spools in a few days. My grandmother was surprised!

In this example the knots were the heuristic points and the short logic was loosening them. A systematician would have started from the objective that it is possible to find a place from which one could wind the thread in one piece.

In dealing with the heuristic points it is important to get immediate and wordless information with the senses. The condition is that we work in the field of the problem with our hands and receive continuos impressions. The history of inventions is filled with examples of how a great discovery has been made by a person or a group of people who were not supposed to have any qualifications to make it. We then have made it a science to analyse and define logically the fruit of their work!

Example 2

The research group of Charles Kettering developed a successful new type of a diesel engine by experimenting for six years with various versions before finally "the machine itself said what it wanted". None of the members of the group had ever even heard the word thermodynamics.[13]

[13] Alex F. Osborne: The Applied Imagination

Example 3

In a small Finnish town called Toijala an experienced saw doctor noticed that straining a circular saw blade failed, when done with a mangle, if the pressing force of the mangle was too high or if the mangle grooves were located too tight. The saw blade simply collapsed and lost its tension. He came to the conclusion that the other roll of the pair of two rolls in the mangle had to be made a little like polygon so that the corners would better resemble working blows of a hammer. He made the changes without permission and succeeded. The hardest work was to find a theoretical explanation to the phenomenon so that the invention could be patented.

Example 4

A storage silo for cement is tens of meters high and the diameter is also about ten meters. One researcher found it useful to gather the cement to be put into sacks in the way that there would be a revolving horizontal conveyor screw on the bottom that would draw the cement out from a hole in the middle of the base. In this way the layers of cement of various ages would incline due to the larger removal in the middle and these layers would get mixed. The result would be a more even quality of cement. My task was to design the revolving screw.

The equipment would have been very heavy and a breaking of the screw would have caused thousands of tons of cement to be unloaded almost manually. Then I remembered that as a child I had already mixed mortar in a foundry for roofing tiles. When I poured out the contents of a cement sack it spread to a wide area as if I had poured water. The spread cement stayed moving for a long time but then gradually hardened similar to what it had been like in the sack. I remembered that I had wondered about this phenomenon and come to the conclusion that air had been mixed with it when pouring.

I decided to use the same phenomenon now and designed the base of the silo to be composed of oblique triangles.

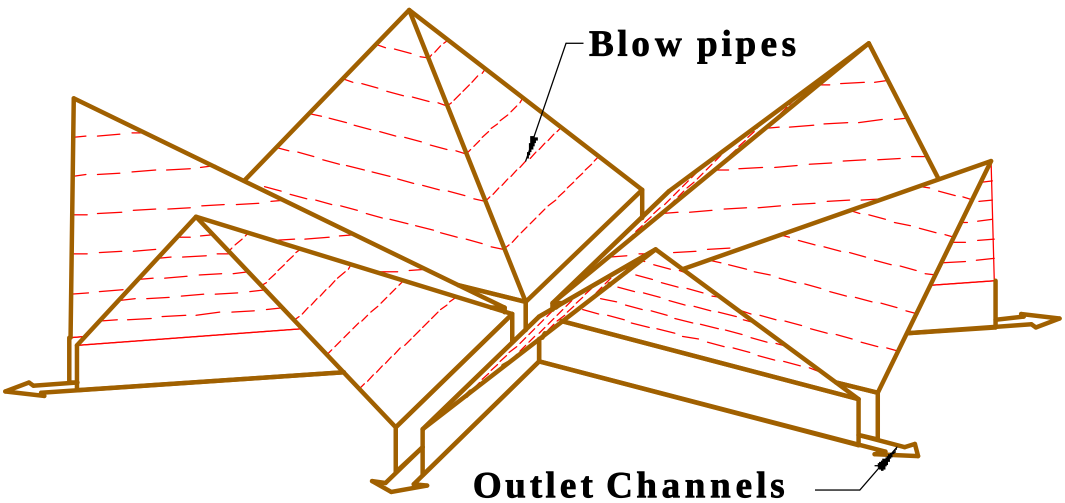

Figure 3.2 The base of a cement silo

Blow pipes with small holes through which the air penetrated to the lower layers of cement were sunk to the oblique triangle surfaces. In this way the cement became fluidisized, i.e. moving as water and flowed between the triangular planes to the outlet channels with a velocity controlled by the partition dispensers. Excluding the dispensers it was possible to construct the equipment with no moving parts. If the dispensers broke they could be descended without the cement flowing out as long as the air blowing was stopped before. The construction was cheap, functional and could be patented world-wide.

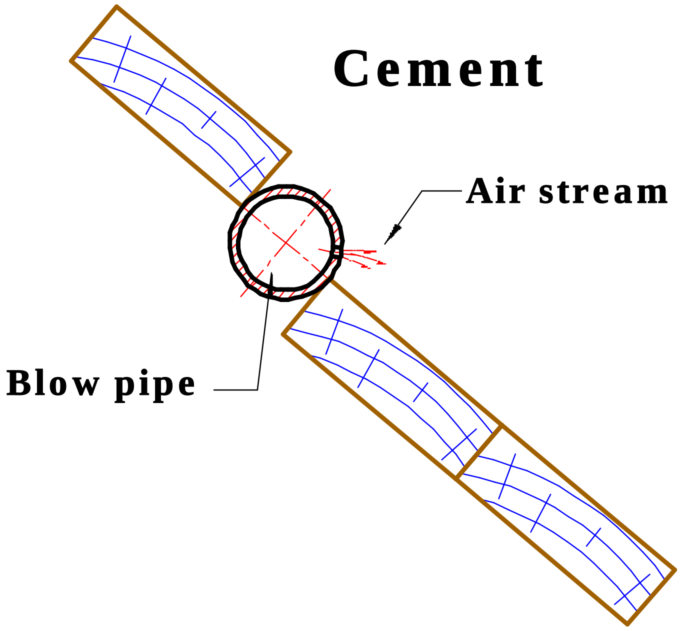

Figure 3.3 The first sketch of the unloading base of cement

This solution came very easily. The most important thing in it was that my father had made me do roofing tiles at the age of ten for a school which I entered the next autumn as a first grade student. I had personally seen the flowing of cement and wondered about this phenomenon eventhough nobody knew anything of fluidization. Whenever I had a chance I played with this phenomenon and made the cement flow through my fingers. Without this experience I could hardly have found the solution even if I had listened for an hour to a lecture on fluidization.

The experience of the fluidization was not a heuristic point in this incident. It was an old insighted information center in my subconscious mind. I had not needed it for 30 years but it was still there. On the other hand I remember very well my first sketch of the inclined flowing surface which was a heuristic point, figure 3.3.

The sketch is not connected with anything. It just presents the blowing pipe with its outlet holes and the placing of the pipe into an inclined plane. The image is of sliding down a frozen shingle doghouse roof in the winter. The shingles were placed so that water would run down easily and it also ensured that I slid down easily. In addition there were a few nails on the roof which meant that I would afterwards get a beating from my mother. So there were no hindrances to sliding in this construction either, only a pipe set between the shade of the board and the next board underneath.

The base of the prototype silo was made as a carpentry work from wood. The air pipes were assembled from water pipes. I contemplated that a hole of 4 mm can easily endure piercing the walls of the pipes and is still light to drill. I decided that the holes should be pierced 10 cm apart. When later on a bigger version of the construction was made I remember being amused at how the designers carefully measured the sizes and the division of these holes and wondered how important these measures were.

Example 5

In designing the cutting head of a chipper canter, a partial problem was how to fasten the finishing knives so that the fasteners would not hinder the movement of a canted log and that the knife would be adjustable when sharpening it shortens it. A slightly inclined fastening surface was possibly needed, but it was expensive to make it to the big cutting head. Also a long controllability was wished for, without any restrictions from the screw holes.

When I was sketching this difficult detail I looked at the person next to me drawing with two pens, the other pen crossways in his mouth. There I found the idea!

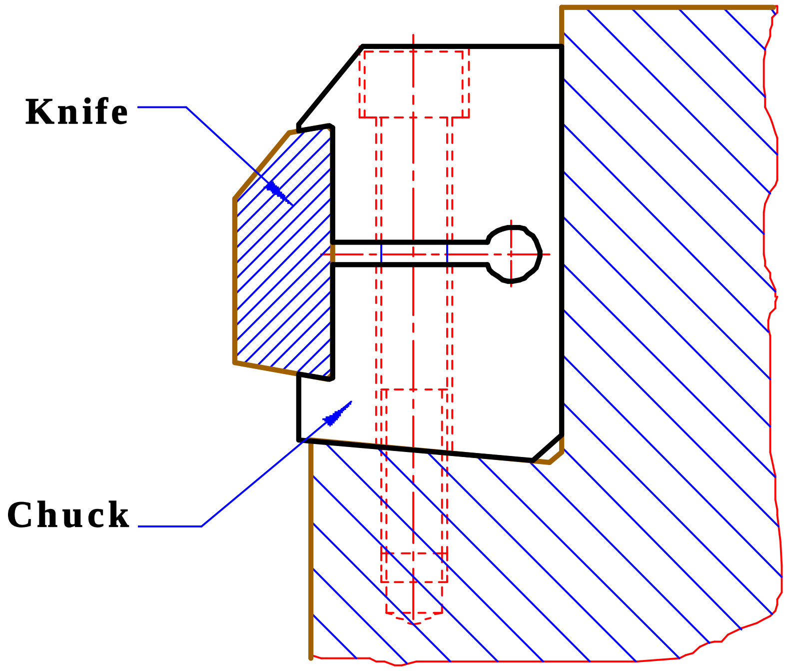

Figure 3.4 Fastening the finishing knife of the chipper canter

The knife is a straight prism that is fastened between the teeth of the chuck. The guidance surface is machined to an angle of 2°. The fastening screw of the chuck presses the blade immovable and also steadily in its place, using the oblique base of the chuck. The elastic hinge in the chuck resembles the starting idea, the human jaws.

Summary of the Examples

The conscious tension tends to always be too logical. It defines the objective and strives for it. When we strive for our objective in the systematic method we first gather information and ideas. In the intuitive method we downright avert getting to the goal by focusing our attention on the details in between or thought to be in between, the heuristic points.

In this way we can free ourselves from the conscious tension and we can focus all our attention on a chosen object. It is in the tension field, but not connected to other structures, i.e. it is free in all directions. This freedom also frees the subconscious mind and the whole action changes. These changes can be described as follows

a) *The information traffic becomes denser since the thinking becomes almost completely based on images. The images can be very old (example 4) or released by sudden visual perception (example 5).*

b) ***Short logic** is being used in the control of work. This is reasonable and consistent but does not aim towards remote objectives. These images can change freely in the mass of logical results, perceptions and the new images they have associated. In the example we can see, that the work itself can be monotonous but the objects of interest alternate quickly. We do not aim to the final ball of thread, only to the logic of the knot at hand.*

c) *The heuristic point is like a ball lightning when it develops.*[14] *It floats freely in different directions but can then fit into the wholeness with a tremendous force. It takes self-discipline that a single ball of lightning does not determine the whole construction too early.*

3.3 Incubation

The internal connections in the subconscious mind take time. If a design is very tensed and energetic the subconscious mind falls behind. On the other hand the subconscious mind does not let the solution into the conscious mind if we try to force the solution to come out.

Luckily human life is rhythmed to day and night, time awake and asleep. We can learn to use this if we recognise our own personal sensitive phase when we can wait for a solution to come. For me it is the slow awakening, for some others it is simply the dreams.

Incubation often takes more time than just one period of dream. Then an excessive systematic seeking after an objective can ruin the ripening. It would be better to place the work in a drawer for a few weeks and do something else. For a designer this could be an installation or test run trip or even just an ordinary holiday. Unfortunately it has become a habit to stress oneself also on vacation with a tight schedule.

Also a distasteful and forced changing of work or circumstances can be productive times for incubation. Waltari´s Sinuhe is an example of this. Many works of art have ripened in prison. Edison had an idea of a phonograph when he was working as a telegrapher during the American civil war in 1864. The first version was made only in 1877.

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[14] In the summer of 1944 my mother was sitting by the loom in the unfinished attic of her parents home during a thunderstorm. Suddenly there was a sizzling ball of lightening next to her, that gradually as if taken by the air current started heading towards the staircase opening, first to the hall and then to the bedroom through the living room. I was lying on a bed in the bedroom scared of the storm. I saw the lightning for a few seconds when it swung about one meter high. It came to the end of the bed, stopped for a while and then disappeared with a terrible explosion. On the wall by the bed there was a telephone and the lightning struck the wall next to the phone. The wall started to burn. My grandfather extinguished the fire with his palm. The ball of lightning had the size of a baseball and there were short sparks flying tangentially outward. I believe that it was an electron whirl that floats with no attraction to anywhere. The material glowing brightly may have been plasma.

The eyes of the child adjust to even bright light quickly so I could see the structure of the ball of lightning. When it disappeared I was so blind that I could not see the fire nor its extinguishing. My sight gradually came back to me.

The favourable effect of the routine-like use of physical motorics is typical for incubation and getting an insight. It has been said that the only advantage the men have over women is the beard. Shaving is the kind of a morning routine that can become a typical moment for an insight to some. Walks and going out into nature also have a positive effect. In the academy of Platoon everything was taught while walking. When the monks from the mountain Athos visited the northern Finnish town of Oulu they walked peacefully along the banks of the beautiful Oulujoki river during a break in the program. Apparently there was a lesson going on since the oldest talked calmly all the time and the others followed him with interest in a dense group.

Physical work is thus an important part of the premises for the action of the subconscious mind. It has been claimed that the mental decadence of the aristocracy was due to putting an end to the use of hands.[15] The modern world has developed in this sense in a somewhat doubtful direction. The use of hands diminishes all the time and even growing children do not have a chance to practice the use of them. One is not allowed to carry a knife with him and there are no places for carving with a knife. The abundance and cheapness of industrially produced goods has taken the will of making constructions. Even drawing and writing is done with a keyboard or a mouse. Is this sufficient?

Heuristics offers the best possible way of working to increase the effectiveness of incubation. There we have an active connection to subconscious action and short logic prevents a premature connection. When this progress stops we move to another heuristic point in the same tension field and continue. The former is left in peace but the subconscious incubation is very active. When moving in the field is free the subconscious connections can arise suddenly between various heuristic points.

In heuristic action there is thus incubation going on in various points while at the same time the active work continues in the same task. This makes it a most efficient way of creative working. In addition the activation of various points sensitises the results of an even longer period of relaxation.

Sometimes an unexplained peculiarity stays revolving in our subconscious mind for decades. Eventhough it may be of no use it still continuously looks for connection points with its peculiarity. It seems that these phenomena that have been revolving for a long time form dualistic insights, i.e. such insights where a new insight is formed when two opposite characteristics join.

A bang is a phenomenon that interests children. There is a sound and its force is sometimes surprising, especially when ones fingers are left in between. All my life I have been interested in a bang. I remember wondering how a big sledge hammer could break a stone but my small riveting hammer only made a small mark on the stone. I once sat a whole summer day in the corner of a field in a small bush hitting the same spot of a big stone. By the evening there was a pit, not a very big one, but I thought it would hold a bird's egg well.

Later on I was allowed to hammer nails, once even six inch nails into a rooftree of a torn down cow house. The nail did not sink in well with my small hammer, only the head started inclining and spreading. When my father hit the same nail in with a carpenter's hammer it sank even under the surface of the wood. No signs of hit were visible on the head of the nail.

Eventhough these observations were later explained in the study of mechanics the blow still interested me. I noticed that in hitting the surface of a fresh tree wa-

[15] Alfred North Whitehead

ter burst out. This lead to the grooving of the counter blade of the edger to prevent sliding of the board. It also helped me to understand that the water in the wood exploded the chips into pins when the cutting velocity was too high. I learned to understand why a smooth sound of running was necessary for the duration of a machine, why stainless steel parts did not resist as well in the shaking machines as the parts made of ordinary mild carbon steel eventhough the stainless was stronger.

In 1983 I heard about a problem that the teeth of the cross cutting saw tended to loosen and needed to be tightened every day. I used my experience of striking loads and of the behaviour of surfaces hitting one another and designed a better construction of teeth that also was patented.

Also a craftsman with no studies of mechanics acts a lot according to how he feels the blow. A man working with saws feels the blow from a feeling in his arm, the hardness and smoothness from the sound and marks left on the blade when he hammers it. A fitter knows how to choose his hammers and strike so that the parts come out but do not break. He knows that hitting a key with a small hammer creates an enormous force eventhough he does not understand anything about the axial vibration that despite the friction "absorbs" it inward.[16]

- *Tension is serving as a motor for creative work starting by the analysis of the task and by the first heuristic points. The force of tension alone is not able to solve the problem. The solution will be created in the subconscious mind and it will pop up as an insight like the Eureka-phenomenon.*

  The subconscious solution preconceives that the subconscious mind is fed by knowledge, it will have time for incubation and a relaxed situation to go off.

  The creation of a heuristic point is combined with, besides the knowledge provided by logical analysis, old knowledge created even in childhood. The more active and curious the child has been, the more useful the old stuff he has gathered is of use in his manhood.

[16] In the beginning of this century steam engines were constructed in Eastern Finland for lake steamers. A mechanic was fitting a flywheel on the shaft with a key when the master went by and, to express his importance reminded the mechanic that the flywheel should be fitted well. The mechanic became angry and growled at the master that the idea was not to break the flywheel. When the flywheel was big and massive and the hammer small the master became enthusiastic and claimed that the flywheel could not be broken with **that** hammer. The mechanic held his opinion and after permission continued hammering. By lunch time the wheel was broken.

4. Intuitive Method of Creative Work

In the previous chapter I mostly talked about the various phenomena of intuitive work in the subconscious mind and their reflections on the conscious mind. Heuristics has so far been the only method and even it has not yet been fully defined. Is the systematic method nevertheless the only method suitable to carry out large development projects?

So has been said and as support large development projects carried out systematically have been presented. These are for instance a container handling system for harbours, Columbia space shuttle, development of the atomic bomb etc. Those who say so have nevertheless not participated in the design themselves, at most they have lead the projects which is a completely different matter. Our technical culture has always tried to avoid the insecurity, which is seen in the use of intuition. Its no wonder even engineers, having used intuition in design work, try to forget the whole matter in management.

4.1 Intuitive Solution

Let us now try to gather together an intuitive problem solving method from the previous statements. It will use tension, heuristic points, short logic and a fixed schedule. Let us assume that a work is given to us, already somewhat defined. We have to first accept, analyse and get an inward sense about it. Only during this an **intuitive tension** whose magnitude depends on the urgency of the work builds up in us.

Figure 4.1 presents the development of a solution graphically. We just discussed the gradual beginning of the great tension arrow. When an inward sense of the work has been received the tension first stays constant and the usage of heuristic points starts.

First the task seems to be **a monolith**, made of one piece of stone. Eventhough an employer think he knows exactly what he needs, the matter is not so simple. Particularly in that case, when a machine or a process in use has to be replaced, the definition of the task is incomplete. The machine in use has no **attributes**, in other words the user is so accustomed to it, that he is not able to define its characters, neither good nor bad ones. A designer starting his duty, has to analyse the monolith into its elements. He has to find and value the **thoughts** the solution is founded on. Only then can he feel to know the object sufficiently. The results of analysis are joined to the first heuristic points.

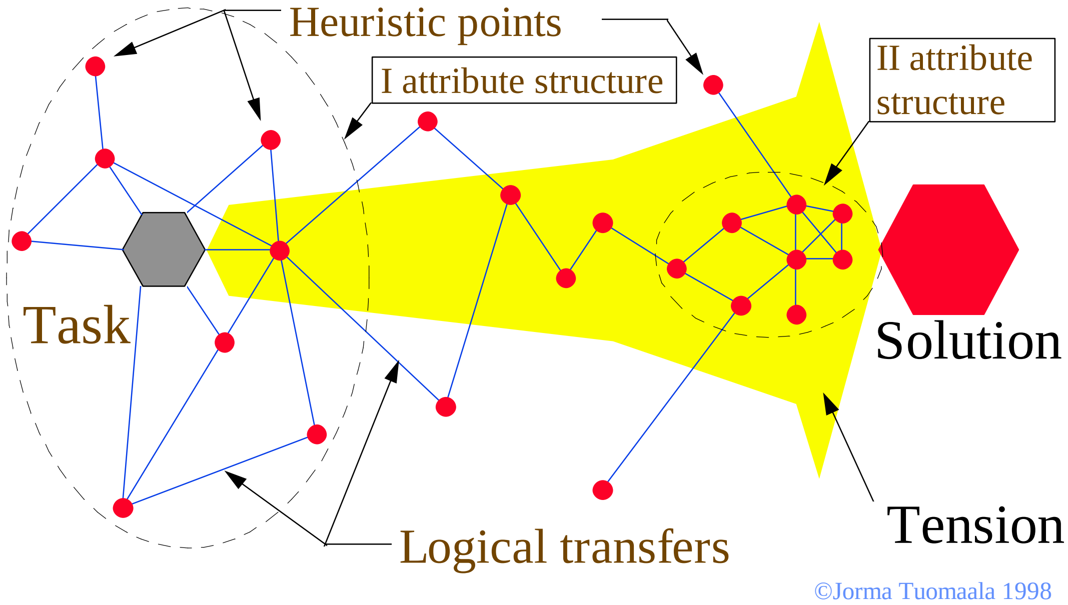


Figure 4.1 Intuitive problem solving.

Eventhough we have become familiar with the work during getting an insight, by reading source literature, having conversations etc.. heuristic points are something else. They are not mature information, they are experimental **assumptions** or **information** still completely **separate** from the work. The tension already exists so that it tries to direct the **insighted** information and ideas to serve in solving the problem.

The first heuristic points can be outside the field of work, i.e. such points that are not even meant to be used for solving the problem. However they are connected to the starting situation so dealing with them deepens the process of getting an insight. If, for instance, we are designing the earlier mentioned container handling system, the first heuristic points could be connected with loading and unloading the containers, manufacturing them, their materials etc. These first heuristic points transfer their information mostly radially to the beginning of the tension field.

Transferring information between the heuristic points has been called **logical transfers**. This is the kind of information transfer where the density is greater than that possible in oral transfer, they are images. The logical transferring channel is left open and through it only the information that is needed flows to a new heuristic point, still as images but chosen by short logic.

The flow of information is a two-way flow. Even if we had just moved to a new point, the insights that have taken place there can move the observation back to the previous point and strengthen it, thus the heuristic points will be activated. Their ability to transfer information to other points is increasing. The results of the first analysis were already active heuristic points, but on the contrary, their activity has to be suppressed. Otherwise they spontaneously tend to form the solution like the previous solution.

When we move closer to a solution the set of information channels becomes net-like, i.e. everything is connected with everything else. Still there is room for points even further apart whose connection is radial. When the net of heuristic points and intermittent information channels is already covering the whole task area, the tension will be triggered to a new sought-after solution. It is important to notice, that in the whole process before that no sketch of the overall solution was created.

Instead the heuristic points were studied in exact graphic scale but with completely open connections to other points. The overall sketch got its birth in the correct scale, not until the end of the process.

Eventhough the intuitive tension is very strong and is directed from the problem to a solution this affects the information traffic between heuristic points very little or not at all. Instead it affects the choice of heuristic points so that when coming closer to a solution they concentrate more clearly on the tension. The short logic is partly conscious, partly subconscious recognition of the causes and effects in the formation of points, alone or in connection with each other. This kind of work would be inefficient if it were not so fast due to the transfer of images.

A creative person tries to move as much action as possible to the side of subconscious mind. In this way he easily ends up in a situation where the subconscious action is lively between the heuristic points thus increasing his deeper knowledge of the field. At the same time the effect of the tension may loosen and the solution is delayed. Then we need to direct the process consciously a little. Usually we end up in this situation already because the time used is running out and the management of the work is already reminding us of it.

Despite the hurry it does not help at all, in the worst case it creates panic and a complete locking of action. The best way is to ask to talk about the situation. We can also tell ourselves but the best form is to tell it to somebody else who can make "stupid questions and propositions".[17] These propositions do not fit into the structure achieved and thus the structure pushes itself to the side of the conscious mind. The effect is often surprising. An insight comes in the middle of a sentence, the process twitches onward and the tension is increased greatly. The reaction resembles the use of brainstorming but here it is more a question of turning over the information structure than an association.

I have described the intuitive solution such as it appears in mechanical design. In other creative work defining the heuristic points is not always as clear. Anyway the transfer of action to the subconscious mind and staying there even for a longer time is generally valid. Just as obvious is that talking to the person next to you about your work helps it move onward. The supporters of the systematic method do admit that the kind of action presented does occur even successfully but it is not suitable for solving larger problems. We thus have to describe a model that is suitable to even larger works.

4.2 Intuitive Method

In large works we are never completely in an unknown field as is often the case with a single problem. There are always means and medium by which the affair or at least a similar one has been handled earlier. We thus have starting material.

If we take the container handling system used at harbours as an example we can always take handling goods sold by the unit as a reference. There are fork lift trucks, cranes, equipment based on rails etc. A systematic method actually starts

[17] Since the 1940´s my godfather wandered around Lapland as a wilderness inspector. He became a hermit and even built his retirement home far from other settlements. There he wrote stories of what he had experienced with his apocryphal handwriting. Every morning after he made coffee, his dog came and sat in front of him with his ears laid back. At first the dog heard a morning lecture about its indecent life. Then the old man told his dog what he had thought the day before. In this way his narration got cadence and scope also in written form.

from the assumption that all the technical solutions already exist, it is only a question of choosing them and combining them to a functioning entity with an optimal result. The whole design would just be this choosing and at most reconstructing and re-dimensioning the details of connections.

4.2.1 Penetrative Analysis

The intuitive method goes much deeper. In the same way it uses all the existing information, often just as it is. But it does not try to combine the pieces such as they are. Instead it tries to learn from them, i.e. it steals the expertise and the point of view of the designers who have constructed them. Only a complete posting of oneself upon the object of reference frees us from copying it as it is and makes it possible to create a solution as it is needed to solve the problem. Posting oneself upon the structure of reference is done with the help of an analysis, downright analysing to pieces. We can give this phase the name **penetrative analysis** or decomposing. It's important to notice, that we are not looking for sub-functions of the structure or the task, we are looking for the **ideas** behind the structure.

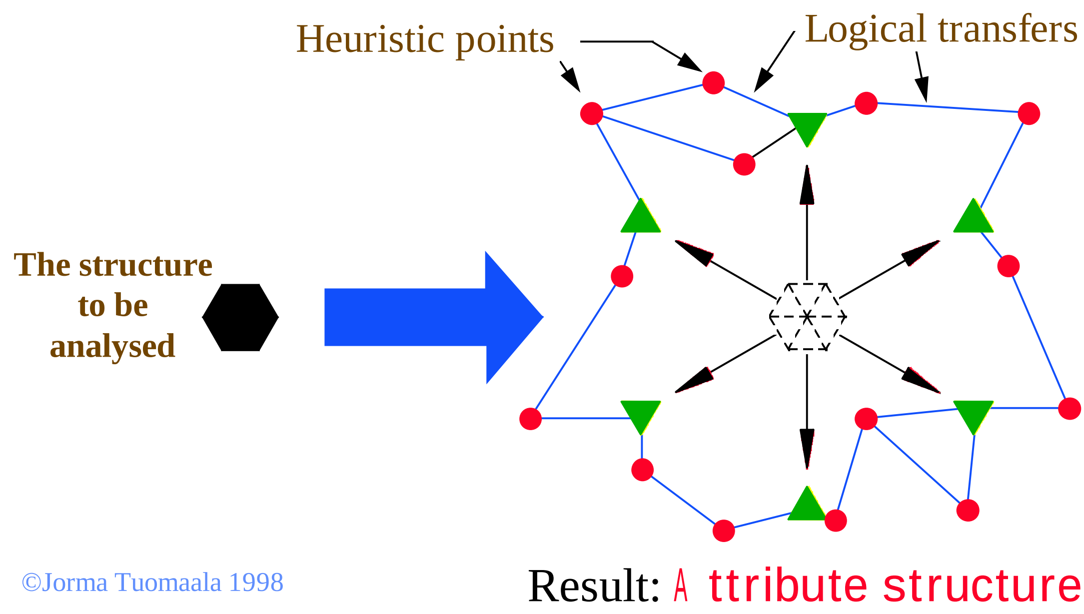


Figure 4.2 Decomposing a structure

A structure is composed of parts that have their own functions, materials, manufacturing methods, strengths, weights, colours etc. These properties have been used only partly in the structure. How have they been used and why has such a part been chosen? All these are explained with the help of an analysis and in this way we can get an idea of what the designer has thought.

An analysis is a critical process where the reasonableness of the structure is also being judged. In this way we gradually come to a situation where the structure is no more a reference or competing entity but a collection of functions, purposes, successes and failures. We have made the **know-how** of the structure our own.

Figure 4.2 is of course symbolic. There the structure looks like a tightly packed entity in the beginning but with the help of the analysis it divides into its basic parts which are represented by triangles. From these triangles we can then construct new entities and use them in other configurations.

4.2.2 Penetrative Analysis of Ones Own Work

It is easy to analyse and criticise somebody else's work. In doing so however, the right attitude is hard to reach, i.e. we should not be depreciative nor too respective. We have to forget ourselves and concentrate on the matter.

It is even harder to handle our own work, especially straight after we have finished it. A creative process is so demanding and finding a solution is such a relief that there does not seem to be enough self-discipline to make an analysis. However in this the creative skills are being measured. It is fine that we have been able to find a creative solution but it is super fine to be able to analyse it again to its basic parts. This demands the paradoxical combination of the designers characters, for which a **humble** but also a **strong mind** is needed.

It often takes time and some impulse that forces us to decompose our own work. There are for instance new possibilities or new requirements. Then we are tempted to make only a **grafting**, i.e. we change the structure only that much that is needed. Then there is a danger that this grafting will make the operations of some parts more difficult or the functions of the structure can not use the new grafted feature.

With grafting we make forced constructions. A typical example of grafting has been the connection of electronics and computers to various equipment's. When the basic structure has not been modified to correspond to the possibilities and properties of electronics, the improvement the grafting has brought is minimal or even negative. We get the same kind of results in cases, where we can't relate the so-called "new technology" to old one. Instead of that we imagine, that it alone is leading the progress.

Experience and self-discipline in one's own works teaches us to consider them soberly. In engineering design these situations appear at least with prototypes. Often it would be desirable that the prototype would fail, because one would learn a lot from it. A quite successful prototype takes unfinished goods to the market if the designer himself is not mature enough to exploit the prototype as intended. Although the structure would be possible to make complete with only a minor change, one should always be ready to perform the profound penetrative analysis.

4.2.3 Description of the Whole Process

In figure 4.3 the whole model of intuitive creative work is at last presented as a scheme. We can distinguish that the tension arrow from figure 4.1 is a little narrowed. In connection with it the net of heuristic points is not drawn any more but it is nevertheless it still has a connected with it. The original task is as before, as also the solution at the head of the tension arrow.

The surrounding decomposed ideas or the competing ideas are new. They can also be other constructions whose applications are somewhat connected with the field of work. As a consequence of analysis the results form heuristic points or join them. In this way the net of heuristic points becomes deeper and making it denser and more mature is more efficient.

The first phase ends in a solution. If the degree of newness of work is low and the product need not very mature due to the circumstances of competition, the whole process can be finished. If a higher capability of competition and finishing level is desired, the solution is a prototype whose testing starts. After the testing there is always an analysis of the results and the prototype is returned to the designer for the design of a actual production model.

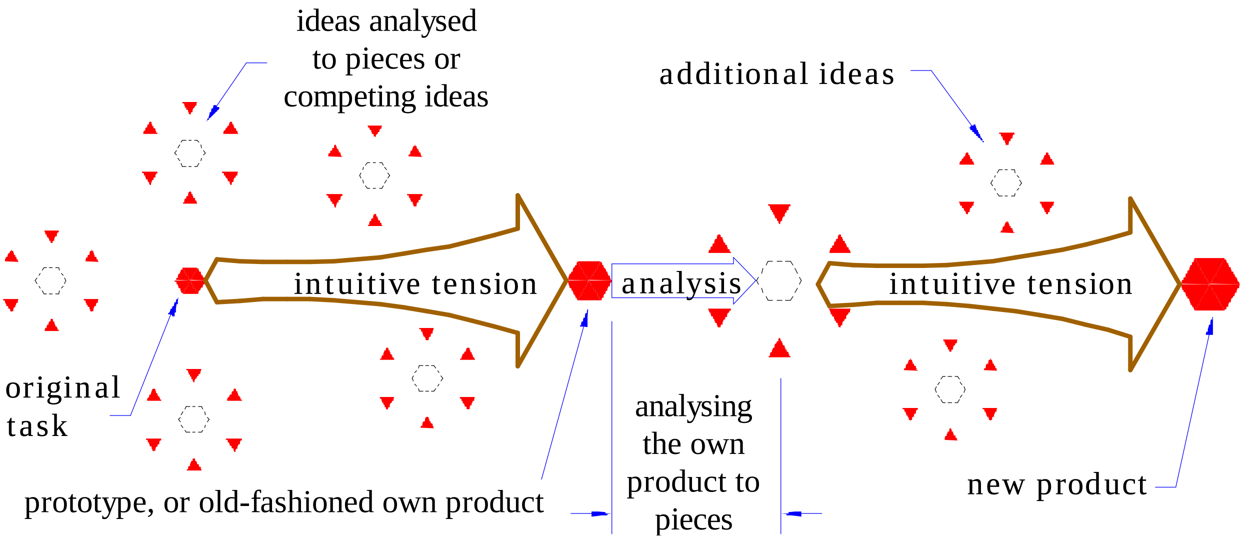


Figure 4.3 Method of intuitive creative work

A better result can be achieved if after testing a penetrative analysis is made on the whole prototype. Once again we have to return to the basic elements and examine different possibilities dispassionately. Creating a prototype and its test run have taught us a lot, so there really are better premises to find a better solution. Penetrative analysis of one's own work is difficult. The failure of the prototype makes it a lot easier. This is why a failed prototype is finally more valuable than a successful one. One has to force himself to make a penetrative analysis on a successful prototype also, otherwise the significance of the expensive prototype is lost.

A new design process is started on this basis. Now the pieces from the penetrative analysis of the prototype form a basis for the heuristic points net which is completed with additional ideas and information about the circumstances of the use. The final result will be better and more mature than the previous one.

The main part of industrial design starts from an existing product which is considered obsolete or becoming obsolete in competition. Then it is set to the place of the prototype in figure 4.3. Sometimes the product is so old that nobody knows its principles. Then the work needed is almost as thorough as with a new work, thus we are in the beginning of the scheme.

In figure 3.1, I presented the formation of the novel Sinuhe, the Egyptian as a scheme and claimed that the preceding play about the same subject was a heuristic point. In reality it was not meant to be that, according to Waltari[18] it was an expression of the extremely idealistic current of thought of the 1930´s, "afterwards thought dreamily idealistic, poetic - should I say outburst by idealism". The leading characters were however the same as in Sinuhe. Earlier points of connection were a poem and a short story from the year 1926 whose background was the

[18] Mika Waltari: The Memoirs of the Writer, edited by Ritva Haavikko.

contemporary findings in the tomb of Tutankhamon. Waltari himself considers the failure of the play as a basis for Sinuhe. The events during the war affected him so much that had Sinuhe been written before the war it would have been quite different.

The play "Akhnaton, born from the sun" can also be considered as a prototype whose penetrative analysis due to failure and forced by war was done subconsciously after a long incubation time that the actual writing was then done in a few weeks. The statement of Waltari also expresses a means to help the penetrative analysis. He had to undervalue and hate his own work intentionally to get a firm grasp of it. The same method is useful for the prototype in engineering design, if one isn't able to find a sufficient humble attitude. In the worst case one is not able to accept any criticism of his prototype but unaffectedly defends his own work.

4.2.4 Example: KEY HOLDER

A theoretical presentation needs a practical example to support it. Thus the problem is to choose the objective so that no special knowledge is needed to follow it. This is not quite possible when we follow the example from the beginning to the end. Let us take a key ring as an example, it should be familiar enough to everybody.

A key ring is perhaps the most common of business gifts. The idea behind them is to place the name of the company in the customers pocket, desk, drawer etc. The main point is that the name is seen by the customer and other people as often as possible. The purpose is to make the gift as pleasant as possible and also so practical that the customer bothers to use it.

The structure is in most cases a simple ring to which the part with the name of the company and the keys are attached. It is easy to see that the design is made by companies who manufacture these rings. They only need to choose the right name tag for different customers. Sometimes the design attempts to resemble some of the company's products but in some cases the result is not so successful and is un-pleasant to carry in one's pocket. An example could be a roller bearing with a name tag. In such a case at least my pockets were worn out in a few weeks.

A key holder is one of the simplest objects we use. Nevertheless it might be worth thinking about it more since it is used almost as often as a spoon. There are as many different customers as people so in the end its importance may be greater than thought. If we think who might benefit the most from manufacturing key rings, the gift makers, shops selling locks and even the manufacturers of locks might be interested.

Are we qualified to design a key holder? Surely we are, at least from the point of view of a user. The manufacturing technics of course sets some requirements but let us leave them now aside.

4.2.4.1 Abstracting

A key ring is not suitable for a definition of a problem. It already defines how the keys are placed in the ring and there is no direct need for this. We need various keys that we should be able to find and take to our hands when we want to open a locked door.

It is obvious that we constantly need to have various keys with us. It is possible to have them loose in our pockets but it would be very hard to find the right one if we had for instance five keys of the same shape. Thus we need to attach them so that we can see or feel them all at the same time to find the right key. A key ring fulfils exactly this need.

The task could be defined abstracted as follows

We are to design a device with which we can easily carry a collection of keys with us and which makes it possible to easily identify the right key to use.

We can limit the task for instance so that all the keys are normal Abloy keys (the most common keys in Finland) and there are no more than five keys to begin with. This limiting might make the subject interesting to even the lock manufacturers. Since Abloy is such a common key type in Finland the limiting would not diminish the number of users. It is also habitual that car keys, which are of a different shape are not kept in the same bunch with the Abloy keys.

4.2.4.2 Preliminary Heuristic Points

With preliminary heuristic points I mean the ideas and solutions preceding the first tension arrow in figure 4.3. Perceptions and analyses connected with the use of the object can also be taken as such. The reason they are heuristic points is that they are not used to create complete solutions, they are only used to load the subconscious mind.

Carrying Keys

Usually the keys are carried in your pocket. Actually pockets are placed in the clothing for such purposes. In the pockets the objects

- *should not press the skin uncomfortably*
- *should not wear the pockets down*
- *should be of the size that they are easy to find and to make sure they are there just be feeling from the outside*
- *should not get caught in the pocket or other objects there*
- *should not be so slippery that they slip out easily*

The placing of the keys in the pockets is bad in the sense that when we change our cloths it is easy to forget the keys. We should not have the keys in the pockets of outdoor clothing since the keys are needed also indoors. We also often take our jacket off so the best place is the pocket of our trousers.

For women the place to keep their keys is most often a purse. The size defined for objects carried in our pockets may also be the size carried in a purse.

Children tend to loose things from their pockets. For them the best place to have a key is on a string around their neck. In this way it's hard for outsiders to find the key and take it fast. A string is also suitable since only a home key is usually sufficient for children.

Taking Keys Out

We often have lots of things with us when we come in to a house and we do not want to place them on dirty ground just to find a key. Then it would be good to find and take out the right key using only one hand. It would also be good to be able to collect the bunch together again and place it to the pocket with the same hand. Since right-handed people usually use the keys with the left hand, the clumsiness should be taken in consideration.

Recognising Keys

Recognising the keys is quite a difficult problem. For the Abloy keys we have small plastic things of different colours to attach to the keys. These help the visual recognising but are of no help in dark since they are all of the same form. They also take space so the use they bring is quite small.

We should take the keys to our hand always in the same order. Thus the ordinary commercial key ring with a tag is useful. When we let the bunch hang down holding the tag the keys easily group themselves to the right order. The bunch with a tag is such a small unit that it is easy to hang it down with only one hand. Now it is easy to recognise the keys by counting from the side. The indexing of the keys tells us which way to hold the bunch.

Solution of the Shops Selling Locks

Competing solutions are also a part of preliminary heuristic points. Since they are realistic realisations their analysis should be so thorough that the solution would not affect too much. There are lots of competing solutions in addition to the already described key ring with a tag.

One of them is a key purse where the keys are attached with a small ring to a chain whose other end is attached to the bottom of the purse. At first these purses had a zipper and it required two hands to open it. I suppose this solution is not on the market any more. Instead the key purse now sold by the shops selling locks can probably be held as the best solution.

One side of the purse is open. There is a tempered steel band around the purse and it forces the purse as wide as possible and at the same time closes the open side. The same band has a loop at the bottom of the purse where the ring with the keys is attached. The length of the chain is such that the ring barely comes out of the purse.

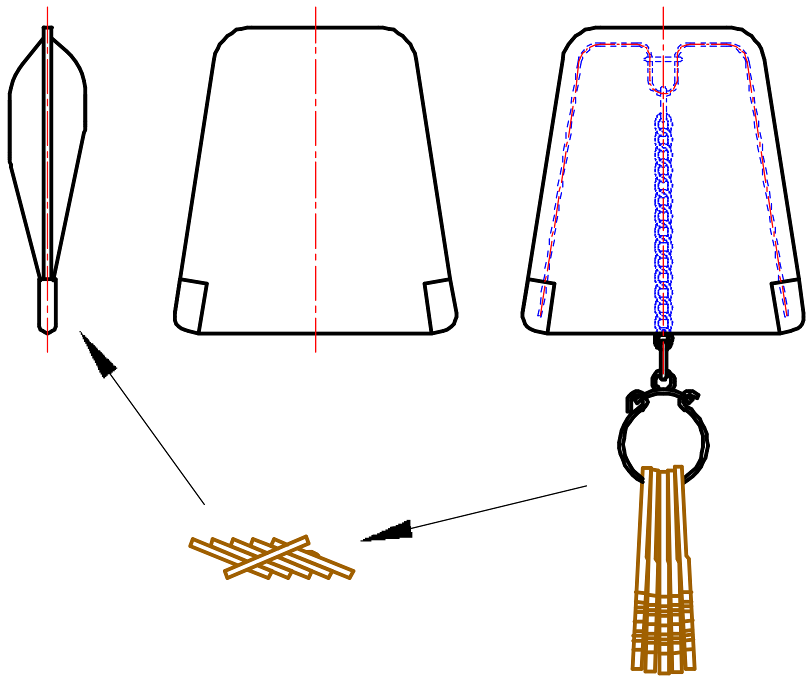


Figure 4.4 The solution of the shops selling locks

The solution is quite comfortable to use. The purse stays well closed but when pressed from the sides it opens and the keys fall down easily and form a neat bunch. After use it is easy to collect the bunch with the fingers and by pressing the sides in the same way to open the purse and let the keys fall back in. This can be easily learned to do with the left hand, also.

Eventhough the solution seems to be good and actually is the best one available its functioning is not always perfect. Experience shows that

a) *The purse does not always open properly, instead the sides of the opening easily bend to the same direction and the opening stays closed even tighter. Thus especially when trying to return the keys to the purse it does not function. It is irritating especially then when we have moved lots of things to the right hand and intend to manage the keys with only one hand.*

b) *The keys can become mingled in the purse so that the mixed bunch becomes stuck to the sides of the purse and do not come out even when shook. This like the previous case can cause a primitive reaction.*

c) *For a business gift the purse is not good since a visible name does not stay on it. A hard tag can not be used since the sides have to be able to bend in opening. Colour printings wear off easily. The name should be burnt to the skin.*

A purse is also quite large, 75x80x19 mm. The corners are quite sharp but they do not wear the pockets too much. Due to the bending capability of the purse it is not very easy to recognise it from the outside by just feeling, but pressing sideways it is possible. As figure 4.4 shows it takes space to pile the keys on a ring eventhough the bunch can incline as shown.

4.2.4.3 Real Heuristic Points

Real heuristic points could be defined as the incidental details examined that **clearly belong to the field of the solution and require creating ideas but not up to the final solution**. The first point can well be the

Key

A key is usually made in a shop from a prepared blank by machining an indexing that corresponds to the lock. We can separate, from the key, the part that goes into the lock, that we can not use for modifying. The cross section of the part pushed into the lock together with the strength of the material determine the greatest possible torque i.e. the moment of opening. The width of the loop that comes to hand, the width of the grip, has been dimensioned so that not even a person with strong fingers can damage the key.

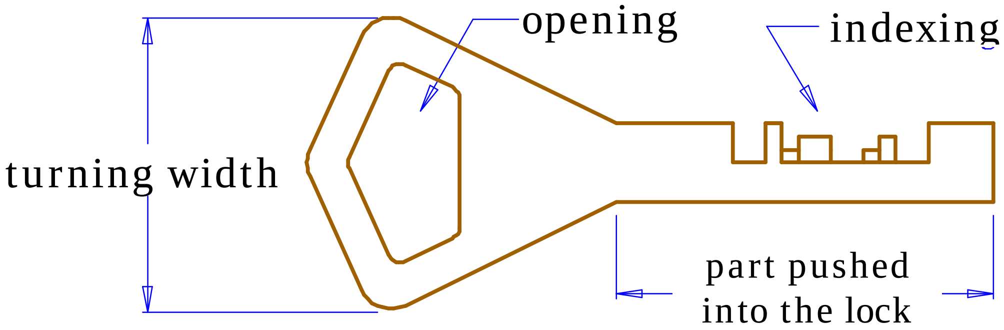


Figure 4.5 Abloy key.

It is difficult to bunch the keys due to the width of the grip. The width is 22 mm and the thickness of five keys together is 15 mm. 22 mm is too big for a thickness of the bunch and it would not be nice to limit the number of keys to only five. It might be possible to substitute the loop with a narrower form with a hole. Thus the torque by hand could be transferred to the key ring which would turn the key. The combination should be steady enough to avoid problems in pushing the key in.

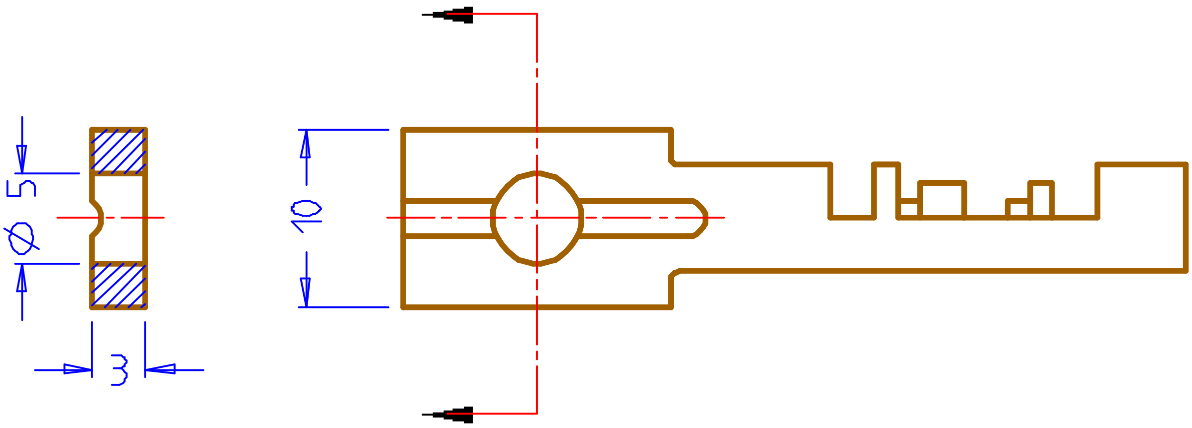


Figure 4.6 The key to pass through a pin

The key might be as in figure 4.6. In this figure we already see a side groove whose idea is presented later.

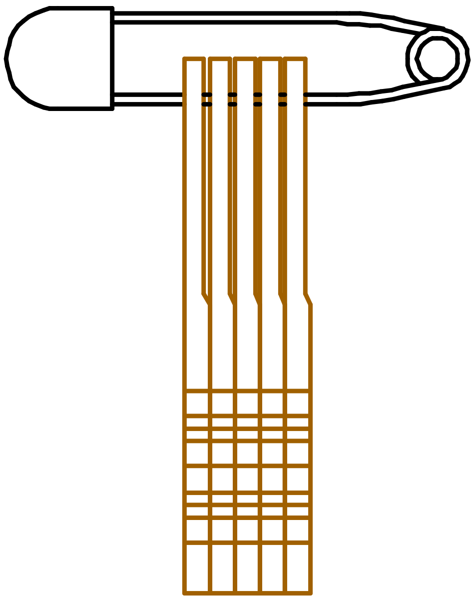


Figure 4.7 Image of a safety pin

We shall leave this image to incubate, i.e. the possibility to turn the key with a pin or a string that goes through its head. Paying attention to the indexing leads to an imaginary excursion eventhough it may reach outside the defined objective.

Perforated Card

Before the time of diskettes the memory contents of computers were run as ASCII code to a perforator that perforated cards or continuos paper ribbon. Same type of coding could be used as indexing of keys and as the entire key.

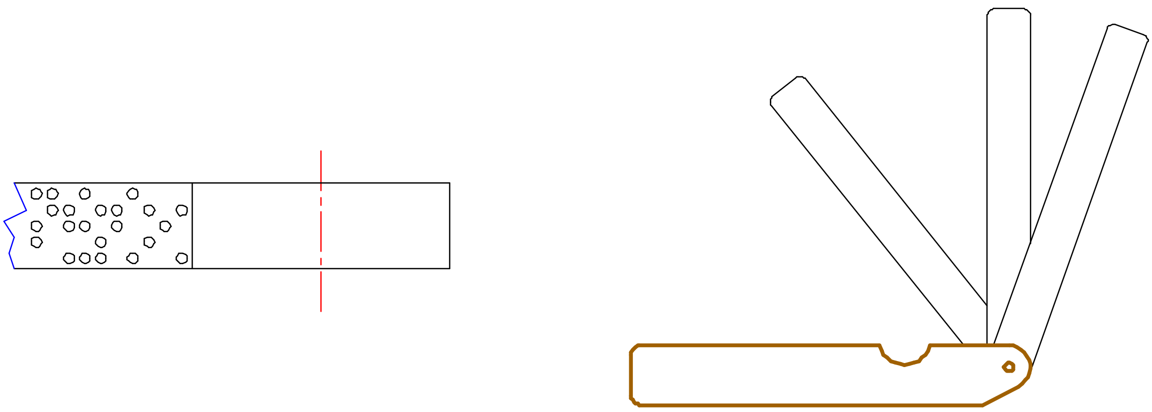


Figure 4.8 An ASCII ribbon and an image of a slit gauge

Only a few lines of ASCII code would be needed and it could be perforated to a sheet of metal or plastic. This instantly gives an impression of a slit gauge whose perforated plates would work as keys. We must not let this image influence us for a long time because it is too close to a final solution and our thoughts could get stuck in it. In addition we have to remember that this solution does not correspond to our objective.

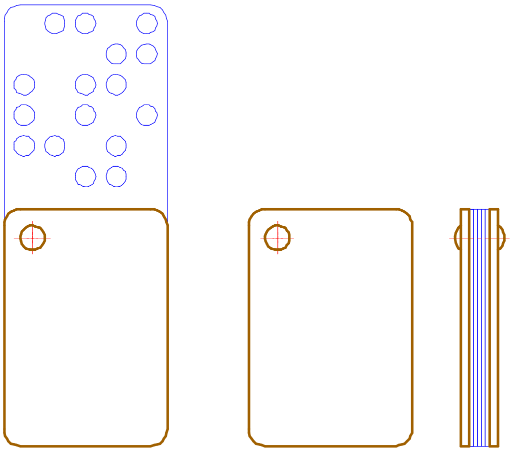


Figure 4.9 An appealing final solution.

Nevertheless it is worth while developing ideas from the perforated code or actually follow ideas already fulfilled. A Norwegian lock manufacturer called Viking produces locks whose keys are plastic plates with perforated codes. They are mostly used in hotels. It would be easy to pile them but

- *the plates break easily*
- *it is even more difficult to find the right plate from a pile in the dark as from a bunch of keys*

Still the idea has good points. Manufacturing the key used in for instance hotels is fast and easy. It also causes people not to pay enough attention to lost keys and the possibility of hotel burglaries increases. It should be possibility to change the codes of the locks after a certain period.

In North America a system where the customer of the hotel can self choose his code by saying or letting the computer choose it has become popular. The key is made at the same time and the door of his hotel room is electrically coded. The customer now believes that he is completely safe but there is still the possibility that some hacker collects all the codes in real time!

The perforated code could be substituted with a magnetic code like the code the bank cards use. It would be quite practical if we could make the hotel doors to function with the customer's bank cards. This would nevertheless require that there would be no interruptions in electricity because otherwise the door would open or stay closed during the interruption depending on the system.

Swiss Knife and Folding Rule

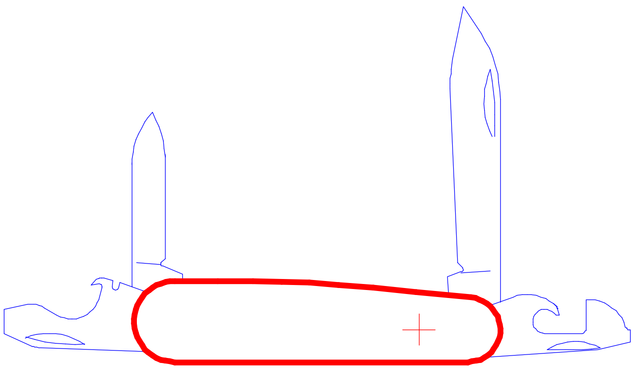


Figure 4.10 An image of a Swiss Army knife

Figures 4.6...4.9 developed the idea of placing the keys side by side on the same pin. The key to be used would be turned forth. It should be so stable that pushing the key into the keyhole would be easy. The images of a Swiss Army knife and a folding rule develop the idea further.

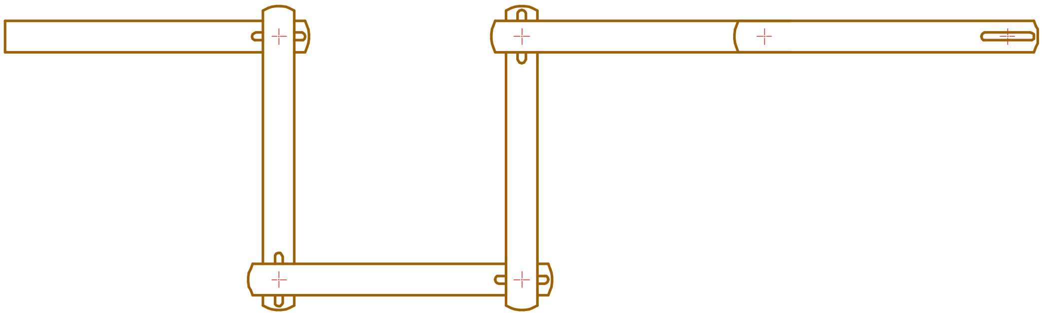


Figure 4.11 An image of a folding rule

A Swiss Army knife is a finished development of a set of tools to be placed in a pocket. It is stable and endures rough use. However its structure is stronger than needed for a combination of keys.

The folding rule was in earlier times made of wood, only the joints were of brass plate. The gauge usually broke due to the breaking of a wooden part. Later on the gauges made of aluminium were strong but their joints loosened. The gauges of today are completely of plastic and are very enduring.

The most interesting detail in these gauges is the joint. There are low grooves on the surface that fit the elevations of the counterpart. In this way the gauge stays quite firmly straight, together or in an angle of 90 degrees. Turning the parts relative to one another we first have to overcome a moderate resistance before the grooves and the elevations depart from one another and the twisting starts. In the plastic gauge the elasticity needed is achieved with a plastic plate of appropriate thickness that bends like a membrane. The best feature of plastic is its excellent resistance to wear with no need of lubrication.

4.2.4.4 Way to Final Solution

We now have almost all the material needed to create a solution. All the comparisons seem to take us to the direction that it would be obviously promising to change the key a little and place the keys next to one another on a hinge pin.

Since all the observation material is easy to get it is worth while to get it and test it ourselves. This is extremely important since we are talking about a solution that will be used by the hands. We thus need a key purse with keys, a Swiss knife, a folding rule and a feeler gauge or something similar. If there is time it is useful to do some other work and play with this medium of observation every now and then picturing them as the needed key device.

Before the final solution we still need one more heuristic point. It is however functionally defined so that it has the characteristics of a heuristic point only in its core from, which the final solution then gradually spreads out from. This core point is the placing of the key around the hinge pin so that it firmly snaps open and closed and stays there so stiffly that the use of it for the required task is easy.

the idea we seek, still deals with some type of a positioning device. An analogous one can be found for instance in the gear box of a car where it acts, so that in moving the gear stick the gears jerk to their place and stay there until a new gears change is done. The positioning device in question is as follows

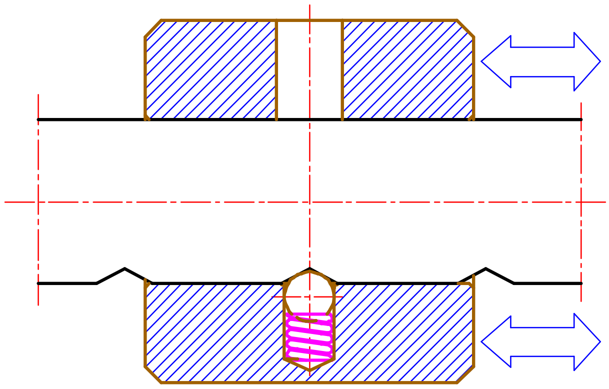


Figure 4.12 A positioning device of a gear stick as an image

The gear stick slides as a socket along an axis where pits corresponding to different positions of the gear have been milled. A hole has been drilled to the socket perpendicular to the axis. On the opposite wall the hole is a little smaller and has not been drilled through. There is a suitable coil spring and a ball pressed on it situated in this blind hole. The ball is kept in its place by upsetting the mouth of the hole when the ball is pressed down. Now when the socket moves the ball is driven into the pit of the axis and tries to stop and prevent the movement by pushing against the walls of the pit.

The size and the use of a gear stick is much rougher and of greater force than is required in the use of a bunch of keys. The force required in image shown in figure 4.11 approximately corresponds to that needed by a bunch of keys. The plastic in it has proved to be excellent when it comes to resisting wear and it is at least ten times more elastic than metal. Thus it is probably worth to choose plastic to be the material for the positioning device of the set of keys.

The small plastic parts are injection moulded. In this way various forms and details can be achieved with low expenses especially when the production amount is high. The key is made of metal so it is probably best to make it as simple as possible. Nevertheless in this case we could make a lengthways groove to the key for the positioning device as already shown in figure 4.6.

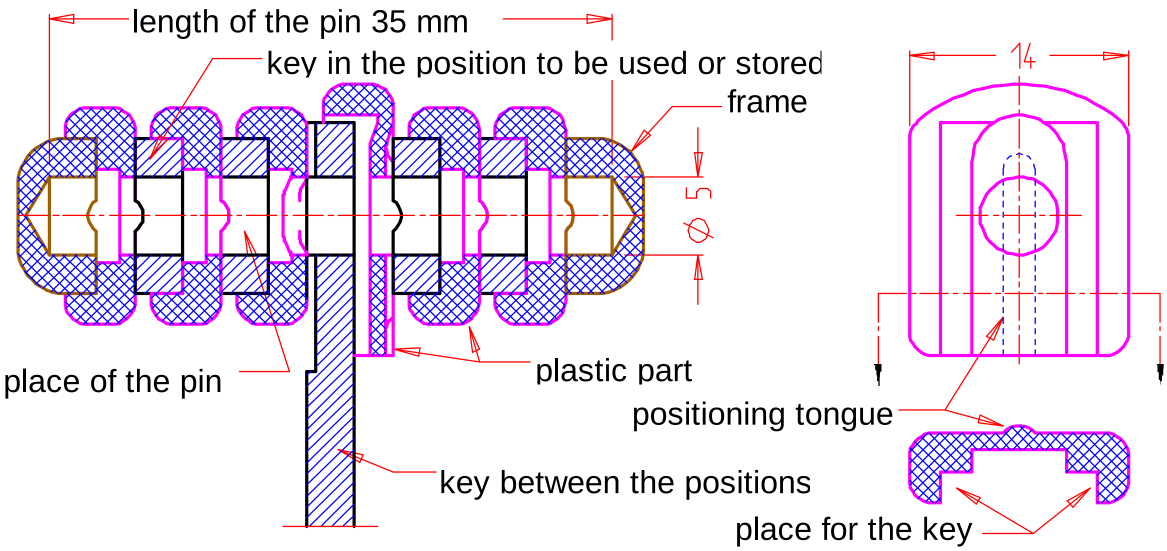


Figure 4.13 Core point: the joint

On the right-hand side of figure 4.13 we see the needed plastic part and its cross section. A suitable material might be nylon or polyacetal. When the key is situated in its place there is so much empty space that the elevation can settle there. Each key will be equipped with a plastic part and a steel pin is pushed through the bunch (not shown in the picture). The whole set is forced between the frame by bending the sides of the frame. The frame is also made of plastic and is of a size that a set of five keys is easy to force into it. The inner sides of the frame have the same grooves for the elevations as the keys have.

In both ends of the bunch there is a plastic part of the same form. When there are five keys the bunch is full. If less keys are needed the missing joints of keys are substituted with corresponding filling blanks so it is possible to add keys later. The plastic parts can be of different colours so that they make it easier to recognise the keys.

An appropriate tightness for the system is hard to estimate beforehand. It can be slightly affected by changing the hardness of the plastic. Instead of nylon, we could choose for instance polyethylene, which is much softer but still enduring enough. The method of mounting may also need some experimentation. The tightness can be controlled by the length of the pin. In an extreme case the mounting can be made easier by warming the frame so that it softens. The result is shown in the next figure.

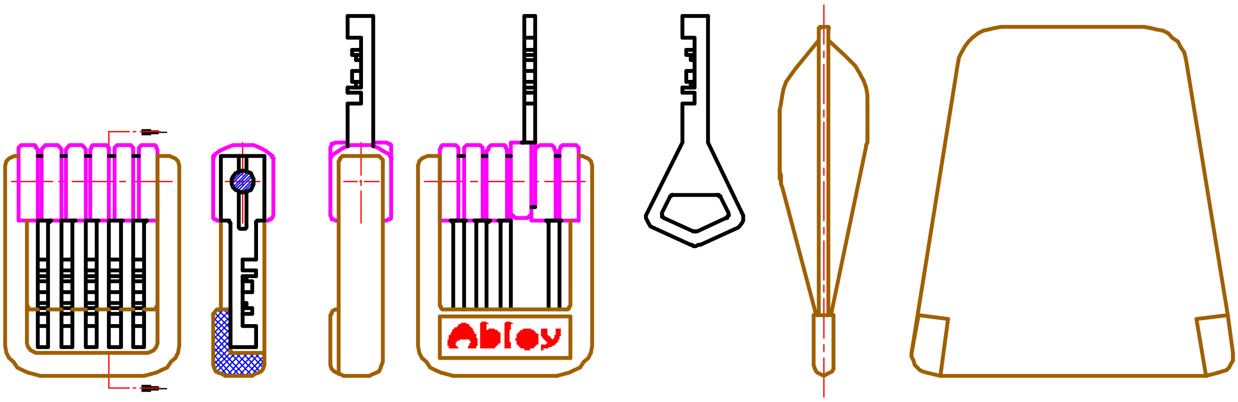


Figure 4.14 The result in comparison

On the left side we see the bunch of keys collected in the storing position. The next figure shows its cross section. The size of the whole device is 40x53x14 mm so the place needed is diminished by 74%. The next pair of figures to the right shows the bunch in the operational position. There is a plate added to the back of the frame against which the keys can be pushed into their storing position. This same plate is also a suitable place for the logo of a company. Any name or information can be attached to it with a tape or using colour printing.

All sides of the bunch which touch the pockets are of plastic with rounded corners so it should not be unpleasant in the pocket. The hardness and suitable thickness make it possible to check that it is in the pocket, just by feeling from the outside. Designing the frame was a purely mechanical design. A small additional idea was the surface for the logo which is also possible to use as a positioning support for the keys. The device is meant to be used with one hand. The wanted key is pressed with a finger through the frame so that it rises up to the using position. Due to the small dimensions surely one or two neighbouring keys also rise but they can easily be returned to their places. Since the keys are in a steady row inside the frame it is easy to feel the right key by counting its position from the side.

4.2.4.5 Examining the Result

The whole development seems to fulfil the expectations set for it. Still it is just a design that has not been tested. Care should be taken in deciding to manufacture or market it. The following open questions regarding its properties remain worrying

a) *The bunch of keys has to be treated as one stiff piece when opening the lock. It is so small that there should be enough space around the lock. However the human hand is very good at handling keys on a loose ring and then due to the small grip width the use of one key is easily done with the fingers. Is the new unit too big and clumsy for this? Does the key go into the lock as easily as before and does it also easily come out? An answer can be found only after testing with a large group of people. The result can be very negative. The situation can be compared to the readability of watches with digital displays and hands. The digital display was supposed to be better but it is better only when the time has to be written down or told to somebody.*

b) *The larger turning width gives more force to the turn of the key. For children and old people it is surely useful but does it on the other hand cause that more keys break?*

This example portrays the progress of an ordinary product development process from beginning to end. It was completely based on the intuitive method but included a lot of structural dimensioning and drawing. Dimensioning consists of the study of the strength of materials and knowledge of materials and it is not presented here.

We should pay special attention to the following. There were no completely new ideas in the developing process. All the ideas used are based on earlier experience and perceptions. Nevertheless the solution is completely new.

This demonstrates the immense meaning of the experience loaded into the subconscious mind, in that the experience is capable of moving and connecting to various tasks. Obtaining this ability is the largest inhabitant to the development of efficient working of a designer compared with other professions.

In addition the example shows how the use of plastics, compared with the use of metal, is learned to be very slowly. This learning process is still unfinished eventhough there has been suitable plastics for decades and their physical properties have been fully known. Designers have always been slow in adopting new materials and methods and still are. Examples are for instance the use of electronics, new ceramic materials, new manufacturing methods, laser's etc. in addition to plastics. However, it is only after the designers adopt these novelties that we can really use them to our advantage.

5. Intuitive Engineering Design

In chapter 4 I presented an intuitive model of creative working, which is based on the efficient use of the subconscious mind. The idea of the model is, that our subconscious mind is that particular area of our mind where the insight is formed. All conscious and subconscious action can be pointed to promote the subconscious process. In practice it means at least as much conscious working as in systematic action models. However, in the intuitive mode of creative working I emphasised, that any too far reaching conclusions should be avoided by all efforts. It can be considered as a criterion for the skill, that one can solve the whole problem without trying any kind of solution.[19]

After the problem is completely made clear and known from all points of view, there should be no problems to find a good final solution. It is only a matter of adaptation of professional skills and purchased knowledge. No super-human Eureka-insights are needed in the matter. However, one can occasionally experience even those super moments, too.

This model of action seems to be universal despite the of lack of published descriptions. My description is based on my experiences as an engineering designer. Hence, the applicability toward machine design is confirmed. I have seen it in the working routines of my numerous colleagues. Where as, I have never seen in practical engineering design, systematic working i.e. brain storming, gallery method, method 635, synectics, construction catalogues etc. In engineering design the creative work is always focused on concrete structures, too. Hence, the action model presupposes the study of operating region, equipment and its optimal use.

5.1 Design Work Environment

Design is a kind of work, where the subconscious mind has a leading role. This makes it inevitably a work of an individual, because a team cannot have a common subconscious mind. However, every individual has his own subconscious mind, which can be activated to take part in the solution of a common problem, after the necessary communication method is attained.

Design is conscious thinking and the use of logical methods and many kind of mathematical methods. These are, however, only tools and after all the most demanding design work is wordless discussion between the drawing and the

[19] "Intuition, I guess, is something that has nothing to do with logical thinking. It's just something that's in your subconscious mind. And I guess the subconscious mind is the much more intelligent part of our mind, compared to just logical thinking of our conscious mind. In this sense, I believe very much in it. I think it's the most important part of us, intuition." - Gerd Binning, Nobel-prize winner in physics 1986 in an interview on Swedish television.

draftsman. It is not possible to emphasise the following fact: **Only by drawing it** can it be designed, not by talking, calculating or criticism! The designer has a continuous discussion with his drawing and his own comment is to add more lines to that drawing.

It is extremely important, that this design environment is made functional. That is to say, that the drafting is technically easy and accurate enough, the old drawings are available and the results of drawing can be preserved and copied for use by all designers in the team.

Machine elements are not always presented in the same way in drawings. Leonardo da Vinci in the 16th century drew his machines in the same way as he painted. They were 3-dimensional and very illustrative, but the drawings did not give any idea of detail in the structures. By the way, Leonardo thought his work to be very logical and systematic! James Watt in the 18th century used the same 2-dimensional manner of representation as we do today. In the beginning of the 19th century, among the dimensioned 2-dimensional figures, there were also 3-dimensional sketches (e.g. Reichenbach) having sometimes dimensioning, too. Later on the normal practice has been to present machines in 2-dimensional projections from main directions added with some cross sections to give more specific information. It has proved to be the most precise method for accurate design and manufacturing. This practice of drawing is a standard, de facto, and it has been completed with standard practice of line thicknesses and line types, dimensioning and tolerating.

Standard practice in drawing is important for creative design, because it guarantees the uniform interpretation of drawings and as a fast subconscious process it makes it possible to get an idea of the structure in 3-dimensions also. The routine use of drawing equipment is extremely important for fluent communication with the drawing. Even the equipment were standardised all over the world, thus the design work abroad did not include any remarkable adaptation to the local equipment. Then we got the new way to design on the screen and it has changed almost everything. Unfortunately this change is not considered everywhere and even the most experienced generation of designers still try to neglect the use of screen.

5.1.1 Adjusting the Drafting Practice on Screen

The Northern standard of drafting especially, was adapted to cope with the use of drafting boards, pencils and ink pens. This standard is not the best to be used with the screen. In screen working there are inevitably features and possibilities to be catered for by modifying this standard a bit. These features are:

a) *The screen is always small and good readability assumes zooming. Therefore the screen area is used as efficiently as possible by making the pictures and their dimensioning more compacted.*

b) *Laser printers has proved to be the most powerful in printing today. It does however have one major problem; the size of prints is small, mostly just A4. However, the precision of the printing is so good, that using skilful packing an ordinary hand-drafted drawing of A1 size can be presented rather well with laser printer in A4 size.*

c) *The information power of a crowded screen can bee increased considerably by the use of colours. The skilful and rational use of colours should be conformed to make the interpretation of the screen faster.*

d) *Output devices, plotters and lasers, are making intermittent lines with the same speed as continuous lines. The use of intermittent lines makes the drawing more illustrative when the plotter can use only one line thickness. This is also useful when transmitting pictures to be used with word processors.*

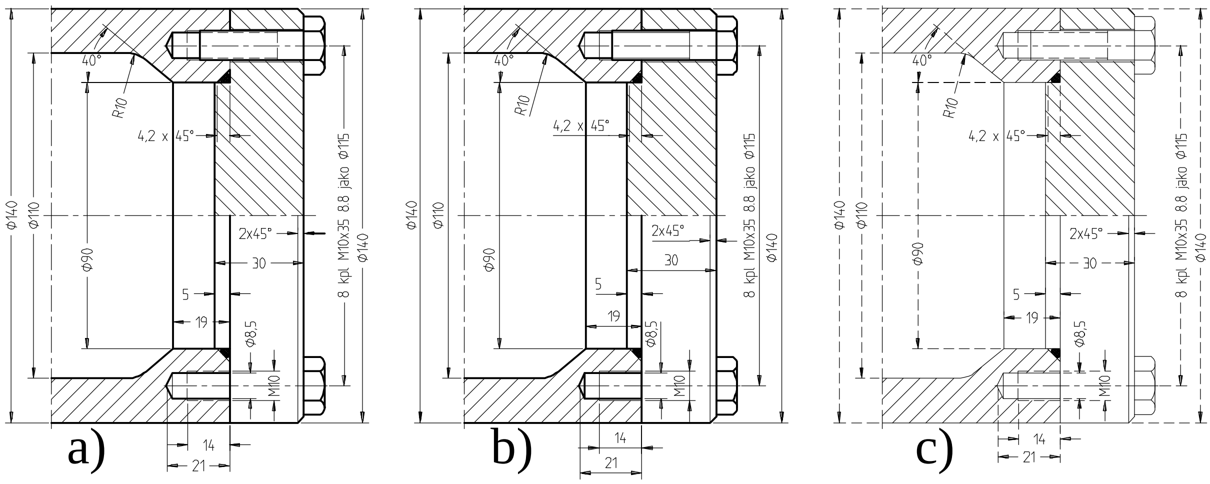


Figure 5.1 Modifying the machine drawing

Fig. 5.1 a) demonstrates the drafting practice in the Northern countries before the 1960's. It was modified in favour of manual drafting as presented in fig. 5.1 b). The placing of dimensions above the dimension lines requires more space and may mislead the interpretation. In fig. 5.1 c) only one thickness of lines is in use, but the dashed lines are more in the background and the form of specimen is clearly visible. Eventhough the continuous lines are thicker than dashed lines, this practice is clearer than the other alternatives. At the same time the marking of dimensions would follow the practice in fig. 5.1 a). It is the same practice Reichenbach already used at the beginning of the 19th century.

All pen plotters love the dashed lines, as they always have problems with clogging thin line pens. By drawing dashed lines the pecking movement of the pen keeps it open in a far better way than when drawing only continuous lines.

5.1.2 Use of Colours

The prints of drawings probably will be black and white even in the distant future. But the screens are mostly coloured and the use of colour screens is more and more common in manufacturing. Only on-site assembly still needs prints. The colours increase the amount information on a crowded screen and they make interpretation easier, with one condition; with the use of colours an uniformed practice should be reached. In the use of colours there are two principles:

a) *In the figure of a part only one colour is used in profile lines. The colour may be changed, if some detail needs to be emphasised e.g. for machining at a special phase. The use of the same colour is favourable for parts of the same* *type. All rotating parts, for example, could be drawn using the same colour. Soft parts like rubber could have a common less frequently used colour like magenta.*

b) *The intensity values of colours can be used to classify different types of lines and at the same time they may be connected to certain thicknesses of lines. Hence, the dimension lines could be dark, which corresponds to thin lines. The most intensive colour is white, thus the use of it could be reserved for the thickest lines only.*

The number of colours should not be increased unnecessarily, because the recognition of them would not be sufficient. The base colours are red, green and blue, thus these colours have the thinnest lines on the screen. The darkest of them is blue and it should be used for dimension lines, hatching and hidden lines. The next in intensity is red and it could be reserved for symmetry axes, but also for hatching and profiles of the smallest parts. Both colours will be plotted with the thinnest line, ca. 0.2 mm. The brightest base colour is green. It could be plotted with mediate line thickness 0.35 mm. It is used for profile lines of tiny parts, because the normal profile line thickness 0.5 mm could not present the shape properly.

All other colours are mixed from base colours. If the full intensity is used in mixing, they also appear brighter and thicker on the screen. Those colours are cyan, yellow, magenta and white. Cyan and yellow are used in normal profile lines and they are plotted with 0.5 mm. White is reserved for the most emphasised and thickest lines and it is plotted with 0.6...0.8 mm.

For the clear presentation on the screen the hatching colour could be the same as in profile lines of the same part. This is not possible, however, because the hatching should be plotted with thin lines and the line thickness is connected to the colour. If all hatchings would be blue, the common expression of the whole cut part would be blue and the individual parts could not be distinguishable. So, we are left with only two alternatives. We can group the sections with two colours, blue and red, which is good enough.

The best colour for dimension lines is blue. During planning on the screen, no dimensions are read in the first place, just the shapes and structures. Hence, the whole mass of dimensions and dimension lines may be less emphasised.

In the use of colours the following order could be considered. All rotating parts are drawn by cyan (colour of machined steel). All bought components despite size will be green. All other profile lines are drawn with yellow, except soft plastic and rubber parts which are drawn with magenta. The use of magenta should be limited, because it is somehow irritating. Many screens and especially video projectors, for some reason, have difficulties to present magenta and it is spread to form unsharp, broad bands.

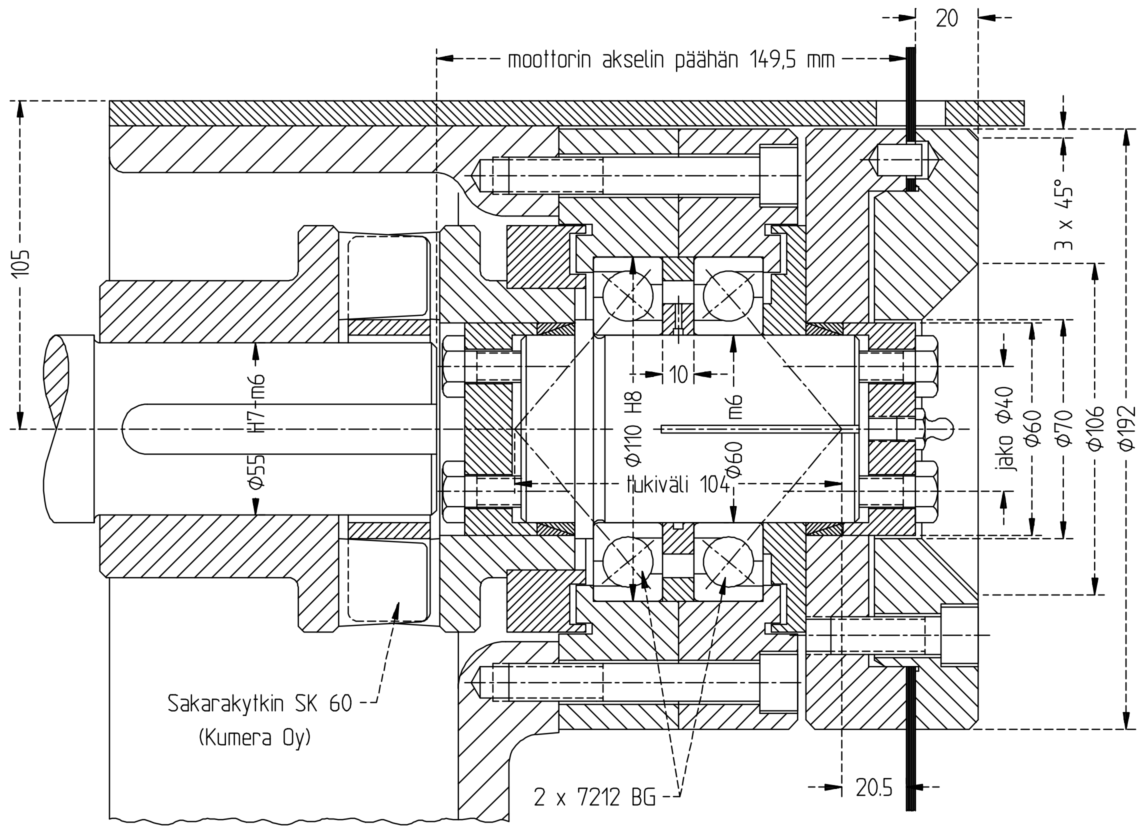


Figure 5.2 Drawing using only one line thickness

Figure 5.2 demonstrates a axle group of an edger using only one line thickness and line colour. The use of dashed lines, however, makes the picture clear and readable, because the dashed dimension lines vanish into the background and the shape is emphasised more clearly.

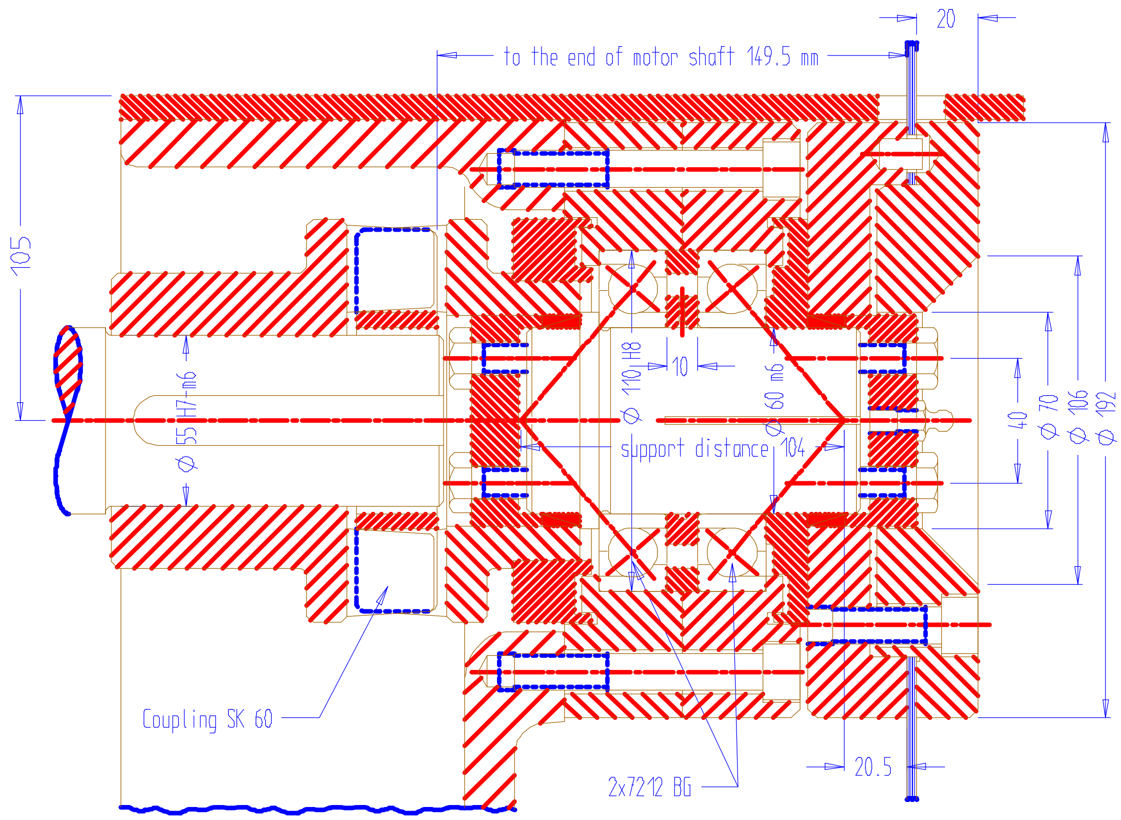


Figure 5.3 Two line thicknesses in illogical order

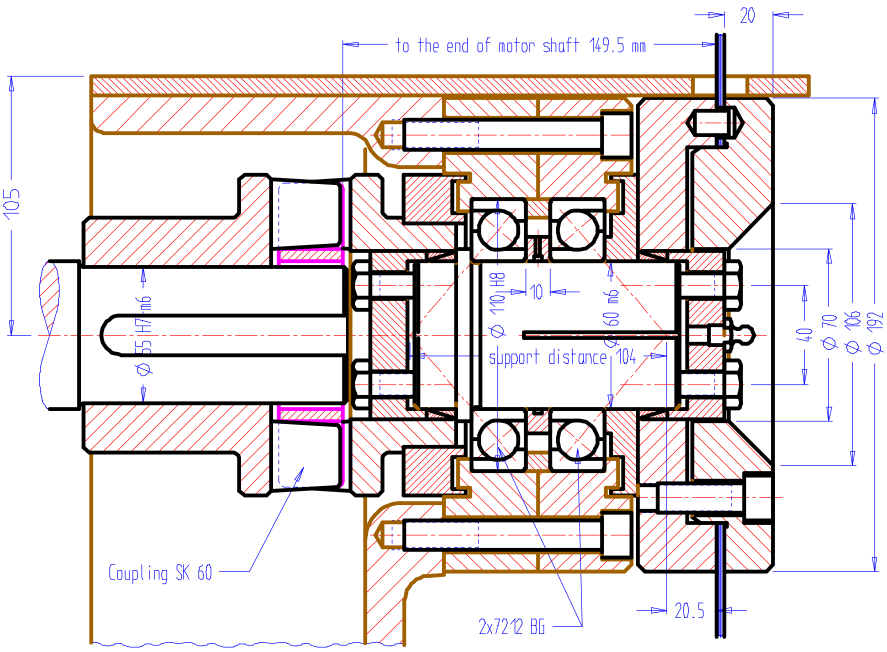


Figure 5.4 Two line thicknesses in logical order

Hatching lines, symmetry axis and dimension lines are presented in fig. 5.3 with thick lines, shapes with thin lines. The impression is very confusing and the interpretation of the picture demands much of time. The impression is about the same as looking at a picture, where all profile lines are blue or red and all dimension lines and hatchings white, yellow or cyan. Even the human eye is very adaptable and quick to learn to interpret this upside down colour sequence, the more natural sequence would be interpreted faster, however.

The most important thing, however, is to keep the same colour sequence in all drawings. The importance of fast interpretation of the pictures cannot be emphasised too much. We are already used to maintain the certain thickness order of lines, as picture 5.4 compared to picture 5.3 demonstrates. We should also find a uniform colour order in drafting practice.

5.1.3 2D- and 3D- drawings

The world and machines are all 3-dimensional. It might be, by all means, natural to reach 3-dimensional presentation in machine drawings, too. This has also been the keen goal in developing CAD-systems for designing on screen. This goal appears so important, that the development of 2-dimensional CAD-systems for engineering design is of interest to only a few companies.

It is true, that a decent visual expression assumes 3-dimensional form. Sculpture had already reached the antique level in the 13th century and the progress after that is not significant. In contrast to that, 2-dimensional painting on canvas was at its antique level a long time ago, nevertheless painting was not able to project the 3-dimensional shape with the correct perspective until the late 15th century. Therefore, even during its antique period the painting was less developed than the sculpture.

Machine design, however, studies more the structure and the function than the visual expression. In the design process it is more important to present the structure to the correct scale, to recognise the use of space and the function and the drafting should be fast enough despite the correct scale. For these purposes the 2-dimensional picture projected in the main planes is a better expression tool than the projection of a 3-dimensional structure on some other plane, not to mention the perspective projection.

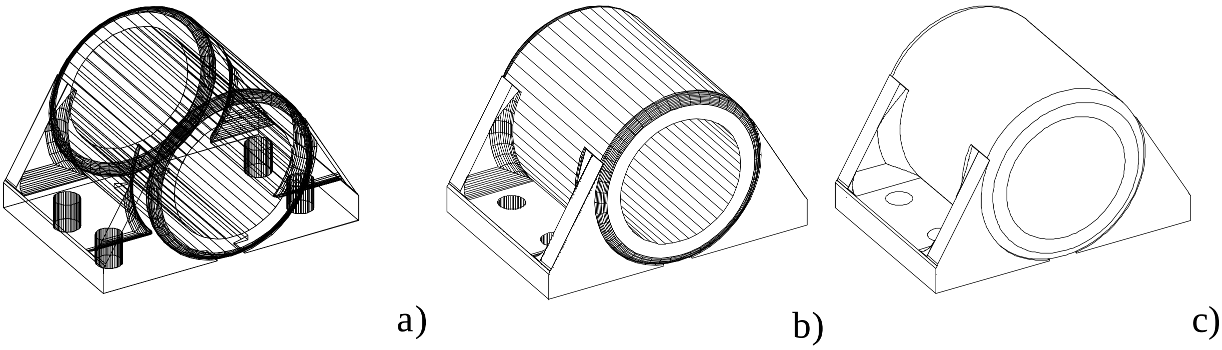


Figure 5.5 Guide block in 3-dimensional projection

Fig. 12.11 demonstrates a cast guide block in two projections on the main levels. The projection perpendicular to the main axis has the left side sectioned. Perceiving the 3-dimensional shape of that kind of picture takes some training and effort, but on the other hand, the projections give the forms more precisely. The precise wall structure in both main projections is presupposed already by the foundry.

Fig. 5.5 presents the same block as another projection giving the 3-dimensional expression on 2-dimensional paper. Item a) demonstrates all needed volume elements. Item b) makes those elements visible, which are not hidden behind the others. In item c) the borders of the elements are invisible and the picture is presented with profile lines only.

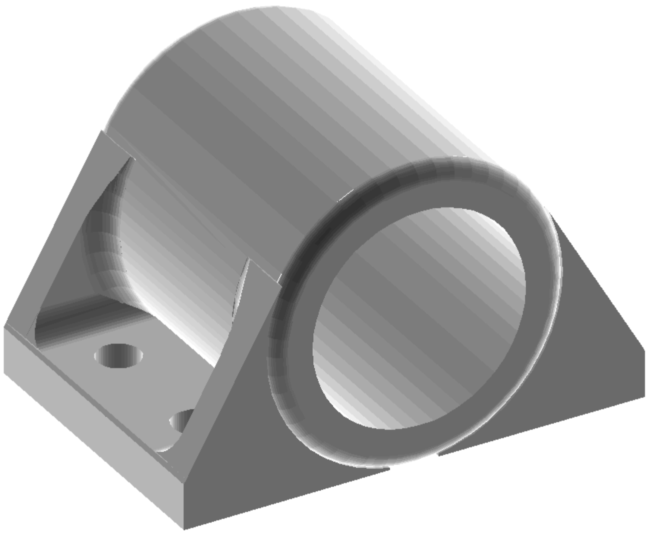


Figure 5.6 Guide block as rendered picture

The creation of a 3-dimensional projection takes very much computer calculation and much space in filing the picture. The size is increased tremendously, if the specimen has much fillets and round forms. Fillets cannot be placed in all corners, at least not in all CAD-programs. In fig. 5.5 the fillet between the bracket and the cylinder is missing. The filing size is over 20-fold compared with the 2-dimensional drawing. The presentation of dimensioning is also rather difficult in 3-dimensional projection.

The fillets are not very illustrative in fig. 5.5. Instead the picture may be rendered using different lights, creating much more natural expression. The rendered picture on a colour screen serves the industrial designers well. Presenting it in black and white does not describe the result very well, fig. 5.6.

3-dimensional projection is not very useful for castings, anyway. It is like wisdom after the event and it does not give the possibility to fix the structure. For any changes we have to go back to the 2-dimensional picture. This matter reminds us of the FEM-method, which is also somehow wisdom after the event. Instead of that the presentation of complicated plate structures in 3-dimensions does not take much work, but it provides an excellent service making the insight into the structure easier.

In welded plate structures the real shape is sometimes extremely difficult to realise, because all parts are thin and it is difficult to distinguish between them in 2-dimensional drawings. On the other hand all roundings in 3-dimensional modelling can be neglected and thus, much space is saved. 3-dimensional projection can be added to a 2-dimensional drawing for manufacturing. This addition is extremely worthwhile because it makes the quick and correct understanding of the drawing possible. This idea proved to be useful in the manufacturing of the radar reflector, fig. 11.17.

5.1.4 Equipment

Manual drawing is already out of date. A personal computer (PC) together with some proper CAD-program can fulfil all the needs of engineering design at least when the main presentation system is 2-dimensional. Today they are able to produce thoroughbred volume modelling, as the former picture shows.

PC's can be furnished with an operating system, which makes single user multiprocessing possible. The most important need of engineering design is hereby reached: At the same time one can draw, calculate and file the calculations as a document. Literal notes can also be written and no paper is used.

Many textbooks of engineering design emphasise the use of 3-dimensional sketching in the presentation of ideas. It is true, that the idea can be presented so, but what benefit is there? In practice the sketch is always inaccurate. It calls for final design and leads to blind pass, because of the actual need of space. A good sketch binds the thinking and the development of the idea is stopped. However, my negative attitude is based on the fact, that I am a lousy drawer.[20]

Sketching may be started directly on the screen, with the idea of adding details and avoiding connections between them, at the same time. Hence, the structure takes shape only in the imagination and it can vary freely betweeen all points of view which pop up. The main idea is, that every design problem has a good concrete solution, which no one has seen so far. A thorough study of the problems different points of view instructs the designer towards seeing, what the solution will be. After the designer has learned enough, making the solution concrete is routine.

As a good quality screen is needed for drawing, the 17" colour screen with an accuracy of 1024 x 768 pixels, sufficiently suits the requirements. The speed of the screen driver has no relevance to machine design. Industrial designers really need fast screen drivers, because they use many rendered 3-dimensional pictures.

[20] My teacher took our class to the bay on purpose to sketch ducks in there actual surrounding. When she saw my sketching on paper, she burst into tears. I could not believe myself either, that I was going to earn the living for my family as a drawer of machines for over 20 years. Still today, I have no idea how to draw ducks.

The area of the screen is limited, thus the use of it must be efficient. The figure must be panned and zoomed frequently and it is important hereby, that the eye contact to the screen is continuous. Therefore the designers prefer screen menus and mouse instead of tablets. The disadvantage of the tablet is, by using it eye contact to the screen is loosened frequently and the head must be turned. The focusing point of the picture is vanished and finding it again takes time. In addition to that, the tablet takes excessive space on the table.

Because of the limited screen area it is difficult to get a common idea of an unaccomplished work. Therefore it is useful to take out provisional prints with laser at its best. The provisional prints help to compare the results of various phases. That makes the choice of which are the best paths to be developed, easier.

Even the design work on the screen is very different from manual drawing work, learning it does not take excessive time, some weeks is enough. If one can manage both working methods, he finds, that making a proposal on screen takes about the same time as making it using manual drawings. However, the possibility of making changes is so fast and all generated material can be used so beneficially, that the final drawings can be prepared in less than half of the time needed in manual working.

Because the planning on the screen always propagates to the accepted comprehensive presentation in the first place, all following detail drawings can be separated and prepared so fast and easy, that the ordinary detail drafters can be neglected. Thus, many errors and misunderstandings can be avoided.

5.2 The Intuitive Method of Creative Work in Engineering Design

Example: Feed Rolls of Logs

In chapter 4 I presented an intuitive method of creative work. The example presented then, a key holder, was very simple and general. It had no dimensional, functional or manufacturing and assembly argumentation, which is typical in all engineering design. In engineering design all of those arguments must be analysed, dimensioned and fitted together. The result must be criticised widely considering the adaptability in different tasks, limitations, possibilities to join with standards etc. The verbal description of this process does not reveal the content deep enough, thus let's try to follow it using an example.

Figure 5.7 Log before sawing and cant after the first sawing

The sawing of the logs is done in two steps. In the first step the log will be placed as exactly vertically level as possible along the feeding line. That means, that the main curvature is directed either up or down. The first sawing in called headrig which involves taking 1...3 boards from both sides. The result is a curved cant having two parallel machined surfaces, which will be turned on the feeding table. During the second saw pass the cant is divided into 2...8 boards and planks using a gang saw with multiple saws. The main part of the lumber is produced during gang sawing, thus the feeding of the cant must be done as exactly as possible without any transversal movements.

5.2.1 Penetrative Analysis of the Task

Fig. 5.8 demonstrates a common structure used in this task as a simple sketch. Its need of power, clearance between feeding rolls and the basic structure is illustrated here as it really is, thus making it a monolith and consequently hard to analyse. Everyone can see, the way in which the device works and how the cant moves forward with constant speed along the feeding line. There are no attributes present for this device so long it works properly. By eventual malfunctions our attention is focused on the elimination of failure, in the first place and the only influence on us is a negative aggression against a badly working device. Only when the user has got enough and he starts to think about purchasing a new one, does he also starts to think about what characteristics the new device should have.

The designer always tries to find a new modern solution based on the best possible knowledge of the needs and possibilities and on the possibilities of unifying them. Hence, penetrative analysis should be done to the structure. The analysis of the old structure teaches us to understand the task. Sometimes this lesson is decisively important, sometimes it does not help us significantly, but we can never know its effect beforehand.

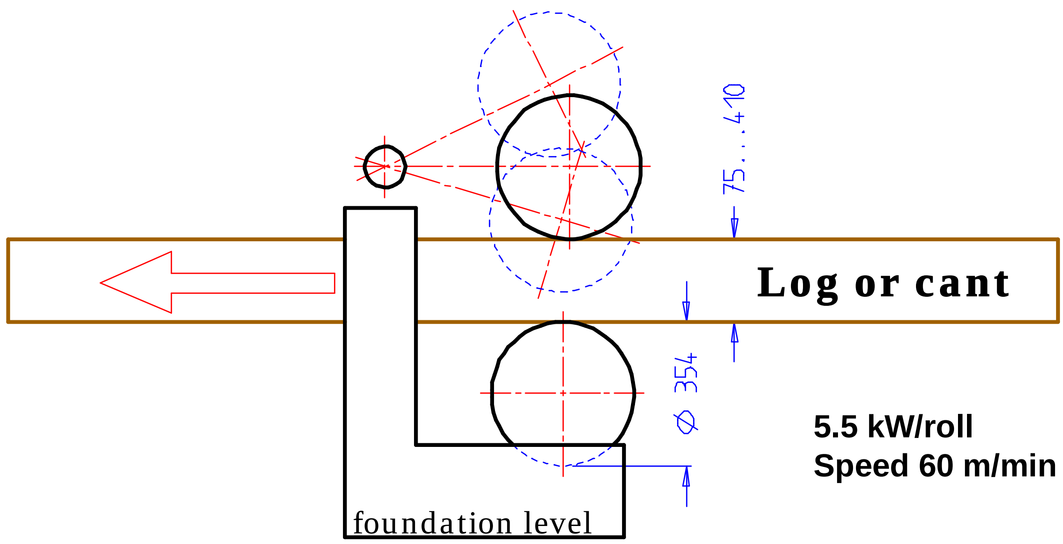


Figure 5.8 Sketch of the feeding device

The feeding device consists of two rolls squeezing the cant on both plained surfaces and pushing it forward with a speed of 1 m/sec. According to experience the feeding power of ca. 5.5 kW is needed for both the rolls, enough for medium size cants in all situations. The surface of the rolls is notched in order to get a good grasp of a wet cant. If the value of the friction coefficient is set to µ = 0.4, a squeezing force of the rolls, F = 14 kN, is needed.

A feeding force is needed e.g. by a double arbour gang saw having motor power of 160 kW on each arbour. The cutting speed of the saws is 75 m/sec. The rim forces are:

$$F_y = F_a = \frac{160{,}000}{75} = 2133 \text{ N}$$

When the directions of the rim forces are considered, the needed feeding force is

$$F = 2133 \cdot(\cos 26.57^0 + \cos 33.98^0) = 3677 \text{ N}$$

This is based on the assumption, that the cutting force is really tangentially directed. When the teeth get dull, however, the cutting forces turn more towards the feeding direction and thus the feeding force may grow considerably.

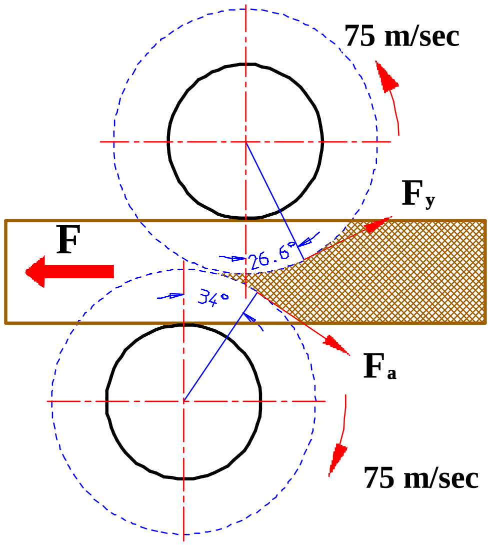


Figure 5.9
Need of feeding force in double arbour gang saw

The feeding power of each roll was 5.5 kW and the feeding speed = the rim speed of the rolls was = 1 m/sec. According to that the produced feeding force is the same as the sum of rim forces

$$F_{feed} = \frac{5500 + 5500}{1} = 11000 \text{ N}$$

The force is about 3-fold compared with the calculated need. But even the dulling of the saws increases the need for feeding force and there are also other losses of power.

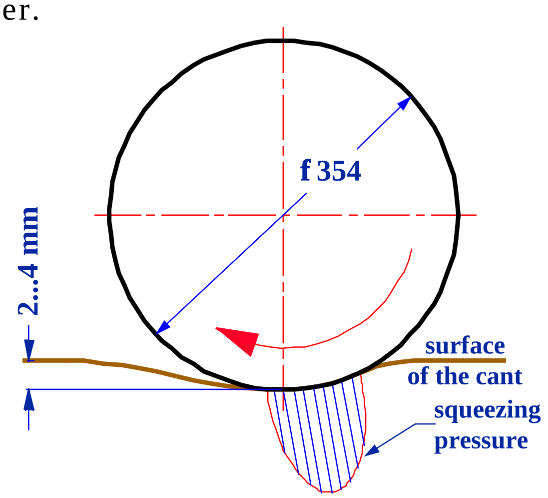


Figure 5.10 Deformation of the cant surface

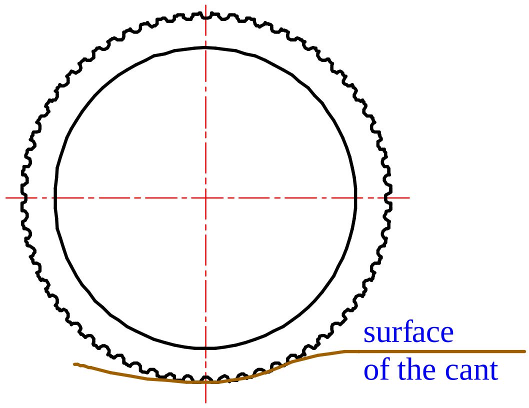


Figure 5.11 Notching of roll surface

The wood to be sawed has plenty of water between the wood fibres. When the roll squeezes the surface, the water comes out at the squeezed point and the deformation is about 4 mm. Because of the removed water the surface does not rise up very fast, thus there is a significant hysteresis of the forces, which turns the reaction force of the squeezing against the feeding force, fig. 5.10. The bursting water lubricates the squeezing surfaces and the feeding power may be lost completely. This can be avoided by using the notches, fig. 5.11.

The tilting of the squeezing reaction means there is a need for extra feeding power. Increasing the diameter of the roll obviously reduces the tilting of the reaction. Reducing the diameter increases the tilting angle and makes the pressing area narrower at the same time. This leads to the situation, where the resulting feeding force is not sufficient any more. The rotating roll digs itself into the cant surface and the feeding is stopped completely. The phenomenon is similar to the situation, when a car stops in sand because of the wheels digging into the sand.

All these phenomena together bring about the fact that the 3-fold theoretical feeding force is not over dimensioned at all, because the actual feeding force is only a varying fraction of that. If the rolls are directly driven with asynchronous electro-motors, they have a peak value of torque of about 2.5...3 times the nominal torque. This extra torque causes the gliding of rolls, because the feeding force is limited by the squeezing forces of 14 kN exerted by the rolls. The damaging of the cant surface is a result of the gliding and therefore the torque must be limited with good accuracy below the gliding. The best limitation is accomplished by using a hydraulic drive.

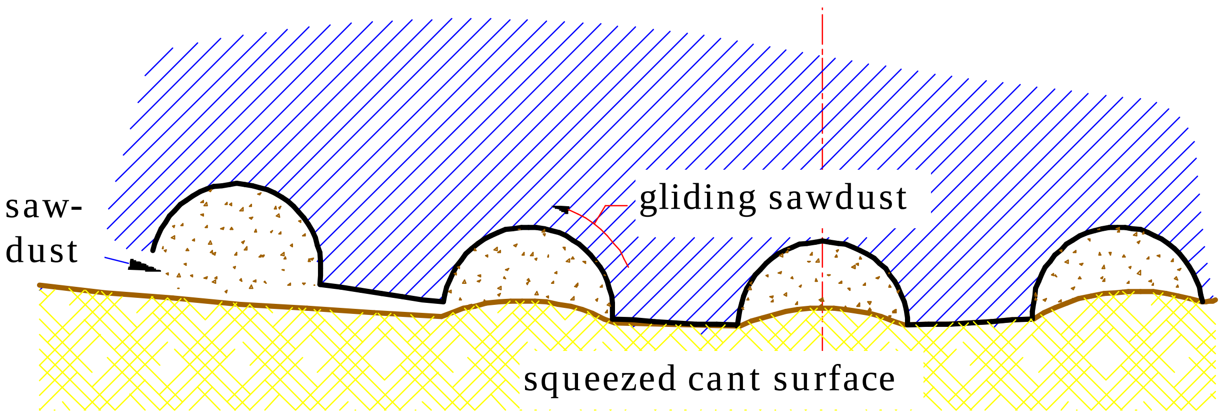


Figure 5.12 Forming of longitudinal notches on feeding rolls

The notching of the rolls increases the friction coefficient enough, that the wood surface sinks partly into the notches and the bursting water has free space to run out. There is always sawdust on the surface of the cant and it tends to seize and fill the notches completely. That was a big problem when using notches with sharp corner in the bottom. But if the notch was formed to have a round bottom, the squeezing function turned the dust making it roll and glide against the notch bottom, thus the notches remained empty and clean, fig 5.12.

There was a thick wall tube in the storage of dimensions producing a maximum outer diameter of ϕ354 mm. The length of the roll (500 mm) has proved to be sufficient. So the main dimensions of the rolls are the same, as before. There is no need to change them. If the outer diameter is reduced, it causes difficulties in the space needed by the driving units. The minimum clearance between rolls is only 75 mm. If the feeding capacity is exceeded, an increase in squeezing force cannot help, because even the notched roll digs itself into the surface of the cant. Friction is not decisive here, because the wood material cannot hold the force exerted by the narrow pressing area and it tears off. According to experience ϕ354 mm is big enough to prevent that and while the proper tube is available, no more discussing is needed.

The first sketch in fig. 5.8 must be completed by a sketch on the level of the feeding roll axes. The driving units can be made visible, too. Calzoni's slow running hydraulic radial piston motors are used in this case. They are well suited to the situation where the motors must not brake the feeding. Before the headrig unit, the chipper canter sometimes pulls the log so strongly, that log feeding must occasionally be braked. To do that a combination of electro-motor and gear could be used. But that has no effect to our design task.

The sketch will be made using the chosen components. The hydraulic motors are drawn exactly already in this phase, because they can be used later in the same form. We are not going to redesign the motors! Following the same arguments shaft couplings, rolls and the cant are also drawn to precise scale. But all body and frame structures get only rough shapes, because we do not have any information about them. The supporting of the driving units is not presented at all. So, our sketch will be rather informative considering the known components, but it does not fix our mind to accept any main structure. If we had used more time for dimensioning and drawing the frame structures, driving unit support etc., the results would be impressed on our mind as a ready solution.

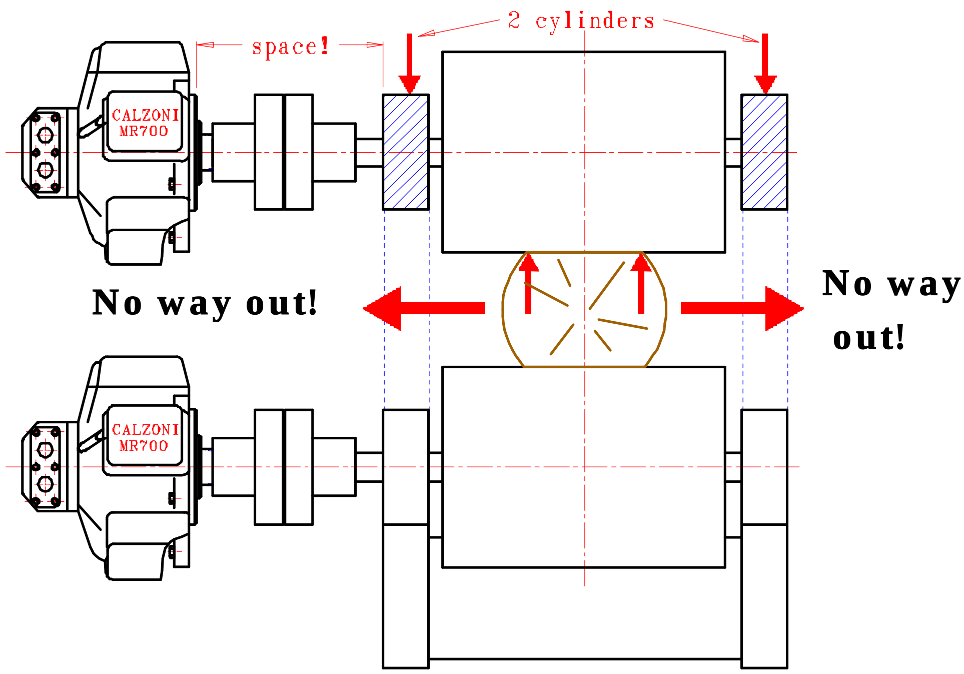


Figure 5.13 Sketch of feeding device in transversal direction

The sketch indicates, that placing the frame on both sides of the cant closes it inside the structure. When the saw malfunctions, the cant cannot be removed to the side. In addition to that the size of the shaft couplings seems to be very inconvenient, because the motors must be placed far away to the side. Because the upper roll is moveable and the motor must follow it, the support of the motor should be made by means of some kind of cylinder around the coupling, connecting the motor to the lever of the upper roll.

The most significant notations are written in the figure. Considering them does not need any texts while the visual impression is penetrating into our subconscious mind. Another impression comes from the weight of the driving units. The unbalance tends to decline the upper roll. Even if the unbalance would not be significant, the declination has an important effect, if the plained surfaces of the cant are not completely parallel. As a result of these notations the monolith of fig. 5.8 gets its first important attributes.

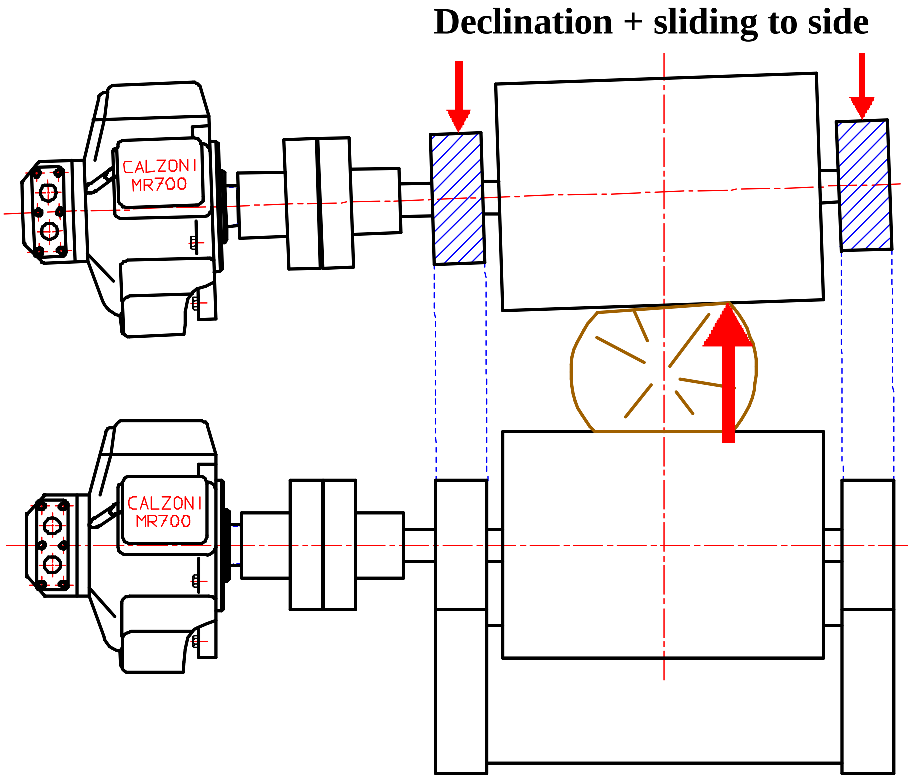


Figure 5.14 Declination of upper roll caused by sawing error

A situation similar to that in fig. 5.14 is real and common. The declination may be caused by the clearance in the bearings of the roll, but in the first place by the clearance of the link bearings. In addition to that the reason may be found in the elasticity of the frame structure, thus it must be considered, too. The practice proves, that some feeding rolls push the cant to the side always in the same direction during the feeding movement. Instead of straight feeding we get more or less diagonal feeding. There are good reasons to suspect, that the declination of the rolls has some influence on that, or the errors in the parallelism of the planed surfaces in the cant have this tendency as a result.

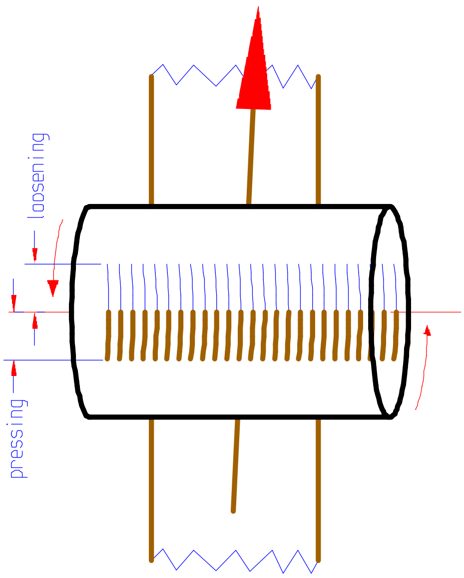


Figure 5.15 Diagonal feeding

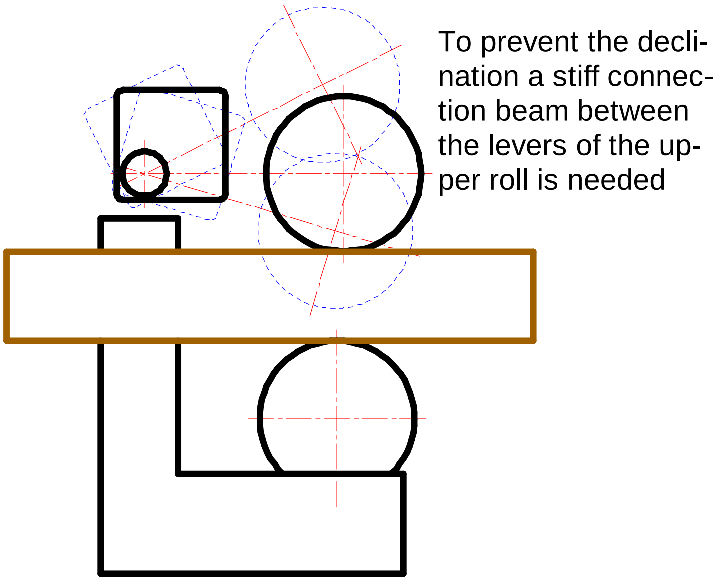


Figure 5.16 Stiffening the lever of upper roll

Fig. 5.15 presents the mechanism causing diagonal feeding. If the roll is declined, the projection of the roll's rim movement during squeezing on the horizontal level is curved. At the beginning the curve is directed to the right and after the vertical point it is directed to the left. Both movements to the side caused by this curved feeding would be equal, if the contact length before the vertical point would be the same as after that point. According to figures 5.10 and 5.11 these lengths are not equal and the pressure before the vertical point is higher than after. Hence, a steady transversal force is created in that point. On this basis the diagonal feeding is caused by the declination of the upper roll, not by the unparallelism of the cant's planed surfaces in the first place. However, the unparallel planed surfaces of the cant make the load of the upper roll unsymmetric causing the declination of the roll and the diagonal feeding, but only in the second place.

As a result, the declination of the upper roll shall be restricted as much as possible. In figures 5.13 and 5.14 the bearing applications of the rolls and of the upper roll lever are symmetric, thus the only reason of declination is the elastic deformation of the upper lever. It may be restricted in the best way by connecting both levers of the upper roll with a stiff beam, fig. 5.16.

The levers of the upper roll must be connected to a really stiff unit in any case. The symmetric structure of that unit has no meaning in the first place, because there is always unparallelism between the squeezed surfaces and unsymmetric loading as a result of that. The curvature of the cants makes the squeezing point to move on the both sides of the feeding line. The upper frame must be extremely stiff because of that, so stiff, that the symmetry of the structure has no meaning any more. The two loading cylinders may be replaced by one only, placed on the side of the structure.

The prevented removing of the cant from the side, caused by the symmetric frame of the feeding unit has proved to be very harmful in practice. Seizing of the cant is a very common malfunction during sawing. The seized cant should be pulled back from the saws. To make this possible, the preceding cant should be removed. It would be practical to remove the cant to the side, but the closed symmetric frame of the feeding unit prevents it. In that case the cant must be cross cut on the line.

The unsymmetric frame of the feeding unit would be beneficial. While the frame is dimensioned to be stiff, this stiffening can be extended so far, that even a completely unsymmetric loading cannot cause any detrimental declination. The steel structure is still very stiff compared to the wood. The unsymmetric structure would make the number of parts almost half that of the other alternative. The frame does not need to be founded on the both sides over the saw dust channel below the sawing line. The final result could be even lighter than the symmetric structure despite the greater stiffness. The number of parts and the simplicity of them has much more influence on the total price, than the total weight of the unit. We should keep in mind, that steel price by weight used in the machine is about the same as the price of corn. Thus the machine price by weight is about the same as the price of the corresponding sausages. In many cases the pricing of the machine using this method has found the more correct value than the use of more sophisticated calculation methods!

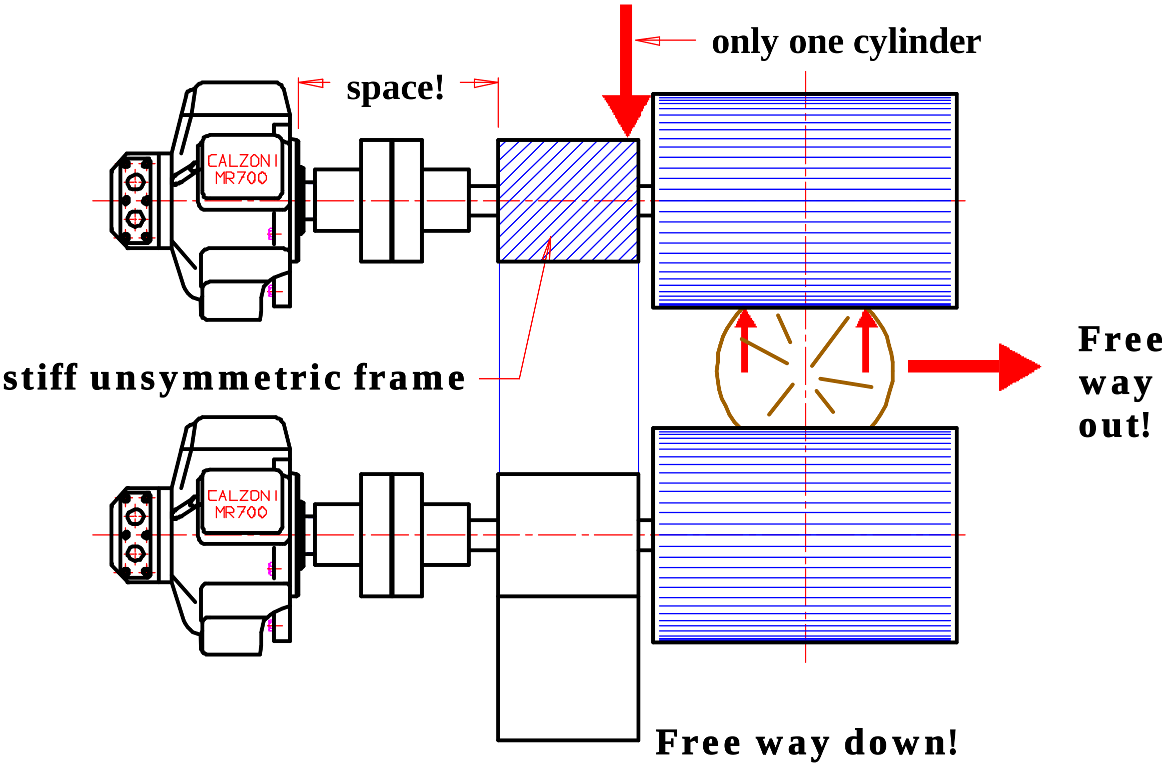


Figure 5.17 Unsymmetric frame

The frame can be made stiff enough using the space freely for that. The bearing application of the roll, however, is very problematic, because the free end of the roll cannot be supported any more. The problem is described in the next figure, where the placement of forces and the value of them is described by the size of the vectors.

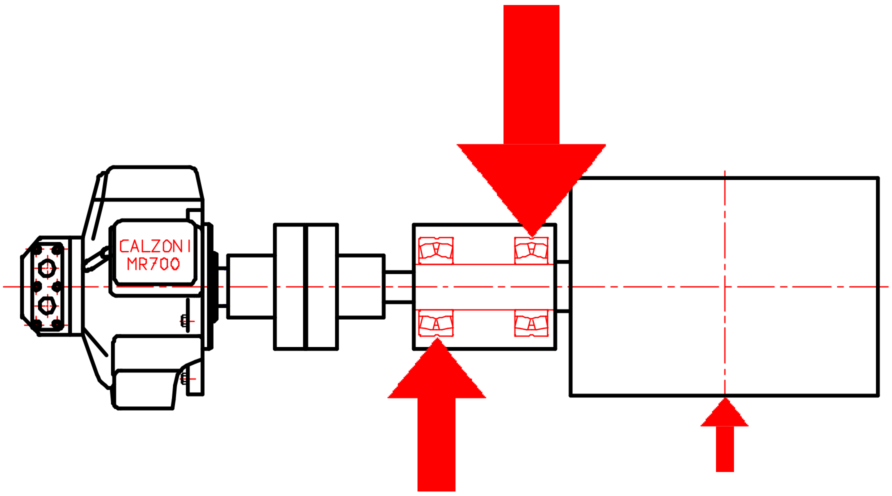


Figure 5.18 Problem in the bearing application

Fig. 5.18 describes a normal cantilever bearing application of a rotating roll. The solution is extremely insufficient in this case, because the load is acting far away from the closest bearing causing such a large bending moment to be carried by the rotating shaft. The deflection of the roll is insignificant, but the deflection of the shaft between the bearings is the biggest factor causing a considerable tilting to the roll. Tilting can be reduced by reducing the bearing distance, but this makes the bearing loads excessive high.

In any case the big problem is the high fatigue bending stress of the shaft below the closest bearing. The fitting of the inner ring of the bearing must be tight. While the hardness of the inner ring is higher than the shaft hardness, the fretting load makes the allowable bending stress of the shaft below $\pm$ 80 N/mm^2. The shaft is very sensitive to fatigue and wear, thus long life for it is not easy to obtain.

The penetrative analysis of the task begins to be ready. The results can be seen in figures 5.8...5.18 and they do not need more comments. At first sight the figure 5.8 did not indicate any attributes. The penetrative analysis created them and now we know, what to do. The analysis using sketches is much more efficient for the development of the final solution, than any verbal argumentation. There are some important principles in creating those sketches:

a) *The parts, which we are going to use, as they are or with minor changes, are worthwhile to draw in scale and with all details at the beginning. The drawing can be copied into all subsequent and even to final pictures. These parts are the hydraulic motor, the coupling and the outer shape of the rolls.*

b) *The joints and the frames need only schematic presentation, if any at all. In the schematic presentation we try to estimate the needed space and we reserve it with a box like structure. In our pictures schematic boxes are used for presentation of all frames and levers.*

c) *All touch points should be studied carefully in details, eventhough those pictures are not going to be used later. These kind of details are shown in figures 5.9, 5.10, 5.11, 5.15 and especially fig. 5.12. Figure 5.12 describes the function of the longitudinal notches of the rolls. The study indicates, that the depth of the notch should be low compared to the width of it. Detailed pictures increase and make deeper our understanding of the function.*

d) *Deformations and different positions are worthwhile simulating as in figures 5.8, 5.14, 5.15 and 5.16. The use of space can be seen and the exaggerated deformation keeps the problem in mind all the time.*

e) *Shields and housings shall not be drawn at the beginning. They give a deceptive feeling of compactness and steadiness for the structure. Like in figures 5.13 and 5.14 the motors are hanging behind the coupling as a long slim cantilever. They really make us think about the possibilities of some shorter structures.*

f) *Notices can be added to the pictures also in the form of short text. The text should not be very comprehensive, because the only meaning of it is, to remind us about the problem. The problem itself can be read visually in the picture.*

We shall realise, that until now only one primitive sketch is created (fig. 5.17) and even that is open to all directions. All other drawings **are studies, not alternatives**. The studies indicate the developing directions, where it is suitable to start the development of heuristic points = studies in details. The studies have also preferred the structure in (fig. 5.17), but they are not closing the other alternatives. We have not made any screening of alternatives until now, and even later we are not going to do so. But the direction of tension is becoming clear and the tension is growing slightly. At this stage it is the right time to concentrate on the details and leave the final solution for the present. The notices and tendencies defining the next direction are:

a) *The hanging motors behind the couplings are very irritating. But we cannot find any solution for it, so far.*

b) *The tilting stiffness must be secured. Because in every case a very stiff upper frame is a necessity and the unsymmetry would bring also practical benefit, the unsymmetric structure could be the basis for the next studies. It reduces the size and the number of needed elements, as well.*

c) *The unsymmetric bearing application of the roll seems to be menacingly difficult. By all means we should try to place the bearings symmetrically inside the roll to reduce the bearing loads. Immediately the structure of the rear wheel bearing application of lorries pops up, if one has ever seen that as a drawing. That could be a prominent heuristic point for the next study.*

5.2.2 Heuristic Points

The results of the penetrative analysis means already logical transfers for the next heuristic points. The functional structure of the old feeding roll unit, presented in fig. 5.8, is torn into pieces and examined in the following pictures. We have got plenty of knowledge about the behaviour of squeezing feeding rolls, of the malfunctions and reasons for them, of the meaning and possibilities of loading symmetry and unsymmetry. If one had eagerness towards the immediate realisation of the structure at the beginning, such eagerness should disappeared now.

In this study the experimental notices (diagonal feeding, power, gliding of the roll, sinking into the surface of wood etc.) have a substantial share. They all lead to the visual study, but not to the mathematical one. That all has increased the tension of accomplishment, but first of all, it has pointed the study into detailed structural problems. By other words, the placing of the heuristic points has become obvious. The total structure has not advanced more, than the point when the symmetry of the structure is not worth pursuing. The stiffness is what we need and at the same time we may get it so much, that even the unsymmetric structure with all its advantages can be used. Let's look at the first heuristic point:

Looking at the Roll, Bearing Application and Drive

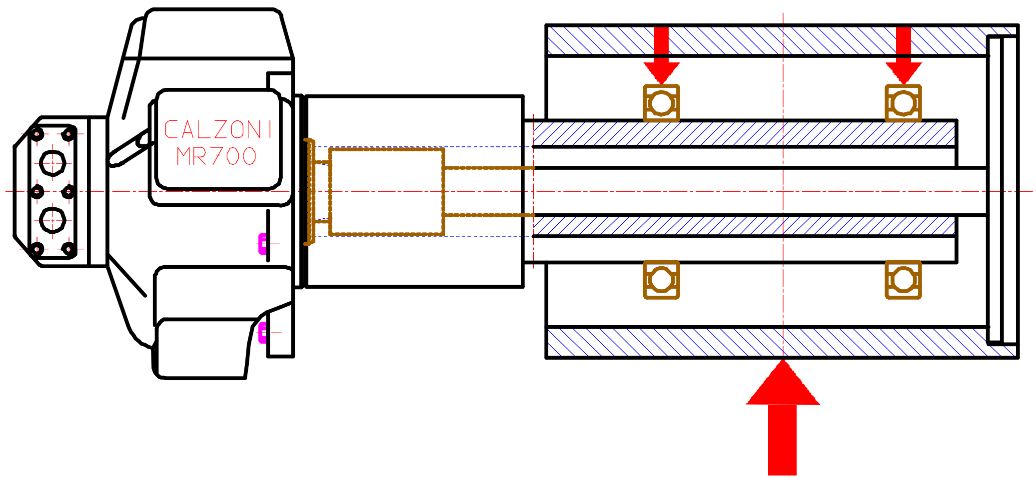


Figure 5.19 Sketch of the internal bearing application in the roll

When the slim ball bearings are placed inside the feeding roll symmetrically to the feeding line, the bearing loads are only half of the squeezing force. The inner rings of the bearings are placed on the cantilever tube attached to the loading lever. The tube has such a big inside diameter, that the slim driving shaft can be put through the tube. The driving shaft is connected to the roll end with a flange. The hydraulic motor can be attached directly on the lever. This heuristic point can be slightly moved to study the next item in more detail.

Inside Structure of the Roll

The idea of the bearing application used by the back wheels of lorries helps to design the structure according to fig. 5.19 in more detail. The material for the axle is a tube of ϕ160/112 carrying two slim 6030 ball bearings with loose fitting. Because the roll is going to be handled roughly, the axial supporting of the bearings must be made by means of sturdy parts. On the left side the ring **A** is fitted tightly onto the axle. It is at the same time a part of the labyrinth sealing structure. On the right the flange **F** is fixed at the end of the axle by means of screws.

The supporting rings **E** are welded inside the roll, making the roll mantle stiffer to eliminate flattening. The axial supporting of the outer bearing rings is made by means of locking rings together with sharp corner distance rings. These distance rings prevent the grease flowing between the bearings. The right side the housing is closed with flange **B** having the slim driving shaft **C** welded to the center of it. If necessary, the thickness of flange B can be reduced to 1...2 mm. Then it makes an elastic tilting link for the driving shaft.

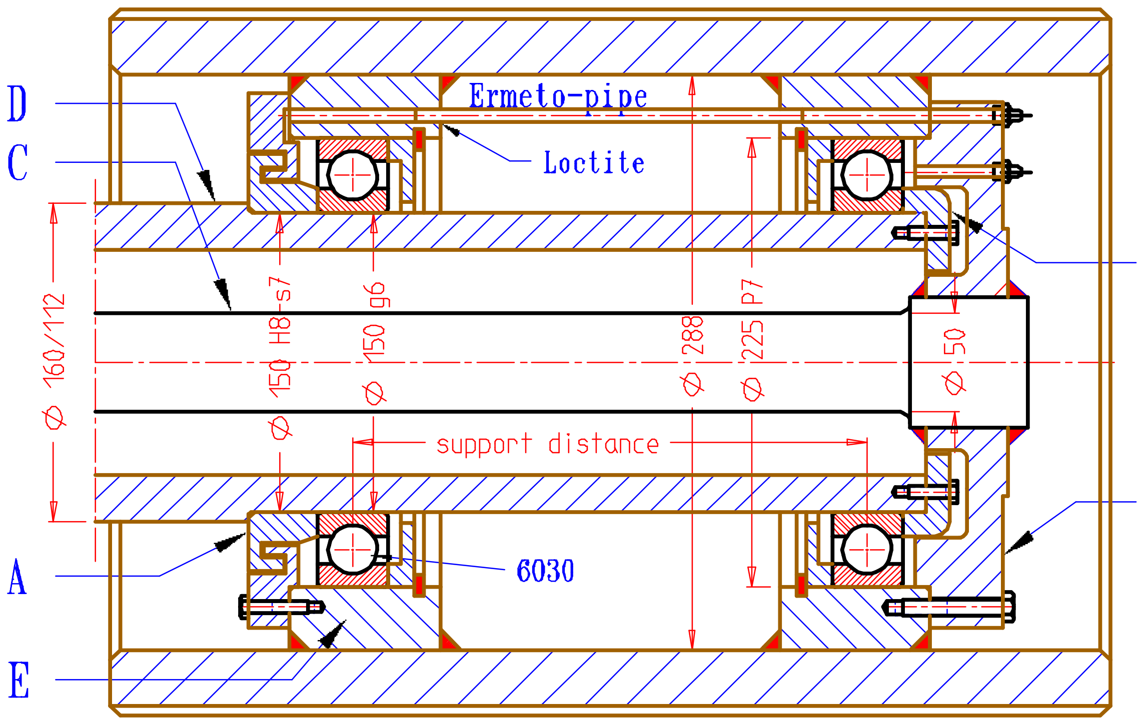


Figure 5.20 Inside structure of the roll

Greasing is done using the nipples at the end of the roll. The bearing on the right will be gradually filled with grease and after that the excessive grease can only flow into the empty center space of the roll. The grease flows into the bearing on the left through a slim Ermeto pipe, which is placed between two drilled holes and tightened simply with Loctite. The excessive grease flows through the labyrinth sealing refreshing it at the same time.

The speed of the roll is so low, that the bearings may be completely filled with grease. On the other hand the continuous influence of sawdust demands effective sealing. The outer end of the roll is completely closed, but at the inner end of the roll a really reliable sealing arrangement is needed. The sawdust consists partly of antacid, which makes the grease into a tenacious syrup and after cooling it becomes hard. This syrup is able to destroy all rubbing sealings, thus the labyrinth sealing is the only reasonable alternative. It must be very robust and the parts of it must be strongly fixed. Therefore part A is shrunk on the axle tube. At the same time its face gives the support for the inner ring of the bearing. It takes time to change the grease to syrup in the labyrinth. This can be prevented by feeding new grease frequently, let's say once in a month, through the sealing. This is done at the same time, as the bearings are greased.

The load of the outer rings of bearings is rotating, thus they must be fixed with tight fitting (P7). The load of inner rings is stationary, thus they may have a rather loose fitting (g6). The capacity of the deep row 6030 ball bearing is completely sufficient and it can also carry substantial axial loads. A slight uncertainty is caused by the loose fitting of inner rings, when the upper roll is lifted from the cant surface. At this moment the direction of the load is changed. This makes it possible, for the position of inner rings on their seats to change slightly causing a little wear and fretting on the shaft in the long run. If this uncertainty should be completely avoided, we could choose cylindrical roller bearings of NJ-type instead of ball bearings. Then we could use tight fitting for the inner rings also. These bearings are slightly more expensive, but the result would be thoroughly safe.

The driving shaft must be connected to the motor so, that it can be pulled out with the flange B. After that we can open the flange F and the whole roll comes out. NJ-type roller bearings would be better here, because the left side inner ring could stay on the shaft.

The next heuristic point could be the lever, of course. The loading is known, but the linking to a large extent determines the structure and the use of space. So let's start at that point.

Linking the Lever of the Upper Roll

Makes a second heuristic point to be studied thoroughly before any other structure. The link is placed on the other side of the feeding line, thus the bearing forces of the link are big and they have opposite directions. When the squeezing stops and the roll rises, the bearing loads change their directions. There are thousands of these kinds of load changes in a day making all loose contact surfaces wear. If rolling bearings are used in the link, both inner and outer rings must have tight fitting on their seats. The clearance of the bearings must be set to zero, that means a preloading of them, in practice. In addition to that the movement of bearings must be big enough for proper lubrication of their contact points (EHD).

The movement of the lever is tens of degrees, thus no lubrication problems come even by using of ordinary roller bearings. The bearing could be e.g. a 22213 spherical roller bearing together with a conical adapter sleeve.

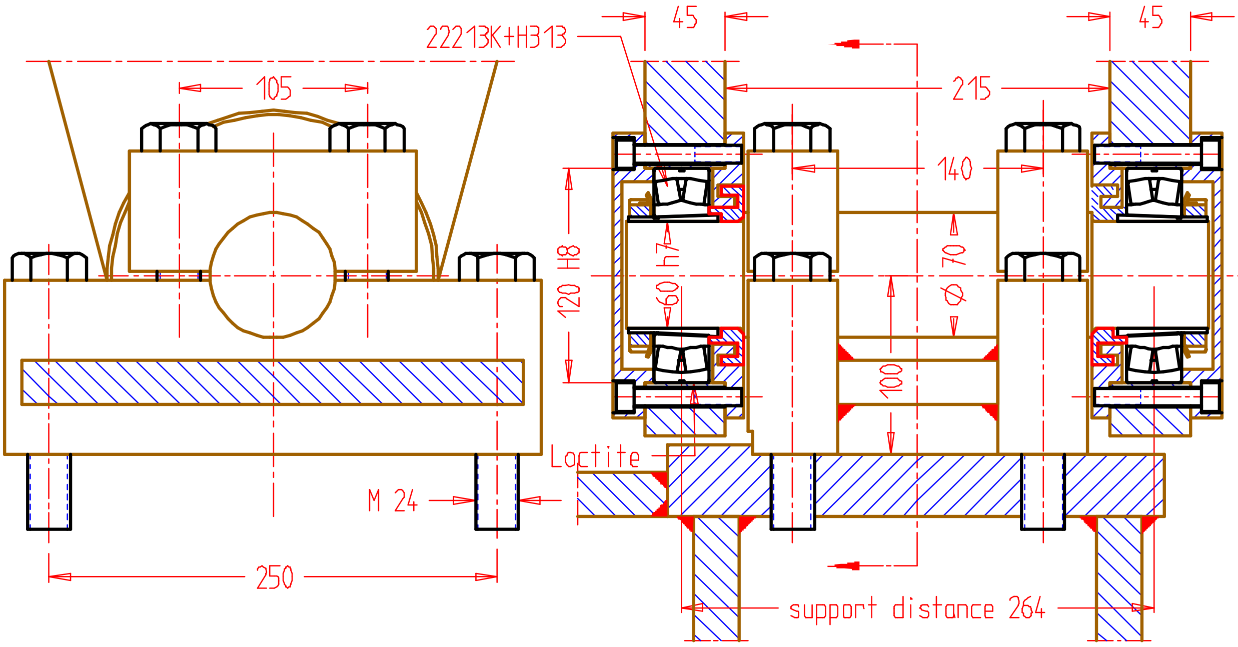


Figure 5.21 Spherical roller bearings in the link

Fig. 5.21 presents only the bearing brackets from the lever. The bearings lean axially against the labyrinth rings, thus the bearing distance is fixed. The adapter sleeves can be used to reducing the bearing clearance to zero. The fitting of outer rings is problematic, because a tight fitting cannot be used because of the assembly. The key is Loctite, which is loose during the assembly.

The link journal is clamped into a special holder with strong connecting bends. The holder is fixed to the joint surface by means of four screws. The border of joint surface on the body gives good support for the alignment of the holder. The connecting bends may be independent, but the holder is connected with a distance plate to be one assembly. This makes it easier to assemble the heavy and unbalanced upper roll unit into the correct position.

The structure is technically sufficient and has been used with good results in practice. Assembly and disassembly of the upper roll unit are especially easy, because the cylindrical fitting surfaces guarantee good alignment every time. The holder is not disconnected, since the connecting bends are used for that manoeuvre. The visual impression, however, is not sufficient. On the contrary, the solution looks rather awkward.

a) *Fixing the outer ring of a spherical roller bearing by means of Loctite is sufficient in assembly and in use as well, but the disassembly proves to be difficult. It is possible only, if the bearing brackets are heated and the whole journal together with the bearings can be pulled out after the melting of the Locktite. The melting requires a temperature of + 150°C, thus careless heating may reduce the hardness of the bearings.*

b) *With the exception of bearings and their attachments this structure consists of 10 parts. Three of them are welded together. Four parts must be machined. In addition to that a machined joint surface in the main body is needed. These numbers are great for such a modest task.*

The awkwardness of the structure makes us think about this heuristic point, once again. Hereby we can benefit from these disadvantages as logical transfers, i.e. the number of parts must be smaller, the fittings for all bearing rings must be tight.

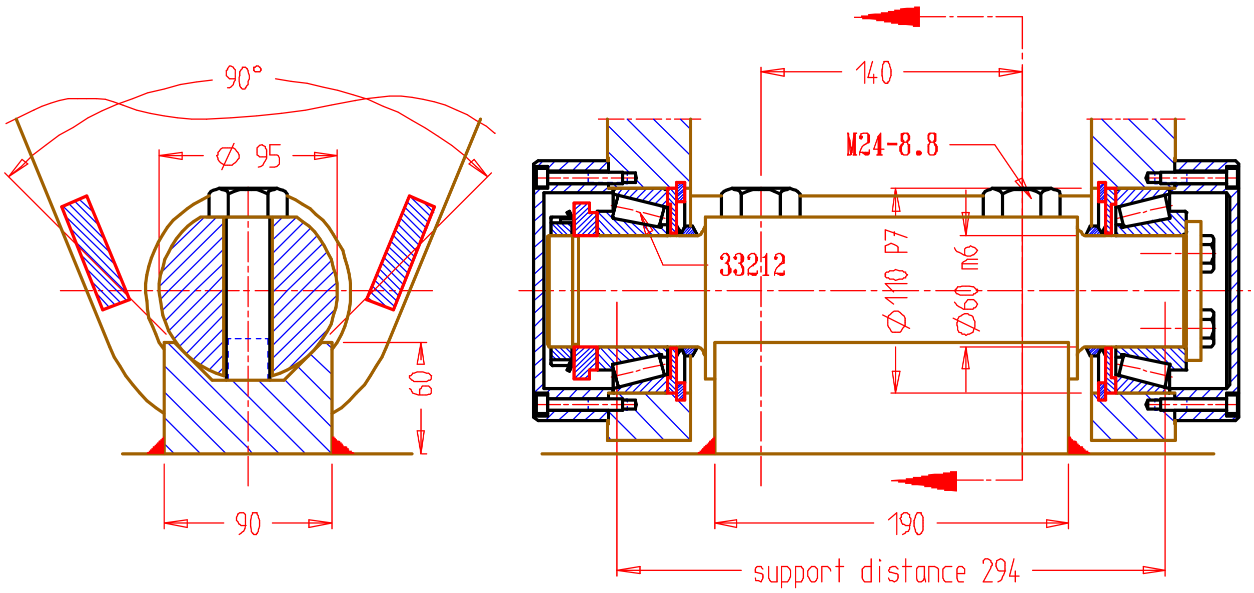


Figure 5.22 Tapered roller bearings in the link

Figure 5.22 demonstrates the result of the new consideration. The bearings are now tapered roller bearings, which have tight fittings for outer and inner rings. These bearings allow only minor misalignments, thus the cylindrical fitting holes in bearing brackets must be exactly coaxial. The best way to accomplish this is to machine both holes at the same time. This presupposes straight holes through both of the brackets without any shoulders. The inside support of the outer rings can be made, if we use locking rings together with sharp corner distance rings. The bearing clearance can be controlled to zero. The link journal is fixed with two strong screws directly against a V-shaped slot, which is milled directly into the main body. The part list now consists of only 3 parts instead of 10. Parts of the fixture to be machined are only one instead of four. The disassembly is done by pulling the journal out by means of the screw holes at the right end of the journal.

The link journal presses with its cylindrical surface the straight flanks of the V-shaped slot. The pressing line plastically deforms after the Hertz pressure has exceeded 1.8 times the yield limit. If we use the full pre tensioning force of the screws, the deformed area has a width of 3.158 mm. The deformation in the direction of the tightening force is 0.026 mm, which is only 9 % of the elastic strain of the screws. Hence, the joint is completely useful and it has actually been used e.g. in the joints of the guidance bars of chippers.[21]

The link according to fig. 5.22 seems to be faultless from a technical point of view. Its dimensions are chosen starting from the required diameter of the journal in fixing. After the structure is ready, even the bearings must be checked. A V-shaped slot is going to be milled into a 90 mm thick block welded onto the main body. It could be made of two independent thick plates, but then we must consider the strength at the bottom of the slot because of the screw holes. If the alignment of the journal must be adjusted, thin brass shims can be used. They are pressed with such a big width, that their soft material does not flow out, even if the pressure greatly exceeds their yield limit.

[21] The use of the cylindrical surface against the straight flanks is a very heretic and frightful solution, in particular for sales engineers. It was resisted so furiously, that I placed it into a chipper without permission and preserved it in secret. This chipper was a good success in all respects. About 10 years later I saw it in a fair presented by a proud experienced sales engineer. I put my head inside the machine and noticed, that the joint was still in use. When I pointed it out to that engineer, he was shocked.

The tapered roller bearing also makes an axial reaction while loaded radially, which tends to push the bearing brackets apart. To prevent this, two extra binding plates are welded on both sides of the journal. We must consider the free movement of the lever and a place for the attachment of fixing screws through the journal. According to fig. 5.23 this movement is sufficiently ± 40°.

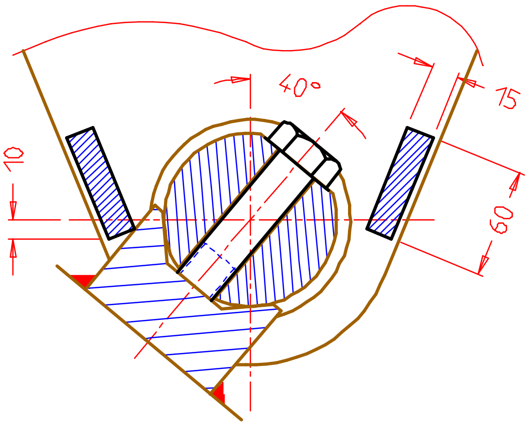


Figure 5.23 Free movement of the lever

The heuristic points are now more or less developed to a level where the structures can be used. The final solution may be a combination of the structures in figures 5.20 and 5.22. The width of the link is not dimensioned, thus it can be adjusted correspondingly. The length of the lever should be minimised, because it reduces the influence of elastic deformation to the misalignment. At the beginning the components are placed in relation to each others using only the axes of symmetry. The visual confrontation imposes to outline the main structure. We can immediately see the ridiculous size of the coupling. At the same time we see the flexibility of the driving shaft, which could be used to substitute the flexibility of the coupling.

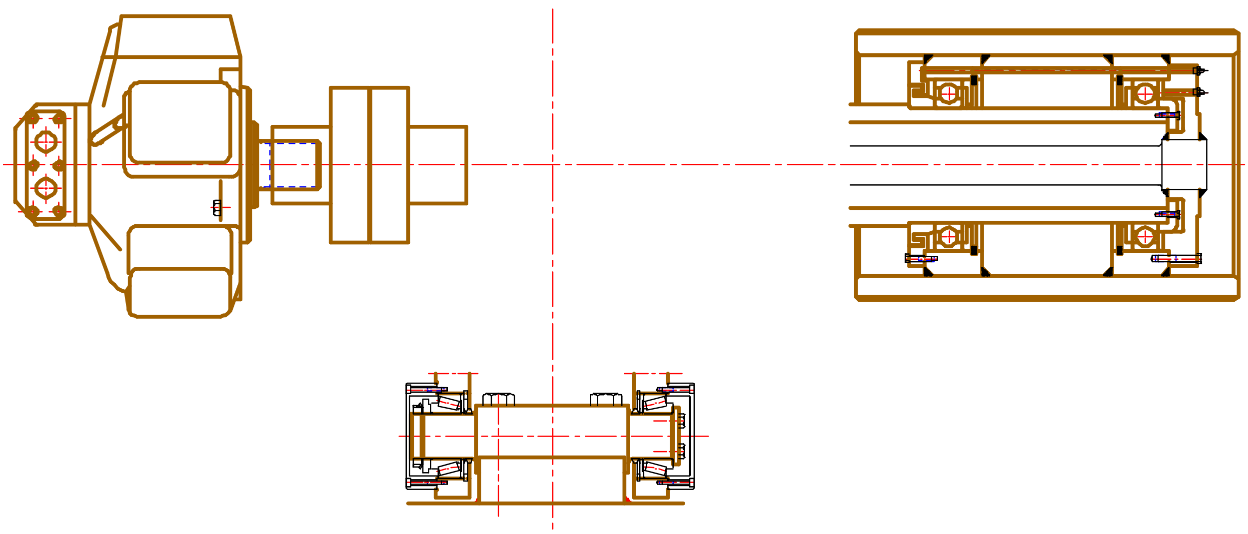


Figure 5.24 Looking at the final solution

The heuristic points are now more or less developed to a level where the structures can be used. The final solution may be a combination of the structures in figures 5.20 and 5.22. The width of the link is not dimensioned, thus it can be adjusted correspondingly. The length of the lever should be minimised, because it reduces the influence of elastic deformation to the misalignment. At the beginning the components are placed in relation to each others using only the axes of symmetry. The visual confrontation imposes to outline the main structure. We can immediately see the ridiculous size of the coupling. At the same time we see the flexibility of the driving shaft, which could be used to substitute the flexibility of the coupling.

The manufacturer of a hydraulic motor has a bushing with inside spline notching in his catalogue. This bushing can be attached to the motor shaft. Because the machining of the same splines into the driving shaft assumes special tools, we turn the splines completely away using a lathe from that end of the bushing and the driving shaft is glued into the turned space. The whole connection can be placed inside a thick wall tube ϕ160/112 and the coupling is neglected. This makes the total structure much shorter, because the motor can be attached directly on the face of the lever.

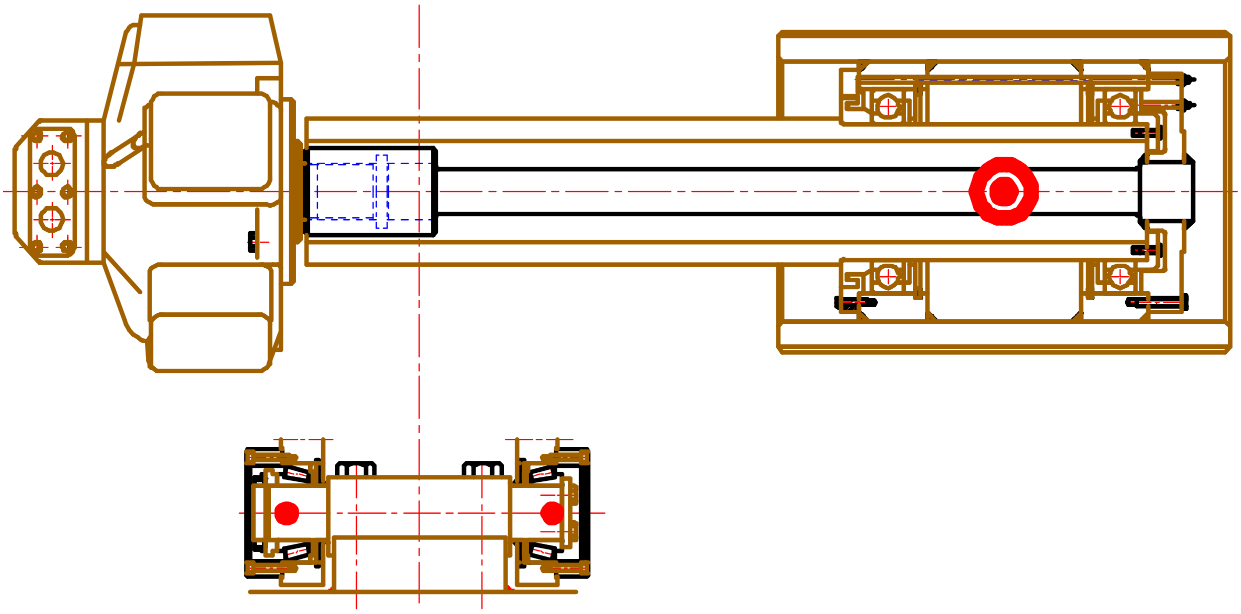


Figure 5.25 Motor and roll are connected together

The bearing loads and distances between components are underscored in fig. 5.25, since the values are only preliminary. The motor needs a joint flange, anyway. This flange continues until it reaches the bearing bracket of the link. Because the bracket shall be thick, we can combine both of them as one plate. There must be enough space left for the motor. The opposite bearing bracket must be thick also and can be made similar to the former flange.

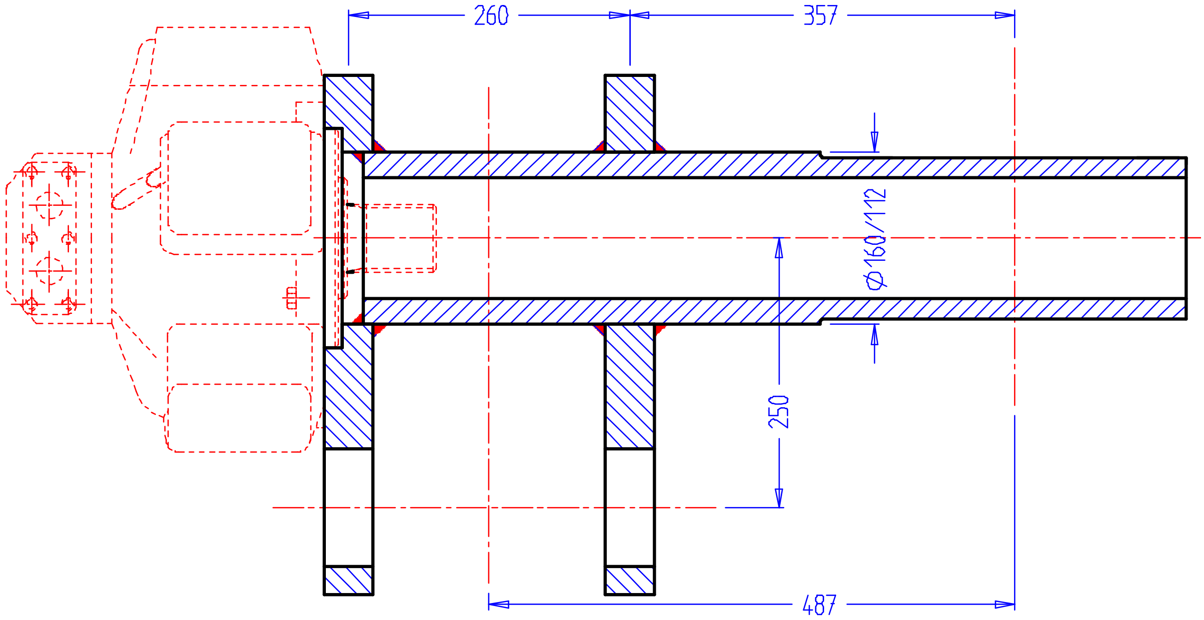


Figure 5.26 Proposition for the lever

The lever seems to be sturdy, but this estimation is not reliable. By taking a closer look we see, that the torsional deformation in the tube between the flange causes a twist between the flanges and a misalignment in the upper roll at the same time. Besides this, the bending deflection of the tube may be significant also. The situation calls for calculation in detail.

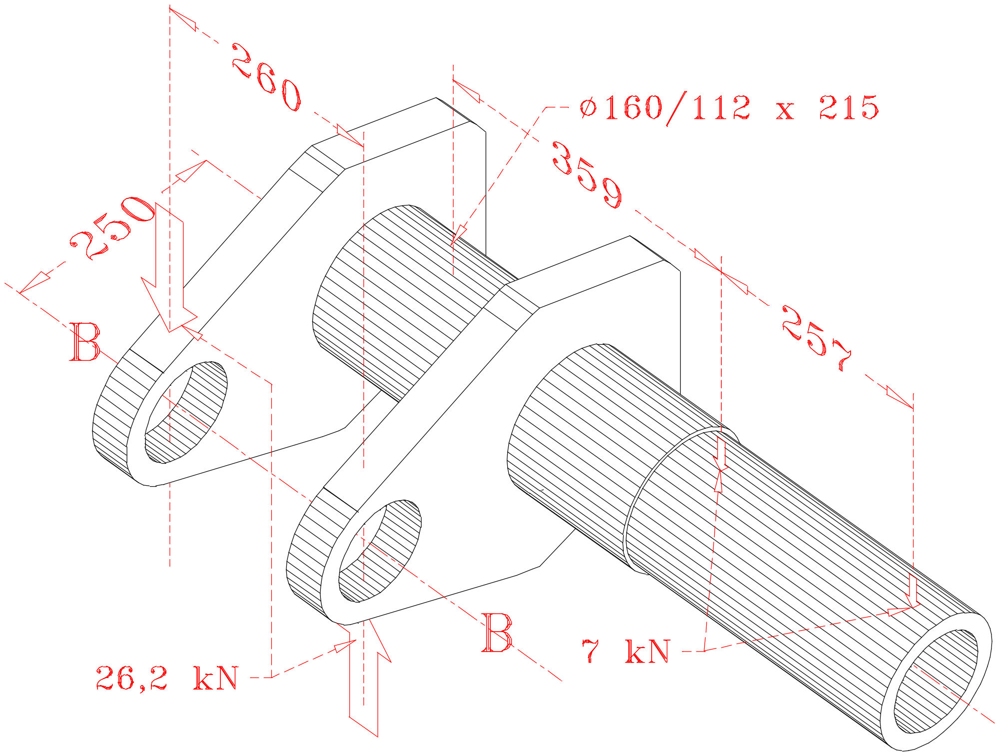


Figure 5.27 Load system of the lever

Fig. 5.27 gives us the placement and size of bearing forces in the roll, the deriving link forces and in addition to that, the distances between different parts. No other deformations are interesting, except the misalignment of the roll. At the same time we can check the stress level at the most loaded point; where the axle tube joins the lever flange on the right side. In this point the bending moment is

$$M_{bend} = 7000 \cdot (359 - 260/2 + 359 + 257 - 260/2) = 5{,}005{,}000 \text{ Nmm}$$

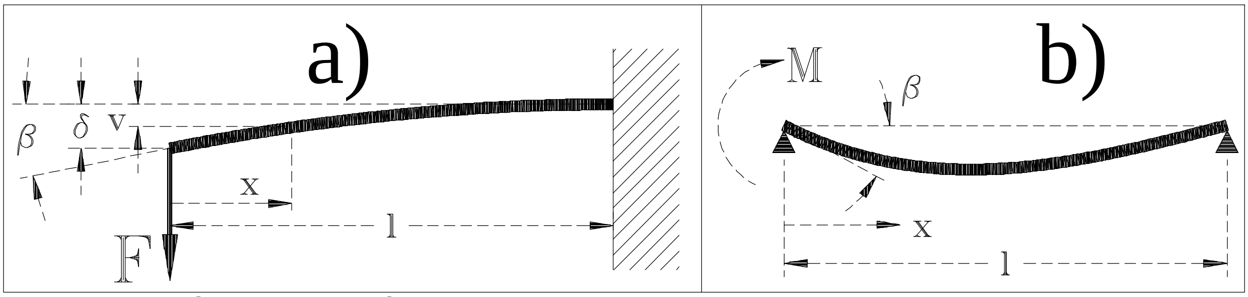
Bending resistance $$W = \frac{\pi \cdot (160^4 - 112^4)}{32 \cdot 160} = 305{,}574 \text{ mm}^3$$

$$\sigma_{bend} = M_{bend}/W = 16.4 \text{ N/mm}^2$$

The axle tube is very strong against the bending. The misalignment of the upper roll produces two deformations, which are the bending deflection of the axle tube supported at the points of the lever flanges, on the one hand, and the twist between the lever flanges caused by the torsional deformation of the tube between the lever flanges, on the other hand. The deflection of the axle tube is based on a complicated combination of several deformations, hence one has to keep the thinking in order, while calculating that using several simple formulas. The bending stiffness of the axle tube is

$$I_{bend} = \frac{\pi}{64} \cdot (160^4 - 112^4) = 24{,}445{,}914 \text{ mm}^4$$

The axle tube is considered as a cantilever beam having two supporting points. These points are located at the center level of the lever flanges. This assumption is made therefore, that the torsional stiffness of the flanges is relatively small. The calculation of bending uses two elementary formulas and sums both results.



$$v = \frac{F \cdot l^3}{6 \cdot E\,I} \cdot \left(2 - 3\,\frac{x}{l} + \frac{x^3}{l^3}\right) \qquad \beta = \frac{M \cdot l}{3 \cdot E\,I}$$

$$\delta = \frac{F \cdot l^3}{3 \cdot E\,I} \qquad \beta = \frac{F \cdot l^2}{2 \cdot E\,I}$$

Figure 5.28 Formulas for calculating the deformation of the axle tube

Deflection Caused by Bending of the Axle:

Deflection at the points of roll bearings (1 and 2) defines the misalignment of the roll. The calculation takes 3 steps according to figures 5.28 a) and b) and 5.29 a), b) and c). The first step presupposes a completely stiff attachment (β_o = 0) of the tube on the flange in point 0. E = 210,000 N/mm²

$$\delta_{1a} = \frac{7000 \cdot 229^3}{3 \cdot E\,I} = 0.005458303 \text{ mm}$$

$$\beta_{1a} = \frac{7000 \cdot 229^2}{2 \cdot E\,I} = 0.0000358 \text{ mm}$$

$$\delta_{2a} = 257 \cdot \beta_{1a} = 0.009189 \text{ mm}$$

$$\delta_{2b} = \frac{7000 \cdot 486^3}{3 \cdot E\,I} = 0.005217 \text{ mm}$$

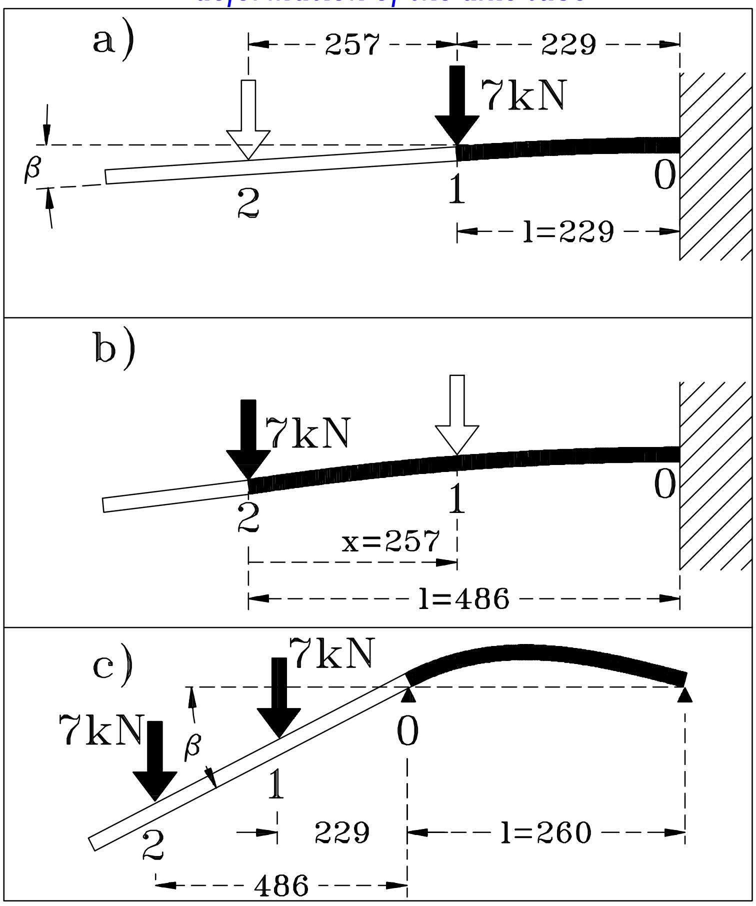


Figure 5.29 Three steps of bending calculation

$$\delta_{1b} = v_{1b} = \frac{7000 \cdot 4863}{6 \cdot E\,I} \cdot \left(2 - 3 \cdot \frac{257}{486} + \frac{257^3}{486^3}\right) = 0.014646844 \text{ mm}$$

All together:

$$\delta_1 = \delta_{1a} + \delta_{1b} = 0.020105148 \text{ mm}$$

$$\delta_2 = \delta_{2a} + \delta_{2b} = 0.061363249 \text{ mm}$$

The inclination of the axle tubes as a difference of the bending flexures at the points of the bearings:

$$\beta_{12} = \frac{\delta_2 - \delta_1}{257} = 0.000160537$$

In reality the lever flanges do not resist the inclination of the axle tube, thus the inclination shall be added with the results of formulas in fig. 5.28 b) and 5.29 c) using the bending moment M = 7000 ·(229 + 486) = 5,005,000 Nmm.

$$\beta_o = \frac{M \cdot 260}{3 \cdot E\ I} = 0.000084495$$

The total inclination is $\beta_{bend} = b_{12} + b_o$ = 0.000245032 = **0.245032 mm/m**

This calculation does not consider the reduced in diameter of the bearings. This has no significant influence in practice.

Deflection Caused by Torsion of the Axle:

The loading system according to figure 5.27 tries to twist the axle tube between the lever flanges on the length of l = 215 mm. The twisting moment is M_V = 26,200 · 250 = 6,550,000 Nmm. The tubes polar moment of inertia is

$$I_p = \frac{\pi}{64} \cdot \left(160^4 - 112^4\right) = 48{,}891{,}827\ mm^4$$

Modulus of rigidity G = 83,000 mm^4. Twist between the lever flanges is

$$\phi = \frac{M_v \cdot 215}{G \cdot I_p} = 0.000347029$$

This means the inclination in relation to the link journal

$$\beta_{tw1} = \frac{\phi \cdot 250}{260} = 0.000333681 = \mathbf{0.333681\ mm/m}$$

While the link journal keeps its horizontal direction that means the excessive inclination of the roll $\beta_{tot1} = \beta_{bend} + \beta_{tw1}$ = 0.578713 mm/m. Because the share of the twist in the inclination is bigger than the share of the bending, we have a good reason to reduce it. We add an extra cylinder ϕ273 x 5.3 mm between the lever flanges

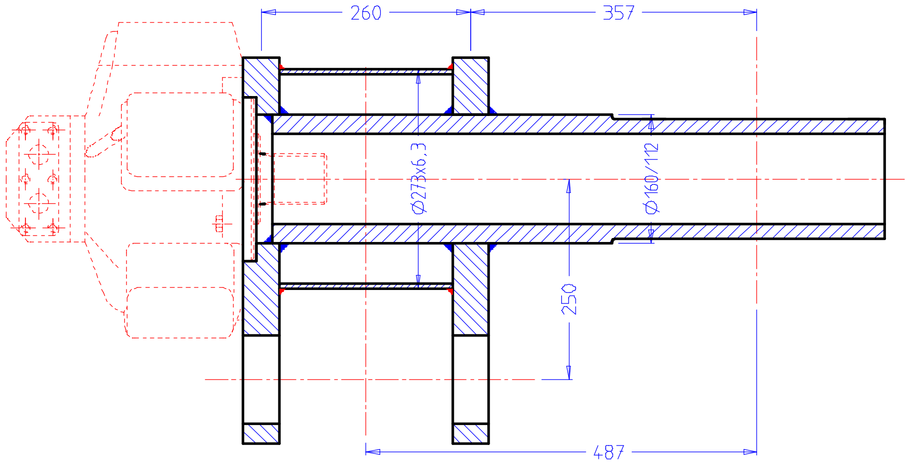


Figure 5.30 Lever reinforced with additional cylinder

The polar inertia of modulus for the additional cylinder is

$$I_{pl} = \frac{\pi}{32} \cdot \left(273^4 - 260.4^4\right) = 93{,}916{,}467 \text{ mm}^4$$

This reduces the twist of the tube to value

$$\beta_{tw2} = 0.000114239$$

The total inclination of the roll is now $\beta_{tot2} = \beta_{bend} + \beta_{tw2} = 0.00035971 =$ **0.35971 mm/m**. The former value was $\beta_{tot1} = 0.578713$ mm/m, thus the reduction caused by the additional cylinder is 38 %. The cylinder gives a more sturdy outlook for the unit, at the same time, without any great increase in weight. For the attachment of the cylinder between the flanges, it must be split first. The longitudinal weld after that must be made with full consideration, because it takes the full load of the twisting moment.

When we look at the structure, we see that in addition to the difficulty in the attachment of an additional cylinder, the machining of the unit may be laborious. The joint face of the motor and the seatings of the bearings must be coaxial. Even the axis of the link must be parallel with the previous axis. This should cause no problems for modern machining centers, but still the long outside cylinder of the axle tube keeps our thinking occupied. If the axle tube could be attached using a shrink joint, the axle could be turned ready in an ordinary lathe, consequently costing less money. The additional cylinder can be kept whole (no splitting) and it gets the duty to combine the lever flanges to an assembly.

In the final structure (fig. 5.31) this alternative is used. The picture more clearly reveals the meaning of the added reinforcements. The cylinder B really makes the lever stiffer while the purpose of the connecting plates A is also obvious. The bending flexibility of the flanges around the axle tube is formidable because of the danger of fretting corrosion. However, the low bending stress in the axle tube does not indicate any danger in this configuration.

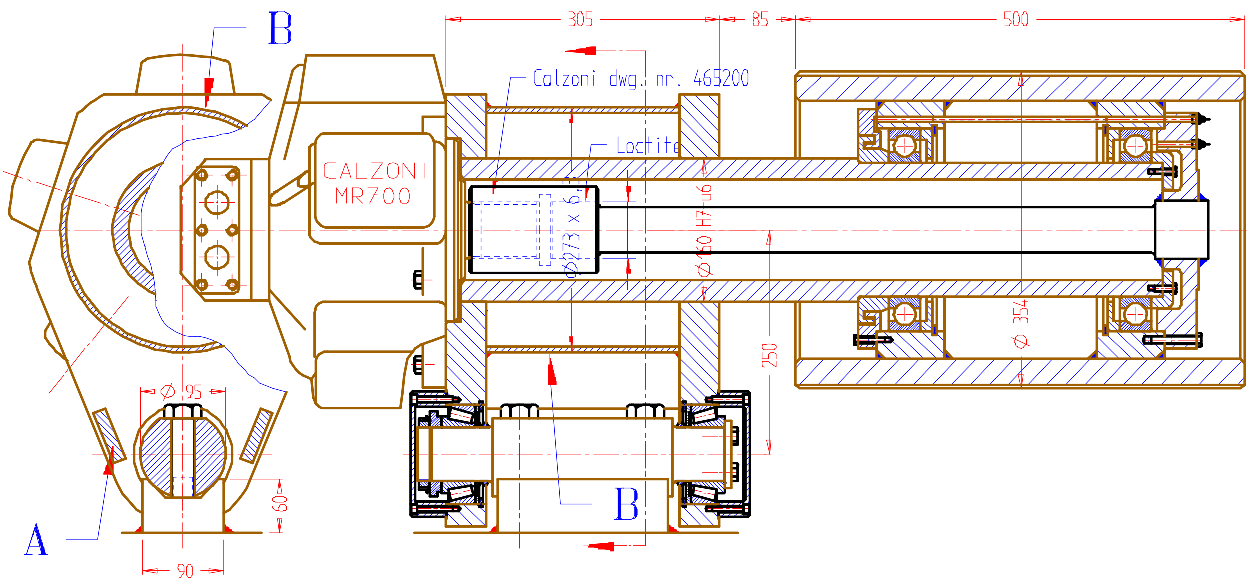


Figure 5.31 Final structure of the upper roll unit

5.2.3 Generation of a Multipurpose Component

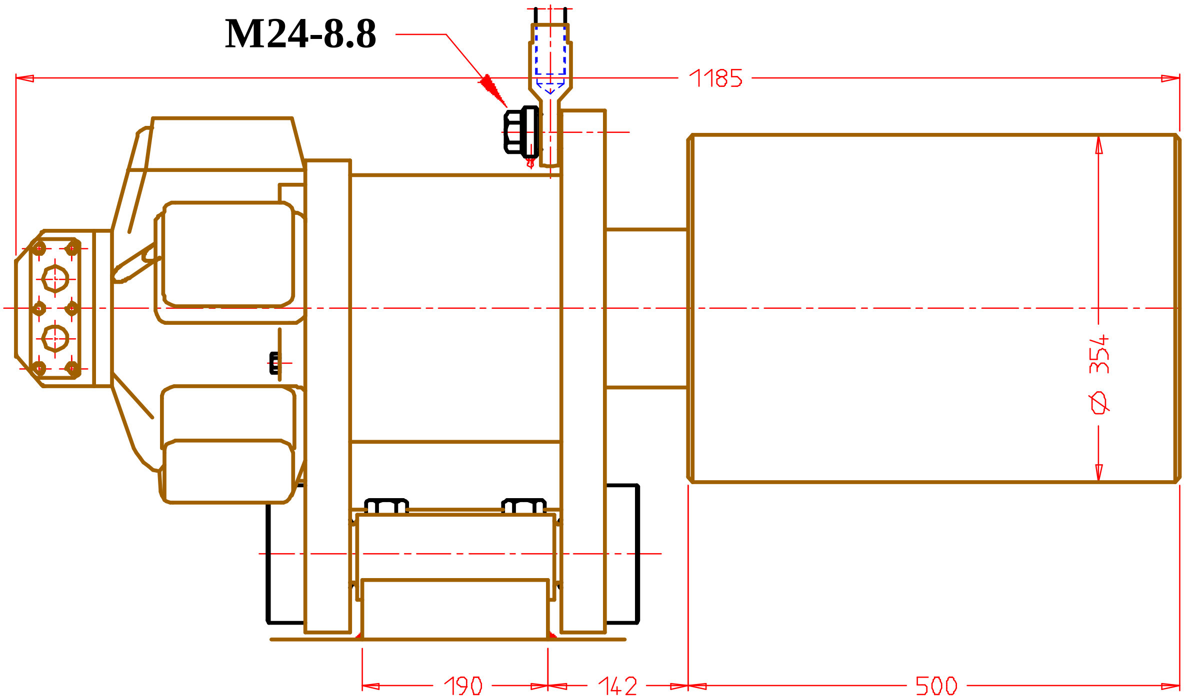


Figure 5.32 Compact unit

Figure 5.32 demonstrates the final result as a compact unit. While the lever flanges have a thickness of 45 mm, one of them can be continued far enough, that the hydraulic squeezing cylinder can be attached to it. The attachment is advantageous, because it needs only a screw hole of size M24 into the lever. These screw holes can be placed in many places and positions, hence we can consider the unit as a multipurpose component for saw mill machinery. The attachment of the hydraulic cylinder is worth of closer look.

Spherical link bearings have a very high capacity even, when the loading is jerky and shocking. The hydraulic cylinders and especially positioning cylinders stress the link bearings with reciprocal shock loads.

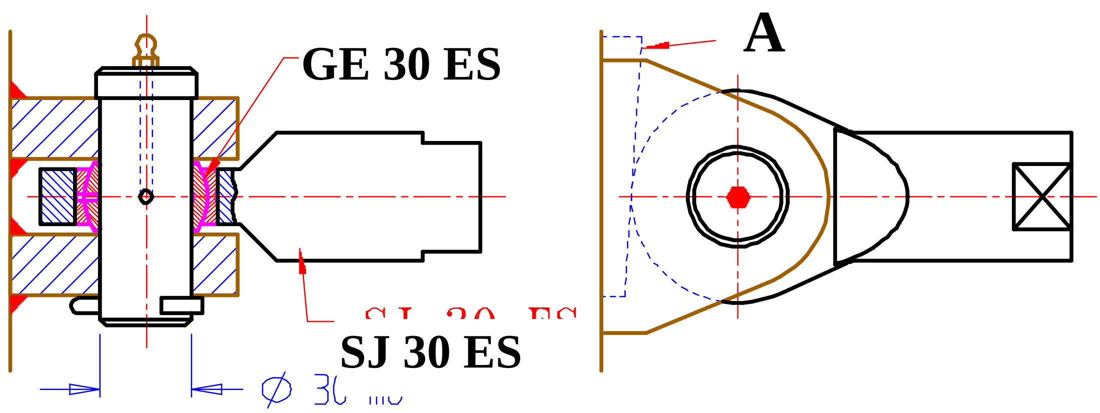


Figure 5.33 Ordinary attachment of the hydraulic cylinder

Link bearings are delivered as components or attached into the cylinder rods, fig 5.33. The picture demonstrates a link of a positioning cylinder in a saw mill. The cylinder was used for the positioning of the chipper canter. The attachment was conventional having two welded brackets on the machine. The cylinder rod was connected with a transversal journal. The recommended fitting for the journal stub was **m6**. This should make the fixture of the link bearing GE 30 ES suitable, because the fitting is tight. The assembly assumes clearance between brackets and journal. If this fitting were tight, assembly is possible only by means of heating the brackets and disassembly would be impossible.

The cylinder rod is dimensioned for a hydraulic cylinder of diameter ϕ63 mm and for a pressure of 32 MPa. Hence, the biggest load is = 100 kN. This type of attachments have already been used for decades in engineering. But this time we used a servo controlled positioning cylinder, which pulls a heavy machine back and forth giving at every stop several reciprocal force impulses. All these forces go through the link attachment. The servo control takes its signal from the position of the machine.

After several months the positioning cylinder started to shake the heavy machine back and forth so violently, that the shaking was noticeable far outside the saw mill. Increased damping in the control loop was not able to kill the shaking. Then we saw, that the holes in brackets were worn out and the shaking was a result of reciprocal strokes over the clearance. As an emergency repair method we put a wedge **A** between the machine and the rod.

A permanent repair was quite problematic, since the brackets were out of use and the re-machining of the holes was not possible at the site. In addition to that extra filling bushings had been necessary, because the size of the journal could not be changed. If the brackets were in a separate bracket unit, the change would have been possible.

The welding of brackets directly into the big machine was a proof of an old-fashioned stupidity in design. If the design had been still more old-fashioned using split brackets tightened by screws (fig 10.42), there would have been no problems. We started to use that mode again, but we got troubles when the journal was worn out under the link bearing.

The troubles increased with the proceeding automation so much, that we desperately needed a better solution. The automation was the influential factor because of the following reasons:

- *the number of strokes per time unit is very big*
- *the servo controlled positioning reciprocates the force at the stop conntinuously*
- *any clearance is very harmful, because they add the control movements and their amplitude*
- *the ultimate result is a furious shaking of the positioned machine*

The link bearing can be attached with a screw through the inner ring despite the big load, fig 5.34. Plastic deformation on the joint surface cannot be avoided, thus it needs more consideration.

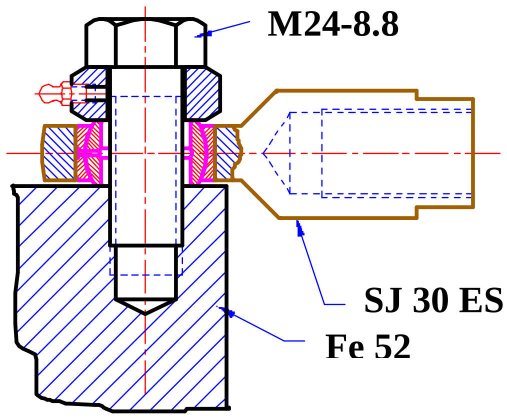


Figure 5.34

Direct attachment of link bearing GE 30 ES by means of clamping screw

The clamping force is made by an M24 8.8 screw using a pre tensioning force of 168 kN. The edge of the link bearings inner ring penetrates into the joint surface, because the starting pressure is as high as 1224 MPa. While the sink is 0.8 mm (rounding of edge) the plastic deformation is spread at least the same way. The pressure, calculated using this increased area, is 378 MPa, which can be considered tolerable as a contact pressure for the steel quality Fe 52. The "friction coefficient" can be set at least μ = 0.6 (Hütte in bridge construction).

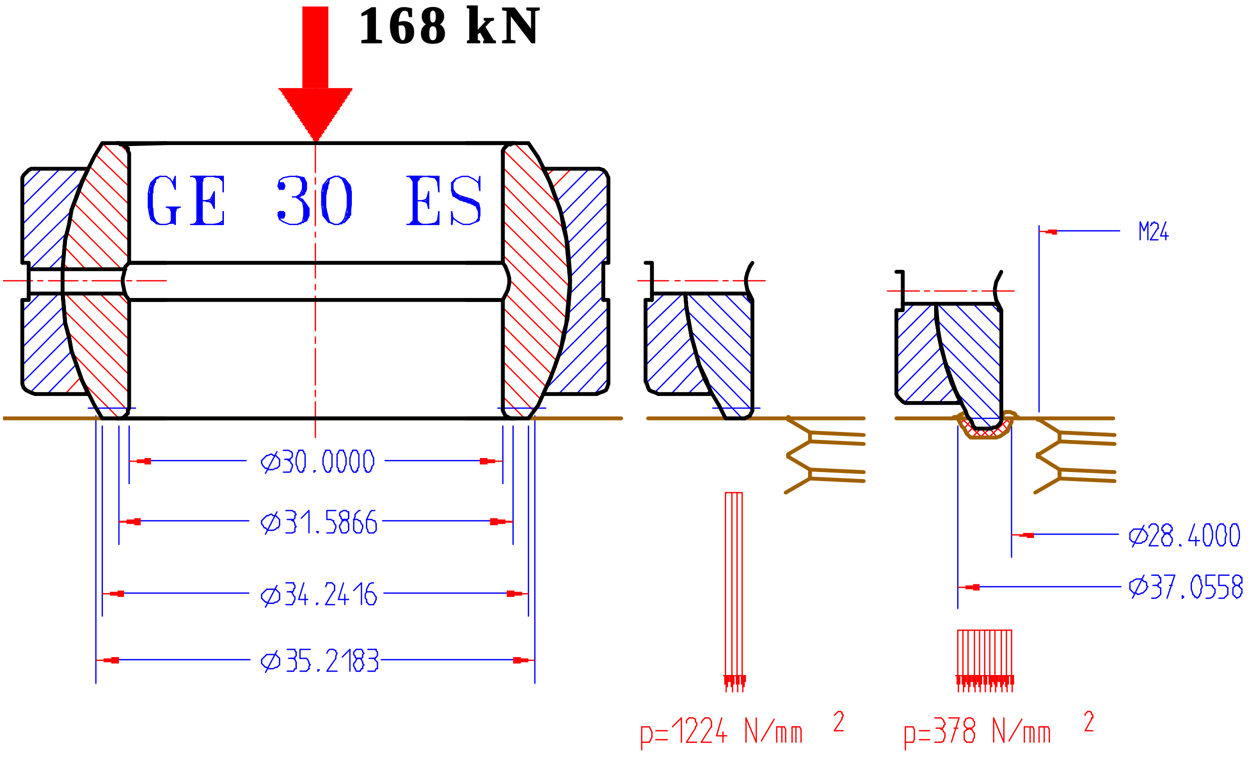


Figure 5.35 Plastic deformation in joint surface caused by link bearing
0.6 ·168 kN = 100 kN . Promising!

If the joint surface is softer than in Fe 52, a hardened washer can be put below the bearing. Below the screw head a thick washer is placed with the following consequences:

- *the elastic elongation of the screws increases*
- *an excellent place for a lubrication nipple, the direction can be selected*
- *a change of washers gives alternatives for arrangement*
- *washers can be standardized*

The first loading slightly tilts the bearing inner ring, but after that it is stabilised. The phenomenon is the same as the plastic deflection of the crankshaft in frame saws caused by the shrink fitting of the flywheels being too tight. Even a small extra load in the direction of the screw force makes progress in plastic deformation, decreasing the pre tensioning of the screw. The reduction is always smaller than the extra load and the attachment remains tight. The loosening effect of transversal load is still smaller.

The substantial plastic deformation appears emotionally dubious. The use of soft Fe 37 makes us especially suspicious, because the sinking into it is still more significant. But the sinking does not continue infinitely, because the sinking edge pulls material with itself from a growing area in the surrounding. Even the deformation is self restricting, the stabilising may be promoted together with some space arrangements without loosing the benefits of the plastic deformation (" friction coefficient")

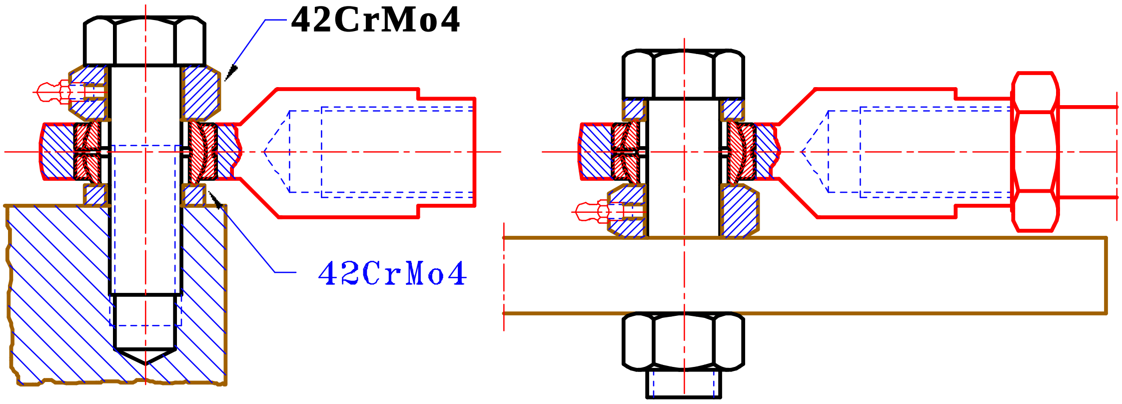


Figure 5.36 Arrangements of the link bearing attachment

A **coarse-textured** tempered washer is put between the bearing inner ring and the joint surface. The rough texture sinks against the soft surface making a form closed connection against transversal forces. The edge of bearing inner ring sinks sufficiently into this tempered material also. The same material is used for a thick washer, having a hole for lubrication. According to the need of space the washers can be changed. The joint face of the thick washer should not be too large, because the sinking must be perfect. In both cases the lubrication nipple can be turned according to the need.

The practical experiences in the pressure class of 10 MPa are excellent. For the bigger load tests should be done. The sinking and the capacity can be increased, achieved by striking the screw head with a lump hammer and by tightening the screw by turns.

The introduction of this structure was very difficult because of many prejudices. Even in this case the threshold exceeded the yield limit. The science of strength and strain has not enlightened as properly and we have learned, that the yield limit is a threshold of all evil. This solution was also kept as a cheap emergency help, which should not be taken seriously. But later on it has become the standard solution in all machines using hydraulic automation because of its reliability and long life. It has the following characteristics:

- *the structure is very cheap*
- *the attachment can be made directly to many kinds of specimens without machining the joint surface*
- *the structure is easy to disassemble and the change of components is always possible*
- *the placement of the joint can be adjusted a bit*
- *the lubrication of the bearing is easy*
- *there are no extra clearances in the link because of the attachment*

When we place the link bearing into the extended flange of the lever, we see the benefits even here. The load is not as rough as that controlled by the servo, however, but the most significant benefit here is the easy placement at any point. If we should make brackets into the lever, like in fig. 5.33, we would get a detail which could cause the change of the whole lever, in case of failure. Such a structure is also expensive.

The task at the beginning, was the design of a whole feeding unit, but in this example we can stop at the birth of this component. This kind of component was not asked for, but the idea of it took shape during the work. The final feeding unit could be, as follows:

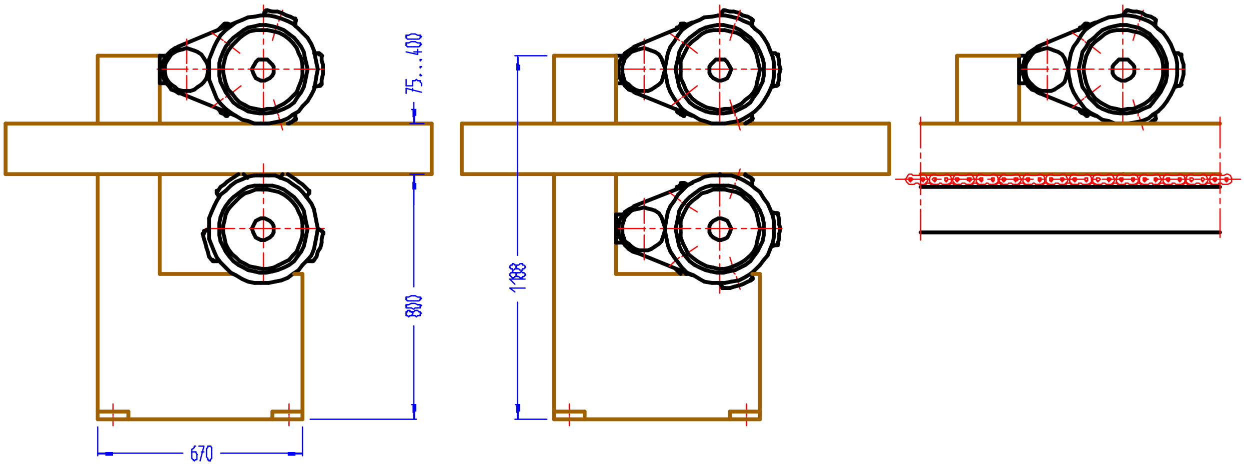


Figure 5.37 Versions of feeding unit

On the left the upper roll is the same, as the new component. The lower roll is made by means of removing the link bearing and adding the brackets to the lever flanges. In the middle of the picture, the lower roll is moveable. It is needed in feeding round logs, when both of the rolls must follow the curvature of the log. On the right only an upper roll is used. It squeezes the cant against the feeding chain.

In all versions of the feeding unit the inside structure of the feeding roll is unchanged. The idea of the component is accordingly useful. The component can be modified except in attachment, also in use of several driving units. Instead of a hydraulic motor, a combination of an electro-motor and a shaft mounted worm gear can be used. In that case the driving shaft can be extended directly inside the gear. The gear is attached, like the hydraulic motor, on the lever flange.

5.2.4 Placement in the Intuitive Method

Our example is now ready. It started at the task and at the schematic drawing of an old solution. There was no tension at the beginning, because of the old acceptable structure. Why we need a new one?

Fig. 5.38 shows the same idea as fig 4.1. We must read it from the bottom up instead of from left to right. Heuristic points are replaced with real structures. The logical transfers are not presented, because they cannot make the picture more informative and are too many to be drawn.

The picture reveals the monolith structure at the beginning. Then it is divided into some details. Because the starting point is an old proven structure, the fragments demonstrate details in process more than in structure. These are phenomena in squeezing, rolling, feeding direction etc. The penetrative analysis reveals important viewpoints and it evokes the necessary tension at the same time. The tension arrow leads to the final solution. All accepted structures are placed on the center line, other studies more to the side. Above the final solution there are still two applications, one for the feeding of the cant on the left, another for the feeding of the log on the right. Loading cylinders are not visible. The figures prove, however, that the solution can be used as a standard component suitable for many purposes.

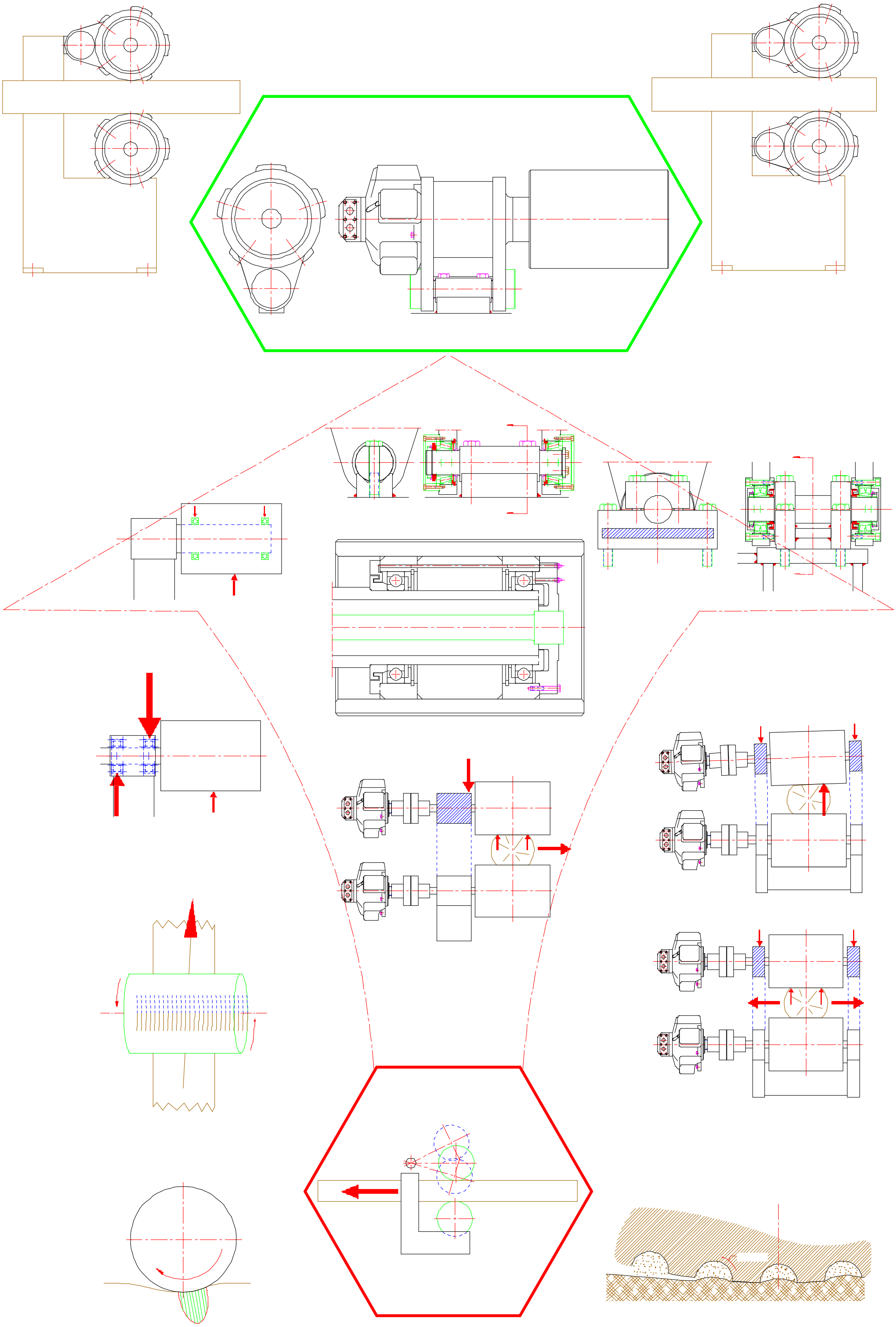


Figure 5.38 Design of feeding unit planted in intuitive method

All steps are demonstrated as figures in fig. 5.38. In practice most of the insights remain plain images throughout the process, and they don't get their real shape until the last step. This is normal practice, if we draw on the drafting board, because the drawing takes quite a lot of manual work. When the picture is so mature, that it could be described as a solution, it is very difficult to neglect any more. Even the manual repairing of the picture is laborious because of the manual drawing method. This inconvenience of repairing and changing was extremely detrimental, because it prevented and arrested the development of the structure.

On the other hand, the laborious drawing restrained the concretising of the structure in a healthy way and the maturing time, needed by our subconscious mind, came into use. The manual drafters developed themselves to masters in this respect, and they were able to handle complicated images without any support of pictures. They made only vague straight lines on the paper with pencil and by adding to them the image was developed. In most cases these "sketches" were impossible to understand for any outsider, they were nothing but a plain mess. At last the designer took the drawing ink and made the final shape on that mess of pencil lines. Extra lines were erased.

Despite all efforts, wrong details and dimensions were created in the inked drawing, too. Those were repaired in most cases by modification of the dimension values. These values were underscored to distinguish them from original ones. This practice was very dangerous, because "the picture talked" to the designer with faulty language and led to errors in use of space and in the dimensioning the parts.

Our example shows, how the screen makes it possible to draw the detail in the final shape at the beginning of the task. The detail can be carried inside the drawing and put in all positions in any place. It can be made to a block and may be invisible also. Sketching lines are not necessary, but all shapes can be drafted as "final". If any modifications are needed, they can be made by stretching, adding or changing the whole block. The advantageous use of screen has given us tremendous benefits in engineering design.

During manual drafting I started my drawing by drafting all bearing sections and other known components in their estimated places. I needed the visual talking of these objects. Today I can call them into my drawing any time by means of some drafting programs. Those programs can be made to furnish our drawing with all standard structures like keyways, chains, sealings, bearings, gears, couplings, screw joints, hub joints, etc. It is no trouble to throw them away or replace them with new sizes or types. They can be moved in any place, of course. The influence of those pictures is enormous for creative design.

Our design example is in many respects very customary. Most of all design work is made based on the old mature structure and now revolutionary developments are evident. There is no need to seek for completely new base solutions starting from elementary ideas. But exactly this type of design work has a tremendous potential for a real progress with some preconditions. The design shall not only be a repeating of the old structure with minor modifications. Any designer knows the convenience of this type of "design". He does not need to take any risks, and the modifications are created by using his professional skills. It is important to make a thorough penetrative analysis for this old structure. Doing so, he makes himself free from the arguments, which the **old structure gives** and he finds the more important arguments, which the **structure is based on**. The given arguments assume the preserving of the structure, the basic arguments makes the designer free of the old structure. This difference is the key.

6. Comparison Between Intuitive and Systematic Methods

Logic is the most important tool of creativity, but only a tool, not the whole content. When the use of logic is extended, chained and standardised to be useful in some specified duty, we finally get a systematic method. The human being has always admired himself and his rationality. After creating the systematic method he considers himself to be able to control everything in that duty and in all conditions. At the same time he has passed the creativity, and the fruitful dialogue between conscious and subconscious mind is hardened to the use of some standard channels, and the "sand layer" between both of the minds is not possible to penetrate any more, from either side.

Two decades ago I tried to develop the idea of creating a textbook for the demonstration of an ordinary design process from beginning to end. The professors of engineering design considered the idea impossible to realise, because there were no clear functions to be found in the design process. It was also difficult to find an objective, which could be commonly understood. Therefore, it became a real problem which required a solution. Not until the end of the 70's, was the project started, with the objective of developing a passenger car jack for private use.

The project was carried out at Tampere Technical University, where I got a position in the comment group. Despite my involvement, the process was realised using the German systematic design method according to VDI 2222. My idea was primarily to design a good car jack. The project proceeded admirable to the final publishing stage.[22] During the project my irritation increased gradually and the final result was completely different from my original vision.

When the publication was ready, I put a new sheet of paper on my drafting board and during two evenings I made my proposal without any systematics. I liked the result and making it did not cause any excessive problem. It was easy for me, like all design works are after comprehensive preparations. It was ironic, however, that in the new publication I could not find any errors, which could be blamed for its eventual failure. On the contrary, the published solution was optimal according to all criteria. Everything was fluent and logical, like the work of Ahasuerus himself. However, it was this unsolved irritation which led to the development of the intuitive design method, described in this book.

In this chapter I shall refer to that publication in describing the design process. In connection to each phase, I shall make comments and point out the obvious errors. The steps of the design process are presented in that publication as the following chapters:

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[22] MET 2/81, Suomen Metalliteollisuuden Keskusliitto, Hanko 1982

- *planning of the design project*
- *sketching*
- *developing*

I shall follow the first two chapters but not the last one. After each chapter I shall add my own comments using the cursive typeface. After this description I shall design the same object once again using the intuitive method.

6.1 Beginning the Planning

6.1.1 Background

The project was started by defining the company, which needs to incorporate the new article into its assortment. The company was a small engineering workshop making agricultural tools and equipment. The machine shop consisted of welding machines, presses, plate cutting devices and a spray shop. All products were marketed through a large trading company. The capacity of the welding department was not fully exploited, hence some convenient work was needed. The product idea was discovered, when one of the employees tried to fix the floor of his car.

❁ *The original idea was created exactly in this way. My wife's car was not in very bad condition, as in fig. 6.1, but the original jack was so slender, that I didn't dare creep under the car when it was lifted by this jack. There was no space for me, anyway! The floor of the car was badly rusted, because the car had been effected by some sewer gas in the garage. I had to cut large sections out of the floor and cover them with new steel plate.*

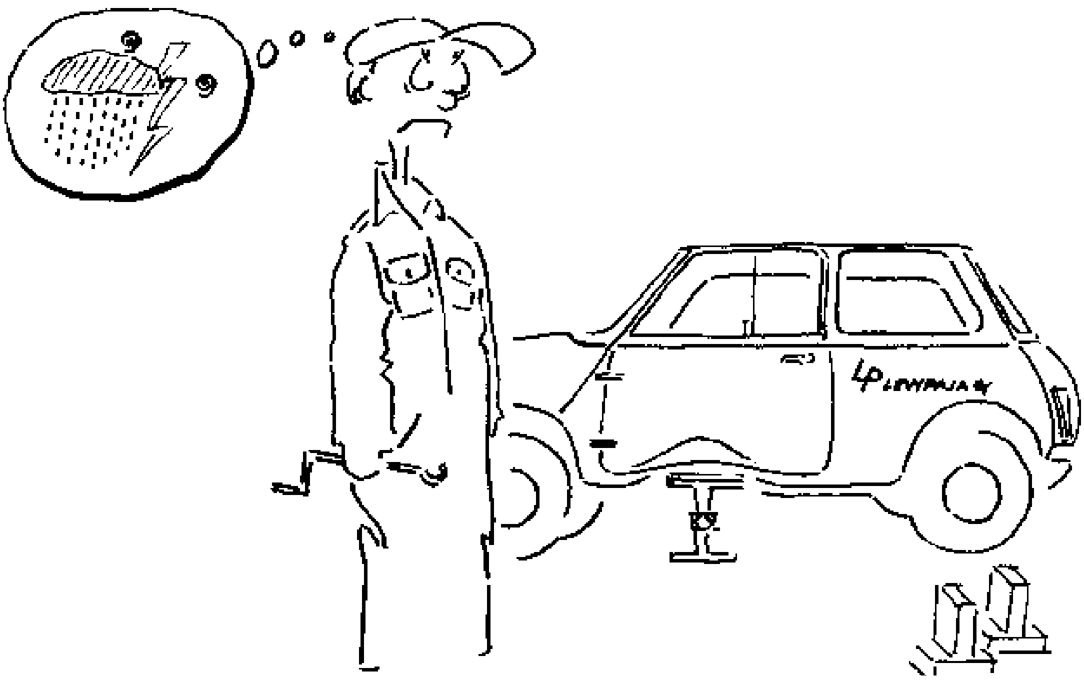


Figure 6.1 Birth of the jack idea

- ☸ *The analysis of the machine shop and the loading of the company leads the thinking to paths, which are specified prematurely. This might lead to a product, which is not convenient for the customer even if it would be convenient for the company. In this case a new product would be too easy to compete out of market by developments of other companies. The essential goal is to find a solution, which suits the customer. Not until the final development of structure should manufacturing capacity be considered. It is, however, a factor which must be remembered in the determining of the price.*

6.1.2 Need of the Product

The eventual demand for the new product must be reviewed carefully. The straight marketing review is not the best method in this case, because there is no equivalent product on the market. The review can be made using an indirect route.

Corrosion is the most significant factor which dictates the life of a car. To protect cars against corrosion special companies have been established. In addition to the use of their services a careful owner crawls under his car to clean and to smear the difficult corners. The hand brake cable also needs cleaning and loosening and the exhaust pipe, or parts of it, must be replaced almost every year.

These tasks presuppose the possibility to work below the car. There are other targets areas around the wheel arch's which are accessible from outside the car, when the wheel is removed, in which case the original jack will suffice.

An interesting market survey was carried out by a magazine in 1979. At that time about half of the car owners did minor repair work themselves or by using the help of their friends. The cheaper the car was, the more, private repair existed. The most active car owners were those who owned a Wartburg, up to 71 % of them, of which the share by Volvo owners was only 15 %. Only 5 % of the owners of luxury cars were willing to get their hands dirty. Patching against corrosion was carried out by 25 % of all car owners.

The skills required for car repair can be acquired from DIY magazines. In addition to this there is a reasonably priced service book available for almost every make and model of car. Cheap tools are also available today, in growing numbers. During the winter a warm garage would be fine, but only 18 % of Finnish car owners had one. In the summer time the car can be repaired outdoors. However, there is always a lack of storing space for such tools, hence the small storing size of our article is of remarkable value. Because of the varying repair environment, we must ensure good quality flooring. In outdoors use the ground may be rather soft.

If the share of car owners, being able and willing to service and repair a car by themselves, would be approx. 10 %, the total market of our product could be in Finland approx. 110,000 pcs. The price could be 550 Fmk, considering the price of the usual garage jack. In these conditions the annual production number could be estimated to 2,000 psc.

- ☸ *The market survey was well done. A closer analysis would tell us, that the jack would be used mostly for corrosion protection and for a frequent monitoring of the condition of the car. The most common actual repairing task would be the replacement of the exhaust pipe. This presupposes a real benefit in price and the good quality of the spare parts. The replacement of the exhaust pipe is such a laborious and troublesome job, that after the first* *endeavour most of the car owners leave it to be done in garages. However, the sales of exhaust pipes outside the garages would have been a very important feature in our market survey.*

- *The biggest percentage of all repair work is done under the wheel arch's. The car can be lifted using the accessory jack, but after that an extra support is required for safety. This support should be height controllable and versatile in it's method of fixing to the car and also should be steady on soft ground. This type of product could be added to our program along with the actual jack.*

6.1.3 Space Below the Car

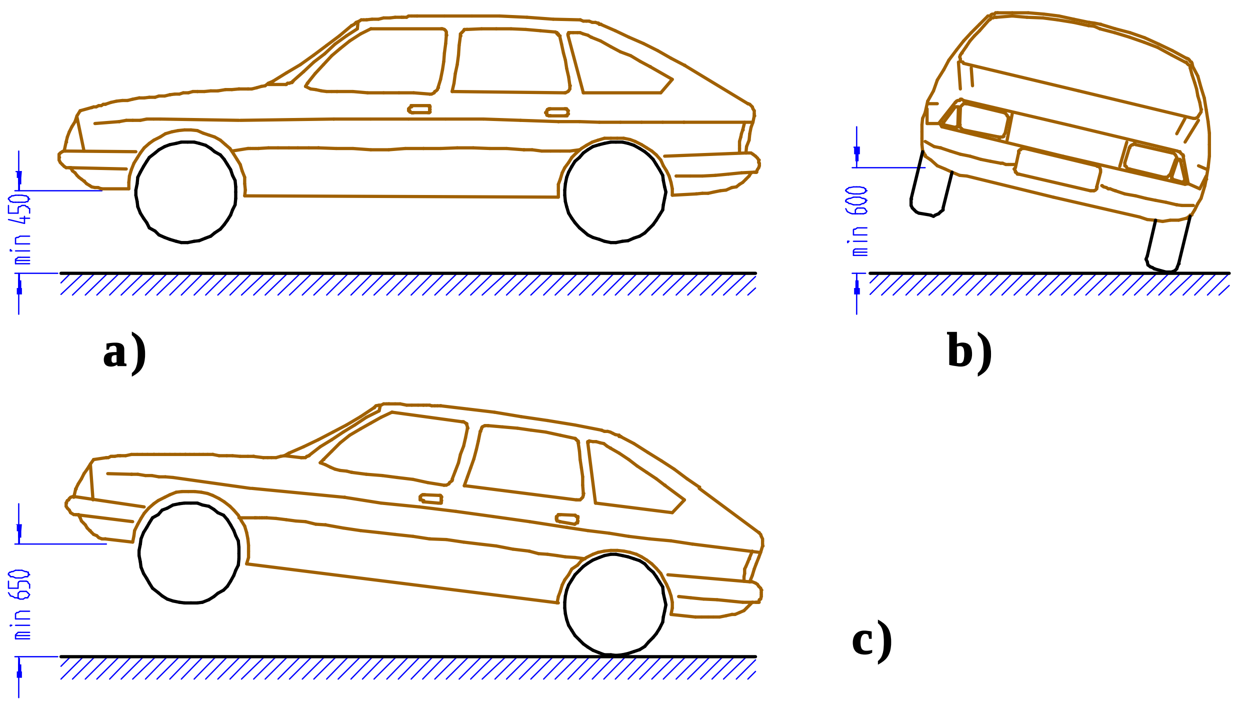


Figure 6.2 The working space below the car

Working below a car is always troublesome. The working would be more convenient, if the car could be tilted onto its side, or lifted up to 2 meters. For this, the necessary lifting equipment would be big and expensive for hobby use. An excessive tilting would cause the flow of liquids into the wrong places or some liquids could leak out.

The standard manhole has dimensions 300 x 400 mm. This is big enough for almost all men, if they put their hands through the hole first. Below the car more space is needed, because one should be able to roll around there. The free height should be at least 450 mm. Fig. 6.2 presents the needed minimum space dimensions with different methods of lifting.

- *The needs of lifting are realistic and very useful for further study, because it is visually presented.*

6.1.4 Jacking Points and Car Size

As a matter of fact the car should be lifted, only by its wheels. The thin plate structure of the body is optimised, so that the body can only be lifted at certain points. For the accessory jack those points are specially marked and sometimes there are special fastening structures welded to the body. For big garage lifting devices the areas marked in fig. 6.3 are commonly used. Those areas are normally junction points of the reinforcing beams of the body making them stiffer and stronger than other areas.

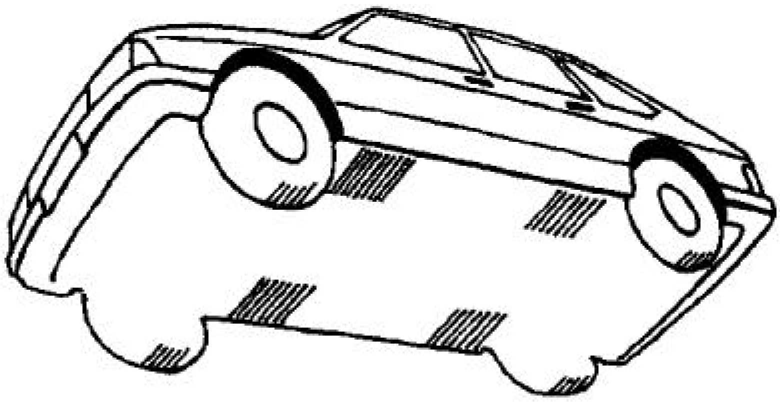


Figure 6.3 Universal lifting areas under the car body (hatched areas)

Our jack must be universal; therefore the marked areas and the wheels can be considered as the only fastening points. It is not practical to design a jack to suit all types and sizes of cars, thus the dimensions of the car can be restricted, as follows:

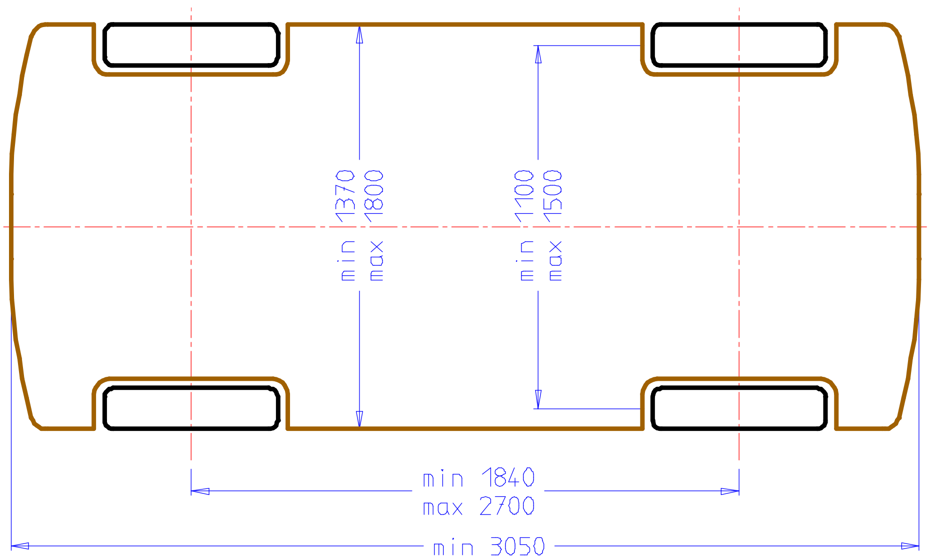


Figure 6.4 Size restriction of the car

- *The definition of the lifting areas on the car is okay. However, the fixing of the jack to the car should have been studied in more detail at the beginning and must be done before proceeding, since it has been neglected up to this point.*
- *A definition of the car size is not necessary in this phase, since the differences among them are not significant now and the size scaling can be defined later.*

6.1.5 Presentation of Available Means and Devices

The specification of every accessory jack allows it to be only used for the replacement of wheels. In addition to this, it is used frequently for servicing under the wheel arch's, i.e. changing

brake pads and brake linings, shock absorbers and link bearings etc. For this work the car should be lowered on a more steady support, because in disassembly high force is required to loosen seized parts. Standard accessory jacks cannot tolerate the 'swing' of the car.

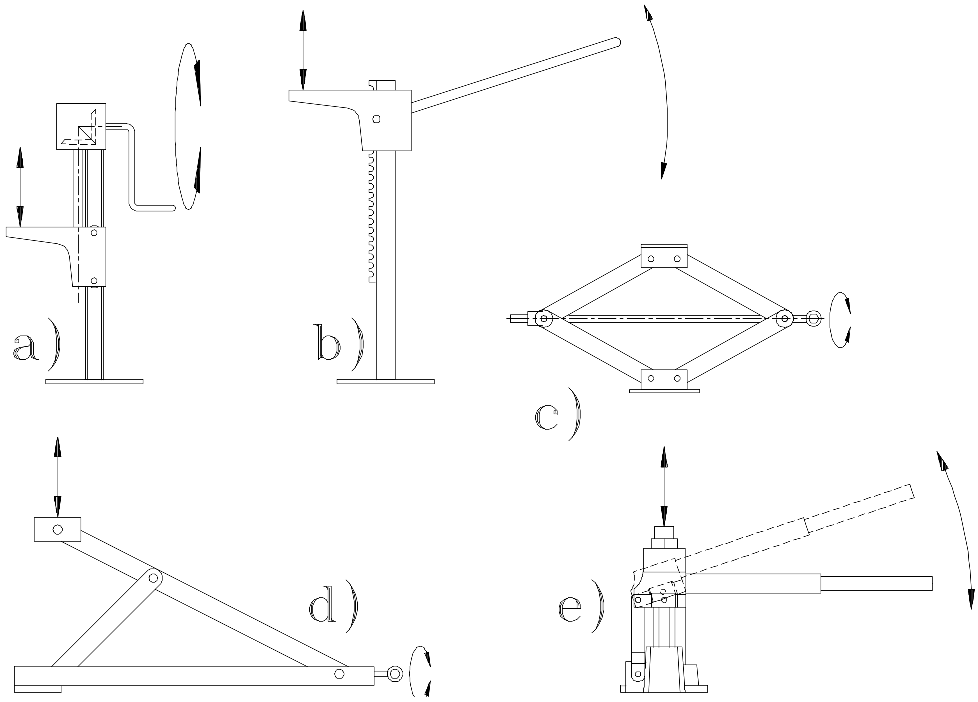


Figure 6.5 Standard accessory jacks of some car types

A car may be driven on planks, over a dike, which allows space for working below the car. Also useful are ramps made on the backslope, which are rather limited in use, because between the wheels on both sides the working space is limited. In this position the changing of oil and the replacement of the exhaust pipe is possible. Moveable ramps can also be used on grass. The car can be driven over them so that either the front or back end is lifted.

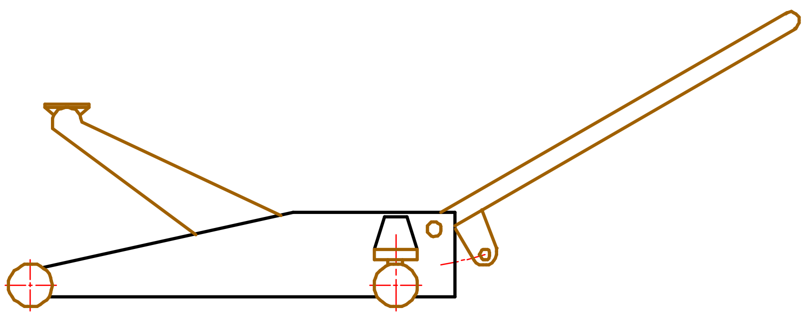


Figure 6.6 Garage jack

The jacks, which can be bought in accessory shops, are more universal than the jacks supplied with the cars. However, they are often very dangerous in use. The reason for this is the lack of proper connection to the car. In professional use there is equipment, which can lift the car up to 2 meters. Most of the garages use a so called garage jack, fig. 6.6. It can be used at any convenient point below the car and the lifting height is at least 450 mm. This could be a good solution also for hobby work, but these jacks need a plain hard floor. The cheapest models costs 500 Fmk, and are also our toughest competitors. In the future the price will be even lower. Even these jacks are not used without extra supports.

- *The presentation of the available jacks is only general and no analysis of them is made. The structure in fig. 6.5 a) was used with expensive cars in the 50's. Version b) was fast and easy to use, but failed after several lifts. Today version d) is very common because of the small space needed for storing. It is also reliable, light and still robust. The articulated jack, version c) is very common in accessory shops. It is rather useful, when rear wheel drive was more common. Its lifting range is short and in practice it is very dangerous, because it overturns easily. Hydraulic jacks are today, the most common jacks found in accessory shops, fig. 6.5 e). They have a large contact area with the ground and are rather safe.*
- *Every jack presented should get a thorough penetrative analysis to reveal the functions and the logic, to be used as material for our development work. In this respect the presentation is not sufficient and can only lead to the copying of some existing structure.*

6.2 Planning

6.2.1 Generating a List of Demands

According to the systematic method, after the presentation of the task, a requirement list has to be created. It is the company's internal list of all the requirements and hopes, which should be considered in a design project. It is also a basis for criticism and decision making later on.

The demands are classified in three groups. Fixed demands (FD); must be realised in every case. Minimum demands (MD); should be fulfilled to a certain amount. Exceeding that amount may be desirable, but not harmful. Hopes (H); are fulfilled if it is feasible.

The power needed is that which will enable the device to be used in any circumstance. The power source may be the car itself, or the muscle power of the user. The car can deliver power in the following forms:

- *electric power from battery*
- *pressurised gas from spare wheel, exhaust or from engine cylinder (spark plug hole)*
- *thermal energy from the engine*
- *mechanical power from wheels or from crankshaft.*

The mechanical power is used, when the car is driven on the ramp. Pressurised exhaust gas is used in lifting sack. The use of the mechanical power, taken from the car, is limited by the following factors:

- *poor safety*
    -- *exhaust gases indoors (all alternatives)*

-- *failure in driving accuracy (ramps)*
- *car is out of condition*
    -- *motor in poor condition (almost all alternatives)*
    -- *battery in poor condition (use of electricity)*
    -- *exhaust in poor condition (lifting sack)*
- *clumsy use (almost all alternatives)*
- *not in line with the company policy (lifting sack)*
- *costs (most alternatives)*

Table 6.1 List of Demands for the Jack

Change date	FD MD H	DEMAND	Importance
		1. GEOMETRY	
	FD	The jack is used in a garage (there is free space on both sides of the car, approx. 1,5 m on both sides).	
	FD	The capacity must be capable of handling cars defined in fig. 6.4.	
	FD	Storing of the jack must be easy without an excessive use of space.	
		2. KINEMATICS	
		One of the lifting modes in fig. 6.2 must be possible.	
	MD	**3. FORCES**	
		Lifting capacity is 1300 kg.	
	MD T	Necessary muscle force $\leq$ 150 N.	
		4. ENERGY	
	FD	Muscle energy of operator is used.	
		5. MATERIAL	
	FD	Steel in form of plate or profile.	
		6. SAFETY	
	FD	Working below the lifted car must be safe: - securely lifted - safe connection with the car - wide contact area with the ground - access to the lifted car possible (fire guarding during welding	
		7. MANUFACTURING	
	FD	No grinding	
	H	Presses can be used	
	FD	Plate thickness $\leq$ 8 mm.	
	H	Simple structure.	
	FD	**8. CHECKING**	
		Testing with car of weight 2000 kg.	
	H	**9. TRANSPORT**	
		Transport inside the car.	
	MD	**10. USE**	
	MD	Weight of jack $\leq$ 50 kg.	
	MD	Weight of individual parts $\leq$ 20 kg.	
		Time for preparation and lifting $\leq$ 5 min.	
	FD	**11. MAINTENANCE**	
		No maintenance needed.	
	MD	**12. COSTS**	
	H	Manufacturing costs < á 250 Fmk (assumed annual production 2000 pcs/a)	
	KV	No investments in machines or buildings.	
		13. DELIVERY TIME	
		Structure ready for manufacturing until ....)	
		FD = Fixed demand MD = minimum demand H = hope	

Because no easy method to use the car's own power could be found, the problem was limited to the use of one's own muscle power. At the same time it was decided, that digging clay was not a feasible solution to provide the required operating space, i.e. a shovel can't be used.

- *A systematic design method is significantly based on the list of demands. All characteristics involved, are gathered into this list. The demand list is, at the same time, a very important instrument when the work is shared among a big design team or among subcontractors. It ensures the accomplishment of the design, according to the intended aims. As the most important document of a design work, it seems to be so important, that it is very difficult to criticise it.*

- *However, a strong emphasise on the demand list, guarantees a poor final result for the design project. In creating the list the biggest error will be made in communication. Thus, the designers need a strong character, and skills to find the required freedom. However, the demand list can always be taken onto the table, when it is least needed. The management, which has no personal design skills or design experience, thinks, that it is able to use the demand list in order to control the design team and to keep the project in the range of a time table.*

- *In this particular project the demand list goes into too much detail without thorough reasons. The existing solutions have been glanced at and the different forms of available energy have been pondered. Manual operation could result in less work. The only important details in the demand list are the definition of the car size, testing methods and the proposed price of the device. All other stuff builds more barriers than paths to progress.*

- *The worst thing, however, is the literal form of the demand list. The written text chains, hence those shackles should be used really very meagrely. It had been more important to think, what manoeuvres go on below the car in garages and what happens, if the jack or support overturns, while the seized exhaust pipe is torn out.*

6.2.2 Formulation of the Problem

In systematic design methods the disadvantages of the chaining demand list are attempted to be avoid by providing a clear definition for the task. The definition is created by forgetting the hopes and reducing the demands to an essential level. In formulation of the problem the kernel content should be realised, and all restricting words and expressions should be avoided. The first formulation of the task is:

> *We must design a jack, which is able to lift a car, which has a weight of 1300 kg, a width of 1800 mm an a wheel base of 2700 mm. The jack must be safe enough, that repair and service operations below the lifted car are possible.*

This formulation has still words, which lead into certain direction (lift, jack). The formulation shall be developed towards a more simple form (abstraction):

We must design a system, which makes repair and service operations possible below a car.

☸ *If we put the demand list into a drawer and we consider only this formulation, the design process can breath again. Why is the list gathered, by the way? The knowledge, notices, and results of analysis are needed, but they do not have an effect throughout the demand list. The systematic method does not produce those factors and it does not contribute them to the design process.*

6.2.3 Decomposing the Problem into Subsystems

One of the most awkward "research" results is the splitting of the total function into several types of input and output. It is true, that this splitting is possible to distinguish in almost all machines, but for the design work the splitting does not give any contribution. It is more or less worthless.

In our example of the systematic design process this splitting of the total function is done, but the result seems to be rather reluctant:

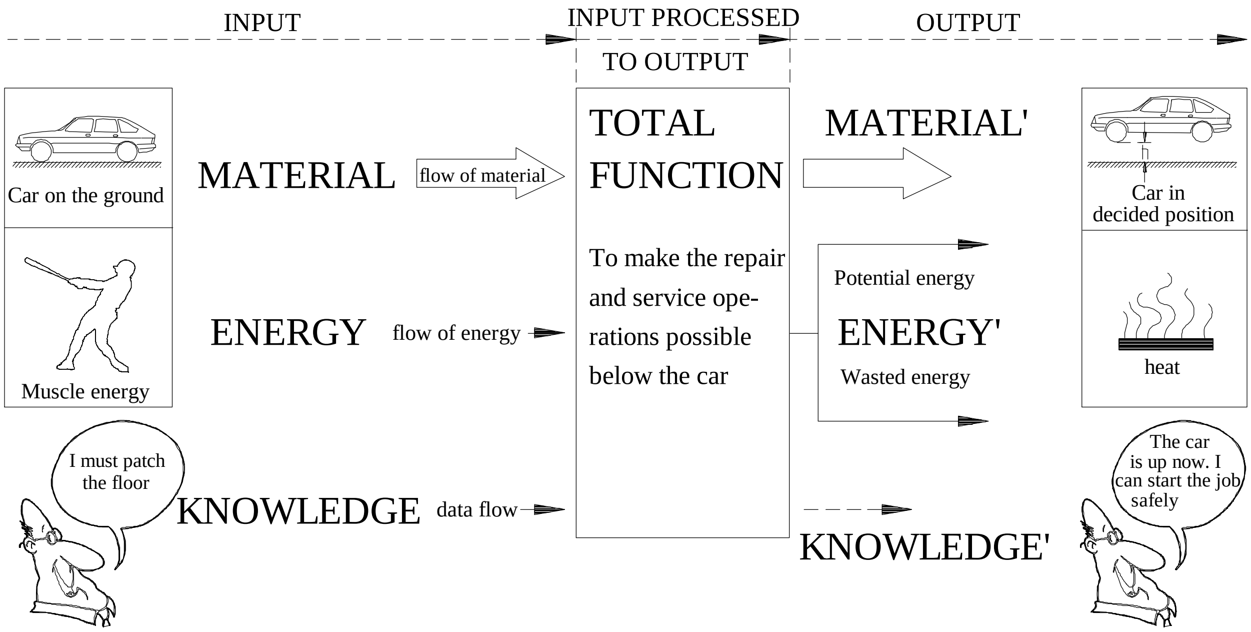


Figure 6.7 Total function of the project

The use of this splitting does not help in search of solution. Instead of that the main function has to be divided into subfunctions:

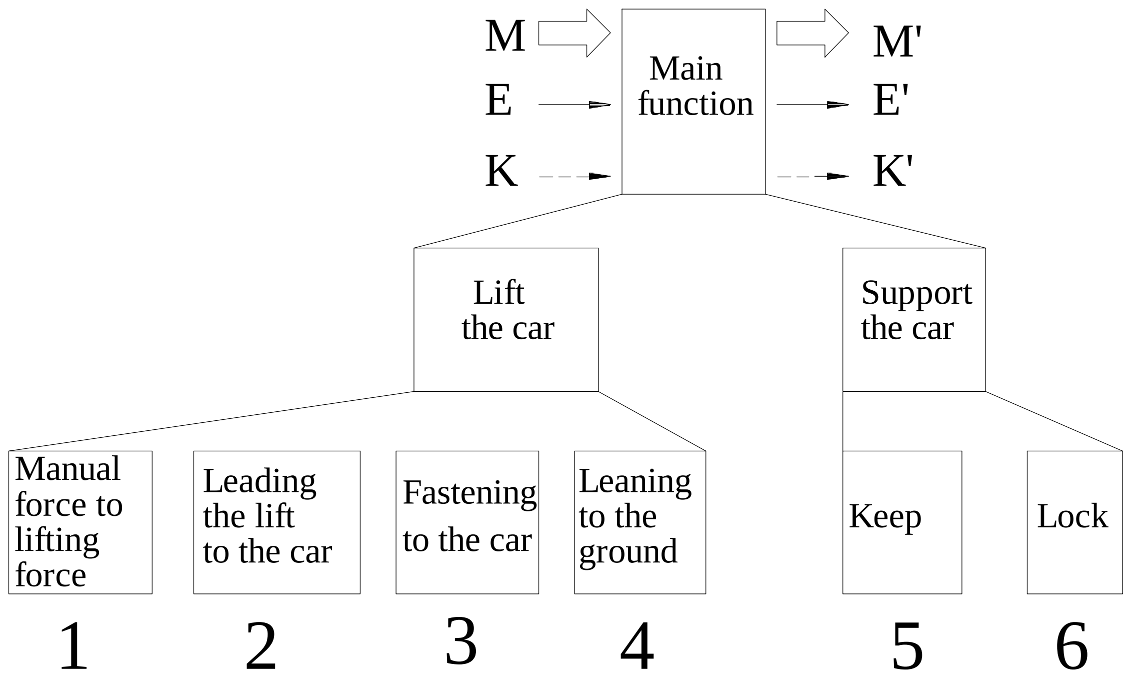


Figure 6.8 Dividing the main function into subfunctions

The customer cannot lift the car directly, but his muscle power has to be transformed to lifting force with the subfunction 1. Subfunction 2 is used to transmit the combination of lift and lifting force directly or in transformed form into the connection points of the car. Subfunction 3 makes the connection with the car. Subfunction 4 keeps the system steady on the ground. Subfunctions 5 and 6 secure the lift and they make operations below the car safe.

Our example is more concerned with the recognised functions of the alternative in fig. 6.5 c). The subfunction 2 is realised by a parallelogram of bars, where a screw moves the link points B and C (with large force) closer to each other. At the same time the another pair of opposite link points move away from each other. Because these link points are attached to the ground plate and to the lifting pan, they accomplish the lift and subfunctions 3 and 4 as well. The screw is self arresting, thus it also accomplishes subfunction 5. There are no means to accomplish subfunction 6, if we do not accept any separate support for that purpose.

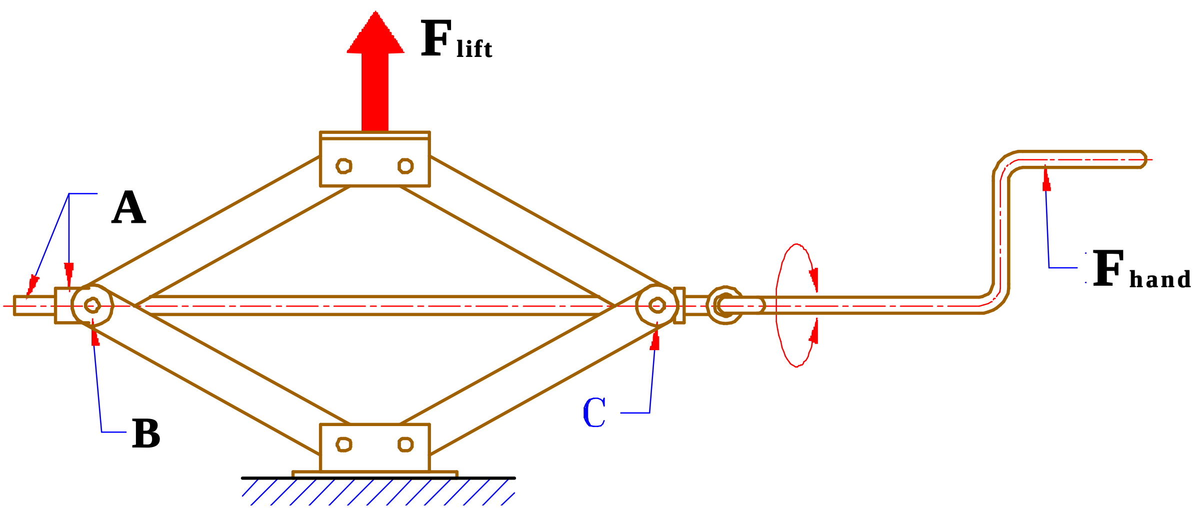


Figure 6.9 Articulated jack

- *The parallelogram accomplishes subfunction 2 with a continuously changing ratio of transmission. At the lower position the lifting force is much smaller than the screw force, at the upper position this ratio is inverted. This feature is useful, if the jack is connected to the body of the car. In that case the springs of the car relieve the lift and the lifting speed is pleasantly high. On the other hand, if the jack is connected below the rear differential, the lifting is very heavy at the beginning. This connection point is also the lowest possible on the car.*
- *If the lifting pan is attached to the ideal parallelogram with two link pins like in fig. 6.9, one of the holes must be replaced with a slot to allow for movement. Another alternative is to connect the bars of the parallelogram with the same pins, as the lifting pans use. In that case the bars must be synchronised with gears.*
- *This jack can be folded into a very small storing size. Its lift is completely straight, but it is very unstable, if the upper connection point moves horizontally, while the car tilts. Today the most common modification of this type of jack is the version in fig. 6.5 d). The connection point to the car is on the body below the door.*
- *Subfunctions division in this example is apparently accomplished on the basis of the articulated jack. It is very logical, of course, but not very practical, if we consider the design by one subfunction at a time.*

6.2.4 Evaluating Alternative Solutions for Subsystems

Alternative Solutions for Subsystem #1

Design catalogues[23] (fig. 6.10) present all the solutions for the transformation of the forces: use of wedge, lever, and the use of liquid or air pressure in cylinders. These principles are very familiar to all designers, hence the use of a catalogue with all the symbols and formulas appears to be too complicated in such a simple application.

A plain wedge can never be very long, hence its lift is not long enough. In engineering the wedge is used mostly for clamping, adjustment and by using its low efficiency in power transmission. It is self arresting. The best application for the wedge is the screw, where the wedge is wound around the shaft. Its power efficiency is low, but the length of the movement is not limited and its self arresting ability is valuable for our application. For such a high ratio of transmission the screw is very inexpensive. Versions a), c) and d) in fig. 6.5 exploit the screw in transmission and arresting.

The power efficiency of a lever is good, but the range of movement is very short. In the stone age the people knew how to extend the movement of the lever. They moved the supporting point after every lift. The same is accomplished in version b) in fig. 6.5.

[23] Roth, Franke, Simonek: Aufbau und Verwendung von Katalogen für das metodische Konstruiren. Konstruktion 24 (1972) pp. 449...458.

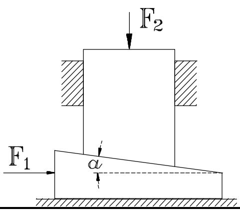
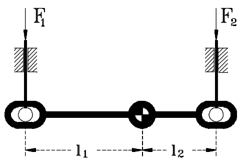
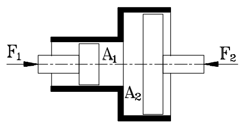
Physical effect	Formula	Schema of device	Amplification factor V	Stroke S	Influence of friction in amplification	Length l	Other features
	1	2	1	2	3	4	5
Wedge	$F_2 = \cot(a+2r) \cdot F_1$		$V = \cot(a+2r)$ $V_{max} \simeq 10$	$S_{2max} = (1/V) \cdot l$	Increasing coefficient of friction reduces amplification	$l \simeq V \cdot S_{2max}$	Self arresting when $a < r$
Lever	$F_2 = \frac{l_1}{l_2} \cdot F_1$		$V = \frac{l_1}{l_2}$ $V_{max} \to \infty$	$S_{2max} \simeq 2 \cdot l_2$ (vipu) No limits (wheel)	Small because of links	$l = l_1+l_2$ (lever) $l \simeq 2 \cdot d$ (wheel)	Stroke not limited (wheel)
Hydr. or air pressure	$F_2 = \frac{A_2}{A_1} \cdot F_1$		$V = \frac{A_2}{A_1}$ Sealing problems reduce the maximum	-	No influence, if proper materials		

Figure 6.10 Principles for power transmission (catalogue)

Fig. 6.11 demonstrates structures derived from a lever. On the left the lever lifts the rider gliding along the pole. By lifting one stroke the rider can move up so much, that the pawl enters the next notch. The lowering of the pawl mechanism is controlled in such way, that the rider comes down notch by notch. The power efficiency of this jack is excellent, but the structure has proven to be weak. In addition to that it requires plenty of storing space, therefore it is out of use today.

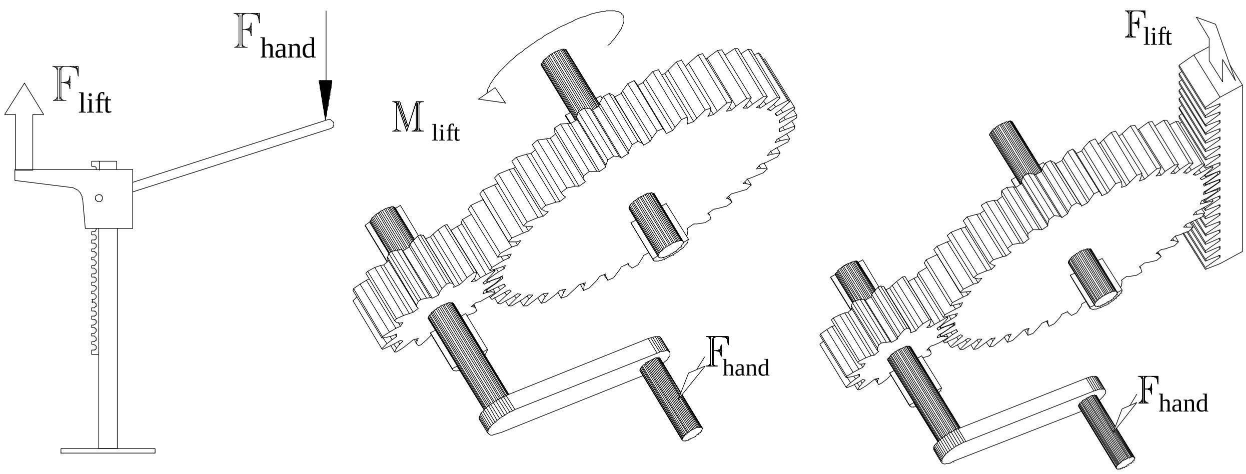


Figure 6.11 Devices derived from lever

A pair of gears produces a lever which can continue its movement infinitely. The levering movement is transformed into rotational movement. In the center of fig. 6.11 the transmitted force and movement is taken as rotational movement. On the right the gear rack (straightened gear) takes the movement as a linear movement.

One derivative of the lever is a combination of the crank and the drum, fig. 6.12. It is very much similar to the gear rack in the former version. The gear rack is substituted by a rope winding around the reel. The rope cannot be used with a very small reel, therefore the amplifying of force is not big. A pair of gears is used to help in that matter.

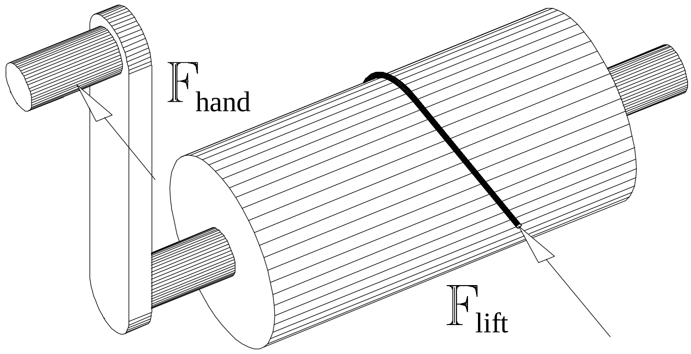


Figure 6.12 Crank + drum

- *The most advanced application of the rope and drum is the bridge crane, which is very common in industry. There are several versions of the same principle. The lifting height is big and the drum is very well utilised. While the car needs a lift of only up to 400... 600 mm, the drum and rope are probably not suitable.*
- *Our example considers the block and tackle also, as a derivative of the lever. After closer inspection we see, that this is not true. There are no moments in pulleys, hence no transmission of force or movement takes place. The function is based on the constant tension of the rope in the whole rope system. By means of pulleys in two groups, the same rope lifts the load as a multiple rope set, threefold in fig 6.13.*
- *The block and tackle is one of the most sophisticated developments of ancient times. It was widely used in sailing. Even today, it is used in the stretching of electrical cables on railways.*

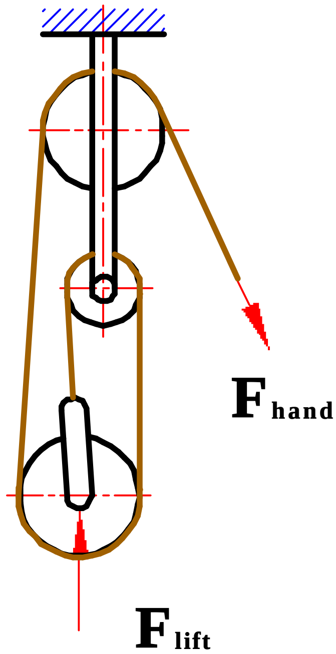


Figure 6.13 Block tackle

- *Alternatives for subfunction #1 are discussed well in our example. More alternatives are hardly needed. But all of these alternatives are very familiar for every engineering designer, hence the presentation in so wide scale, it cannot be very reasonable. Here the work is done for the method, because the so called morphological box needs them.*

Alternative Solutions for Subsystem #2

The leading of the lift between the car and the ground is studied as a problem of plain mechanism science. The first alternative is the mechanism of rectilinear movement by Scott Russell in its several variations.

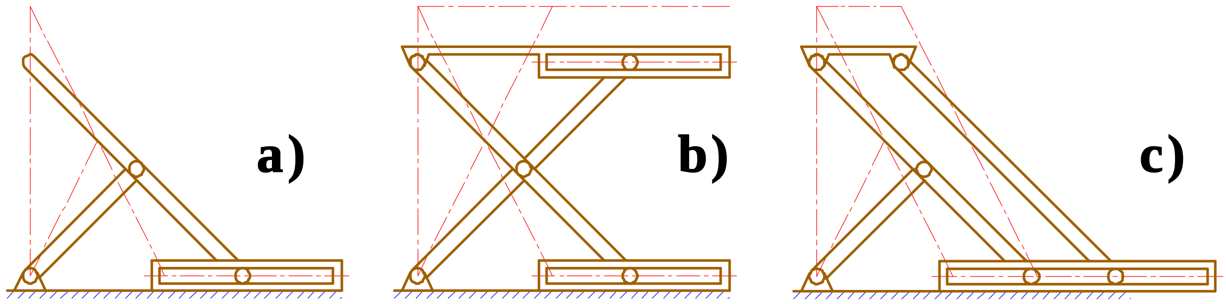


Figure 6.14 Mechanism of Scott Russell in three versions

The basic version of the rectilinear mechanism is presented in fig. 6.14 a). It is used as a jack in fig. 6.5 d). Version 6.14 b) is completed in symmetric form. This ensures a lifting plate keeps its horizontal position all the time. The same plate position is accomplished in version 6.14 c), when the structure is completed to a parallelogram.

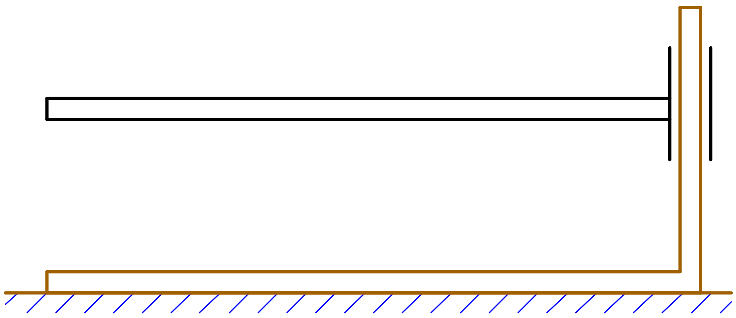


Figure 6.15 Gliding cantilever bar

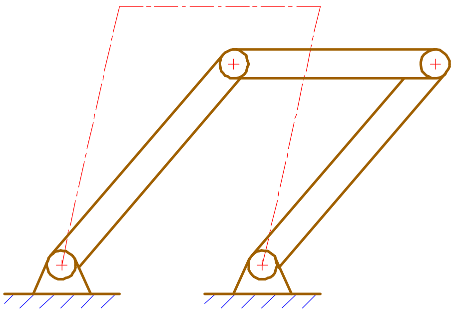


Figure 6.16 Parallelogram

The structure in fig. 6.15 has a long horizontal gliding bar, which could be put below the car for lifting. The bar glides along a vertical pole. Some garage hoists use this mechanism, but the gliding guide block is replaced with a rolling guide block.

The parallelogram according to fig. 6.16 is common in garage jacks (fig. 6.6). This makes the lifting pan keep its steady horizontal position. The horizontal movement of the lifting pan during lifting, is compensated by the jack moving on its small wheels on the floor. Therefore a hard plain floor is important for garage jacks.

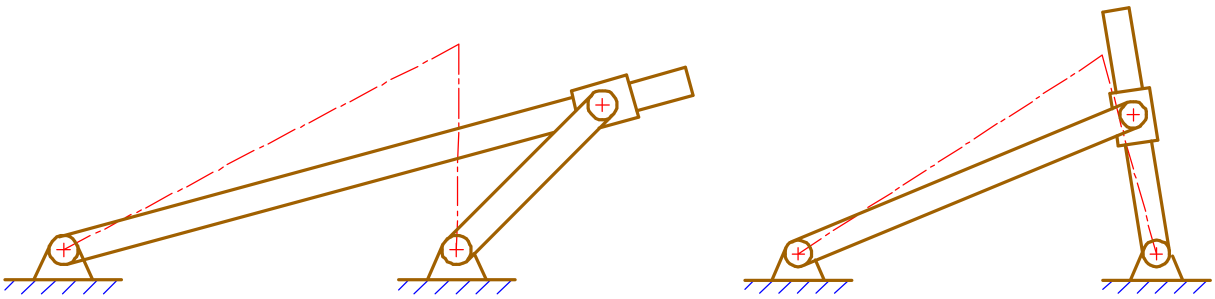


Figure 6.17 Structures using gliding block

If one link of the linked triangle is replaced with a gliding block, the result is a rather simple structure, which could be useful in tilting the car.

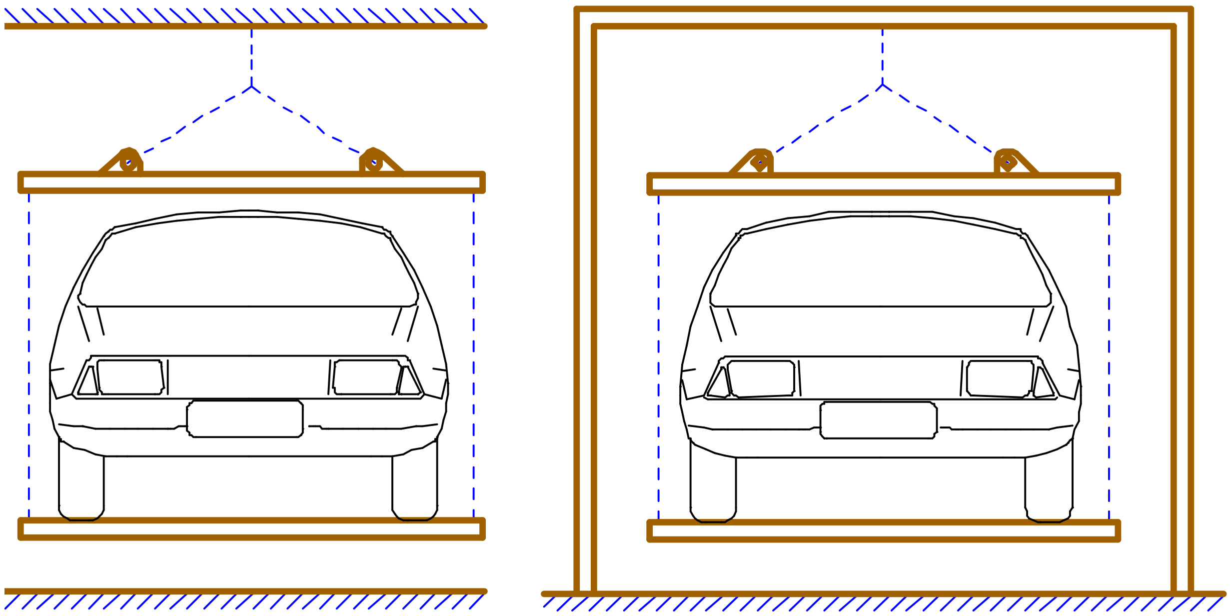


Figure 6.18 Lift of car using horizontal beams

Two horizontal beams can be used to lift the car straight upwards. The ropes are fixed on the end of the beams and the lifting tackle can be fixed into the ceiling or into a frame build around the car.

The lifting beam in fig. 6.18 is placed below the wheels of the car. This placement is good, because it leaves the whole chassis free for operations. The beam needs rolling stops for the wheels and the fixing point of the rope must be placed so high, that the wheels do not roll during the lift.

- *Proposals for this subfunction are gathered so eagerly, that the main function (working below the car) slips out of the mind. However, this limited concentration can be defended. At the same time we learn more about lifting and we will probably find completely new ideas.*

Alternative Solutions for Subsystem #3 and #4

In the example the common lifting points are defined. They are the wheels of the car and some points in the body, shown in fig. 6.3. The connection to the body was intended to be done by means of friction only. The lifting force should be spread out with some kind of lifting pads.

Rolling stops are required on both sides of the wheel when they are to be lifted. Attachment may be possible through the use of wheel bolts. In that case only half the bolts could be used, because the wheels should be kept on.

Suspension bars are so robust, that they may carry the whole car. Their structure is, however, varying and complicated, which makes them unsuitable for use with universal jacks.

The alternatives for leaning on the ground are one, two, three, and four point support.

❆ *These alternatives have got only superficial handling. The suitable connection points for an universal jack are correct, but the plain mentioning of lifting pads is too simplified. For leaning on the ground should some sketches have been presented?*

Alternative Solutions for Subsystem #5 and #6

If the solution for the first subfunction is self arresting, subfunction # 5 is also solved. If not, the rotating can be arrested by means of a mechanical pawl or dummy coupling. For the arresting of linear movement the following structures may be used (fig. 6.19):

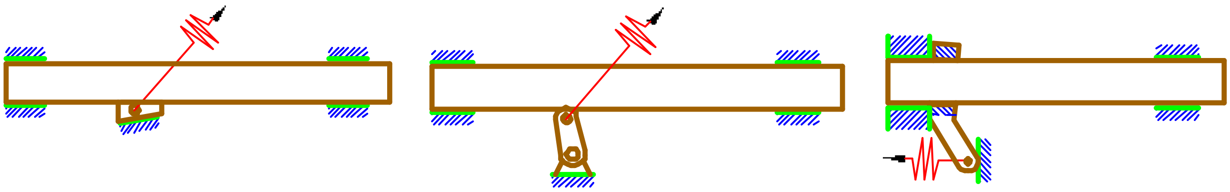


Figure 6.19 Arresters of linear movement, based on use of friction

Mechanical pawls may be used for the arresting of linear movement as well. In hydraulics the common back stroke valve is an excellent solution.

When working below the car, it must be ensured that the car is definitely be secured in its upright position. Mechanical pawls and screws are so steady, they can be accepted, as they are. Contrarily, the friction arresters can get oil or water on the friction surfaces. The fall may be then very shocking event. Even the hydraulics is never completely safe without any mechanical verification.

One of the simplest arresters is the locking pin, if its position and correct use is secured. Another alternative is an external support. The car is lowered on it immediately after the lift. Their use is very common in the garages.

❆ *The discussion about the arresting and the means of security is reasonable. The demonstration of the different structures is so schematic, that it does not fix our thinking about anything at a premature stage. It is good to notice, that this type of presentation is sufficient for* **internal** *structures. However, all details, directly connected to* **outside** *objects (connection points, leaning to the ground) should be studied with some sketches as the first step. Together with the former item, (lifting pads) this was totally forgotten .*

6.2.5 Linking the Solutions of Subsystems

After all of the subfunctions have been given their alternatives, the systematic method gathers them together and makes a so called **morphological box** of them.

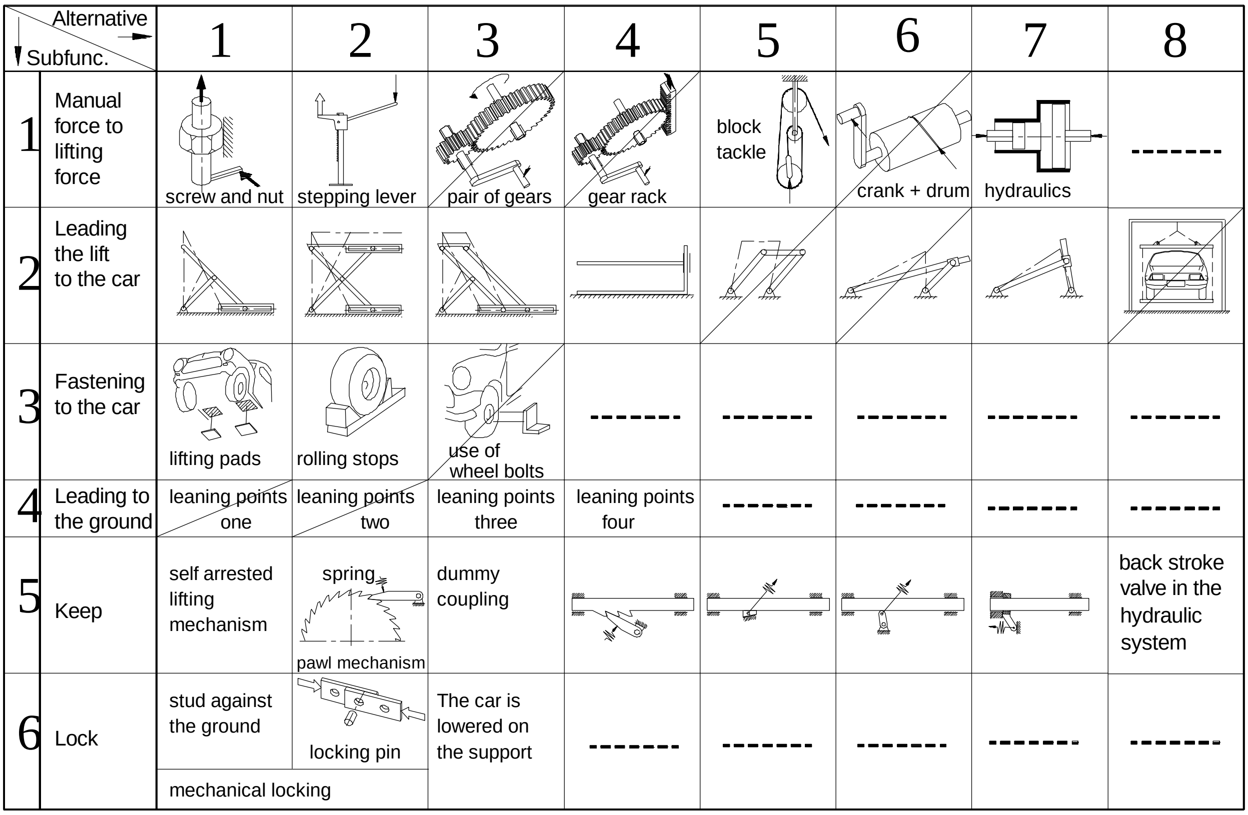


Figure 6.20 morphological box of universal car jack

In the morphological box all subfunctions and their solutions are presented on their own rows. The number of row gives the number of the subfunction. There are not the same number of solutions for all of the subfunctions, hence at the right end of the row there are empty boxes. If we imagine that we can combine these alternatives freely, then the number of main solutions would be $7 \cdot 8 \cdot 3 \cdot 4 \cdot 8 \cdot 3 =$ 16,128 pcs. This is an unrealistic number, because such a combination is not possible with all subsolutions. We must discard the vain solutions as a first step.

For the first subfunction we can imagine the acquisition of some commercial components, e.g. a hydraulic jack or an articulated jack. Since the manufacturing of the gears would be hopelessly expensive, the boxes 1.3, 1.4 and 1.6 may be discarded.

For subfunction 2 the last alternative 2.8 is hardly appealing to many customer because of it's large size and clumsy structure. Alternatives 2.6 and 2.7 are almost functionally equal, but 2.7 has a more constant speed and force, thus it is accepted and 2.6 is discarded. The parallelogram in box 2.5 is difficult to furnish with a force device. If we try to use the screw as a force device, there is not sufficient space for operation, so it may also be discarded.

For subfunction 3 the last alternative 3.3 may be difficult to use, because the attachment of the wheels varies depending on the car, i.e. the use of more than one bolt could be difficult and so we discard that alternative. The alternatives for subfunction 4 are very schematic. The wheels resting on the ground are also considered as leaning points. For stability we need at least 3 points, thus the alternatives 4.1 and 4.2 are discarded.

After the elimination's there are still $4 \cdot 5 \cdot 2 \cdot 2 \cdot 8 \cdot 3 =$ 1920 pcs. left. As a next step we start to look at possible combinations, figure 6.21.

For the accomplishment of the combinations we walk between the subfunctions and we try to choose the most interesting combinations. All of the combinations, V1, V2, and V3 use the screw as the best force device. For the leading to the car two rectilinear mechanisms are chosen, and in addition to that, one tilting triangle. For the connection to the car the wheel and the common lifting areas are used. The tilting triangle leans on the ground using 3 points, the others 4 points. Subfunction 5 has only one alternative, because the screw is self arresting. Combination V3 uses a stud to secure the upper position of the car, other alternatives use a locking pin for that purpose.

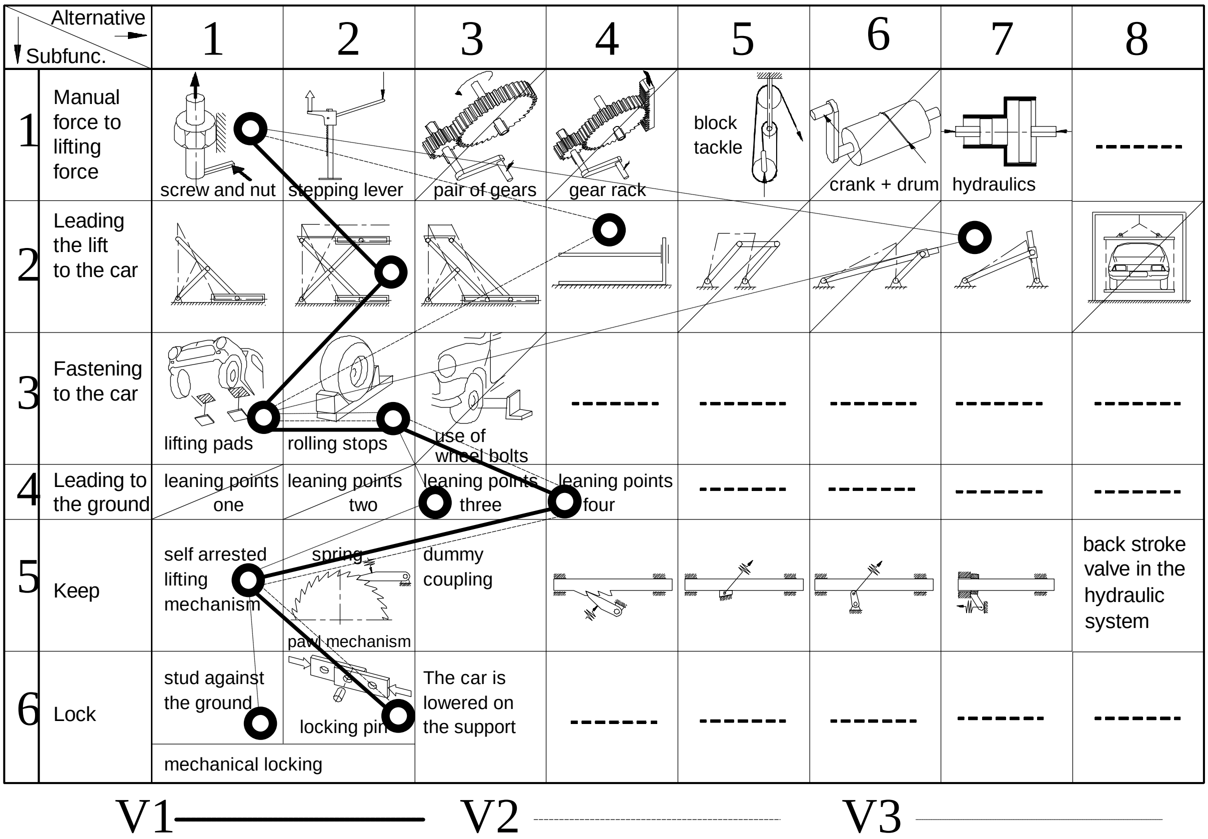


Figure 6.21 The 3 best combinations in morphological box

Choosing criteria	Decisions
(+) yes	(+) forward
(-) no	(-) discard
(?) lack of knowledge	(?) more information
(!) check the demand list	(!) change the demands

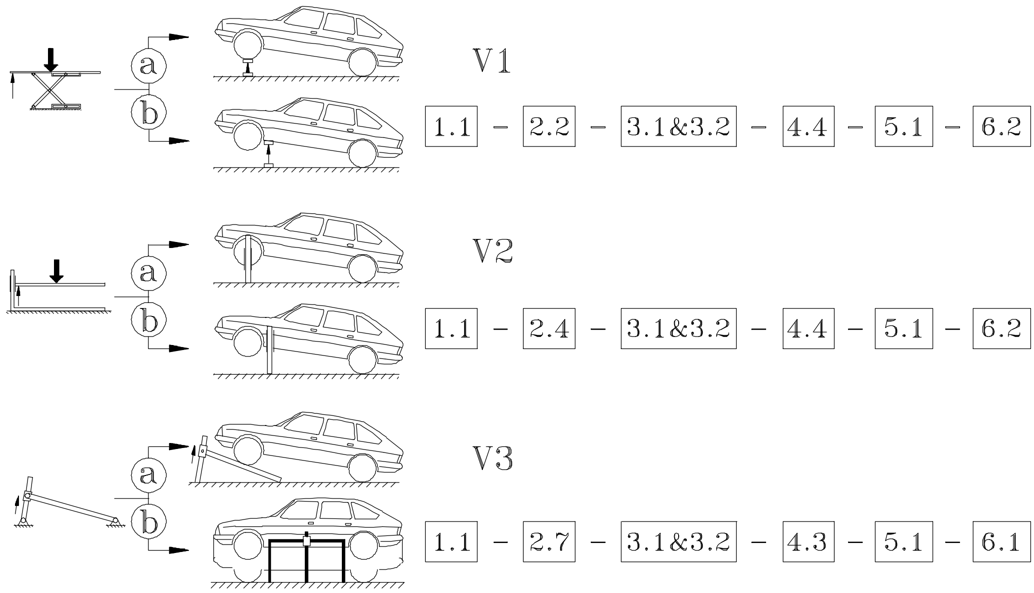
A: In line with the task; B: Realistic; C: In line with the fixed demands; D: Costs acceptable; E: Safety O.K.; F: Easy to use

Combination	A	B	C	D	E	F	Remarks, explanations	
V1	+	+	+	?	+	+		+
V2	+	+	+	?	+	+		+
V3	+	+	+	+	+	+		+
V4	+	?	+	+	?	–	Lifting difficult and takes time	–
V5	+	–	+	?	+	+	Lifting force big at the beginning (--> heavy structure --> space problems)	–
V6	+	–	+	–	+	+		–

Figure 6.22 Choice table of jack

The most important criteria is gathered into the choice table in fig. 6.22. All possible combinations are judged according to the table. In this table the combination V4 is similar to V3, but as a force device it uses a commercial hydraulic jack operated step by step. Versions V5 and V6 are similar to versions V1 and V2, but the mechanisms are the rectilinear mechanism of Scott Russell in its basic form, completed to a parallelogram.

Versions V4 and V5 have minus signs in the choice table, therefore they are neglected. Only version V3 has a plus sign for all criteria. This might indicate a superiority in relation to the others.



ⓐ lifting by the wheels ⓑ lifting from the body

Figure 6.23 The best three of the combinations

- *The use of the morphological box gives an unquestionable impression of logic, if all possibilities are present. The choosing of the three best alternatives, however, gives the bad feeling of hurried progress.*

6.2.6 Concretising the Linked Solutions and Evaluation

The publication admits, that selection is based on very rough black and white arrangements. They could be specified more precisely, if we made sketches for each alternative. The final selection could be made after that, using more accurate criteria derived from the demand list.

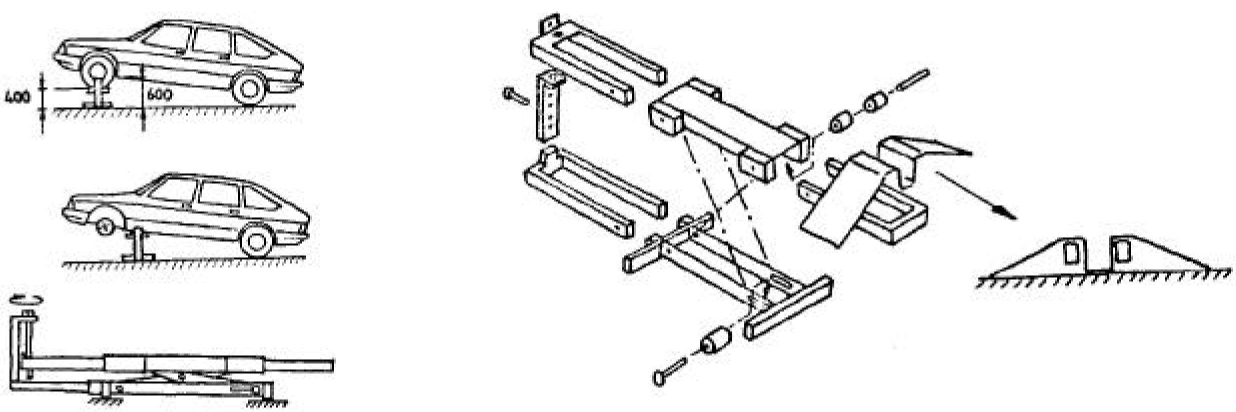


Figure 6.24 Alternative V1

The first version, fig. 6.24, presents ramp plates, which should help the driving of a car onto the lifting bars, if the wheels are used for lifting. The step is, however, rather high, thus the correct positioning of the car is not easy. The link forces are not considered, when the lifting screw is placed on the side of the car.

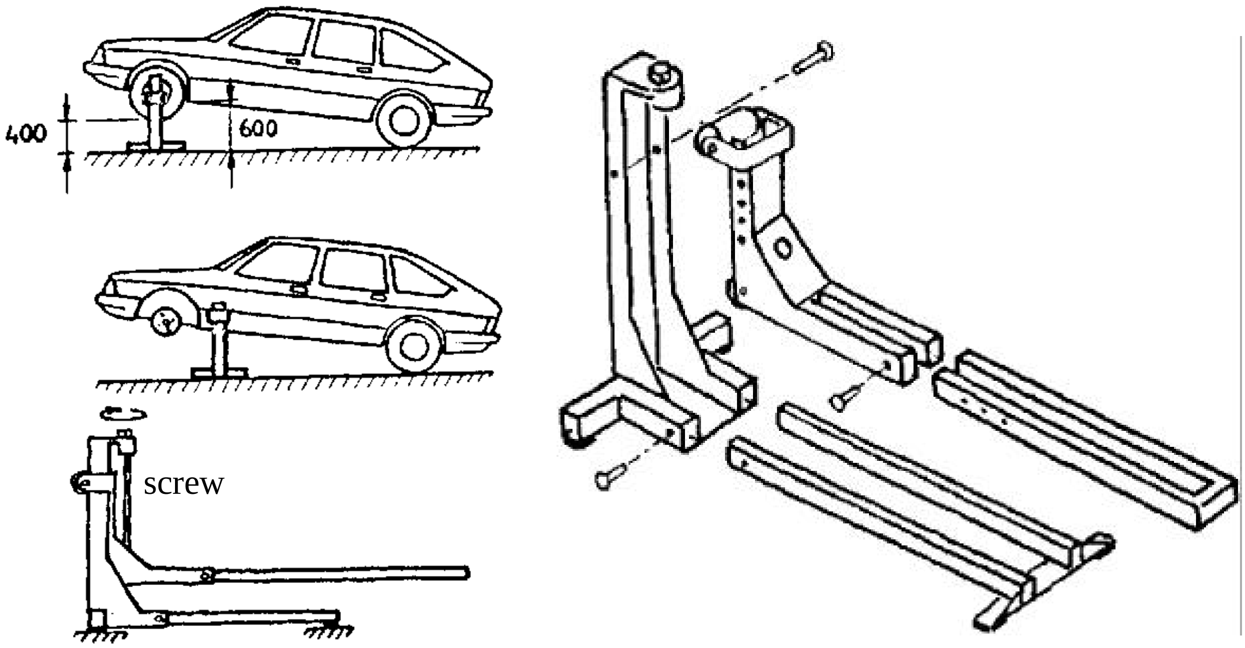


Figure 6.25 Alternative V2

The second alternative is more realistic. The double fork may have enough space between the legs, to ensure that the fork may be pushed directly below the car on both sides of the wheels. Even this structure is heavily loaded, thus its weight will be large.

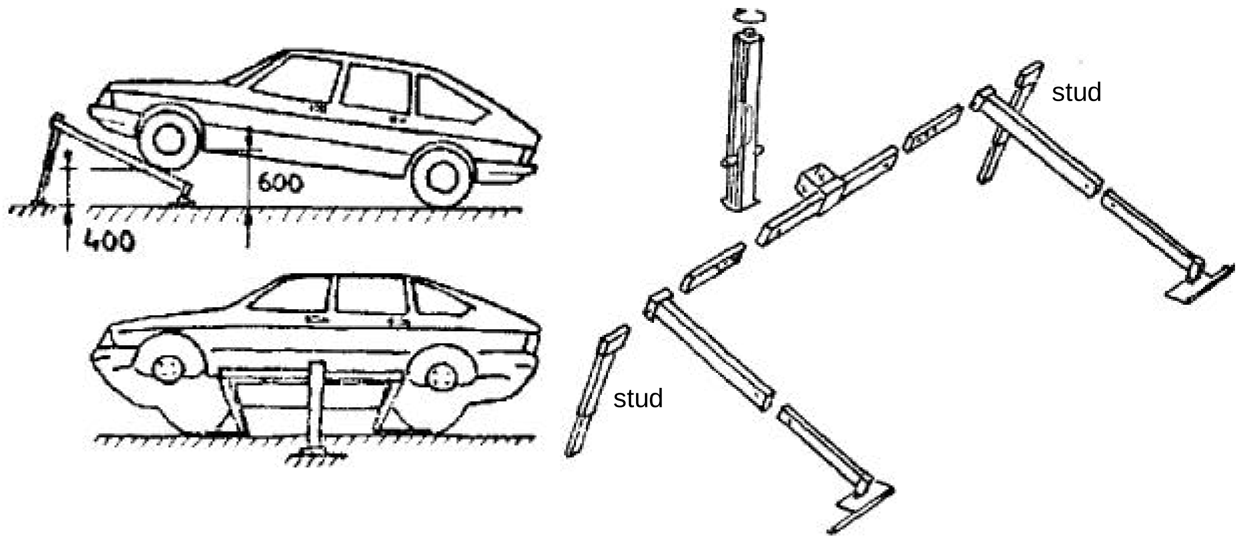


Figure 6.26 Alternative V3

The version V3 does not lift the car, but it tilts it. The best tilting direction might be sideways, because the car is then more stabile. Lifting from the front or the back end is hardly possible.

The value of each versions may be counted using unweighed (Σw_j) or weighed ($\Sigma g_i w_j$) criteria. The ideal solution gets the maximum values for all criteria. The relative value can be counted, when the weighed sum is divided by the sum of ideal solution.

$$W_{gj} = \frac{\sum g_i w_j}{w_{max} \sum g_i}$$

gi = weight factor
wj = value of score

The perfect review should consider numbers for economical and technical values separately. In the example only the technical value is counted. If the criteria are derived from several factors, the weight factors can be shared from the main criterion in the following way:

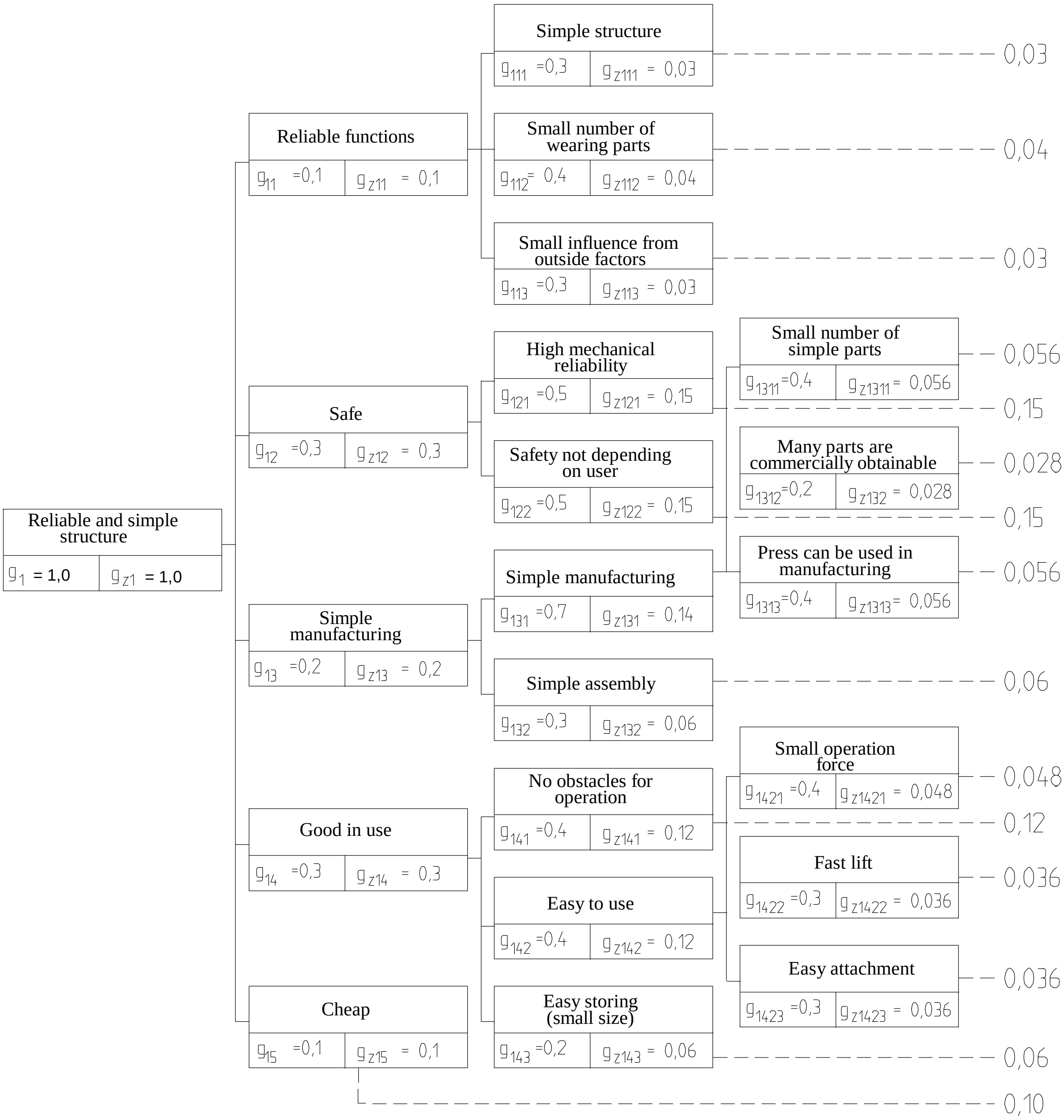


Figure 6.27 Marks and weight factors

The table structure in fig. 6.27 demonstrates, how the weight factors in each box are derived from the main weight factors. In each box on the left the number indicates the share of the weighing. The sum of these shares is always = 1 in all partitions. On the right this particular share is multiplied by the value of the weight factor in the mother criterion (next column to the left). The result of the multiplication is the weight factor of that particular criterion. So in each box: **share number** on the left, **weight factor** on the right.

The main demand is **A reliable and simple structure** and it gets the weight factor g_{z1} = 1. The main demand is divided into five derivatives. All boxes of this first partition are located in the same column, next to the main demand. The sum of the share numbers g_{11}...g_{15} on the right in this partition is = 1. Because the mother weight factor g_{z1} = 1, all weight factors g_{z11}...g_{z15} of this partition are the same as the share numbers on the left in the same box. The last criterion in this partition (column) **Cheap** is not derived any more and its final weight factor (last column at the right) will be = 0.10.

All other boxes of this partition are divided further into their own partitions. E.g. the first box at the top, **Reliable functions**, has three subcriteria. This partition has the sum of its share numbers g_{111}...g_{113} = 1, of course. When these numbers are multiplied with the mother weight factor g_{z11}, we get the weight factors g_{z111}...g_{z113}, of this partition.

There are some partitions of third generation in this table for some boxes of the previous column. From all the boxes of the last partition the weight factor is transferred to the last column on the right. If we add together all the numbers of this last column, the sum will be = 1, again.

Table 6.2 Review Marks

Value	Meaning	Value	Meaning
0	not tolerable	6	good, small lacks
1	insufficient	7	good solution
2	difficult solution	8	very good
3	acceptable	9	more than assumed
4	reasonable	10	ideal
5	very satisfactory		

Table 6.2 gives us the meaning of the given marks. Table 6.3 presents the result of evaluation, when the marks are used as a basis. We see, that the last partitions on the right are not used, but the weight factors are read from the partition of second degree. The division of criteria may be done in arbitrary depth, as fig. 6.27 shows, but the same depth in division is not necessary for all criteria. The sum of the final weight factors must be checked anyway.

The final result shows that the alternative V3 is slightly better than the others. The most important reason for this is that, it is obviously cheaper than its competitors.

Table 6.3 Review of The Alternatives

Criteria	Weight factor g_i	Alternative V1		Alternative V2		Alternative V3	
		Value w_i	Value g_iw_i	Value w_i	Value g_iw_i	Value w_i	Value g_iw_i
Simple structure	0,03	6	0,18	7	0,21	8	0,24
Small number of wearing parts	0,04	5	0,20	7	0,28	7	0,28
Small influence from outside factors	0,03	5	0,15	6	0,18	6	0,18
High mechanical reliability	0,15	6	0,90	6	0,90	6	0,90
Safety not depending on user	0,15	7	1,05	7	1,05	6	0,90
Simple manufacturing	0,14	6	0,84	6	0,84	7	0,84
Simple assembly	0,06	6	0,36	6	0,36	8	0,48
No obstacles for operation	0,12	8	0,96	8	0,96	8	0,96
Easy to use	0,12	6	0,72	6	0,72	6	0,72
Easy storing	0,06	6	0,36	5	0,30	7	0,42
Cheap	0,10	2	0,20	2	0,20	4	0,40
	Σg_i = 1,0	$\Sigma w_i = 63$ $\Sigma g_iw_j = 5{,}92$		$\Sigma w_i = 66$ $\Sigma g_iw_j=6{,}00$		$\Sigma w_i = 73$ $\Sigma g_iw_j=6{,}32$	

6.3 Critique of Systematic Method

Part of the critique I have already presented together with each chapter. For completeness it is useful to study the whole series of matters, once again, and think about, where we should have done otherwise.

The need of the product was studied creditably. Many intuitive designers tend to underestimate this step and they start to develop their thinking too early. In this respect, systematic thinking is absolutely necessary. In the market survey the study of the working below the car should have been analysed more deeply. It is doubtful, if the surveyor himself was below the car, even once. The analysis of the work had revealed the significant needs of the lifting system structure. The demand list had been a living view of the needs instead of a mere list.

The available accessory jacks were gathered sufficiently. They could have been used as an informative reference, but this possibility was not understood thoroughly. No penetrative analysis was focused on that material.

The demand list can be criticised further because the demands were too detailed and even unnecessary . For example, the time for preparations and lifting was limited to be less than 5 minutes. In the hobby use this has no value.

The use of abstracting in the forming of the task is an excellent possibility in the systematic method to compensate the disadvantages of a far too detailed demand list. It should reveal the real essence of the problem. If one can benefit from it properly, he is able to get the creative process moving again. In this example it has failed. The possibilities were ruined, when the design was based, to a large extent on the individual solution of the subfunctions. Doing so, all consideration was focused on each particular mechanism without sufficient connection to the main problem. A good example for that was the fruitless study of rectilinear mechanisms.

The sketch of the final structure was derived through the use of the morphological box. During this step it was not noticed, that the value of each subsolution greatly depends on its function in respect to other subsolutions. The available space is important for its value, and the joint possibilities as well.

The example does not report the phases, which led to the sketches in figs. 6.24...6.26. Apparently there was some preliminary drafting work to the correct scale and the particular sketches were created after the sketches for the presentation of the principal solutions. Direct sketching, to the correct scale, without previous drawings does not give a clear and well-proportioned view of the solutions.

The structure of the alternatives is fixed at too early a phase. Once they have got their shapes, it is very difficult to neglect even the details, any more. In this example the engineering design is changed to mean the same as the *choice between the alternatives*. That means, the alternatives existed already, and the design of them was not necessary. The creative engineering designer studies the familiar structures to learn the thinking behind them and to furnish himself with a even better knowledge and understanding of how to create a new structure. The gradually forming structure is also an addition to the knowledge of the designer. The new structure is, as much as possible, open to joining with other structures. It is continuously ready to be developed in dimensions and in details and in the last step it takes its final shape, when joined with other structures. The creative design is the same even when the final solution is in all details the same, as that which was known at the start of the job. The study of it was visual and it taught us more than any description could have done.

The derivation of weight factors according to fig. 6.27 gave us an interesting and useful method. Its use presupposes the thorough knowledge of all alternatives. In this case it was used for the estimation of the sketches, which were vague and did not have attributes enough for any reliable marks. The addition of the attributes causes much work, focused on the costs and characteristics in use, but not on the development of the structure. In the intuitive process we use the fact, that a little change in a structure can improve it immediately much more, than could be derived from the use of heavy calculations of strength. A little change in a drawing does not cost anything. The aim of the designer should be to obtain a connection, as competent and rich in details as possible, between the operating characteristics, structure possibilities, and the real developing structure on the screen.

6.4 Intuitive Solution of the Task

As I have said, my own solution was created during two evening. One could criticise that by saying, that it was only a creative swipe with only questionable value. It is not possible to create any good machines so impulsively! The process was really fast, but I have absolutely to deny the opinion, that it was only a result based on my long design experience. Not at all, but behind it there was a long development process, which I had not realised. I did not possess any drawings about it, anyway. I had really worked below the car doing all kinds of needed repairs, even welding. Many times I was scared because of the unsteady support after jacking. I was in the position of being an experienced car fitter and an experienced engineering designer, at the same time.

At the beginning I studied critically the new structure, and tried to discover its insights and faults. The solution in fig. 6.28 has some details, which are difficult to understand. What was their idea? For example the pads at the end of the arms are cut in a way, that about one quarter is missing. It took a while, before I understood the meaning. The pads should be placed in line with the wheels. As a result the car would not glide on the arms during tilting. For easy placement, the nibs of the pads may be pushed against the tyres.

Muffs of box beam 100x60x3 mm are placed in the corners of the jack frame. The lifting beam and the arms should be connected into them. After lifting the extra studs should also be possible to connect into the same muffs. Theoretically this is possible, because the sizes of box beams in connecting order are 80x40x3 mm + 100x60x3 mm + 90x50x3 mm. But during the lifting 80x40x3 is carrying 100x60x3, thus it is not possible to put the size 90x50x3 coaxially between the others. There we have an obvious failure in thinking. The error can be fixed, if we make the lifting beam 80x40x3 longer and connect the lifting arms and studs side by side. The size of the muffs at the end of the lifting arms can be reduced to dimensions 90x50x3 mm.

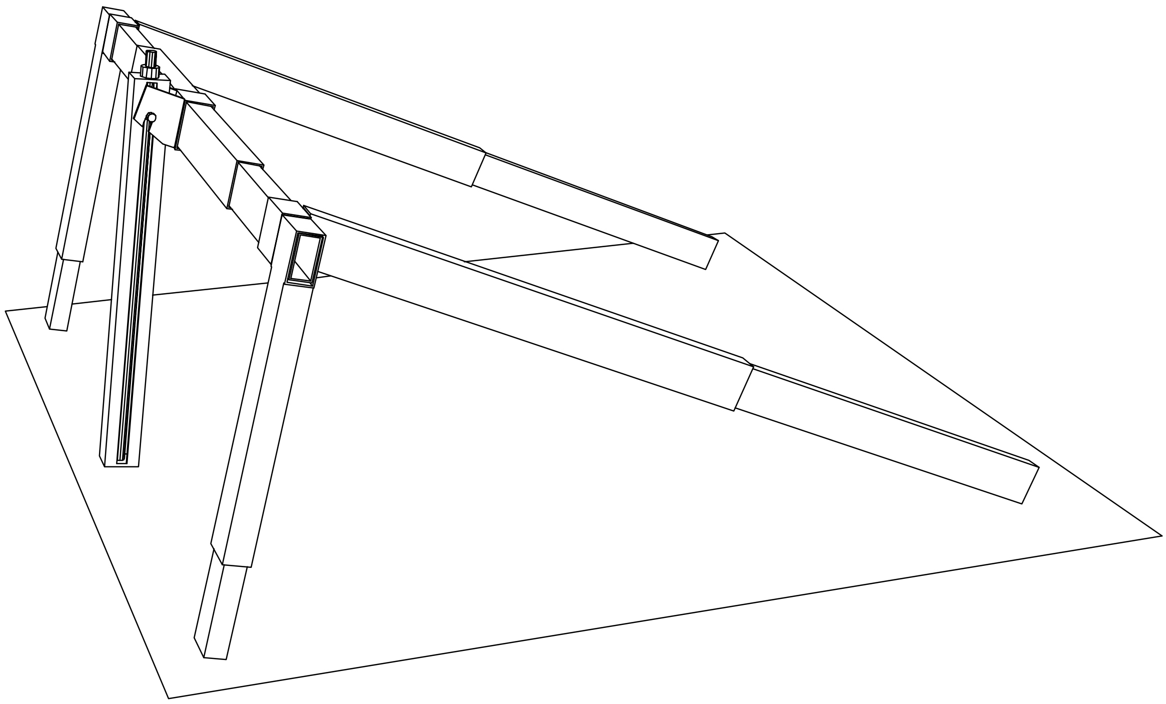


Figure 6.29 Fixed version of the final jack

The lifting arms do not need any sleds, because the load pointing to the ends is very small. The tilting angle of the arms is small too, thus no sinking into the ground should happen. The tilting angle is about the same for all car types. The angle can be used by design of lifting pads. These pads are really necessary, and they must be adjustable along the arms. In fig. 6.29 these pads are not presented. On the other hand, about half the car weight is carried by the lifting screw and supporting studs; therefore they could need extra pads against the ground.

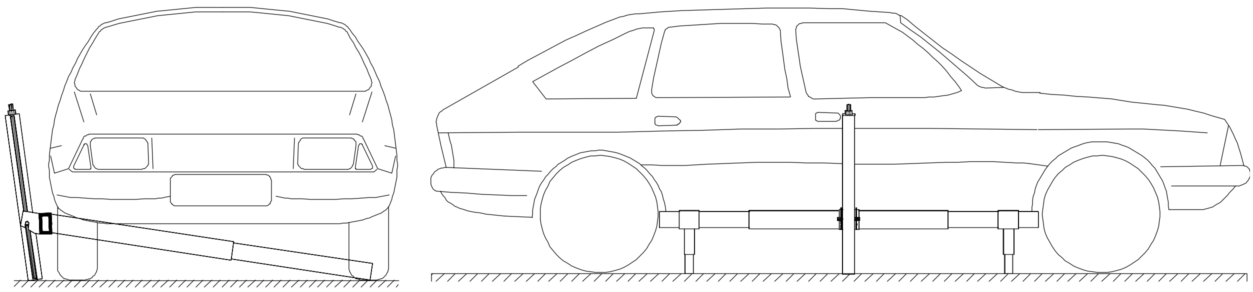


Figure 6.30 Start of the lifting

At the start of lifting the jack is assembled to a convenient width. The end points of the arms are set in line with the wheels on the opposite side. The screw assembly is put at an angle so, that the assembly will not tilt too much in the final position.

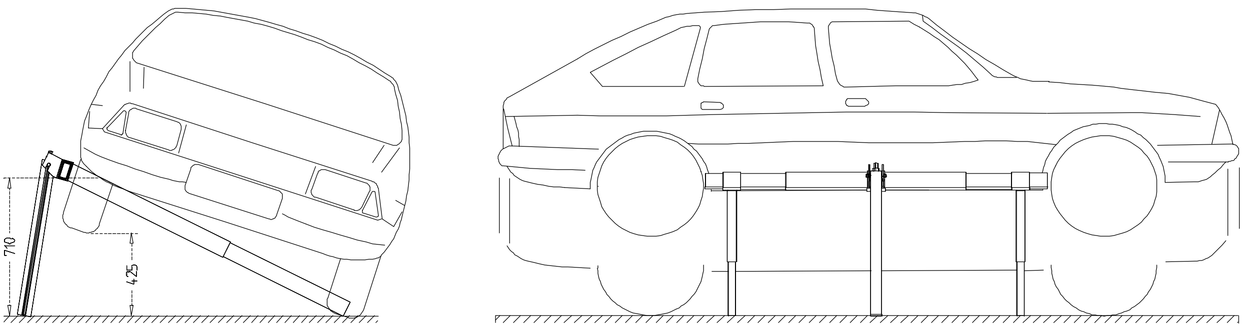


Figure 6.31 End phase of lifting before the studs

In fig. 6.28 all telescope joints are locked with locking pins, which are clearly visible in the lifting arms, but is it necessary? The end points of the lifting arms have such small loads, that they can glide easily. The whole stability depends on the friction between the lifting pad and the car. The pad may also glide along the lifting arm. The lifting pad definitely needs a locking pin, which should also be locked to the car. Otherwise the whole jack may collapse due to strong handling, since the locking pin in the lifting arm cannot prevent it. Fig. 6.31 shows clearly the danger.

The weight of the front end of a car is always bigger than the weight of the rear end. The screw assembly must be placed so that a balance is reached. The connecting muff on the lifting beam is moveable, hence this is not a problem.

For safety the lifting pads must be locked with the car and the lifting arms securely. The published example needs that correction in the structure. After this improvement it is safe and all other joints are safe without locking pins. However in the use it has serious disadvantages:

a) *The lifting arms reduce the working space in such a way that the exhaust pipe is very difficult to replace. Also during the welding these arms are harmful and prevent free moving while working.*

b) *The device is big and difficult to store anywhere, eventhough it can be disassembled. The total weight of 50 kg is rather big.*

c) *The jack should be used for lifting at both ends of the car. However, it is hardly possible, since the overhang of the car body is so big that the lifting points, the wheels, would be placed almost in the middle of the lifting arms. The arms should be placed on both sides of the car and should be connected* *with two transversal beams, which form the stops for the wheels. It is possible but very laborious, and the lifting height would be too small.*

d) *The efficiency of the lifting screw is poor, hence the lifting takes time and energy. The use of the screw is still not very favourable, because it must be rather long. The screw needs good lubrication and it tends to smear everything during transport and storing.*

The most serious of the disadvantages is item a). There seems to be no possible compensation for it. After the unnecessary locking's, the links and sleds are removed, the price should be lower and manufacturing more simple. There is, however the feeling, that a good help in car repairs is missing, a feeling is based on my personal experience from working below the car. This experience gave me immediately some heuristic points for studying:

Heuristic point #1:

The jack shall safely keep the car in the upper position, even when the fitter works below the car and looses his temper when breaking the exhaust tube out of its fasteners!

The accessory jack was very slow to operate and I looked for something more convenient instead. I bought a cheap hydraulic jack, which had a starting height so big, that I hardly could put it below the body beam. The lift was only 80 mm, so I needed an adjustable support and a pile of bricks to lift the car step by step, fig. 6.32.

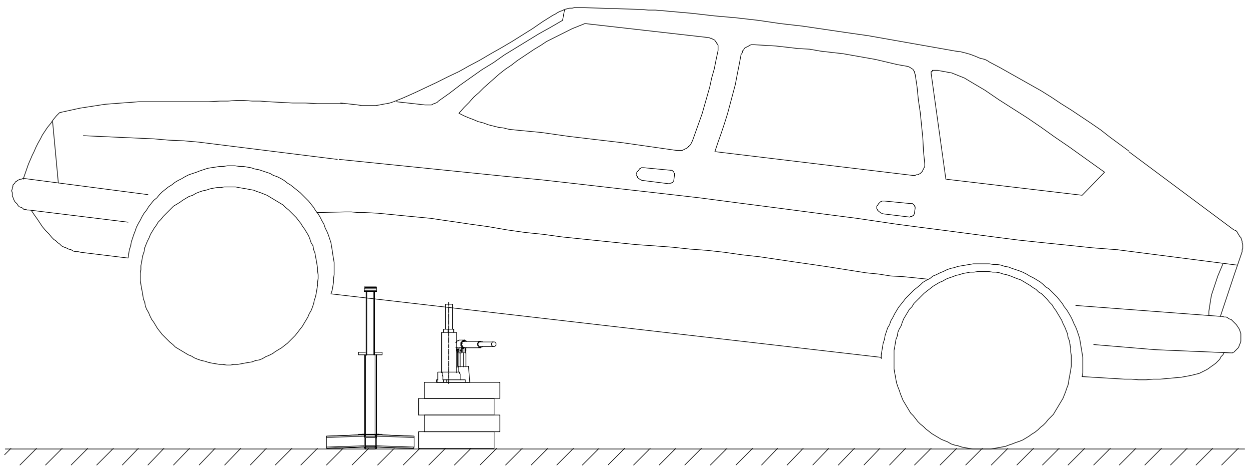


Figure 6.32 Lifting the car by means of hydraulic jack

For the required height more bricks were needed and the pile threatened to overturn at every step. The problem was the lateral movement of the car because of the growing lifting height. Especially harmful was the lowering on the stand and the lateral movements misloaded my jack so much, that it started to leak.

*Heuristic point #**2**:*

A commercial hydraulic jack is cheap and practical. For a high lift it can be used step by step.

There are commercial adjustable stands available, but I did not like their characteristic of leaning on the ground, which was catered for by means of a round thin plate, or by means of three slim legs, which tended to penetrate the soft ground. Therefore I manufactured two stands by myself. As the material I used box beams 40x40x3 and 30x30x3 mm. The minimum height was defined to ensure that I could place the support below the car after I lifted it to its maximum height with the hydraulic jack. The minimum height is 300 mm and the maximum height approx. 550 mm. This range was sufficient for my purposes.

The supporting surface and foot structure against the ground should be big and steady. I made it as a cross beam, fig 6.33. The arms (c) of the cross act like short cantilever beams. Their maximum bending moment should be carried by the full capacity of the cross section. Therefore the crossing must be formed so, that the upper and lower walls of the arms can carry most of the bending. The arms end at the column (a). The inner space of this column must be kept empty, because the inner column (b) needs the space. Hence, an end wall can be used in the column (a). This gives full support for the lower walls of the arms (c). The upper walls get their support, when the extra collar (e) is welded around the cross. The arms are not exactly horizontal, but misaligned a bit so, that the outer ends of the arms make good contact with a hard floor giving good stability.

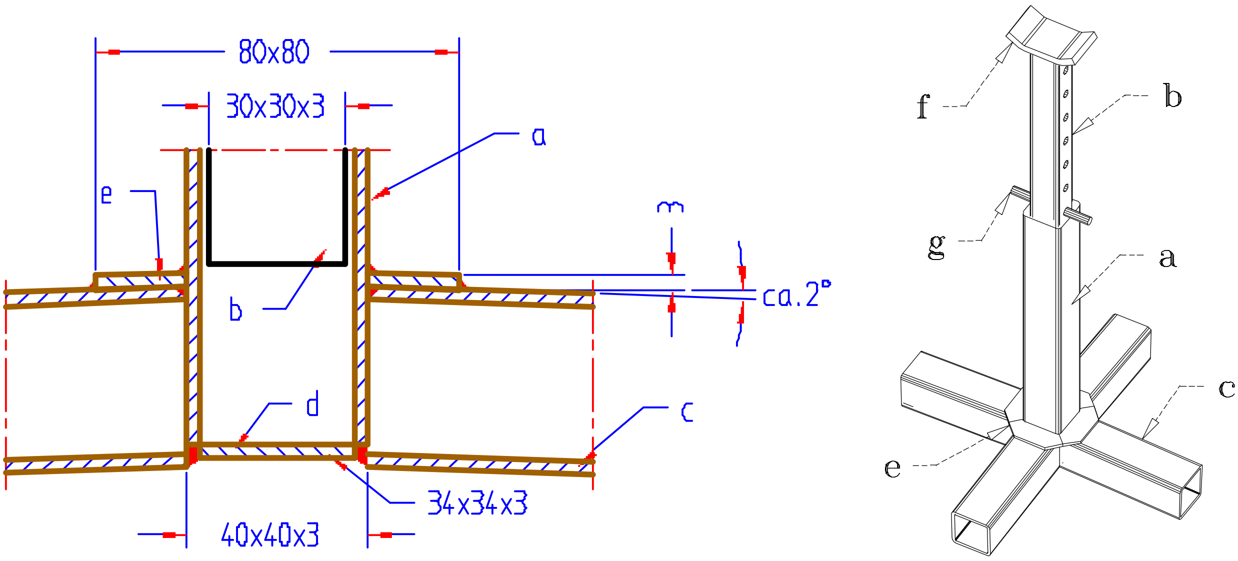


Figure 6.33 Adjustable stand and its supporting structure

The adjustable column (b) gets a lifting pad (f) onto its upper end . It is bent so, that it works better in connection. Height control is accomplished by the pin (g). The lower column does not need any hole for that pin, because the use of the pin like in fig. 6.33 is much easier and does not need any locking.

These adjustable stands were light and steady, but I was not satisfied with them. They took up much storing space. When they carry the weight of the car, they always got a transversal force, which remained after removing the jack. That made me nervous, because it became apparent by small movements of the car during the work below it i.e. the stand was too steady. I got an idea, that the cross formed foot structure could be replaced with a longitudinal bar. It prevents the rolling of the car, but allows a free tilting and transversal moving, when the car is mainly supported by the wheels on one side.

Heuristic point #3:

The transversally tilting stand could be an idea. In the longitudinal direction, however, a steady stand is needed. A long longitudinal bar would be a very good carrier even on soft and uneven soil.

One troublemaker was the fast lowering speed of the hydraulic jack. When lowering the car on the stand, the control screw had to be opened very slowly. If this did not succeed, the car came down against the stand at high speed. If the locking pin (g) had broken, the damage could have been serious.

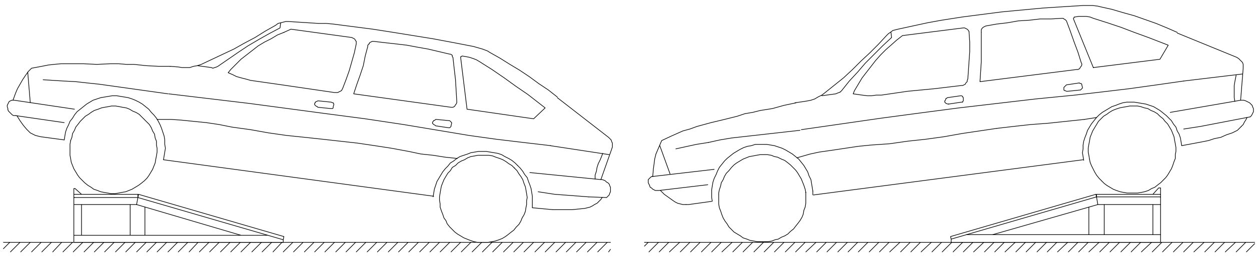


Figure 6.34 Portable ramps

Even the adjustable stands provided a good space below the car, but the lifting of the car was still a laborious and demanding operation. There was also the danger of the car falling down with serious consequences. Therefore I made portable ramps, fig. 6.34. They were very reliable, but storing them was another problem. When they were used for replacement of the exhaust pipe, both ends of the car had to be lifted. That was only possible one end at a time. On a concrete floor driving onto the ramps caused no problems, but outside the driving wheels slipped sometimes. The ramps could also slip away, which caused some dangerous situations.

Heuristic point #4:

The car is intended to be carried by its wheels alone and only then, can all forces be handled arbitrarily.

These four heuristic points were already mature in my mind. I had studied them even consciously now and then, but I started to handle them more actively after I saw this example published. Their existence even generated too active a reaction in me and only a closer analysis made it more precise and cool. This type of excessive reaction is typical of creative designers, but one must learn to cope with it. It produces a contradiction between a new unfamiliar structure and ones own subconscious experience. We have to change it to a positive aggression, which contributes a strong fruitful tension towards a new better structure.

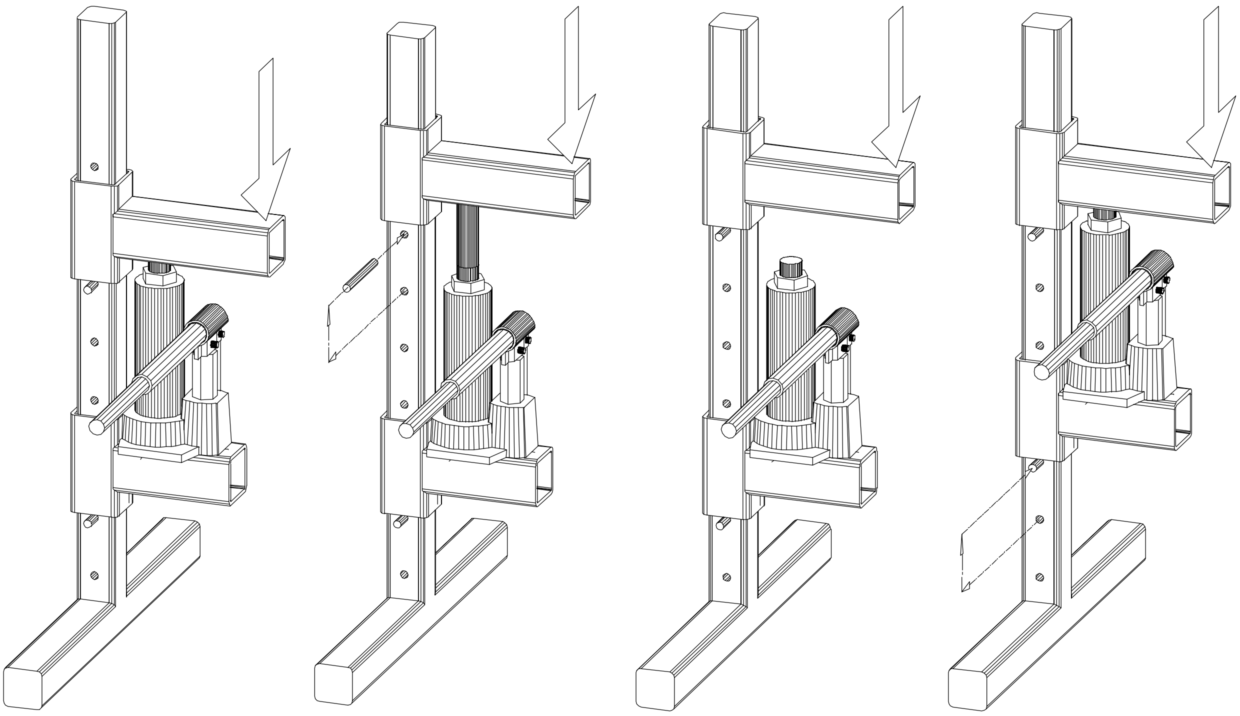


Figure 6.35 Steps of lifting

Figure 6.35 demonstrates the idea of how to act according to heuristic points 2 and 3. We have to notice, that this structure contains the leaning against the ground according to point 2, a commercial hydraulic jack, which climbs along the column using two gliding cantilever arms. The position of the arms is fixed by means of locking pins. All other joints are open, although the load is marked at the end of the upper arm.

The picture is presented 3-dimensionally. During manual drawing this type of picture was practical only as a manual sketch. The scale was inaccurate and only led to illusions. Today the sketches on screen are accurate, but we should still prefer the 2-dimensional presentation for heuristic points. That is so, because 2-dimensional details are easier to change and use again in other combinations. An accepted idea can be transferred further as a picture. 3-dimensional modelling is neither difficult nor laborious, any more, but the editing of the models is much more difficult and it increases the file size of the drawing. At the same time the needed calculation time for a computer is increased enormously. However, in complicated cases an accurate 3-dimensional picture is worth creating, fig. 6.35. We should print it and hang it up, as its visual appearance has a much greater influence on our thinking, than plain words or 2-dimensional sketches have. We must however be aware, that this type of picture locks our thinking very strongly. Therefore the idea must be already accepted and this picture is needed only to show its demands for the joining of structures. Only after much experience are we cold-blooded enough to be able to abandon completely this type of picture.

The joining interfaces with the car in fig. 6.35 are completely open. We shall keep them open until we have solved the basic problems of joining: where and how to connect to the car. All structures below the car should be avoided, because they restrict the repair and service operations. The bodies of modern cars offer practical lifting points only for their own accessory jacks. The body is intended to be carried only by the wheels. Therefore, as the first alternative we should place the new heuristic point on the wheels, preferably on the tyres.

Let's imagine, that we lift the wheel with a L-shaped hook. The hook is made of box beam 25x25x3 mm. Its upper end leans on the front face of the tyre through a transversal beam, made of the same material. This arrangement gives us space for the metallic parts of the wheel (rim, bolts, and nuts). Let's imagine that we carry the hook using a cantilever arm so, that the force distance from the vertical center level of the tyre is 195 mm, fig. 6.36.

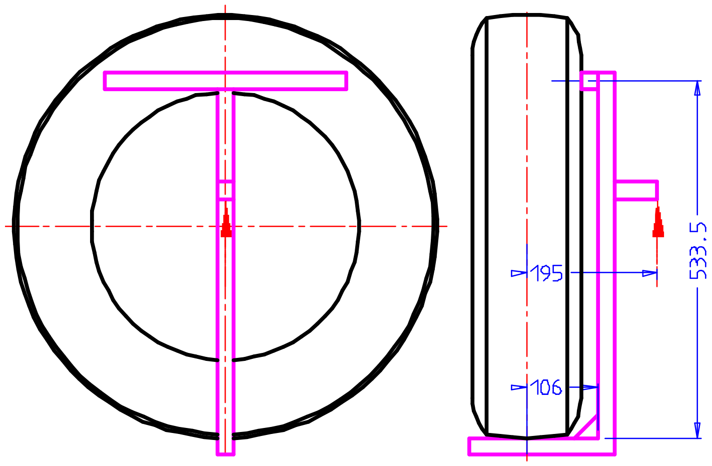


Figure 6.36 Wheel hook

The car wheel cannot be locked completely. Therefore the lifting point must be above the rotation axis, so that the hook does not overturn with the rotation of the wheel.

The distance between the horizontal leaning beam and the bottom point of the tyre is 533,5 mm. The moment distance of the lifting force is 195 mm. The friction coefficient between the tyre and carrying hook should be at least μ_{min} = 195/533,5 = 0,3655. If the surfaces are clean and dry, the real friction is big enough. However, we have to think, that there is oil on the surfaces. In that case the hook slips away. This can be avoided, if the end of the hook is bent upwards.

According to the demand list the maximum weight of the car is 1300 kg. The front wheels take about 60 % of that. The lifting force on one front wheel is

$$F_{max} = 0{,}6 \cdot 1300 \cdot 9{,}81/2 = 3826 \text{ N}$$

The manufacturer of the box beam says, that the maximum bending moment of that beam is 630 Nm. When the moment distance is = 106 mm, we get the loadability 630/0,106 = 5943 Nm. However, this is such a big load, that we should reinforce the rectangular joint of the hook with an extra corner piece.

One hook alone is not enough to carry the car. Its connection with the tyre is not acceptable and driving onto it would be difficult. It is better to use two hooks making a cage, which can be pushed below the wheel without lifting the wheel at all.

In the next picture, fig. 6.37, this type of structure is presented. The hooks are placed diagonally so, that they press the tyre perpendicularly from two points. There are two link points now, with a fair distance between them. If the link points are kept at the same height, the wheel can be stabilised even when the link line is below the rotation axis of the wheel.

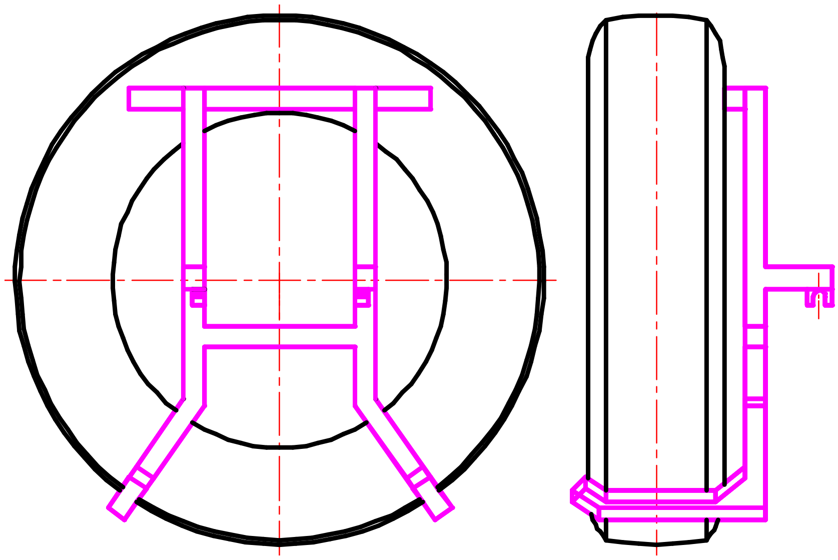


Figure 6.37. Wheel cage

The heuristic point is ready now, because the cage carries the wheel properly. It can be positioned without lifting the wheel and it has clearly defined lifting points. The exact location of these points is still open, and we have even deliberately increased the freedom of their placement.

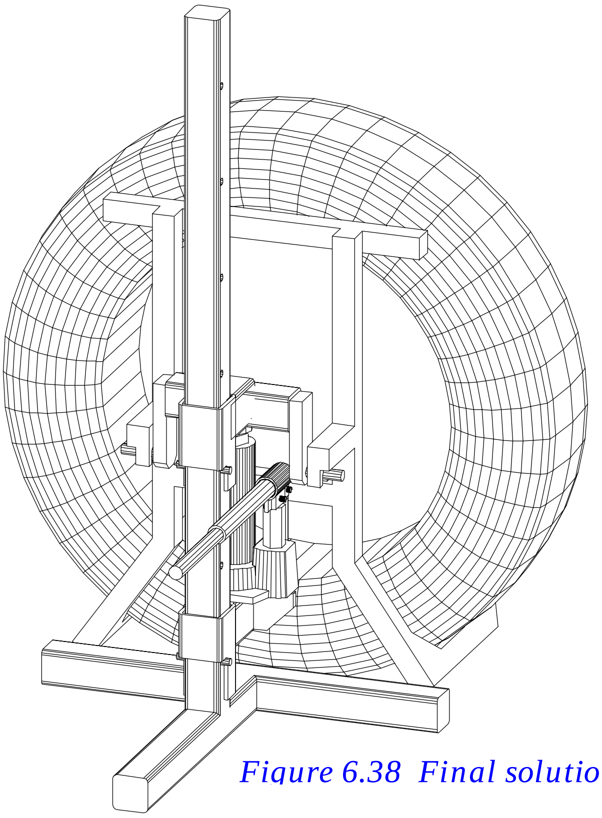


Figure 6.38 Final solution

As the next step we will try to combine the structures of figs. 6.37 and 6.35, which is not difficult, because all the functions have been solved. The final structure has some supplements, who's meaning will be described, when we study the function of the structure.

The wheel cage is exactly the same as in fig. 6.37. The lower cantilever arm is also about the same as in fig. 6.35. The hydraulic jack is turned so, that it takes up as small a place between the wheel and the column, as possible. The lower cantilever arm has got an extra plate to keep the jack as steady as possible. The jack is in the same vertical line as the lifting link. This makes the movement of the upper cantilever arm easier.

The functioning of this type of structure must be checked with the help of pictures in several phases of use, as in animation. The portable ramps, fig. 6.34, proved to be very practical, because the lifting of one end gave plenty of space for welding operations. Therefore I wanted to use this new jack also for lifting from one or the other end of the car. If the stand according to fig. 6.35 is used, the car is not stabile on the stands. Therefore the stand gets an additional arm, which makes the stand very stabile even on soft soil.

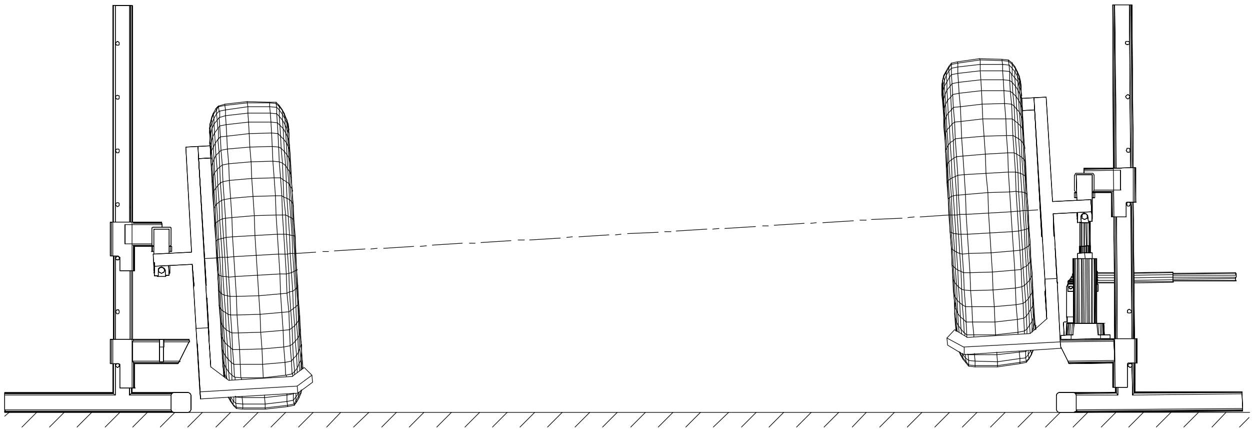


Figure 6.39 Lifting from one end of the car, first step

The wheel cages will be pushed below the wheels and they will be linked to the gliding upper cantilever arms. Hereby the stands are placed on both sides of the car. Fig. 6.39 demonstrates the situation, when the right side is lifted 110 mm by the hydraulic jack. The whole lifting height of the jack can be used safely. The lifting of the upper arm makes it possible to move the locking pin one step upwards. The jack will be released and placed on the other side of the car, where it is used to lift the wheel up two pin places at the same time. These alternating operations are done until the car is in the upper position. The maximum lift is 440 mm on both sides and the gained space below the car is generous.

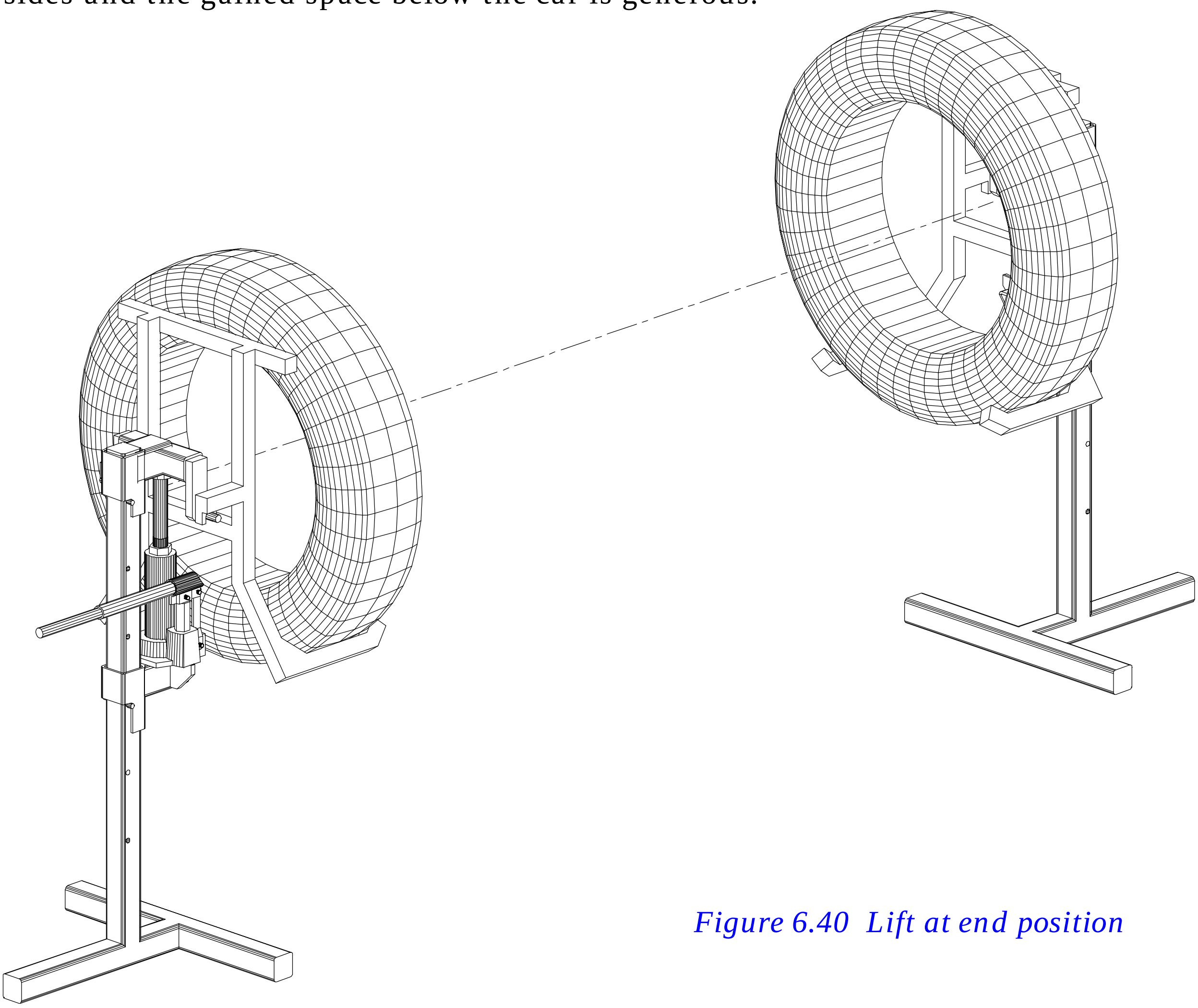


Figure 6.40 Lift at end position

Figure 6.40 shows clearly, how the transversal base arm together with the longitudinal base arm provides a wide and steady stand. At the same time the vertical column is placed on the transversal base arm and the longitudinal arm has got its place close to the wheel.

The body beams below the doors often suffer from corrosion. For repair welding the car should be tilted sideways. Both of the lifting devices are placed now on the same side of the car, and the wheels are lifted stepwise, alternately up. In the final position the view is as follows:

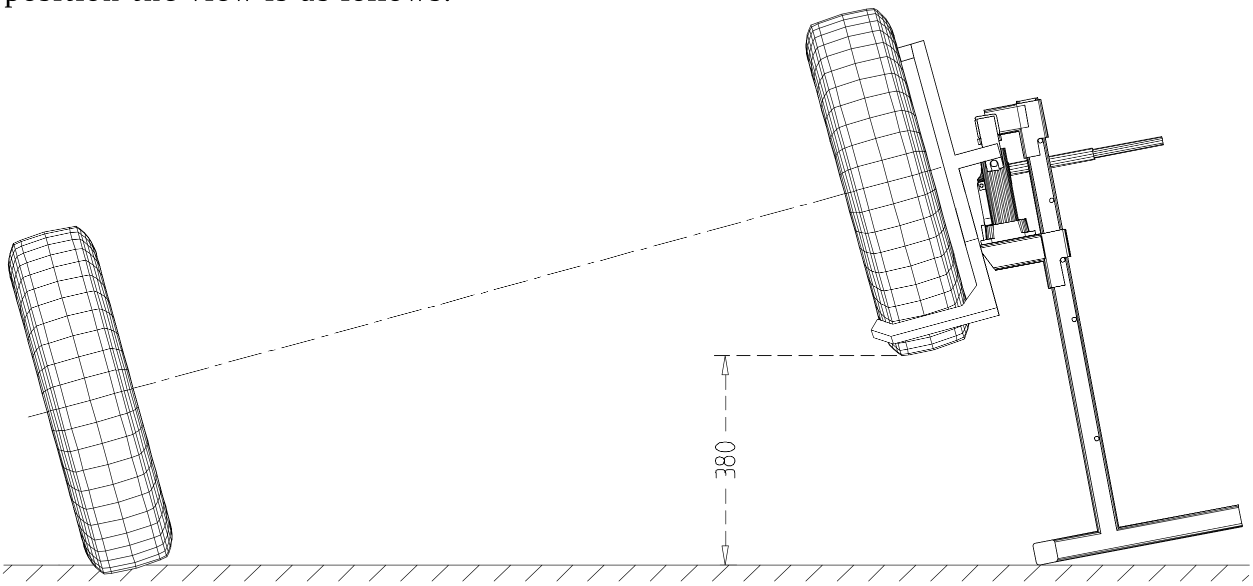


Figure 6.41 End position of tilting

When the car is lifted sideways, the stand tilts around the longitudinal base arm making location on the soil good. The lift is long enough, because the free height below the body beam is over 600 mm.

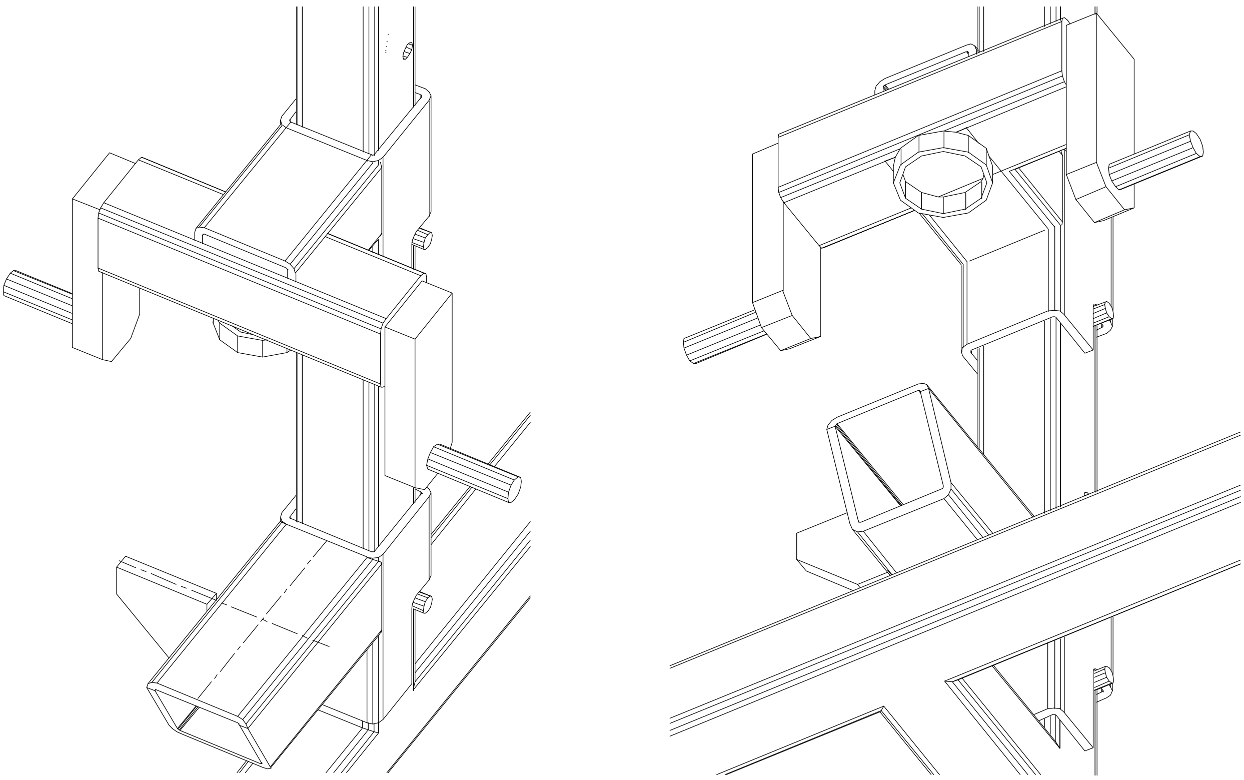


Figure 6.42 Close up picture of the gliding cantilever arms

Figure 6.42 presents the shape of the gliding cantilever arms. The lower arm is simply a piece of box beam, which has got extra plate to support the hydraulic jack. The upper arm has a transversal truss with hanging thick end plates. These plates have the pins for the connecting link. The lowering of the link is necessary to give space for the tilting. The rod of the jack is put inside a round collar in the middle of the truss.

The link pins are made of hard tempered steel for better wearability. They cannot be fixed by welding, hence they must be shrunk or glued. Gluing is a very good method in this case, because the load has always a constant direction. The glued pins are easily detached and replaced with new ones. Only heat is needed for this.

Comparison of the Results

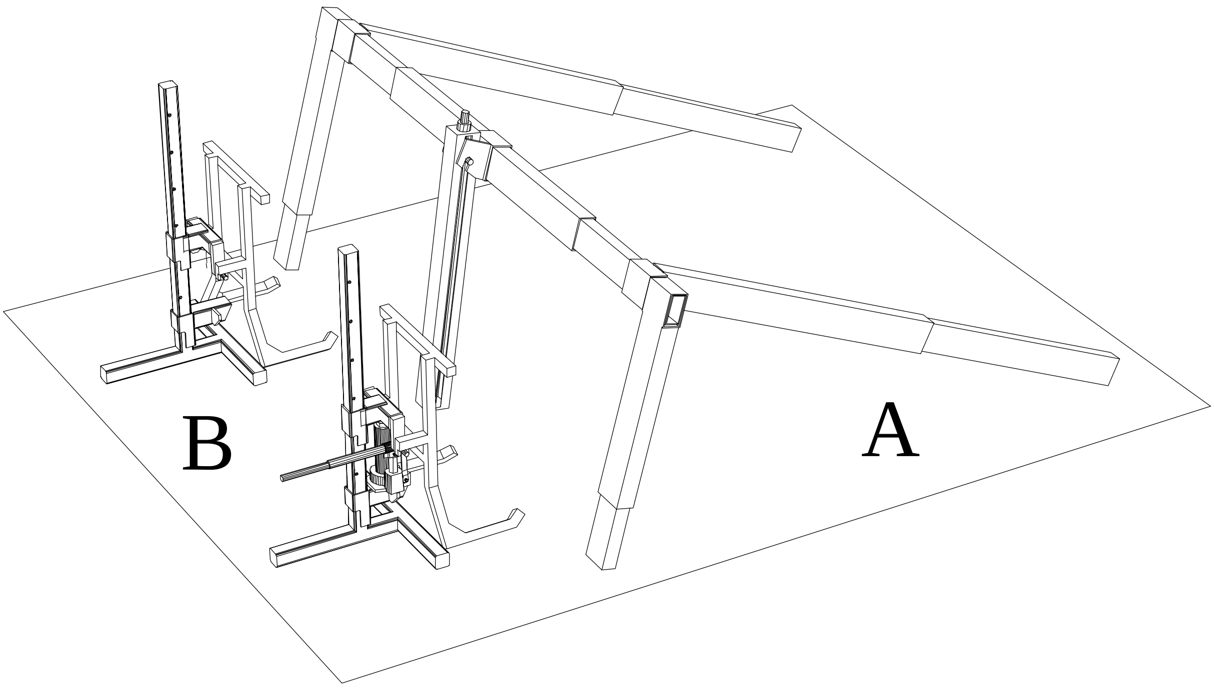


Figure 6.43 Results in the same perspective picture

The solutions are very different in size and principle. Their possibilities on the market are based on different points of view as well. The systematically developed version **A** is heavy (50 kg). It consists of heavy parts and it is heavy to handle. The intuitively developed version B is light (2 x 13 kg), easy to use, but the structure is more complicated. The characteristics in comparison:

Version A

- *the structure is suitable only for tilting the car sideways*
- *the connection point has to be chosen carefully and the lifting pad must be placed with care*

- *strong leaning against the car during lifting may cause the collapse of the whole system*
- *harmful penetration into soft soil*
- *the working place is badly restricted*
- *makes working inside wheel arches possible*
- *lifting takes much muscle energy*
- *may cause damages to the body of the car*
- *without extra stands dangerous*

Version B

- *car can be lifted from both ends and sideways as well*
- *connection points are explicit and natural*
- *does not penetrate into soft soil*
- *leaves the space below the car completely free*
- *space inside the wheel arches can be handled only with extra stand*
- *lifting very light, but slightly complicated*
- *car body is never damaged, because there is no contact with it*
- *overturning is hardly possible and no extra securing stands are needed*

Version A could be made more interesting for the customer, if the delivery consists of a plain screw lifter with gliding bracket plus the junctions for the arms. Transversal arms, external studs and lifting pads could be made by the customer using wood of size two-by four inches. They will be made to correct length and the lifting pads may be attached by nailing for the customers individual use. For the use of wood, thorough instructions are necessary, of course. However, the capability of the device is difficult to improve and it won't sell well, because the technical attraction is low.

Version B has plenty of technical attraction and the customer is easily interested in it. Besides it is easy to demonstrate and the interested customer may try it on his own car at a parking place. Even the weight of the device is not an obstacle for that. Many car owners have an emotional attachment to their car and thus, rough handling in service or repairing irritates them more than one can imagine. On the other hand, the car body structures today are very light and substantial lifting points are hard to find in them. In this respect the version B is beyond compare, as it does not touch the body at all. This could be a useful argument even for professional use.

In the garages the car is supported by fixed stands. The new lifting device could use the fixed height of 410 mm for such a stand. This height makes the free operation height below the car up to 600 mm. This is a very convenient height for operations, because it is the same as the arm length. The correct height is very important, if the mechanic is in a laying position, otherwise the work is excessively strenuous. The height is adequate for a mechanic to turn below the car as well.

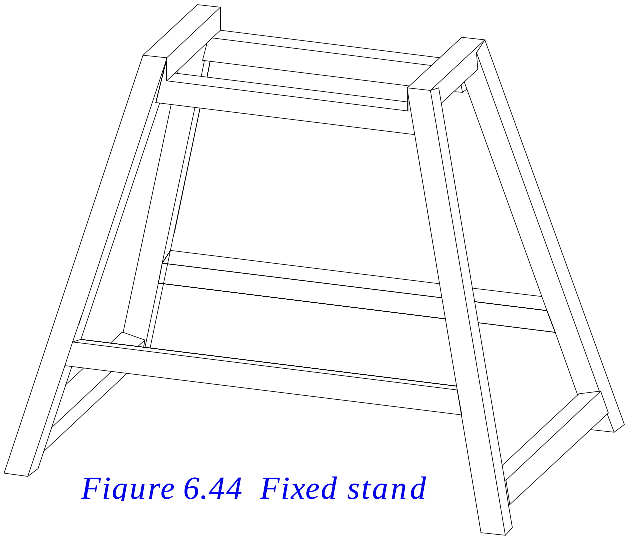


Figure 6.44 Fixed stand

The fixed stand in fig. 6.44 has two rolling stops. Another pair of stands should have no stops. They will be put below the first lifted wheels and the car may roll on them a little, when the other end is lifted.

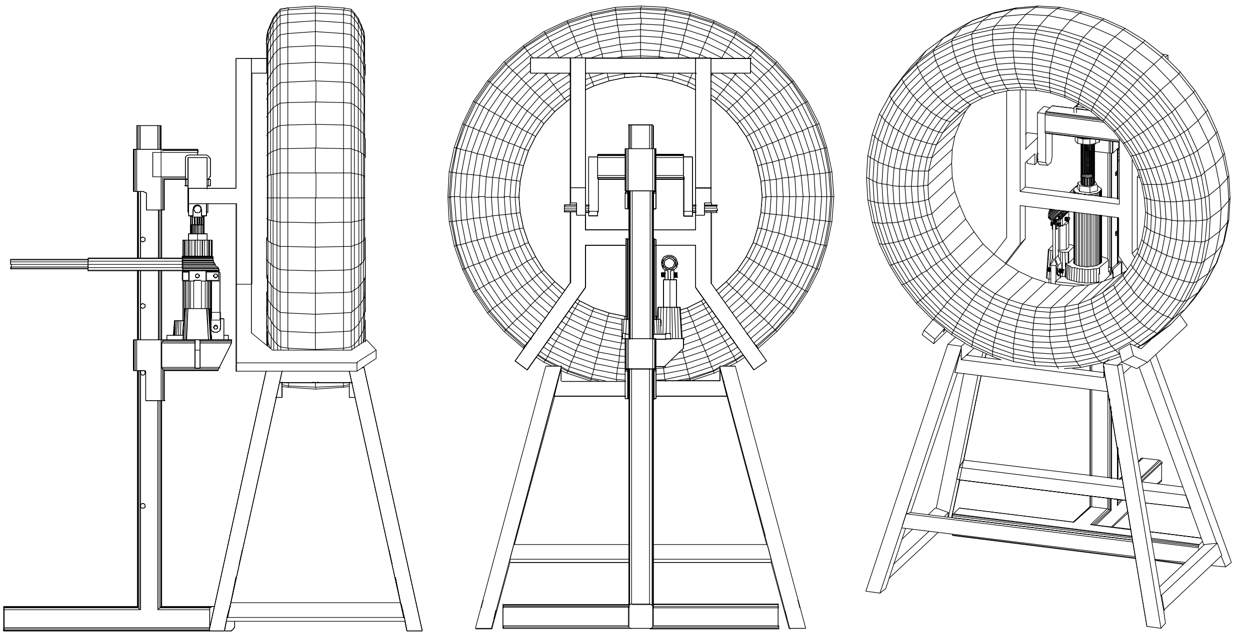


Figure 6.45 Use of the fixed stand with the new lifting device

The legs of the fixed stand touch the floor at first. Their ends can be straightened into the same level. The legs are connected with horizontal bars close to the floor on both sides of the stand, which will lean against the soft soil. Another pair of connecting bars are located higher up, to leave space for the stand of the lifting device. The fixed stands may be piled on each other, hence storing space is saved.

6.5 Survey of the Methods Used in the Example

The main part of all design tasks is the adapting of the present structures to changing needs. That may be redesign, in purpose to reduce the costs, or an adaptation to modernised manufacturing systems or materials, or redesign only for changed dimensions. This type of design work may be approx. 80...90 % of all engineering design.

In this example we designed a product, which the market can offer but only for professional use. For hobby users these commercial products are too expensive or too big. Hence, the object is a new product. The object is suitable for the presentation of different design methods. At the same time it reveals, that the systematic and intuitive methods have their own preferable adapting areas. It cannot be denied, that our example favoured more the intuitive method, than the systematic one.

The common trend in engineering design is, that the "soft" values are emphasised today. This example presents that emphasis, too, because these are the most important selling arguments. The soft values here are the feeling of safety, the gentle support of the car, easy and light handling and the technical attraction. These arguments should be visible, when the customer sees the product for the first time. The customer purchases the product, if it pleases him. If the product seems to be clumsy and suspicious, the technical characteristics cannot save it.

In systematic handling, the control of the process was found to be poor and the process ran out to the line of "hard" arguments. The main function was divided unnecessarily into clear subfunctions, which were developed using only familiar mechanisms. Despite that, the birth of the solutions in figs. 6.24...6.26 was not described. Perhaps they came intuitively, but that admittance would not suit. However, the situation was not fruitful for the intuitive process any more, because the morphological box already had frozen the possibilities due to its figures.

In the intuitive process the starting points of the problem were completely different. Those points were the functions required by the customer, the handling of the car, commercial supply, safety factors and the operation environment. None of the starting points were developed until final decision time, all of the points having been thoroughly studied.

The systematic method has some excellent routines, like the selection based on the use of the table (fig. 6.22) and the sharing of weight factors according to the sharing of the functions (fig. 6.27). They give the impression, that there is a trend of computer selection of structures behind them. The same trend can be seen in design catalogues, fig. 6.10. This trend has strong support especially in electronics and automation. For an engineering designer, however, this trend is unpleasant.

The systematic method is very advantageous, if we have to choose between **finished and unchangeable** alternatives. If, for example we have to select a new machining center for our engineering workshop, the selection table and the sharing of weight factors are really useful in the task. We must carefully estimate the needs of our workshop, the capacity and characteristics of the offered alternatives and their possibilities to meet our needs. However if we have to develop a completely new solution, big and complicated or small and simple, we have no possibilities to estimate the value for the solutions of different subfunctions. These values are very much depending on the influence of adjacent, still unsolved subfunctions, that the selection is like orienteering in the jungle. The precise marks and weight factors mislead us in such an entangled selection situation. The worst thing is, that the complete techno-economic estimation using marks and weight factors embed the result in unbreakable concrete and gives the impression of an optimum solution.

Neither of the final jack proposals are manufactured, even as a prototype. Hence, it is impossible to tell, which of them is really better. Never the less, if the intuitively developed proposal really works as intended, the winner is obvious.

However, the morphological box (fig. 6.20) contains the intuitively developed solution, too! The route of the solution is unambiguously 1.7 - 2.4 - 3.2 - 4.4 - 5.8 - 6.2. The systematic method has, also not failed in giving a possibility for this particular solution. Its problem is, that slowness and bureaucracy suppress the creativity of the designer. It gives an impression of a very functional system and neglects the creativity. If the design management does not understand it, it chooses and appreciates the designers on the wrong basis. This might be the reason for the disfavour of the systematic method among the older experienced engineering designers.

However, the systematic method has elements, which are able to clarify operations in the case, when co-operation is needed between several design teams and design departments. In those situations the design process has to work against its internal character. The internal character of all creative working is, that a creative insight is always made below a single hat. One of the greatest achievements of the human race may be, that which happened at the end of the 19th century. At that time we learned to use a team of creative individuals on the same problem. This kind of team is able to create even below their shared umbrella.

The systematic method also tries to fence in the design team. This becomes evident from the creation of the demand list and in the abstraction of the task. These documents try to prevent any disturbance by outsiders in the most sensitive phase of the process. The possibility for outside influence is given within the design review. This privacy is important for the intuitive process as well.

Our example also talks about the importance of the graphical presentation. During the accomplishment of the example, no screens were available. This lack was substituted with the help of 3-dimensional manual sketching. My intuitive accomplishment comes from the same time, but I did not use any sketching. The task requires much study in the use of space and in stability during the function. Since the material for the structure is mostly box beam, 3-dimensional modelling of it is very easy and provides the possibility for the visual presentation of different phases in use, as are presented in figs. 6.29...6.41. The time needed for the modelling of a whole device and for the creating of these particular drawings, is less than one week. The cost of it is very small, if we compare it with the importance of understanding the complicated procedure.

The 3-dimensional modelling technique is useful for welded structures in most cases. For the beginning of the design it is not useful, especially when there are no problems in the use of space. However many welded structures are very difficult to read and interpret from 2-dimensional drawings. Therefore, a small 3-dimensional picture in the corner of the drawing may be very valuable in saving time and eliminating errors in interpretation. A good example of this is the radar reflector in fig. 11.17. Castings are not very favourable for 3-dimensional presentation. If they are needed, they should be presented without roundings and with as simple a form as possible.

Finally, one common item we notice is the applicability of box beams in steel structures. How could we live without them any more? However, up until the beginning of the 80's they were an unattainable material in socialist countries.

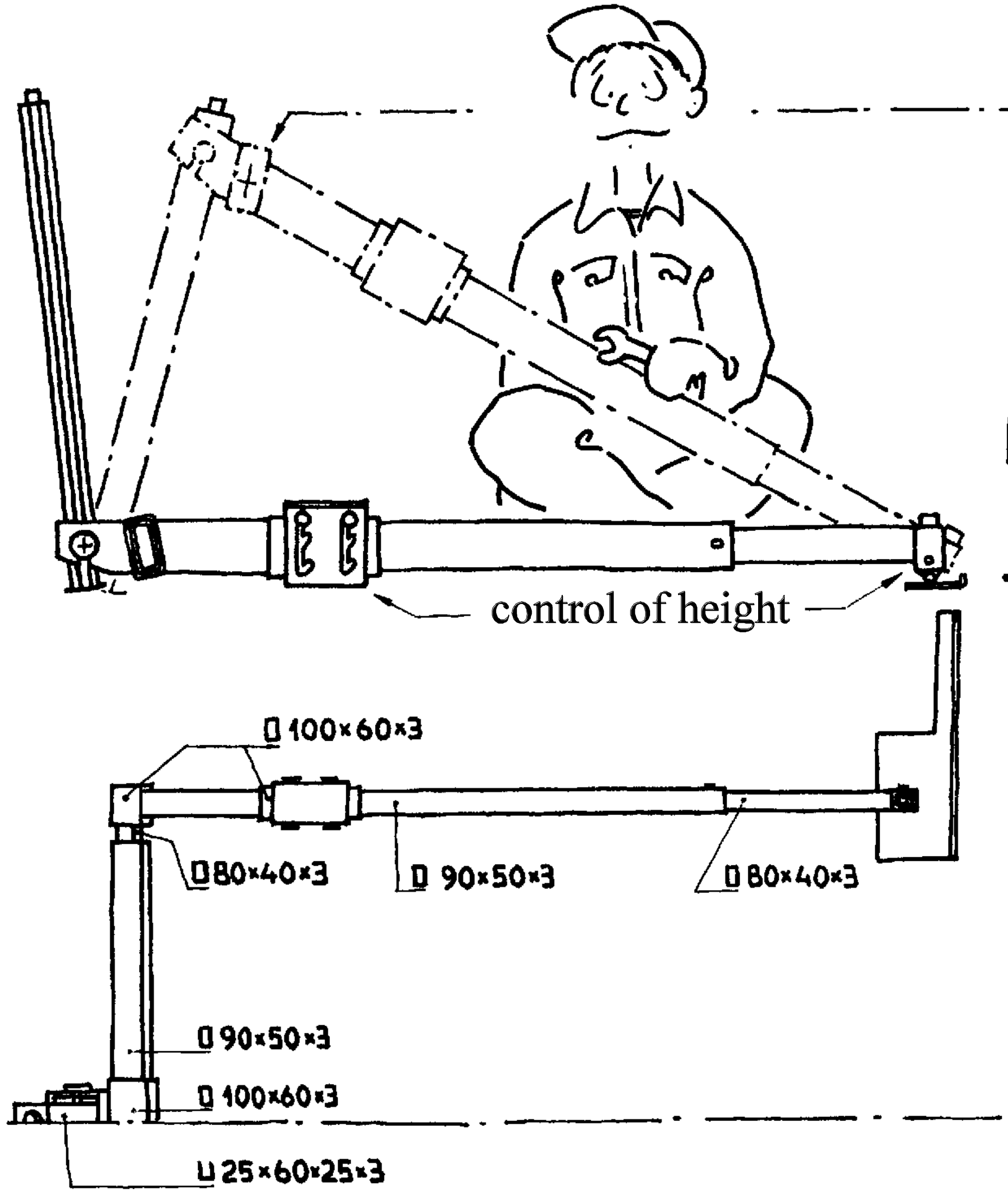


Figure 6.28 Sketch of the final result in actual scale

Figure 6.28 is referred from the original publication. It is presented as a free hand sketch, but it shows the actual scale more or less accurately. The choice of this kind of representation seems peculiar, since it would be more informative, if the final placement below the car was presented.

I have not handled the developing phase of the final jack here, because its content is mainly calculations. No accurate drawings are presented in the publication. The lifting pad is studied a bit more, and it was decided to use controllable pads on the beams. Both arms of the jack were given extra sleds to make sliding below the car easier. The length of the arms and the width of the whole jack is controllable according to the size of the car. This makes it possible to disassemble the jack for more convenient storage. The total weight of the jack is approx. 50 kg.

7. Organisation for Intuitive Engineering

We have so far discussed, the creative action of an individual in engineering design. We have not studied his work in a team, or his action in the organisation of a company, in general. However, since the end of the 19th century the technics have developed enormously, and this development is based mostly on the individuals ability to work in a team towards a common goal. How much more we could have learned, if Leonardo da Vinci and Isaac Newton had previously gathered the same kind of team, as Thomas Alva Edison and Henry Ford did?

Team working is based on fruitful communication between individuals. This communication is much more than a plain discussion. The exchange of ideas, based on speaking with words, is only a few percent of the thinking capacity in the conscious mind, without mentioning the capacity in the subconscious mind. As I tried to illustrate at the beginning of this book, the knowledge and know-how of an individual mainly consists of the data nets in the subconscious mind. Creativity is simply an ability to adapt these nets for the understanding and solving of new problems.

However, a man typical looses his creativity gradually, if he cannot keep it active and in training. It is more correct to say, however, that the creativity does not just disappear, but the desire to use it is reduced with diminishing needs. If the man always has a competently finished data or function net for all everyday needs, he must not be creative any more. The laziness towards creativity finally leads to a state, where the man does not want to see situations where creativity is require and thus, his mind becomes fossilised.

The human knowledge structure also tends to fossilise, if it is not kept in continuous use. This phenomenon is very useful, because it reduces the need for thinking work even in demanding duties. In creative work these fossilised knowledge structures should be made mobile again in order to contribute to the creation of the solution. This mobility is normally aroused through some of following elements:

The latest knowledge

It is said, that the human mind is like a kaleidoscope, which creates always new figures using the same material. If even one chip is added, the figures can never be the same, as were created earlier. Man loves his own knowledge structures, hence the problem is, how to put a new chip into that structure.

A new fact has no influence, if it is not handled within an old knowledge structure. Hence, even the orders of management and new facts stay out of consideration, if one has not the ability or the desire to receive them. In the *same way the acquaintance with competing solutions remains useless, if their characteristics and the thinking behind them is not extracted using penetrative analysis. The new knowledge is created in the heuristic points, too, if the intuitive method is used.*

Inside a good working team the transfer of knowledge is fluent and rich in forms, thus it is also efficient. This is even more evident when knowledge diffusion is used.

Reforming of the knowledge

In many cases old knowledge has to be adapted to circumstances, which differ from the circumstances, where the knowledge was created. In this case the knowledge should definitely be activated. While working in a team on the same main problem, the designer notices the ideas of his colleagues, which are different from his own. A good team worker is not irritated by this, but he is positively activated. Visual information works best in these situations.

New knowledge changes the circumstances of other knowledge used in the structure, after it is thoroughly integrated into it and thus, the old knowledge is also reformed.

Association

The ancient Greeks defined association, according to which, any term brings up unintentionally related or opposite terms. Hence, a shoe of a child remains us the child, a dwarf remains us the giant, a cat of a lion etc. referring to the ancient examples.

Association has an important meaning in brain storming, as well as in synectics and in many other technics of creativity. In brain storming the knowledge structures are continuously reformed by the penetration of the known ideas. The most important factor for success is, that instead of a negative, defensive attitude, the participants are able to develop and adopt a positive aggression.

Association is a strong agent in all team work, even without any of the technics of creativity.

7.1 Creative Team

Most major discoveries of mankind were made until 17th century. However, the utilising of them did not succeed even in the following century, except sailing, perhaps. At last in the 19th century, technical and economical development began accelerated growth. It is said, that a method of invention was invented at that time.

What was this method of invention? I suppose I am quite right in saying, that it was a creative design team, a type of team which did not exist before that. There were masters, journeymen and apprentices, all working together, not as a team but in clear hierarchy. After the journeyman got his master certificate, he started a new workshop as an independent entrepreneur. There was never more than one master in one workshop in full harmony.

Otherwise professionals had a lot of co-operation, i.e. guilds, pubs and what was most important, they had a well developed social security system for family members of the guild. Not until the 19th century it was found to be necessary to cut the excessive bindings to tradition, and on the basis of the new discoveries, something completely new was invented: a design team. A concept which required the co-operation of many masters.

7.1.1 Gathering the Team

If a new design team is set up, it is usually gathered together with some new project with the purpose of contributing to it. It is natural, that the team is composed so that, its know-how is appropriate and many-sided. If the team is established for engineering design, the aim is, that it can manage the design from the very beginning to the finished product. This is not always possible, thus in special tasks occasional specialists or subcontracting must be used.

It is normal to mix the professionals of different ages into the team. Thereby aiming to form subteams and working couples. Someone of the experienced designers, who knows widely the area and who is able and willing to guide the work, is going to have the leadership.

The team can accordingly be gathered carefully, preparing for all possible needs, but the final result, however, is more or less depends on fortune. The operations of the team can never start without friction, but the members of the team must be used to co-operation. Fortunately the people are rather flexible. However, the internal relations of the team must be kept in view and an unadaptable individuals should be replaced by some more co-operative.

7.1.2 Key Couples

In a design team, not depending on how it is gathered, some members find themselves to be able to cope exceptionally well with each other. While working on their own tasks they keep in view the working of the others. They ask for comments according to their problems, but these comments are not advisory, they reflect rather the problem from the commentators point of view. Otherwise there is not much discussion in the team, but this commenting couple finds themselves to be comfortable in the work. In this way the **key couple** is formed. The key couple is distinguished by following features:

a) *Professional know-how is emphasised in different points. If they are engineering designers, one is familiar with strength, another one more with hydraulics, or manufacturing etc. A deal may be made in the way, that one knows best the rotating machine elements and structures, another the welded structures, and the cast structures etc.*

b) *The characters of the individuals may be what ever, even opposite types can learn to work perfectly well together. The work activity, however, should be on the same level.*

c) *The members of the couple find themselves comfortable outside of the work, too. They became family friends in many cases.*

The formation of the key couple should be seen as a positive phenomenon. This kind of relationship increases the know-how and reliability of both of them and a prominent key couple is very valuable for a company. The team leader should have a good psychological eye to discern this type of couples and he should slightly favour them over the lonely individuals.

7.1.3 Key Teams

If the key couple adopts other members, a key team is created. This establishment takes much more time, because each member of the team should be professionally distinguished in some way. After a sufficient period, different experiences and emphasis in the use of mathematics etc. is a sufficient differing feature. The same features are valid for a key team, as they were for a key couple, but in addition to them:

a) *there is never any competition between one another in the team*

b) *It is not necessary to share the tasks for the individuals, it will be shared inside the team and the sharing is shifting*

In a favourable atmosphere the key team may grow up to include the whole design team. Then we can consider it as the maximum creative capacity in the group. This kind of unifying is rare, but it can be accomplished with a very careful personnel policy. That policy includes the replacement of the unsuitable individuals in the team.

7.1.4 Reducing and Increasing the Size of Team

The size of a well harmonised design team must be administered carefully. If some of the members of the team are transferred to other teams, the impression of temporality prevents the forming of key teams. If the situation demands the permanent reduction of the team size, it might be the best way to transfer one of the key teams as a whole. Before that the unadaptable individuals should be replaced. When we get so far, we should think about the whole organisation once again, because the transferred key team has essentially reduced the know-how of the whole team.

This extent of elimination is, fortunately, very exceptional. The main principle must be, however, that the established key teams are never deliberately separated.

There are problems in recruiting, too. The most difficult situation occurs, when the team must be completed with several experienced designers at the same time. It might be advisable to handle this new group like a key team, i.e. they should get their own task.

The occasional completing designer can sometimes join with an old key team easily, if he has some needed expertise and experience of working in a key team. If he is a loner however, his adaptability is poor. One problem is the different backgrounds of the designers. An experienced designer of agricultural machinery cannot be adapted into a design team of paper machines, and vice versa. In the same way the designer who comes from maintenance has difficulties in design of serial products.

The best form of recruiting to a well harmonised team is the use of young students preparing their diploma or other young people after their certification. They can now see the working of a well functioning team, they will understand the value of experience and they submit to the leadership of the older members. After training for a couple of years it will be obvious to the team and to the candidate, if he is a designer by his nature and if he will become a member of some key team.

The youngsters bring some new knowledge into the team, too. This is usually knowledge of the most modern methods, which still are unfamiliar to the experienced members of the team. This situation is very favourable. The newcomers do not depress too easily and the experienced members get some ventilation in their thinking and also obvious help in their tasks. At the same time the bridge and the mutual respect builds up between the generations.

Creative engineering design demands a certain amount of natural talent and the ability to adapt it into the nature of the work, that it is not attractive to everyone. Despite this the experience of a designer is useful in any area. Hence, a creative design team is a valuable recruiting method for employing even sales engineers. The team profits from this, because it gets the possibility to screen good individuals for use in the team.

The best design team can be used for the education of the recruits. This activity does not disturb very much; on the contrary "stupid" questions and proposals are valuable. The mode of the team working and the confidence of the members of the old team is useful for the sales engineer, too. The design team profits through the formation of good personal contacts with other department.

7.2 Knowledge Diffusion

7.2.1 Substance of the Knowledge Diffusion

- *Any team creativity does not exist. There is only the creativity of an individual. It manifests itself best, when the individual works isolated from his mental surrounding. A creative man closes himself inside a shell, where he can co-operate with his own subconscious mind.*
- *A team of some creative individuals can be declared as a creative team. The team is able to work together towards a common goal. Brain storming and*

> *other creativity technics create idea producing situations based on an association. In those situations, a creatively activating progress in the participants can be distinguished, but the situations do not create anything new. They might accelerate the creative process and produce premature developments. The team of creative designers very seldom uses any creativity technics, but the fruitful influence on each other seems to work in some invisible way.*

After I started my design work in a design department of approx. 100 designers, I wondered about a big gentle man, who almost every day came to look at the drafting boards and to discuss things with the designers. I was told, that he was a designer from the work preparing department, who visits us without any specific duty. This was not accepted by his boss, but he was not able to stop it completely. On the other hand I noticed, that many designers approached him an asked him to look at their drawing. I was just certificated M.S. and I certainly did not need the advise of this technician.

Then one day he appeared at my side, when I had some structure visible on my drafting board. He asked nothing and did not give any advise, but he started mumbling his own plan of how to machine that structure. He studied, in which position the structure should be placed in the milling machine, was it possible to reach every surfaces to be machined, and was it possible to check the dimensions when milling. He did not meet any problems, thus he disappeared. Next day he looked again at my progressed structure, repeated the manufacturing process and asked me, if he was allowed to add a small machined spot at the flange. I had nothing against that but I asked: why? That spot should provide a reference for the measurement of the placing height of the cylindrical surface to be machined, he said. Hereby I got the insight, that this spot could be marked in the drawing, too.

I realised, that his visit did not irritate me in any way. My work was interrupted, of course, but only because I found myself following his thinking with interest. After his visit I noticed, that I saw my task in a wider perspective. After several contacts with him I learned to design for the manufacturing together with the structure. In a short time at the beginning of the 60's, I had learned the method of simultaneous design, which much later got the name "Concurrent Design". The process, which taught it me, was **knowledge diffusion**.

The gentleman, who taught it to me, was a born **knowledge carrier**. He visited us only because he needed information about the structures which he would later prepare for manufacturing. After he had left our company, the management understood his enormous value at last, but it was too late. His successor was nominated, and he got the duty of visiting the design department with the purpose of transmitting manufacturing knowledge. The successor was professionally as competent as his predecessor, he was the chairman of the local flight club and very harmonious in social relations. In this new duty, however, he was not able to contribute anything, but fights. He never learned the **pressureless** transfer of knowledge.

What happened, deserves a closer look and a visual attempt to explain it. Fig. 2.7 demonstrated the co-operation of our conscious and subconscious thinking. However, it gives no description of the structure of different individuals. In fig. 7.1 a socially active, lively, and logical mind is demonstrated as a sack, which consists of a bottom part (b), where the subconscious mind is packed in a small space. The mouth part (a), presents the conscious mind, which is, in contrast, open, spacious, and responsive to all outside information (d). The filter (c) might even be bowed out pressing the subconscious mind into a still tighter space.

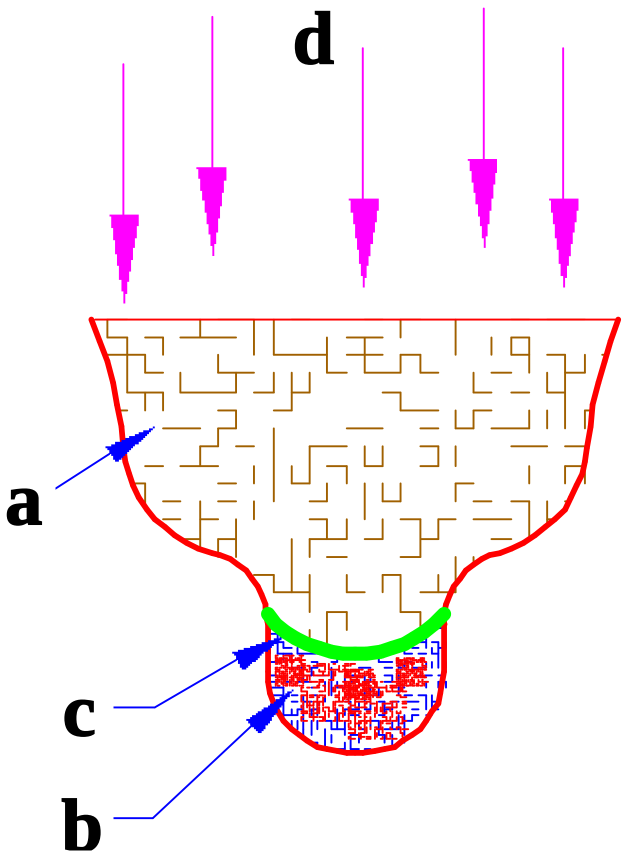


Figure 7.1 Socially active mind

A young individual is often like this, as well as the people in such professions, where alertness is needed, like public servants, merchants etc. Especially during the student years it is important, that the receiving of information is done with a really open collecting net. This type of human is also very respected, because his alertness is loud and visible.

The consciously alert human is incapable in creative work, because he is not able to benefit from the capacity of his subconscious mind. He trusts the ability of his logic to work out the problems and causal connections, but he has no idea of, how to proceed, when there is no knowledge available from the surroundings, literature or data banks. The student must adopt knowledge in the form it is presented in the study programme. He is not immediately able to apply it in practice.

When he must apply the knowledge, or form a completely new knowledge through research, he must gradually change his opinions. He begins to think and he sees, that gradually his thoughts become clearer in a mysterious way.[24] The importance of the subconscious mind increases and at the same time the receiving ability in the conscious world is reduced.

[24] "We always have to make steps without seeing the logical consequence from one step to another. And, very often, we can follow the logic backward, once we have made the step. Probably you always can, otherwise it would be the wrong step. But if you have made it right, you can certainly do it afterwards. But first you have to be able to do something or to reach the point without going logically step-by-step." Heinrich Rohrer, Nobel-prize winner in physics 1986 in an interview on Swedish television, January 1987.

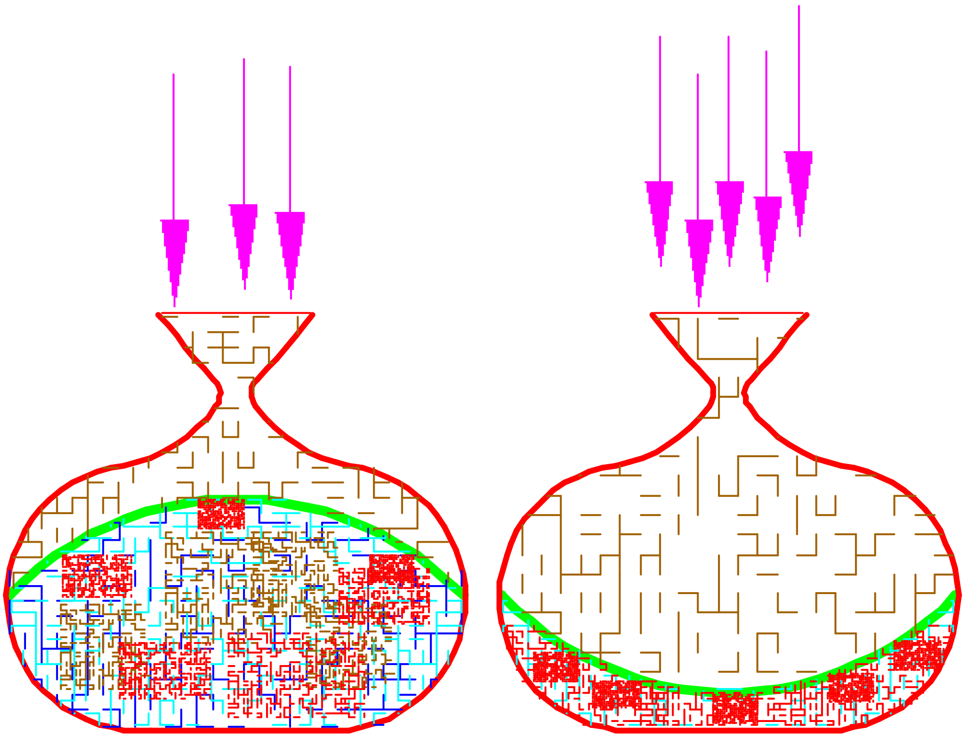


Figure 7.2 Action of creative mind

The most essential change is the growth of the subconscious mind in capacity and power (bottom part of the sack). The border surface between the conscious and subconscious mind becomes elastic. On the left side of fig. 7.2 the mind is working on a heuristic point, the subconscious mind activates and expands while it tries to relate that particular point to the other knowledge content. During this phase, however, the receiving ability for outside information becomes lower and more selective. At the right side the work has changed to be more critical and analytical. That means, control has changed over to the conscious mind. The volume of the subconscious mind is reduced and the ability to receive outside information is increased.

The extent of the variation depends on the individual qualification. Some designers can stretch their receiving ability and social activity until they reach the level of the youngsters. Some designers tend to close themselves almost completely to outside effects. The speed of this metamorphosis depends on personal qualification. The total change of focus from one side to the other (fig. 7.2) takes time, typically, from a few hours to a couple of days.

The metamorphosis from the mind type in fig. 7.1 to type in fig. 7.2 takes time at least several years, but the change is possible and the change direction is typical and natural with ageing. If the nature of our work changes, the metamorphosis is also possible in the opposite direction. Our education system, however, tends to form the students as in fig. 7.1 and social appreciation tends to keep the people that way.

Figure 7.2 indicates, that human communication is reduced on the conscious level. This is a problem we must continuously fight with. However, the transfer of subconscious knowledge increases and it uses all our senses without presentation by formal language. The closest social surroundings are essential for that and the result is what we have just defined; knowledge diffusion. The ability of the subconscious transfer of knowledge, however, is not always connected with creativity, it assumes an open mind, demonstrated visually:

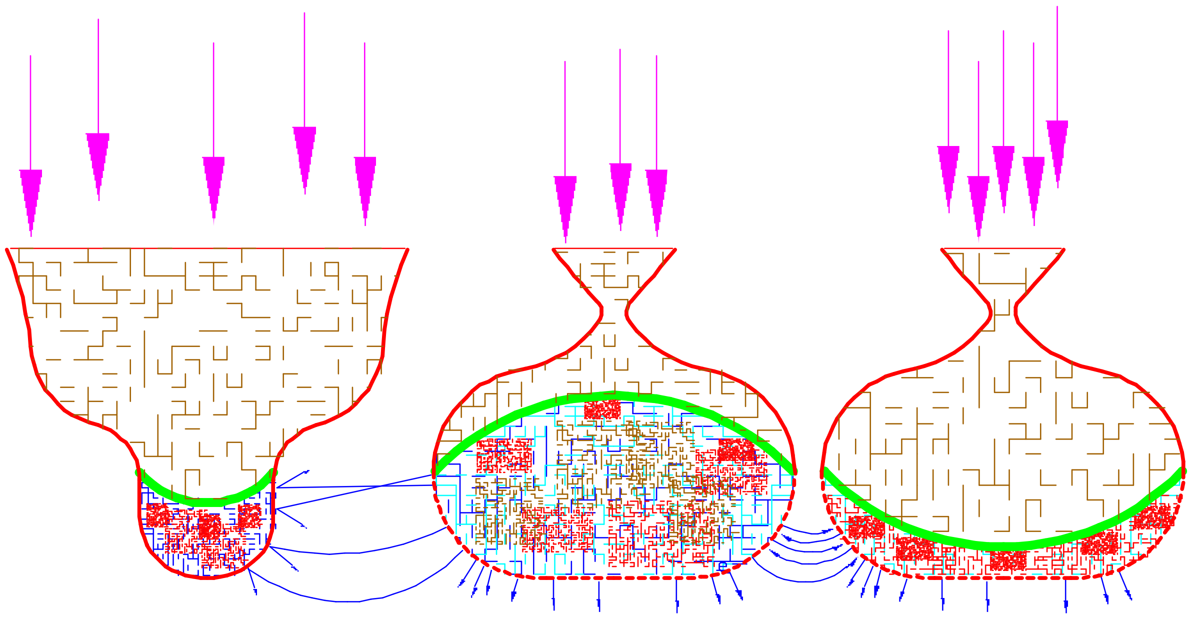


Figure 7.3 Knowledge diffusion between the subconscious minds of individuals

The increased activity of the subconscious mind has a consequence: the walls begin to "leak" outwards and inwards. This diffusing information consist of something, which is able to create images in the subconscious mind of the receiving person. These are induced images, caused by seeing, hearing and being together in a team working on the same task. At the beginning the induction must be as unnoticeable as possible, but later on, when social trust has grown up in the team, even the strongest gestures and opinions can be induced to constructive images.

The consciously active, alert human has difficulties in adapting himself to knowledge diffusion, and he wards off all influences of it and follows only direct orders and instructions. The intuitive human type has also difficulties at the beginning, and he needs handling by a really efficient knowledge carrier to learn the process.

- *Knowledge diffusion is the transfer of knowledge between human minds* ***without the use of any pressure****. The transfer does not disturb or irritate the receiver and his own observation picks up the knowledge, when he has an opportunity to it. Knowledge diffusion assumes a mutual knowledge and trust in that:*

  - both of them want the work to be successful

  - knowledge of both individuals is necessary

  - there is neither contest nor priorities

  - both of them are just working and not giving advise

  - neither of them hide anything

  - neither of them assumes, the other should follow his work pattern

  - the attitude between them is humble and sincere

The importance of a good knowledge carrier is very large, but finding one is difficult. In many cases such a man might be an experienced engineering designer or manufacturing engineer, who might be already exhausted by his own demanding work. Then the respect of old age may be able to increase the responsiveness. The responsiveness can be found easier, if the knowledge carrier possesses an expertise unfamiliar to the receiver. Hence, an electrical engineer familiar with machine automation, might be an easy choice, together with a data handling engineer or a mathematician. These experts cannot completely compensate a good knowledge carrier from engineering design, but they might be able to teach knowledge diffusion in the team.

Active knowledge diffusion is a very important model of action, in the focusing and utilisation of company resources. It should be active between all individuals and professional groups, but first of all, it should function between designers and all other groups in the company. Only in this way is it possible to **realise company know-how in its products**.

The following definition may sound like excessive emphasising of the importance of only one professional group, but it is not so. I mean:

- *The designers are the only professional group in the company, which have the ability and know-how to **concretely** develop new competitive products for the company, based on the experience of decades. All persons in the company are able to produce splendid ideas, but only the designers are skilled to study and adapt these ideas into concrete products. Therefore it is important for the success of the company, that the designers get, through knowledge diffusion, all the information which can be afforded by the company and found from its territory on the market.*

The application of knowledge diffusion is not difficult, but finding of the proper attitude, really is. A good knowledge carrier has a sound self-awareness, but at the same time, he has the ability to appreciate the work and knowledge of other people. Apparently, one learns to accept the correct procedure, if one has the opportunity to experience its fruitful influences. The knowledge carrier must learn to understand, that his knowledge is not valuable in all details and in all problems. He cannot and he must not know the value, only the receiver has the possibility to know it, and the receiver picks up what he needs. In many cases only a small part of knowledge is useful or its influence might be almost invisible. The transfer of the knowledge is, however, bi-directional; an intellectual contact which seems to lead to a personal contact. However, most people in an organisation seem to be afraid of such personal connections.

Knowledge diffusion must be taught to the most important professional groups and to representatives of several levels in an organisation, because the most efficient learning mode is experience of its influence, the possibility for that should be arranged. Even better than formal education, is the wide practical use of knowledge diffusion.

7.2.2 Knowledge Diffusion in Organisation

The intuitive design process is individually oriented, and the outside control of it is not easy without damaging the process itself. Therefore knowledge diffusion should be activated in the design teams and in the whole organisation, as well.

The engineering designers, themselves, produce plenty of product ideas, but their arguments are mostly based on the use of technical possibilities. Very often they are blinded by the splendid views of the possibilities and they do not see the meaning of the market clearly enough. The reason for the disregard of the market forces is, that the designers are not sufficiently connected with them. Since the 1960's the quality of product ideas has been tried to be improved by the introduction of product planning, which should work according to the following schema:

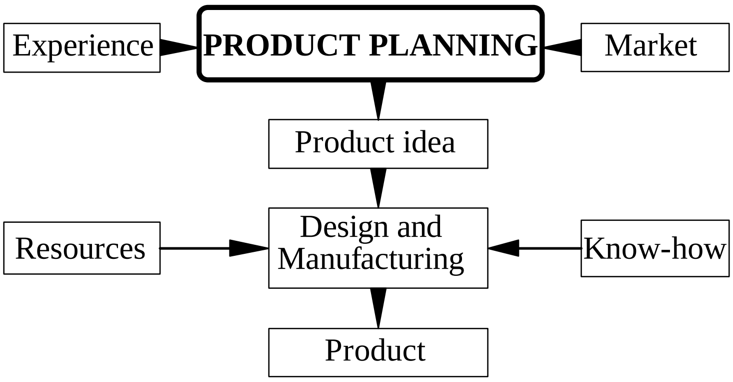


Figure 7.4 Product planning

Better product ideas can be found, if the resources and the territory of the company is studied. Thereby several kinds of techniques can be used to find product ideas in good accordance with the study results. The process is called *product planning*. Product planning receives participated from the management of the company and representatives from manufacturing, design, economy, and sales. The representatives of manufacturing and sales are usually the managers of these departments. They are considered to have the best knowledge of the resources of their departments. However, contact with practical creative work in manufacturing and design is broken by those managers, hence the ideas produced by the product planning group prove to be false and inadequate in many respects.

A remote product idea proves to be expensive to realise, and their characteristics are not the best possible from a market point of view. The basic reasons for this are:

a) *The users of the products have the best knowledge of their own working environment and they have adapted the available techniques to serve their needs and also they have adapted themselves to these techniques. They are able to present the hopeful developments of their functions, but they do not have any view to the possibilities of the technique, except by comparing it with the technique their competitors are using. In other words: they know, what they* ***want****, but they don't know, what they* ***could get****.*

b) *The designers who design the product, are able to get the information of the task only in schematic form. Their hands are bound at an early stage, similar to what happens in the systematic design method. If they had the possibility to compare their own know-how with the needs of the market, before the definition of the product idea, they might be able to find possibilities to fulfil such which the customer hadn't the faintest idea of. If the designers use their technical ability in the realisation of a remote product idea from product planning, without any deep contact with the market, the success will be only arbitrary.*

c) *Manufacturing has insignificant possibilities to improve the product idea directly through product planning. Its influence could be much better through the co-operation with the designers in definition of the product idea.*

If instead of the schematic process the principle of knowledge diffusion is used in product planning, the generation of the product ideas will be more efficient and these ideas will be used more thoroughly throughout the background premises, fig. 7.5.

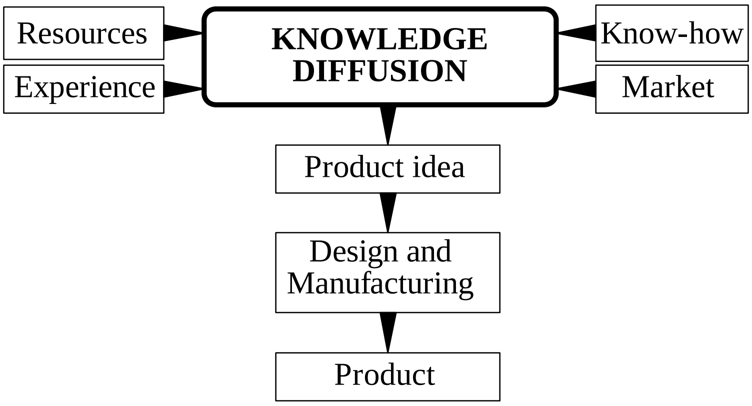


Figure 7.5 Product planning based on knowledge diffusion

Here the whole product planning is gathered under the title knowledge diffusion. It is neither team nor department, but it is a recognised mode of action which takes care of the modernisation of the whole product assortment and the activity. This mode of action is valid in sales, manufacturing, design, economical management, research, and in general management. The mode of action means the use of knowledge diffusion in transferring information between all participants in discussions, in mutual and in team. It is used in handling ideas, analysing market data and in close contacts of the design activity with manufacturing, sales, economical management, laboratories, etc. This activity hardly needs any written reports, but very much personal contacts, visits etc.

The purpose is to make everyone aware of the company policy, activities in all departments, successes and setbacks. This vivid intercourse gradually gives the correct view on the possibilities of the company among the parties. It brings up the best factors for success, too. On the basis of this rich awareness the best product ideas pop up without any formal techniques.

The product design activity of the engineering workshop is divided into two different areas. The products in continuous manufacturing need adapting, tailoring, fixing and development design. They shall fit with the varying needs of customers and they shall be offered as competitive versions. This kind of design operation is placed under control of operative management in the same kind of line organisation, where also are sales, production and accounting.

This so called **line design** takes care of documents for delivery projects, planning of start-ups, and the production line design following the customers needs. The continuous development of the product has a very big importance. Hence, every product has in line organisation a **responsible designer**, who really devotes himself for the product for long times. In many cases there is a small group of designers in such a responsibility. They make only occasionally design work outside their own article.

Some articles keep their position in the production for many years, even decades. Hence the design in line could be kept as a static and boring job. However, there are examples, when a moderately skilled designer with moderate education is able to develop his **devoted article** to the top in international competition. The precondition is, that the main function is kept unchanged and the new technique cannot change drastically the product and its using circumstances.

If big changes of premises appear, the article needs a thorough modernisation. This leads to the complete redesign of that product. The situation is close to that, when a completely new product has to be designed. The company is privileged, however, because it has the long experience from the old product, including the wide knowledge connected to it. Then it is considered as a development task, which is perhaps too big to be done with sufficient freedom and thoroughness in line organisation alone. In this case a hybrid project management structure will be established inside the main organisation. The necessary resources are given to this structure and it can be preserved for this demanding task only.

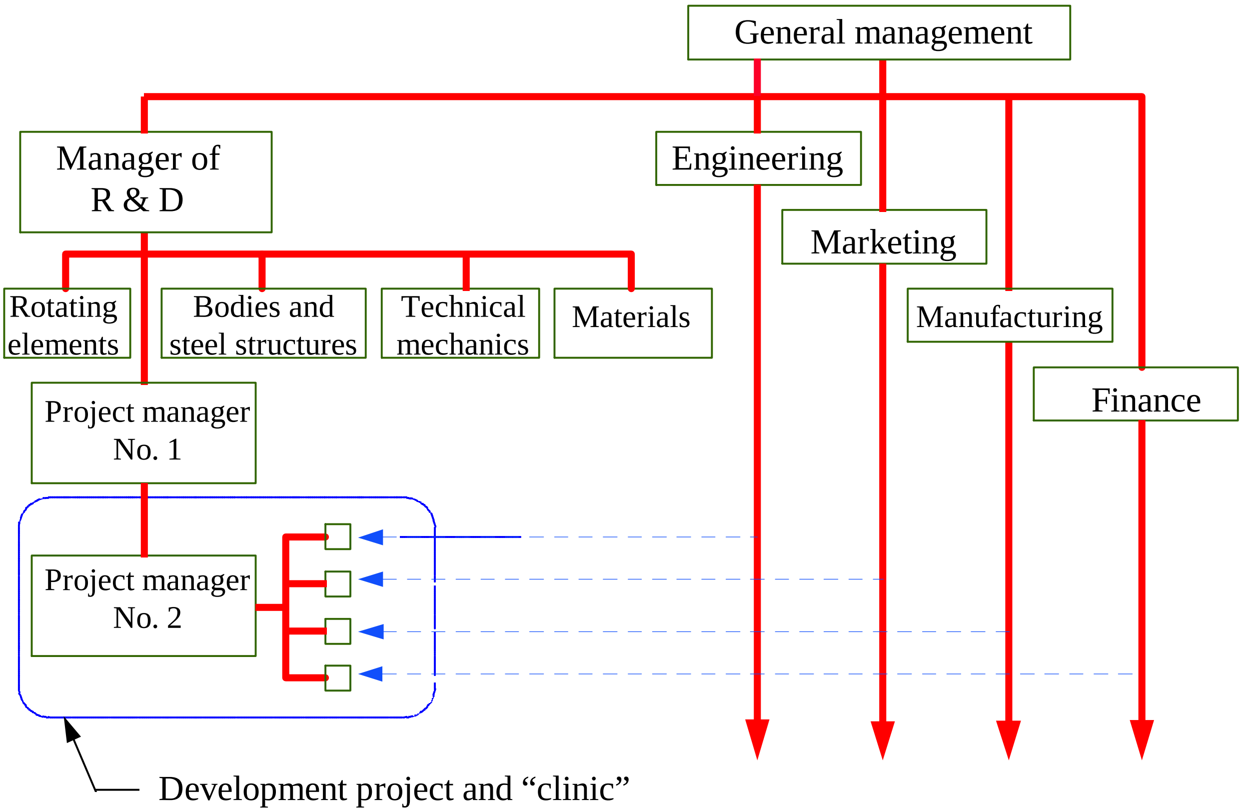


Figure 7.6 Hybrid design structure

Hybrid structure should be used only as a part of design activity focused on the development of some specific product. Person in charge is the **manager of R&D**. This post can be placed on needed importance according to the policy of the company. His main tool is a highly qualified group of designers and experts. In fig. 7.6 these are experts for design of rotating elements, bodies and steel structures, and experts for technical mechanics (strength and strain), and materials. Sharing to the rotating elements and static bodies is only a common suggestion. The sharing can be enhanced with blocks of hydraulics + pneumatics, rolls, bearings, castings, welded structures, automation, etc. However, it is not good to go too far in this, because the differentiation reduces creativity and still more ability for team working is needed to compensate it.

The development tasks are divided into projects. Each of the projects get its own boss and team gathered from those named experts. In addition to that more members are named from the line organisation. From these "hired" participants the designers work in the new team during the whole project, other participants (from sales, production and finance) only shorter periods now and then. The representatives from the line structure visit this hybrid structure like visiting a "clinic" in purpose to learn and practice the creative working, but first of all, they should transfer their expertise and knowledge in production, from the connections with customers and other activities in the company. This can be done effectively by using knowledge diffusion, which in this occasion is taught for everybody.

The participants of the hybrid structure, who come from the line structure, are in no case coming to subordinate position, but they will be not dominating, either. But the experience and the know-how, which is accompanying, has an essential value. At the same time they must work over a period, which activates their creativity and their understanding of their devoted article is widened and sharpened. After they have gone back into the line structure, their responsibility is grown up, because they must be able to launch the new structure into the production and market.

It is considered as a disadvantage of the hybrid structure, that the designer from the line structure considers the placement into the hybrid as a rising appreciation. After that the returning into the line is some how frustrating. This kind of attitude on valuation should be avoided by all means. Eventhough the permanent designers and experts in R&D are the best the company can find, they never know the application circumstances of the article so deeply as the line designer of that article. Hence, the know-how of the line designer must be considered very seriously and with all respect and he should be offered with all the help, that the technical expertise can afford. In the respect a slight exaggeration is very useful in purpose to build up the knowledge diffusion. This relieves the valuation problems and the returning designer feels, that he has been useful and he can use his expertise spontaneously in more efficient way.

Unfortunately it may happen, that the valuation problem cannot be dissolved. In this case the line designer starts to cancel or water down the results of the clinic. He comes back to his old structures with have his own handwriting. The reason for that might be in failed acceptance of the knowledge diffusion.

The "clinic visit" of the line designer is continuous during the project and it may take time several months, even years. Even his physical placement is in R&D in that time. In most cases the visiting line designer is the devoted designer of the particular article or one of the best designers from his team in line. Any completely new and inexperienced designer should never be used as the visitor. After his returning into line the conflict with the leading designer is well prepared. The visits from sales, production, and finance are shorter and they may be intermittent, too. Such a short time participation does not disturb the main duty. Even these participants are nominated into the project, also the visits of management and other specialists are very welcome. The nomination means for the participants of sales, production, and finance, an education to the use of the knowledge diffusion. This ability is very desired in the whole product planning of the company.

The use of the hybrid structure tends to take advantage of the principles of the **integrated product development**[25] by means of the clinic procedure. The sales, production and finance are continuously informed from the progress of the project, and on their behalf, they may start preparations for production and sales. At the same time they are obliged to transfer knowledge into the project in order to find the best orientation. The understanding on both sides of the participants should be increased. The difference, compared with the integrated development, is, that the project is accomplished distinctly in R&D using the special occupation. There are **hardly any project meetings**, but the co-operation with other departments is based always and only on the personal contacts at the work, at the screen or in the laboratory.

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[25] Andreasen, M. Myrup & Hein, L.: *Integrated Product Development*. IFS, Ltd. Kempston 1987

7.3 Product Design Process

All design methods are using some kind of working schema, which starts with the *definition* of the task. In the systematic design method by VDI 2222 it was followed by *sketching, development and refinement*. Ullman[26] reduced these steps so, that after the definition came only *planning* and *design*. The definition by Ullman is much more comprehensive than by VDI. Both of the methods, however, only refer to the background, where the product idea is born.

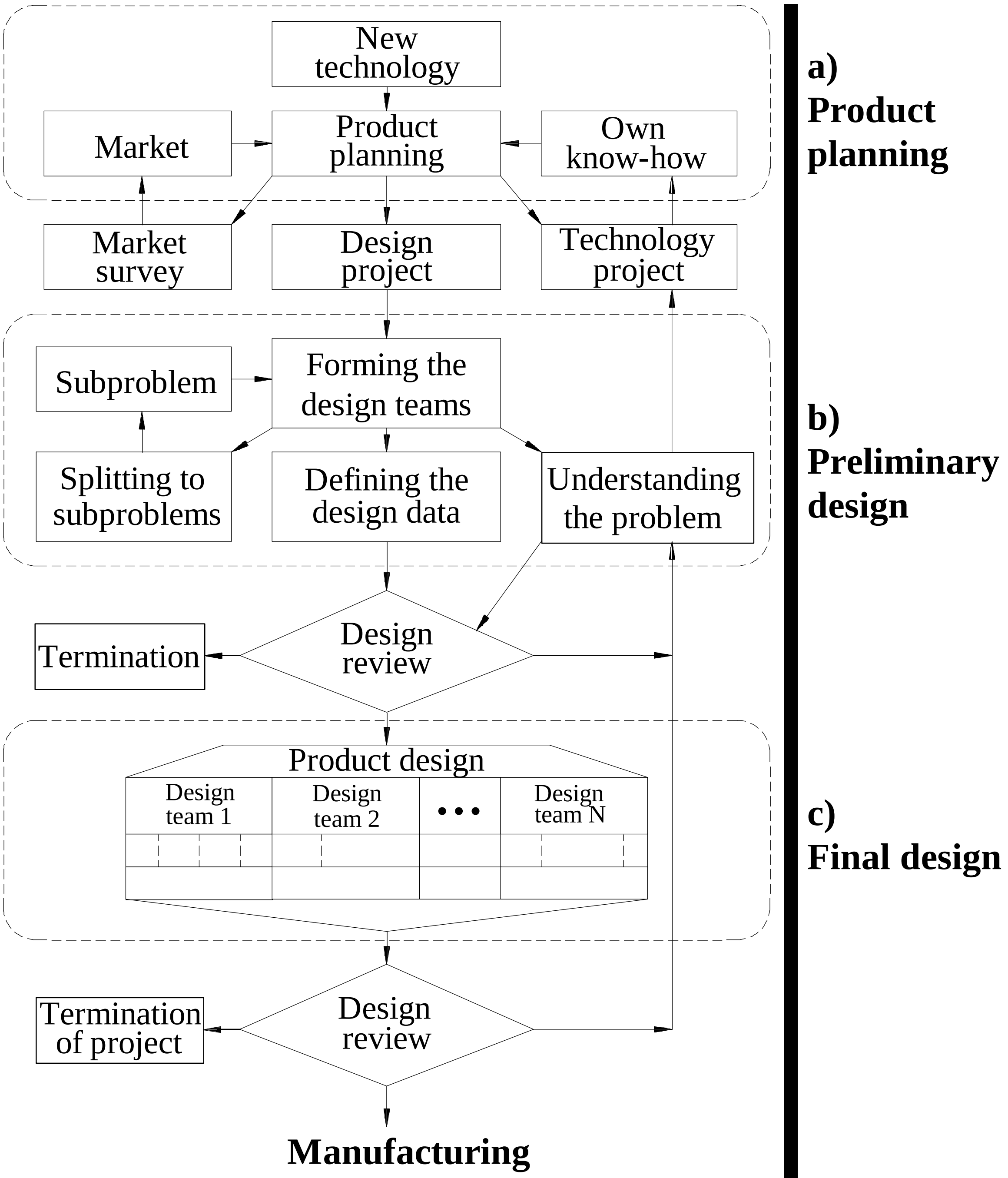

Figure 7.7 Schema for intuitive product design

[26]Ullman, David G.: *The Mechanical Design Process*. McGraw-Hill 1992

Figure 7.7 demonstrates the intuitive design method from product planning until the start of manufacturing. The second part in that schema is very much the same as by Ullman. His presentation in that matter is so good, that I cannot see any need of improvement. The project planning, however, I have discarded.

The proceeding in the schema is directed from up to down, but every part has an arrow pointing backwards up. That gives a possibility to iteration and it means the need of additional knowledge.

7.3.1 Product Planning

The traditional starting points are the *needs of market* and the *own know-how*. In addition to them the third strong starting point today is the *new technology*. It has always been an important starting point, but today its importance is tremendously increased and it is coming along from several directions: from materials, electronics, computers, automation, measuring methods, new mechanical structures, and new manufacturing technology. This new technology gives frequently new possibilities for new solutions in products.

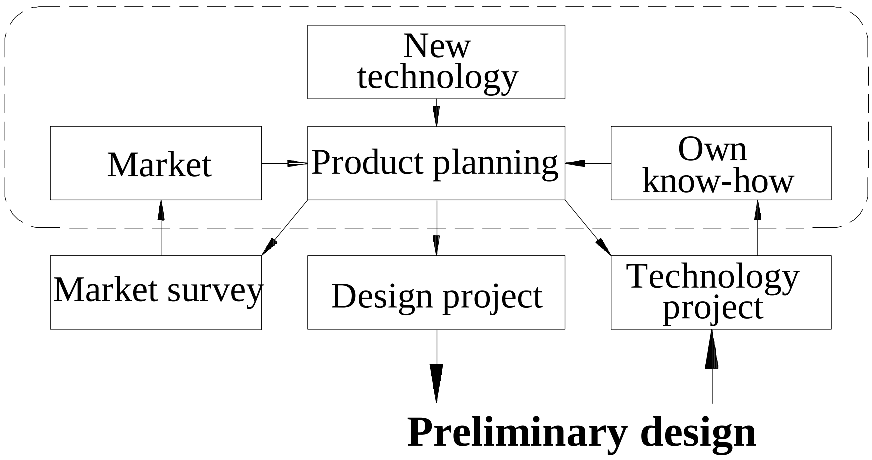

Figure 7.8 Product planning

Product planning is in very high level in the organisation, hence the top management should actively participate in it. The involvement of the financial department is also very desired, because the modern technology assumes often high investments and the controlled high risk is one possibility to reduce the competition.

The product programme bases on the policy of the company and the continuous defining of this policy is one of the tasks of product planning. Policy is not any phrase, but it shall include the definition of all activities, which the company can afford based on the technical, financial, and personal resources in its possession. The policy should manage to the best possible result by using these resources. At the same time when this organisation develops the product programme, it develops the policy, too.

Because product planning is in crucial important position on behalf of the success of the company, the occupation of that activity must be selected carefully and its working mode must be tuned to be at its best. The administrative and operative management must be represented, of course. In addition to that the representatives from sales, R&D and production must be present. Formal meetings cannot be avoided completely, but the communication according to the principles of the knowledge diffusion, should be preferred.

Product planning might call representatives from all stages of the organisation for discussions. For example, the fitters of the field assembly have very important first hand knowledge from the market, which is not used thoroughly, if it is reported only formally. These representatives can prepare their presentation, of course, but it is important to reach a comfortable atmosphere for free discussion. This can reveal such a hidden notices, which can be extremely important when caught by appropriate ears. Once again; it cannot be emphasised enough, that all ideas must be born in the own thinking of the participants. The discussions should not make any decisions, when the time is not mature, yet. The main idea is, that the participants have an influence on each other - **without any pressure**. The common viewpoint will be found in time.

Product planning must consequential go in the affairs and trends of the own business territory. The main output is the launching of new development projects into the preliminary design. For the better view of the possibilities it may start some market surveys and specific technology projects in purpose to increase and test the own know-how.

7.3.2 Preliminary Design

In this phase, the personnel for the accomplishment of the design project, is gradually gathered. The task could be handled in the same way as Ullman has described it, that is to say, by using the principles of QFD. The understanding of the problem is the most difficult point in this phase. In the common way it consists of the recognising and estimation of the customers needs and the acquaintance of the application field of the product. According to the results the aims of the design will be defined in clear numbers and specifications.

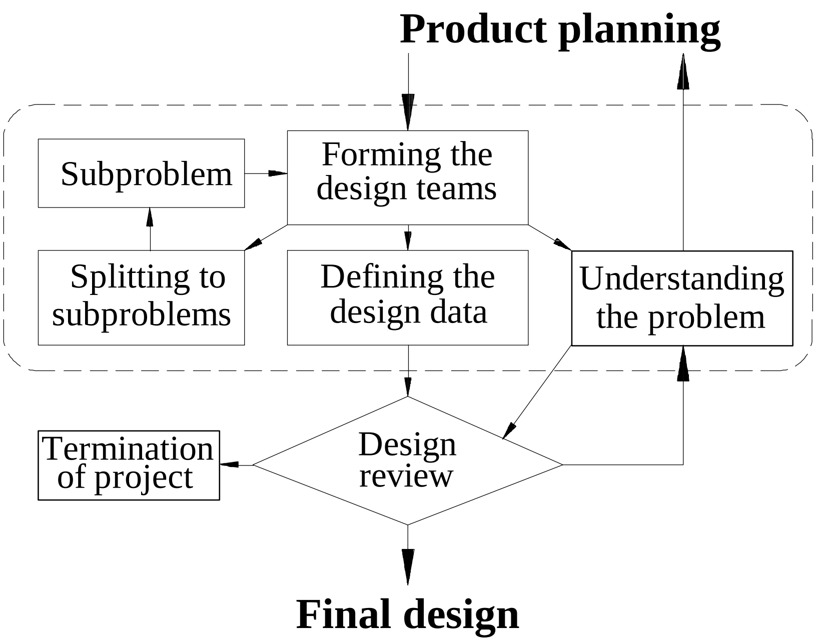

Figure 7.9 Preliminary design

We should go so far in the understanding of the design problem, that the realisation of all needs are to some extent found. The final structures are not specified, but only some useful functions. Without these recognised functions we are not able to go further. If any familiar function is not found, we must increase our understanding and possibilities by launching some technology project.

The understanding of the problem produces gradually a conception of the main function and the deviation into subfunctions. This may be a very long process, if the design task is completely new. In usual case we have only a modernisation of some degree, hence the function structure is familiar already at the beginning.

The design teams are formed according to the function structure. The number of teams and the degree of the distinction between their tasks is depending on the size of the design task and on the needed accomplishment time. The technics used in the subfunctions might speak for the distinction, but as a common rule, the distinction should be so light as possible, and the number of the teams should be kept in minimum.

In the preliminary design should be used so many designers, that every established design team get at least one of them. The final team occupation is not defined in this phase. The phase ends with the design review, where the result is discussed and its destiny is chosen between acceptance, rejecting and sending back into the earlier phases.

Sketches about the final solution should definitely be avoided in this phase. Even the design review can be done without any general sketch. Instead of that details and substructures are discussed by means of detailed drawings. These drawings can be considered as some kind of technology projects, because they help to penetrate into the problem and the needed technics is specified.

The lack of general picture makes the participants to go deeper into the suggested technics and its alternatives. If the general picture would be prepared, it would be based on already selected technics. The critic would be focused on the whole and the selection would be made between the main solutions. With the discarded solution would many valuable subsolutions be lost and with the approved solution many unqualified subsolutions would be accepted. It is important to estimate the proposal according to its substance, technical functionality and the tolerances of function. The time for the selection of main structure, is not mature in this phase.

The preliminary design needs an active representation from all branches according to the principles of the knowledge diffusion. The work is team work, even the main responsibility belongs to the designers. This phase prepares the information of the project, which will be dealt to all parties, who have been able to co-operate.

7.3.3 Final Design

The final design in fig. 7.10 is completely separated from the other organisation. It gets the task from the preliminary design mostly without any general sketches or layout drawings. However, many of the designers participated the preliminary design and the design review. Hence, the task should be well specified for them. The final design prepares all final documents for manufacturing and sales, that means detailed drawings and part lists. Any specific detail design or drafting is not needed any more.

Many design results are forced therefore, that changes are ordered when the work is almost ready. The changes are done trying to preserve the work so far as possible. The whole cannot reach such a maturity, which would be possible, if the working peace had been unbroken.

If the specific team of detail design is used, they make the drawings on basis of the layout drawing. This may cause blurring of the solution, because the detail designers form the parts according to their own habits. If the design is made on the screen by using some CAD-programme, the layout-drawings can be divided into details so easily, that no specific detail designers are needed any more.

Thus, there are many arguments to make all needed drawings ready inside the same design programme. This will guarantee the correct use of the solution until final product. We know very well, that a complete freedom and the isolated position in design lead to use of the own favoured methods. This creates unnecessary details and structures, which are not in full harmony with the original solution.

For the fusion of these two points of view there are protecting mechanisms in fig. 7.9 and 7.10. On the one hand, the thorough preliminary design makes the aims clear into the details, but it leaves the solution completely on responsibility of the final design. The final design gets the full freedom it is always seeking for, but this freedom is furnished with such an amount of instructions, that the path is clear. On the other hand the design is continuously followed and informed by the clinic visitors from sales, production and finance. Because this is absolutely the only channel to influence the design work, it calls for taking it seriously. While they have no power to guide the work directly, they must adopt the character of diffusion in their information.

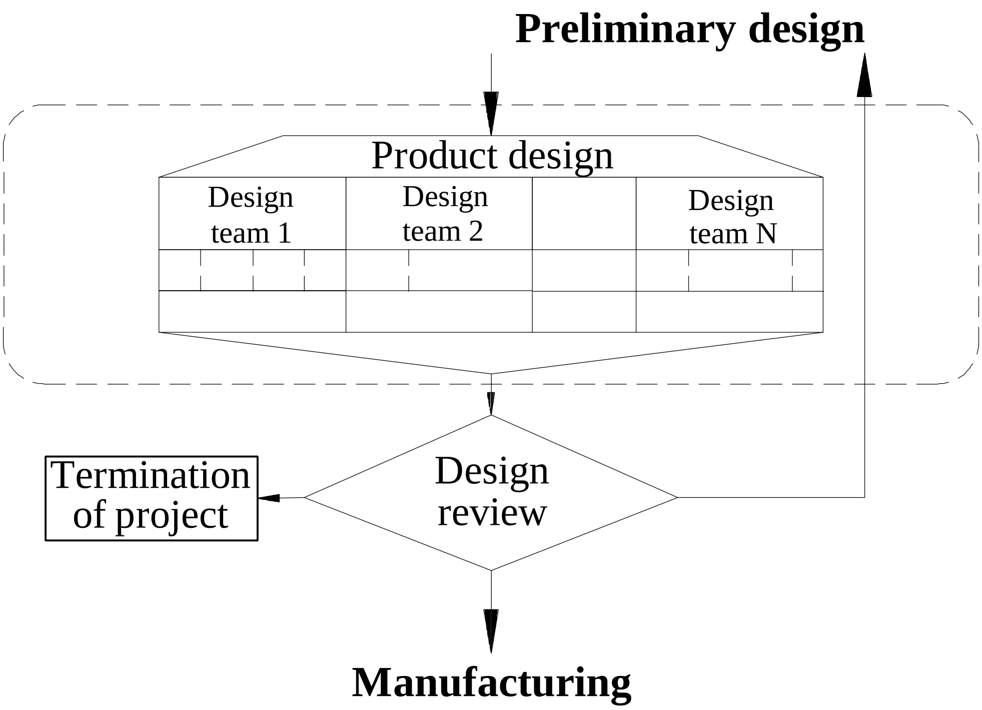

Figure 7.10 Final design

The design is controlled by the principal designer. At the beginning he prepares a very common layout of the final solution. This layout is discussed together with team leaders. The layout is free of connections with any adjacent structures, it should present more the task than the solution. After that the teams begins the work from inside of the details. That means, that all joints with other details are still open. If the task is very comprehensive, the teams may be recruited further.

The size of the teams is not constant during the work. It is always possible to split the teams into subteams and gather them back again. Individual designers can be moved from one team to other. The splitting may go until single individuals, if necessary. This flexible variation in number and size of the teams can be accomplished even without any control of the principal. If the designers are really experienced in team working, they do it by themselves. The only controlling clue is the design work itself.

After the substructures find their acceptable forms, they are transferred into the layout drawing which is adapted according to the need of space. The substructures may have alternative versions, too, but the layout is one all the time. The flexibility of the layout drawing is in responsibility of the principal. He attend the work of the teams and gives advises, if needed. When the substructures start to be mature, the joints and joining effects are discussed then. This work does not start at the same time with all of the joints, but the adjacent substructures may already be joined for long time ago. During this phase of work the subteams are diluted back to the main teams.

The final result is a detailed exact layout drawing, where every team have their share. The final design review can be done now. After that the detail drawings are elaborated from the layout. The part lists are gathered from the inputs made during the design.

7.3.4 Design Review

Design review is a meeting, where the decision of the project is made. The alternatives are: go on, reject, or repeat the handling. All participants attend the meeting. The review should be so well prepared, that all parties are aware of the content of the material. Hence, the design review is actually a meeting, where the decision only is written up for the knowledge of all parties.

If the management, making the decision in the design review, is not in beforehand aware of the content of project, and the decision has to be formed in that particular meeting, the result may be a fight between designers and other departments. This is able to destroy the motivation totally on all parties.

7.3.5 Summary

- *It is distinctive to the intuitive design, that no sketched alternatives are used and no selection between them is made. Different possibilities are analysed close to their birth and the gradually forming structure is preserved flexible for long enough.*

- *The forming of the structure is left completely on the responsibility of the designer. He is trusted more, than in other methods. But he is informed continuously and better than before by using the knowledge diffusion and knowledge carriers.*

- *The preliminary design is so thorough as possible. In this phase all parties have all possibilities to influence in the birth of the design material. The possibilities continue until the design review aster this phase, but not longer. In the final design phase the other parties can influence only throughout information.*

- *The design reviews are prepared in advance between the parties. This is possible because of the continuous informative connection between design and management. The review is only the official ratification of the common decision.*

8. Designers Personal Growth

I have described in this book the work of the engineering designer. I have also studied the methods, which could tune his mental capacity to the maximum in relation to creative design work. The designer tries, by using cold mechanical structures, to help the man accomplish such functions, where the human physical and mental structure is not applicable. The cold mechanical structures call for the use of cold mathematical and scientific theories and laws (Hooks law, formulas of strength and strain). However, the ability to transform and utilise these structures assumes the soft play of images and wild variation of substructures in all directions, as well. This development increases the data nets in our subconscious mind and flames their ability in transformations and connections. The mental tension takes care of the proceeding towards the goal.

8.1 Human Capacity Required

We are all unique individuals, as far as the mental characteristics are concerned. Thus, we cannot be adapted to any task in an optimal way. We must always compensate our less developed characteristics with those we have. Therefore it is not possible to present the one and only working method, because it is always connected with the characteristics of the presenter. Hence, the content of this book has to be read as a demonstration by an individual having a certain combination of mental characteristics.

This book is based on my own experiences, of course, which I have got by using these abilities I got in my birth. Hereby I have compensated those abilities, which are poorly developed. These poor abilities in me are the lack of free hand drawing skill and the poor talent in mathematics. The drawing skill I have compensated by using first the drafting board and ruler, later on the PC with a CAD programme has helped me wonderfully.

In the working method I described it can be seen, when I tend to underestimate the free hand sketching and even to avoid it. Instead of that I have emphasised the meaning of scaled simple sketching based on only few straight lines. Hereby I compensate the incomplete picture with the imagination and as a compensation I am faster and more efficient to find an almost perfect solution without other crystallised alternatives. The point is the free and fast transformability of the structure in the mind. The poor mathematical ability is compensated with the functional visualisation and with the use of such calculating methods, which are simple but illustrative. As an example I will present in chapter 10.2 a clumsy but illustrative interpretation for the intermittent load and bending vibration on the shaft.

8.1.1 Imagination

A vivid and always alert imagination is a characteristic, which hardly is possible to compensate for an engineering designer. If it is poor, there are certainly more suitable tasks for him than the design.

The child's imagination is much praised and described and the preserving and activating of this talent is very important, too. But still more important is the ability of the imagination to take into consideration the logicalness of nature, realised functions, obstacles, and clear knowledge and still keep the imagination alive. A well developed imagination is like a running water, which constantly seeks for new channels, yields the obstacles, and forms the creek.

The old folklore finds the constant development of the imagination very important. That was supported by the fairy tales and games and later on the party games, enigmas, even ghost stories. The engineering designer develops himself own fantasy games when he looks at the structures in equipment of railways and vehicles, in technical fairs, and first of all, in technical museums. Even museums give an excellent opportunity to follow the developing vision of structures combined with the developing technical possibilities. Hereby much foolishness are revealed, which could been possible to avoid decades ago. As an example of that I will present in chapter 11.9 the rear suspension of a passenger car.

In the beginning of the II part I will demonstrate a chart wheel as an example of a mature structure, which is now disappeared from our use. It was an universal structure, which served formidable as a cannon wheel and which was used also as a car wheel. In the charts pulled by horses it was as the best, because the spokes gave a good possibility to help the horse in the most difficult circumstances. The materials and the manufacturing technology were developed in the agricultural environment and were there completely adapted. The use as a car wheel was an extension of the use into a strange territory and the structure was there not well adaptable any more. This kind of extension of the use happens in these days as well, because the maturing of the optimal structures is very slow, still today.

The bicycle was an object, where the circumstances already were different. The wooden chart wheel got to begin here again, but very soon the need of lightness was understood and also the optimal possibilities for that. This valuable insight was the use of tightened wire spokes to connect the rim and the hub together so, that the assembly was loadable in every directions. This time the structure had to be design more carefully, because in the chart wheel the spokes carried against push, pull and bending. The final solution could possibly be found by understanding one detail in chart wheel. There the pull of the spokes was useless and the rim must be tightened by a steel band, thus the spokes were always loaded by push.

Spokes made of steel wire, were not able to be loaded with anything but the pull. Instead of that the rim was rather stiff against bending too. Hence, the spokes had to be directed so, that the combination of the directions formed a 3-dimensional stiff and strong structure.

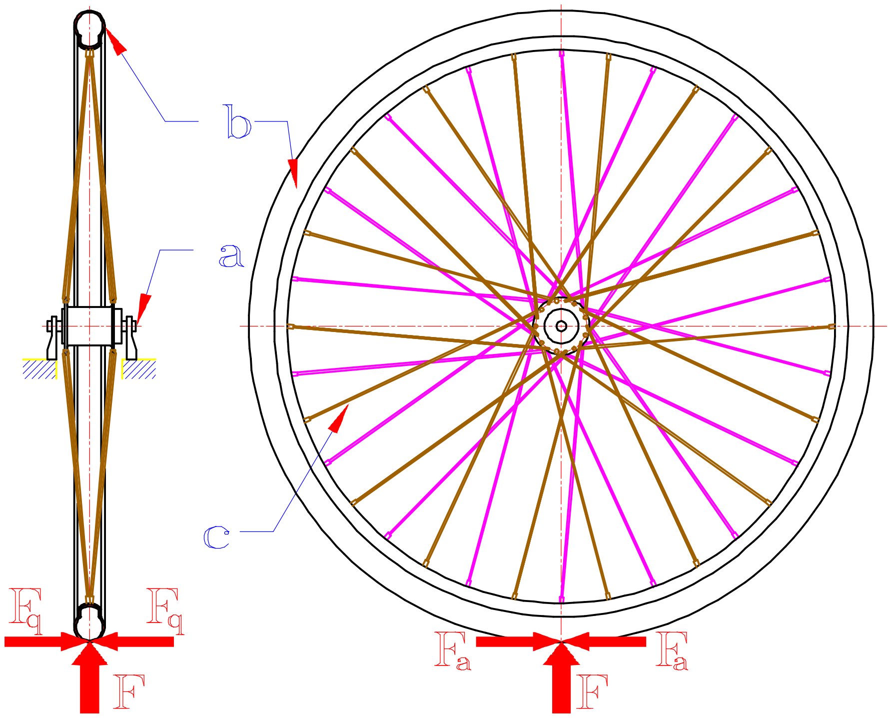

Figure 8.1 Bicycle wheel

The rim of the wheel is a steel profile of thin steel plate, which carries the pressurised rubber tyre (b). The hub is pillowed on a stationary axle (a) fixed on the frame. There are 36 spokes (c) made of steel wire tightened between the rim and the hub. According to fig 8.1 they meet the rim in one level, but at the hub they are divided to meet it on both ends of the hub. When the spokes are evenly tightened, the structure can be loaded with the main force F, but also with a transversal force F_q.

As a front wheel the spokes could be directed radial from the rim to the hub, but this kind of structure would not be strong and stiff when torque should be transmitted between hub and rim. The radial direction has to be changed so, that they meet the hub more tangential. This tangential direction is shared in the way, that half of the spokes turn to the left, half of them to the right. After that the spokes can be tightened again.

The spokes make four fan-shaped groups of 9 spokes. One group of them (the closest to the reader, left hand fan) is presented in fig. 8.2 as black. It is balanced with a right hand fan on the same side of the hub. On the opposite side of the hub same kind of assembly can be found. There must be a step of angle between the spoke groups in purpose to get the distribution uniform at the trim. Now the wheel is stiff and strong in every directions and the bicycle can be driven and broken.

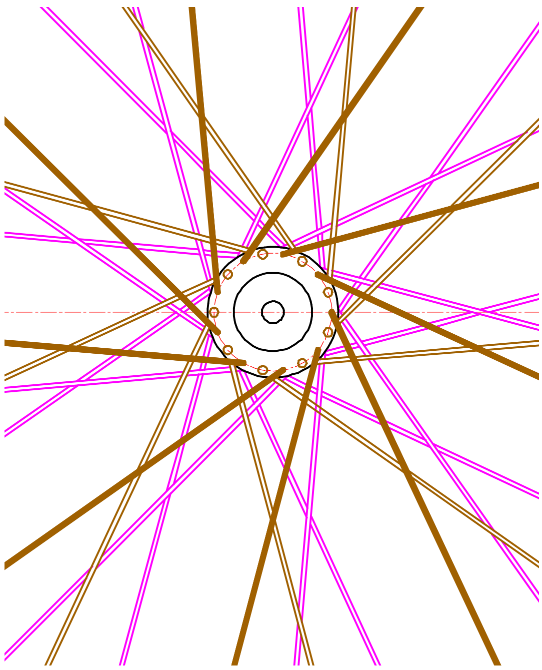

Figure 8.2 The organisation of the spokes

The structure is very far optimised. It is excellent for motor cycles as well and even as a car wheel. However, because of the high grade of the optimisation, it has some disadvantages, which have reduced its range of use. When children are transported on the bicycle, the spokes are very dangerous. The spokes can be damaged easily, thus the rim is not straight any more. If one wants know all of the structure of bicycle wheel, he could assemble it by his own hands. After that he understands thoroughly its ingenious structure and he is able to use it elsewhere.

How about giving freedom for our imagination. The tightening of the spokes can be done by means of threads and nuts like in the bicycle wheel. The spoke going through the rim makes a leaking point, if the tubeless tyres should be used. This has been an important factor in displacing the structure in motor cycles. But the tightening could be made by using the same principle of shrinking, as in chapter 11.7 is demonstrated. Hereby the result could be as follows:

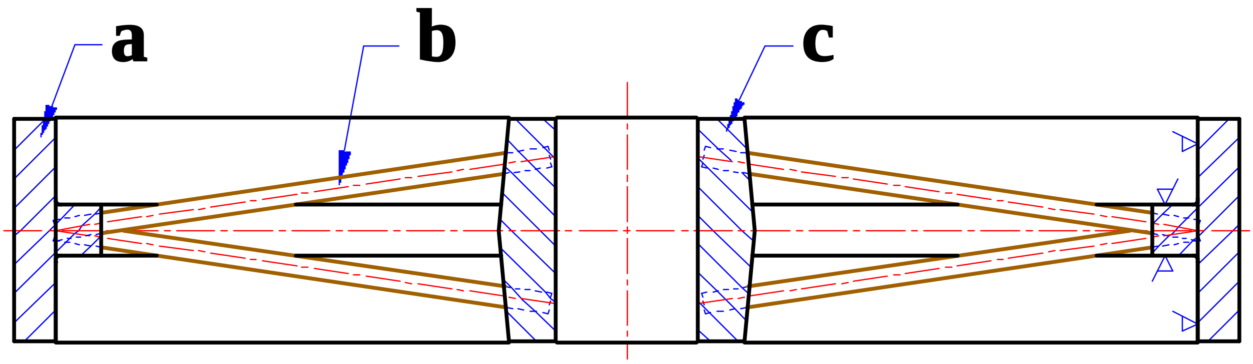

Figure 8.3 Wheel of band saw, so called Norwegian wheel

There are band wheels in United States and Canada, which have cast spoke structure. The biggest diameters are ϕ2100 mm, hence the casting of spokes in so a big structure is very difficult. But the spokes can be made of straight steel bars (b), which are inserted into the mould in the same order as in the bicycle wheel, fig 8.3. The connection between the hub and rim will be extremely stiff and strong, but still very light.

After the spokes are inserted into the mould, the rim (a) is cast first. When it cools, it shrinks and the spokes are pushed deeper into the hub space. After cooling the hub is cast. The spokes are heated up even outside the hub mould (c). The spokes come still deeper into the hub and while the hub is cooling and shrinking, the spokes get a very strong pull. And what is important, this pull is evenly distributed, if the spokes were straight. The rim can be turned in the lathe even from its inner surface. The result is well balanced, strong and light.

Such kind a flow of thinking through different spoke structures is very useful for the designer. Especially in the situation, when he tries to fix the bicycle wheel and tries to reduce the cast of the rim keeping the even distribution of tightness in all of the spokes, he really gets an thorough insight of this structure. It is a very useful experience for the understanding of the concrete ironing, and today, especially the idea of the composite structures. At the same time, it supports the understanding of the dimensioning principle of hub joint, presented in chapter 11.7.

In an exam of engineering design I asked for a description of the bicycle wheel structure. I wanted to know, if the students ever had been thinking at the principle of this ingenious solution, which they use every day. No one of them had any idea of it!

8.1.2 Humbleness and Cultural Relations

In creative work the man is always operating at the limits of his intelligence. If he would know more and he would be brighter, the problem would be solved. A genius only push out the ideas and solutions.

Except the first sentence this conception is completely wrong. The creative work is not a test of intelligence; the increment of knowledge helps, of course. The insight and understanding of the knowledge gradually creates the possibility for solution. The work increases the intelligence. After all, nothing in the world might be so difficult, that anyone cannot learn to understand it, if he can concentrate in it thoroughly. But everyone of us can never have time, chance or energy enough to accomplish it.

Everyone cannot be developed to be any Paganini, Caruso, Mozart or Napoleon. However, Caruso had only one lung left, Mozart was frequently mentally ill and Napoleon had a slight epilepsy, like Händel, Caesar, and Dostojevski, as well. So many great people of history have had so many kinds of illnesses and physical shortages, that one might ask, if a perfectly well individual can do anything. The individuals, which are called as genius, do not see himself as a special, they see genius only as work and trying.

One of the seven wise men in ancient Greek was a Spartan Khilon. His text **gnothi seauton** (recognise yourself) is written on the capital of Apollo the temple at Delphi. The same suggestion is familiar in many other philosophies and in freemasonry as well. According to this suggestion the main purpose of the human life ids to find his own talents and to use them.

The essential element of creativity is humbleness. It is not, however, toadyism, but it is the searching of himself. In the creative work an individual is always searching for his limits. That is to say, what talents he has got with his genes. The creative human must respect that tradition of the culture, where he is grown up. Eventhough we are individuals, we are not so significant, that we could be required, that the world were interested of our personality alone. On the contrary, the individual can find himself, as his best, only as a small link in the continuing heritage of our culture.[27]

[27] In a small countryside hotel bar I collected a good breakfast before me and started to eat it. Above the common din I faintly heard the radio playing music. Then suddenly I woke up when I recognized it was *Jesu meine Freude* being played on the piano. It's very beauty and the devoted rendition stopped my breakfast. After that I distinguished hardly the announcer, the player was *Dinu Lipatti* - of course.

The melody comes from reformation time Germany, it is a hymn von *Johann Schop: Werde munter mein Gemüte* anno 1642. *J.S. Bach* used this melody, as it is, in his cantata *Herz und Mund und Tat und Leben*, where he accompanied it with a wonderful lively parallel melody alternating with the Schop melody. An English pianist *Myra Hess* was delighted by this cantata in the 20´s and pondered it in her mind for several years, before she wrote it as a piano arrangement.

A Rumanian Dinu Lipatti was considered to be one of the best pianists during World War II. He studied the arrangement of Hess all over his life and he played it at every performance at the beginning or end "as a prayer". After the war he got leukemia, but continued his playing in concerts and for recordings.

A performance in the music festival of Besançon 16.9.1950 was his last. He got too tired to play the whole programme, so he had to interrupt it. He rested for a while and the audience waited for him patiently. After several minutes he came back, but he did not continue with his programme. Instead of that he played for the last time this work he so much loved: *Schop-Bach-Hess-Lipatti*: Jesu meine

The humbleness in the creative work is the free making acceptance of the facts. A real obstacle must be accepted as an obstacle, thus it should not be tried to break down with violence. On the contrary, the obstacle can be used. A strong obstacle is a strong holdfast. It is good to struggle supported on it. But it does not prevent to study the nature and reality of the obstacle. If all obstacles are familiar, it is easy to orientate himself while evading them.

The demand of the humbleness presents the dualistic and paradoxical mind of a creative human. If it is realised in correct way, the humbleness:

- *does not passivate, but it activates*
- *does not make frightened, but it makes brave*
- *does not reduce the self-confidence, but it strengthens it*
- *does not lead to underestimation of himself, but leads to search of the talents and knowledge.*
- *the fail does not depress us, but it increases toughness*
- *the success does not make us arrogant, but it gives satisfaction*

The connections to the culture are exceptionally important for the engineering designer. He should be acquainted with fine arts, literature, and architecture to be able to place his own activities in right scale.[28] The mental versatility supports the humbleness and makes him to understand that it is the strongest stabiliser also for the design activity.

The religions carry with themselves life experience and wisdom reaching until the ancient times. The Holy Bible contains many wise advises adapting perfectly into the creative thinking, too. One of the most important advises is this: **Take therefore no thought for the morrow: for the morrow shall take thought for the things for itself**. This is a strong advise to synchronise ones own will together with the present moment. Unnecessary worrying is one of the worst brakes of our creativity.

The parable of talents is a strong advise to search, use and increase in himself all that talents, which one has got as heritage in his genes and education. However,

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Freude. This work was the result of over 300 years of development. After that he died on the 2.12.1950 at the age of 33.

The concert is recorded, but just this particular performance is missing. It will never be published, because it would be a penetration into the human prayer.

Johan Sebastian Bach expressed the meaning of the composition, when he was asked for it:

"The glory of Good and the recreation of the human mind. If these are not present, there is only devilish nonsense".

Mika Waltari emphasized the importance of humbleness, too, but he added: *A slice of beautiful vanity could be appropriate, too.*

[28] When in a concert hall, a modern famous pianist prepares himself to play a sonata of Beethoven, the audience holds its breath. The feeling of the finest culture in the range of almost two centuries is present. The moment belongs to Beethoven, although the importance of interpreters is well understood and rewarded with flowers and applause after the performance.

Despite that the applause is mostly directed towards Beethoven with the understanding of that wonderful cultural connection, which reaches us over the centuries as genuine and original using only a note text, clumsy and poor in expression. Nobody gives a single thought for the engineering work, which is needed to accomplish that. There is no glory any more for Bartolomeo Cristofori, who developed the hammer mechanism anno 1709. It had already been the basis for all pianos 100 years before Beethoven. Nobody remembers Gottfried Silberman either, who made pianos in the time of J.S. Bach. Americus Backers is also forgotten. He made piano's in Beethovens time. Who was the acoustic architect, who has struggled for this wonderful acoustics in this hall?

it is also a consolation, because **with the same measure that ye mete withal it shall be measured to you again**, not more.

Whosoever therefore shall humble himself as this little child, the same is the greatest in the kingdom of heaven. The human should never loose his straight curiosity of a child and his ability to penetrate into the problems with his all personality without any prejudices. But peace in mind is the fundamental problem and desire of his whole life. It seems to be, that in this point the human is left some how incomplete and he needs some kind of mental support in his life. In religions this support is available, but only with the sincere attitude of the child. If one has reached this state of his mind, his whole mental capacity is free for action.

The rational thinking is always necessary for development. However, it shall not destroy the creative thinking. The human self has rationality only in his physiological structures. The psychological side is more or less mystery for him. Only a small part of it can be studied rationally and the deepest essence of human is kept as mystery like the religion as its expression.

The human cannot damage himself more than in denying the irrationality in himself. In that case his whole capacity is occupied by his ego, which is insatiable in demanding meditation care.

Let your women keep silence in the churches. This expression by the bachelor Paul can be understood as a positive matter for the creativity. Decisions in an organisation cannot be made by an individual, who is not aware of the preconditions, background, and consequences of them. In the time of Paul the woman's position was such low, that the necessary knowledge was not available for them.

The prayer is very emphasised action in the Bible. Martin Luther added his famous advise to it: **pray and work**. In the prayer the human acts in the same way as in building up the tension for his creativity. The same humbleness needed in prayer is needed for creativity as well. The adapting of the will is the same as well: **nevertheless not as I will...**

The prayer has the same clarifying and relieving effect as the oral explanation of a long incubated thought. At the same time it will be declared for himself as well, what is really needed, what is my will. The Bible advises to pray in silence in purpose to hear himself better. Even the crossing of hands has its meaning. The human closes all his activity but declaring his will in prayer.

This declaration does not deny the mystery of the prayer. On the contrary the creative happening is mostly outside our declaring ability, too, and somewhat mystical. This affinity is proving how the mystical experiences in arts as well as in religion contribute the creative insight.

8.2 Faults in Progress of Designer

The growth of the designer until he reaches his full potential takes more time than any other branch of engineering work. It might be about 10...15 years of development time. The reason for that is, of course, the wide and deep subconscious experience which is necessary for efficient design work. This long development process can lead in the wrong direction, however, and such a designer will never be the type of qualified professional, which he could have been on the basis of his mental capacity. The responsibility for that should be carried by himself, but also by his work atmosphere.

8.2.1 Mental Petrifaction

This expression does not mean any dementia of old age or other reason for brain efficiency decease, but the development of the intuitive process so that the creativity is lost in it. The petrifaction is possible only in experienced designers, hence the loss is a very big loss for the company. Actually, it is only a minor error in the course, hence it should be possible to fix it in time. But if the error is already stabilised, the fixing of it is as difficult as the fixing of s-error for the child.

In chapter 2.2 I have tried to illustrate, how the subconscious knowledge center tends to sink deeper with time. An experienced engineering designer has finished knowledge centers for almost every task and he is used to pull them into use like from a card bundle. The organisation might praise him and his speed without seeing, that he does not create anything more. During the time this designer is even afraid to use any new thoughts, but he trusts only his experiences. These experiences are growing in value constantly and as a result we have a designer, which is proud about his qualifications, far from humble and still a real coward in relation to everything new. In addition to that he might become an irritating arrogant terrorist, who prevent the sound development of everyone in his surrounding.

The reason to this development is in the designer himself, but also in the incapability of the organisation. The design activity is not led in the right way. This situation can be generated, if the designer always gets tasks, of which he has the best experience. The designer should be frequently used to new problems, too, and he should be ordered to create new solutions. On the other hand, he needs freedom and space to manage these tasks and especially in the critical moment he should keep the initiative and decision in his own hands. Exactly for this reason, there is only one route in and one route out in fig. 7.7 item c).

A humble mind is the best protection against petrifaction, because the main reason for it is a dazzling professional pride.

8.2.2 Inventions and Mania for Patenting

A long and successful creative development work of the team leads to the situation, that the team finds itself at the top level of its branch. In that situation new progressive inventions begin to appear and the patenting possibilities grow up, sometimes surprisingly rapidly. There is always an inventor connected with a patent, and in most cases, he is one of the designers or team members.

If we look at the accepted patents, only a few of them have any real importance.[29] Even the protection of the others is weak and nominal. It looks like the patents are pending unnecessarily and somehow an opinion is reached, that the acceptance of the invention as a patent is a statement for the value of the invention.

[29] Since 1960 I have got approx. 40 patents to my name. Only three of them has proved itself economically successful. I have never owned any single patent.

The birth of a new solution, which can be considered as an invention, is for the designer a pleasing and inspiring experience. His eagerness for patenting is understandable, but often in contradiction with reality. The management of design needs a good ability to control the situation in a way, that the denying of unnecessary patenting does not depress the designer. It should not create any negative aggressions in him. Hereby the action is not always successful and the designer, delighted with his ability to invent, leaves the organisation and declares himself an independent inventor. He might even establish a company for the realising of his invention, which might lead to tragic consequences for himself as well as for his family, as the possibility for success is really very low.

There are many persons in history, which have earned their nomination as great inventors. They are **Marconi, Faraday, the Wright brothers, Bell, Tigerstedt**, and first of all **Edison**. If we look at their work, we see, that all of them, actually, were not researchers or developers of the newest techniques in their time. Many of them did not invent very much, but despite that, they have moved development forward in such big steps, that they have earned their positions.

Edison seems to be an exception, because he made very many inventions. He got 1093 US-patents. It is true, that he was very talented, but he was also a very efficient, even ruthless business man. All this with a formal education of only two weeks. He could make money with his inventions and he furnished a big laboratory to help him in the tests and in the research. The whole cinema industry was in his hands at one time, because of his patents in that area.

Edison really knew how to do his developing work. He made more tests than anyone before him, except the ancient alchemists, perhaps. Only they could compete with him in making unsuccessful tests. He restricted his invention activity inside the field of electrical and optical technics. That means, in the area, where much could be achieved and where the advanced manufacturing techniques of mechanical structures gave him good realistic options.

The latter combination is significant. Let's look at the time, when **James Watt** made his first steam engine. Watt was very delighted, when he was able to make the inside surface of the steam cylinder to an accuracy of 1/4". At that time steel plates were hammered on anvils and they were joined by riveting to make a tight steam boiler. Using these manufacturing techniques, the production of an internal combustion engine would have been impossible.

Edison was first of all a researcher, tester, developer, and businessman. In addition to that he was a brilliant organiser, who could take full advantage of his laboratory, and a talented team of professionals. He was in no way a lonely inventor, who now and then came into publicity to complain, how the industry does not understand its own and his advantages and how it does not pay the unreasonable price of his invention. Hence, he must sell it abroad.

Edison had a clear need tension. He realised, that the applications of physics and electricity were not developed yet, and also, that the possibilities due to manufacturing techniques were better than ever before. In addition to that, he lived in a big rapidly developing state, where the launching of new inventions was exceptionally easy. The resistance, that the new textile machinery met in England, did not exist in America. The whole society was preparing itself to grow and develop rapidly.

Edison found friends among those, who also decided to accelerate the development and take full advantage of it. One of the most important of them may have been **Henry Ford**. Ford was neither an inventor nor a significant engineer. He was one of the most talented organisers, that the history of mechanical industry knows. He was able to gather talented people around himself and he furnished them with incredible resources. Although many of the Ford principles, gliding assembly lines etc., are old-fashioned today, his empire in car industry is exceptional for all times.

What about the "unregarded" inventors? Anyone can learn the technics of creative working in the same way as any other skills. If one has his own imagination and talents, it is quite easy to find himself an area, where he can afford new patentable inventions. There is a big danger in turning to be an inventor. An inventor likes to set himself equal to great inventors and he enjoys the sweetness of the insight.

Making insights becomes a loved hobby for him and it starts to work on still flimsier facts. There is no other need tension, except the aspiration for money and glory. In addition to that the inventor suffers from a severe mother complex about his inventions and he tries to protect them first against all virtual competitors, then against all kind of testing and proving.[30] His mental state gets worse and worse and the final state is in many cases manic-depressive mental illness.

There are organisations supporting the private inventors. They provide capital for their activity and they help the inventors to find other support and connections to the industry. Unfortunately these organisations do not always distinguish between a serious invention activity and the loose hobby inventing clearly enough. Many inventors in mental unbalance have got some money for unrealistic attempts. They consider this as an official confession of the quality of the invention. After that, they put all of their own money, even the value of their house and property into a business, which has no possibility of success. The final result is often a personal catastrophe for the inventor and his family.

The hobby inventors, however, are very talented people. But almost in every case, their knowledge and education is completely insufficient for the technical evaluation, development and economics of their inventions. Despite that they might find even some exceptionally new solutions, but no one has expressed the need for them. There are always several problems and obstacles in the technical development, too. The whole invention should be redesigned in a completely different form and for the need it could best serve. The mother complex, however, prevents any co-operation with the inventor.

The hobby inventors should be utilised, as their activities are a waste of mental resources without any sense. It might be possible to use them in some of the design teams with very good discipline. Their talents should be utilised in the first place, not their inventions.

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[30] At an invention fair, a honourable gentleman stands next to a carefully manufactured machine. The machine looked like a pump and I was interested in it. - Is this some kind of a pump? It is a pump and a compressor and it can be used as an internal combustion engine, too. - What can it pump? Anything. - A company I represent, might be interested in it. Would it be possible to test it? It is not necessary. It is calculated to the last millimetre and it works perfectly, if it is lubricated with Shell Vitrea 42. - Why exactly is this oil necessary? It is calculated for it. - Is this machine tested anywhere? Yes, in Kuusankoski. - Did it work? Of course, it worked. - I wonder, if the production figures were measured? No, it was not necessary. It has power enough! - But how can I use the pump, if I do not know the maximum pressure and the capacity? They are calculated and they are sufficient. - Was the test running long? Long enough to see that it works. - Is it capable of running continuously for several days? No, because the frame of the motor was broken, as it had so much power. - Immediately at the start? Yes, but we could see, that there was power enough. - Could it not be possible to fix the frame and test it once again? IT WAS NOT NECESSARY! IT IS STRONG ENOUGH! IT IS CALCULATED UNTIL THE LAST MILLIMETRE!!! The company I represented, lost its interest.

What features make a hobby inventor? Depending on his mental alienation his invention has some of the following features:

a) *The invention is universally applicable. It can solve several tasks in a revolutionary way.*

b) *The invention joins in a very common use. In many cases it is a new internal combustion engine. The time of new steam engines is over even among inventors, although the modern techniques would give more possibilities today in that old area than for the modern engines. Most inventions reflect the latest items in publicity. The new engine is clean, not vibrating and more economical than the predecessors. The invention may be an oil saver for the boiler, or an automatic fuel feeder for chips or peat.*

c) *The invention is designed and calculated to the last millimetre. It is robust and stands forever.*

d) *In most cases the invention is not tested at all. Sometimes tests are made by using very vague 'stick models', which have given the full reliability, in their opinion.*

e) *If there is some model of the invention, the inventor does not present it for testing. He demands first the full price of his idea.*

f) *Nothing can be changed in the invention. Although the bargain is accepted, the inventor prevents any development of his idea.*

If the organisation, where the inventor is working, is not able to cope with the unnecessary patent proposals but gives way to the enthusiasm of the inventor and pays for the invention, the development of the designer may lead astray. He continues his job in the company and he still could be useful, if he would work in harmony with company policy. However, I have met in engineering many talented designers, which have reached the top level in their branch and who are able to produce new inventions now and then. But they have become victims of **patent mania**, because they spend most of their time only searching of patentable ideas. The motive behind this kind of activity may be the payments for patents, but also a plain ambition.

Such a designer is nothing but a burden on the company, where he works. His value is going to be lower despite his inventions and he is not reliable any more in the pressure of the design work. The payments he gets for his inventions may be remarkable, but at the same time the development of his salary is rather negative. When he retires, his pension will be small and it makes him bitter.

These problems express shortages in the company considering the flow of information, clearness of the organisation and inability in forming policy. If the designer is clearly aware of the scarifying and back drawings, which the realisation of the new inventions assumes, he would be more careful in his work and he would take into consideration all impacts from the application field before his patent proposal. The high standards of an organisation would be the best answer in this matter.

8.3 Far-reaching Thinking

With the description of the design process I have all the time emphasised the importance of the insight of the knowledge as a basis for all design work. This basic knowledge can be gathered by studying, but the subconscious form can be reached only by work and practical experience. Even a new language is not possible to learn without speaking it. Now as the last item we should discuss the possibility to classify the quality of our knowledge according to its ability to support the creativity. In this classification we have no rational fixed points, hence we must use our estimation and emotion for it.

A Russian **Altshuller**, as a patent reviewer has directed attention to the phenomenon, that almost all patents are based on the coincidence of two opposite characters. In the wider perspective we really can find a new solution, if we are able to combine two factors, which in common sense, do not fit together. Even this notation is correct, the theory of the technical creativity based on it, has not reached any remarkable acceptance.

As I have told, only three of my own inventions have had any significant economical value. Surprisingly two of them are based on an understanding of the essence of the impact. The third is based on my experience of optics, which comes from my hobby on photography. As I said in chapter 3.3, my interest of impact came when I was a small boy and it has continued all through my life. My knowledge of tribology is not very good, and vibrations are rather complicated for me, but the understanding of the impacts nature is based on simple notations and experiences. If I try to classify the knowledge from a creativity point of view, based on this single fact, the conclusion is, that a simple knowledge, based on ones own experience and on simple interpretation, is much more fruitful than any deep theoretical knowledge.

- *There is no need to underestimate the value of theoretical research and knowledge, but to use them for the purpose of leading to creative insights the theoretical knowledge needs support of a simpler knowledge based on the own experiences.*

- *A simple experienced knowledge alone seems to lead to creative insights, if its content and the need situation fit together. Sometimes these insights are so advanced, that long theoretical research is needed to get a perfect understanding of the content.*

Subconscious knowledge is the more efficient the longer it is repeatedly activated. My knowledge of impact received several activating occurrences as a result of many different machine failures. It might be in place to tell, how this knowledge of impact acted to produce two of my most significant inventions.

8.3.1 Spring Teeth of the Cross Cutting Saw

The circular saws for the cross cutting of big logs are rather big, $\phi1500...\phi2500$ mm, weight up to 200...300 kg. The placement of these saws is difficult considering the sharpening and straightening of them. The sharpening reduces the diameter of the saw, hence the saw must be rejected frequently, because of the reduced size only. This disadvantage is eliminated by using inserted teeth in them (US-patent n:o 4,084,470/ Jack K. Reed), fig 8.4.

This type of saw was tested 1982 in Valkeakoski. The saw was placed outdoors very high at the top of a big steel structure. The conventional saw made a lot of noise, which was carried all over the city in the cold weather of winter time. It was started every morning at 6.00 a.m. Of course it was heartily hated by the citizens.

The saw of Reed was not so noisy, but the inserted teeth started to loosen after only one day. All locking rivets had to be tightened every day.

The inserted teeth were put into U-shaped slots in the rim of the saw by using tight fitting practice. This caused the strain of the rim and the specific vibration frequency to become too low. It also caused seizing and heating of the outer rim, which made the behaviour even worse. When the center part of the saw was stretched to compensate this phenomenon, the tightness of the teeth was lost.

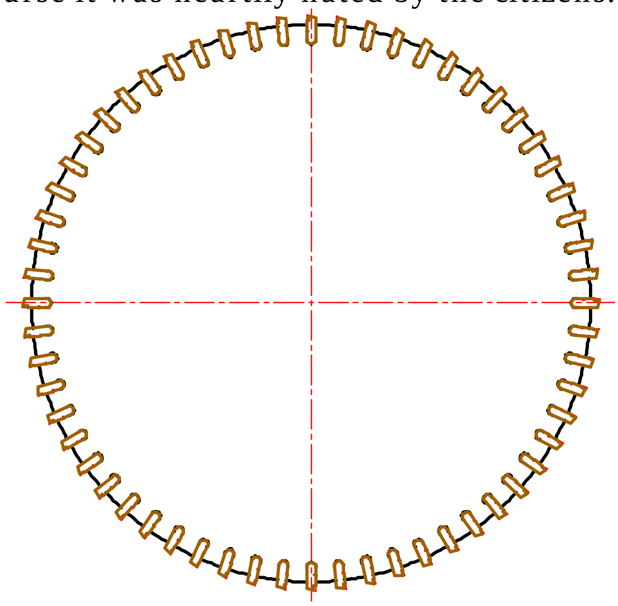

Figure 8.4 Reed saw

The customer complained about the excessive service costs and the manufacturer star-ted to search for a better solution. The problem was presented to me in January 1983.

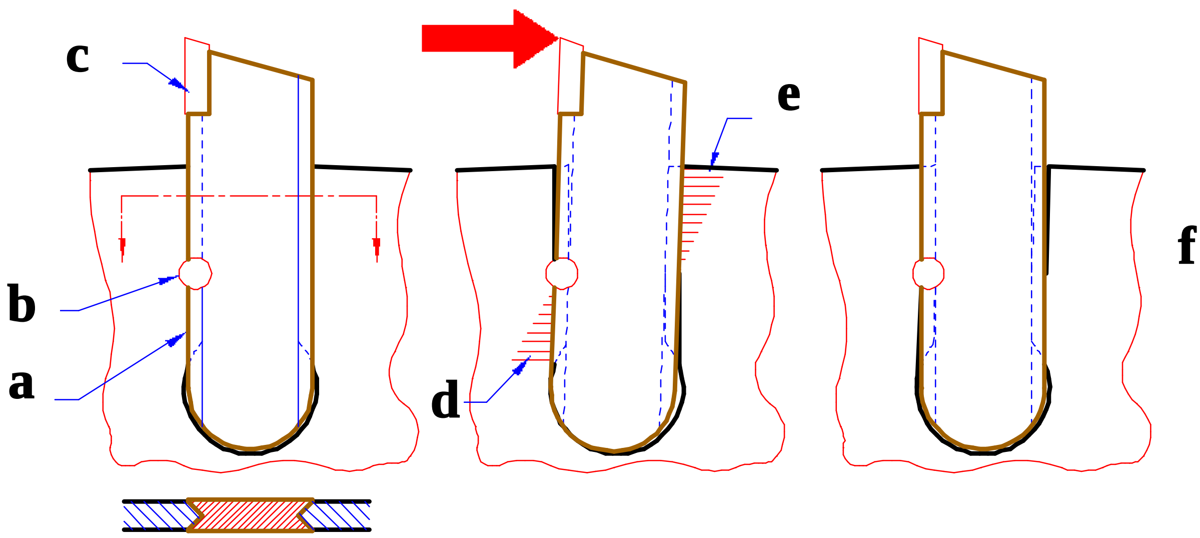

Figure 8.5 Analysis of Reed saw

The tooth of the Reed saw was a straight bar (a) with V-shaped edges. Its cutting edge was formed in tungsten carbide inserts (c). These inserts are so wide, that the saw blade and the teeth bodies can run inside the sawing kerf. In practice no sharpening of the tungsten carbide inserts was needed. In the front edge was a rivet (b) preventing teeth from been thrown out even by a loose fitting.

When I looked at the structure, the reason for the loosing was immediately obvious to me. The rivet presses the tooth against the back edge of the slot. At the same time it made a link with the consequence, that the cutting impact turns the tooth around the rivet against the supporting back edge. The supporting pressure (e) is formed. Because the area (e) is close to the rivet, the load against the rivet is remarkable. After the cutting the centrifugal force pulls the tooth out and it turns back to its original position (on the right side in fig. 8.5)

In the same way, as in knocking a stone with a hammer frequently at the same spot, the stone is eroded, but here both the rivet and the area (e) wear, because contact on a micro level does not ensure it hits the same spot twice, but the peaks of the contacting surfaces suffer from plastic deformation during every impact. The peaks are cut out and they are oxidised. This makes new peaks on the surfaces and the process goes on. First the rivet becomes loose and its only task is to prevent the throw out of the tooth. Then the area (d) starts to carry the moment instead of the rivet. On the right-hand side of fig. 8.5 we can see the result. If wear is proceeded so far, the tightening of the rivet helps only for a while, any more.

I used my hammer not only for stones, but I hammered pieces of wood on the ground, too. Doing so, I noticed that the wood piece jumped up from the earth at every blow. If I pressed it against the earth, it did not jump any more, but I felt the impact against my pressing foot. Afterwards I learned, that a rigid thing on the flexible surface jumps every time, if it gets a fast stroke downwards. It needed a bigger clamping force than the peak value of the impact to prevent the jumping. Hence, almost in every cases the contacting surfaces wear out by frequent shock loading and only a sufficient clamping force is able to stabilise the contact and prevent the wear. If a remarkable bending in the impacted thing was the result, even clamping force was not able to prevent the wear. I experienced that trouble frequently with chipper knives.

The impact phenomenon has followed me as an interesting problem and it has offered me possibilities for many analysing. Hence, I knew the answer immediately. The tooth bars should be pressed constantly against the slot edges. The tight fitting can offer this, but the stability of the saw is not possible to control any more. The flexibility of the fitting was too small and even minor differences in tightness caused the loosing. Consequently, I had to create a flexible tightening. In this case I calculated for the tolerance only 1,5 µm for the elastic tightening deformation.

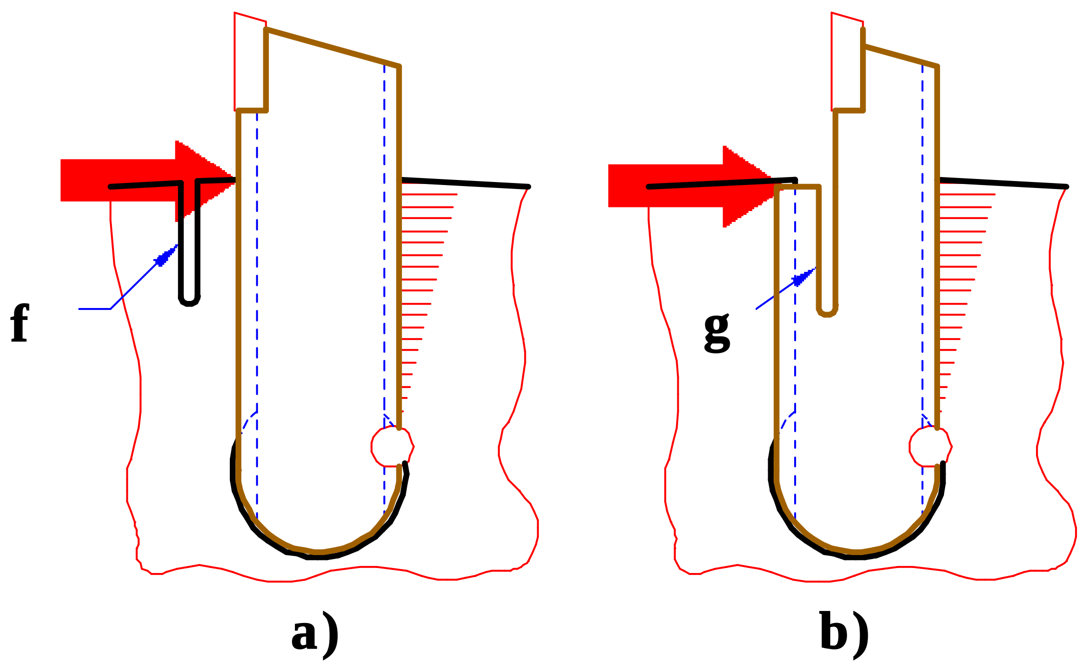

Figure 8.6 Adding the flexibility

The first correction was to move the rivet to the end of the tooth body on the back edge, where it cannot get any extra load because of the impact. A deep narrow slot (f) will be cut at the saw blade rim. This slot is widened with a wedge so, that the tongue bends a bit plastically. This makes a strong spring to press the tooth body against the back edge of the slot. The elastic bending of the tongue is approx. 26 µm, that means 17-fold flexibility compared the previous. The flexible tongue could be formed in the tooth body at the point (g) in fig. 8.6, as well.

The use of a flexible tongue looked like a rather good solution, but the small supporting contact surface of the tongue made me suspicious, as well as the bending flexibility of the tooth body. The solution was probably more durable than the Reed insert, but not "everlasting".

The cutting force of one tooth is according to my calculations approx. 400...500 N. The flexibility's I calculated with a load of 1 kN. According to the manufacturing tolerances the original clamping force of Reed inserts would have been in order of 100 kN, which was intolerable for the behaviour of the saw blade. The accuracy needed for maintaining 1,5 µm flexibility (responding to the clamping force of 1 kN) were completely impossible in practice.

How about replacing the tongue with such a form of the insert, which would be flexible enough? This could have a half moon shape with such dimensioning, that the clamping force 1 kN would give a big enough flexibility. When I studied it, I found that the flexibility of the ring would be 43 mm. At the same time, the strength of the ring would respond to a flexibility of over 200 µm.

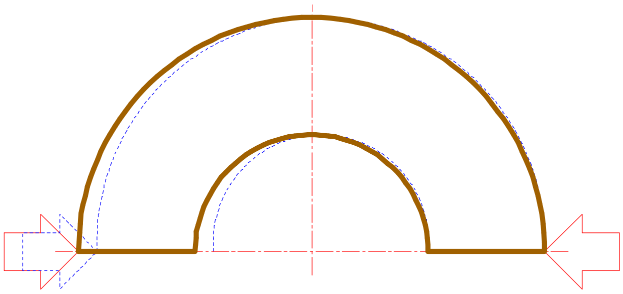

Figure 8.7 Half of ring as tooth insert

This structure looked like a satisfactory solution giving tolerance in every respect. I designed the saw using it. The application in ϕ1800 mm saw looks like in fig. 8.8.

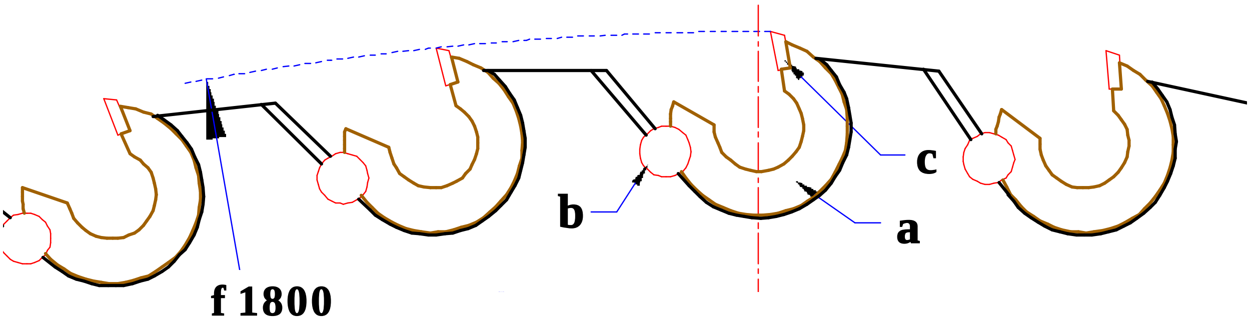

Figure 8.8 Spring teeth in the saw

That size of saw can take 60 teeth, which is the same number as before. The slots at the rim of the saw are U-shaped, but wider and shorter as before. The parallel flanks are tilted. The tooth insert (a) has a circular edge and it is locked in place by means of a big rivet (b). The rivet is placed a bit aside of the transversal axis of the slot bottom. This makes the locking effect better. The fitting is tight, of course, but the big rivet can afford the tightness in any case.

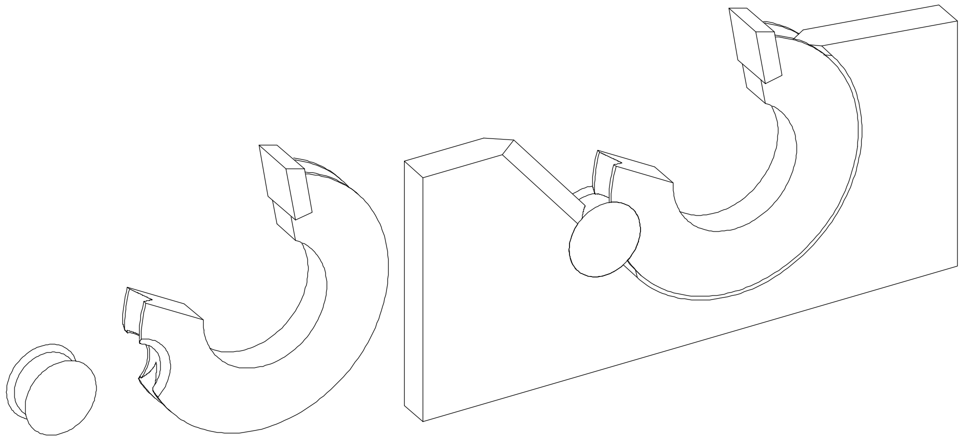

Figure 8.9 Spring tooth in 3-dimensional presentation

The rivet pushes the biggest pressure into the place, where it is actually needed, i.e. on the back surface of the insert. The cutting force tends to turn the insert against the rivet increasing the tightness against the bottom of the slot, at the same time. The contacting surface is very big and the flexibility is 28...130-fold compared to the Reed solution.

For the practical tests both types of saws were manufactured. The first big surprise was the noiseless running of the spring tooth saw. The reduction of the noise was approx. 20 dB and put this solution into second place of all improvements in the Finnish Noise Register. Another positive surprise was that the insert was able to split the rivet when it hit a stone, thus preventing damage. The durability reflected our expectations and it could be used without any service for several months, when the running time for the Reed saws was only 8 hours.

Also the structure according to fig. 8.6 was successful. Its noise reduction and its durability were far behind that of the spring tooth, but much better than that of Reed saws. Both structures were patented and one of the competitors made an offer to buy the structure of fig. 8.6. It was not sold.

The long study of the nature of impacts, found in this project an optimal appropriate need. The solution was exceptionally fast and easy. Actually all original drawings are dated 5.1.1983, and I did not use more time for it than one weekend. The reason such a simple solution was not found until then proves the importance of the deep subconscious impact knowledge. Probably Jack Reed has not played with his hammer enough. My knowledge did never take any struggling, but so much more naive curiosity and play with images. I must confess, however, that without the first version of Jack Reed I probably would not have found such a solution, proving the importance of our predecessors as well.

8.3.2 Removing the Soot and Ashes in the Waste Heat Boiler

While that saw invention was a very light but lucky work of one weekend, this next one was so much more difficult and laborious. When I started with it, a real hell was going on. The company in trouble was not that which I was serving the time. It belonged to the same concern, however, and I was called to save the situation before legal proceedings and the cancelling the delivery.

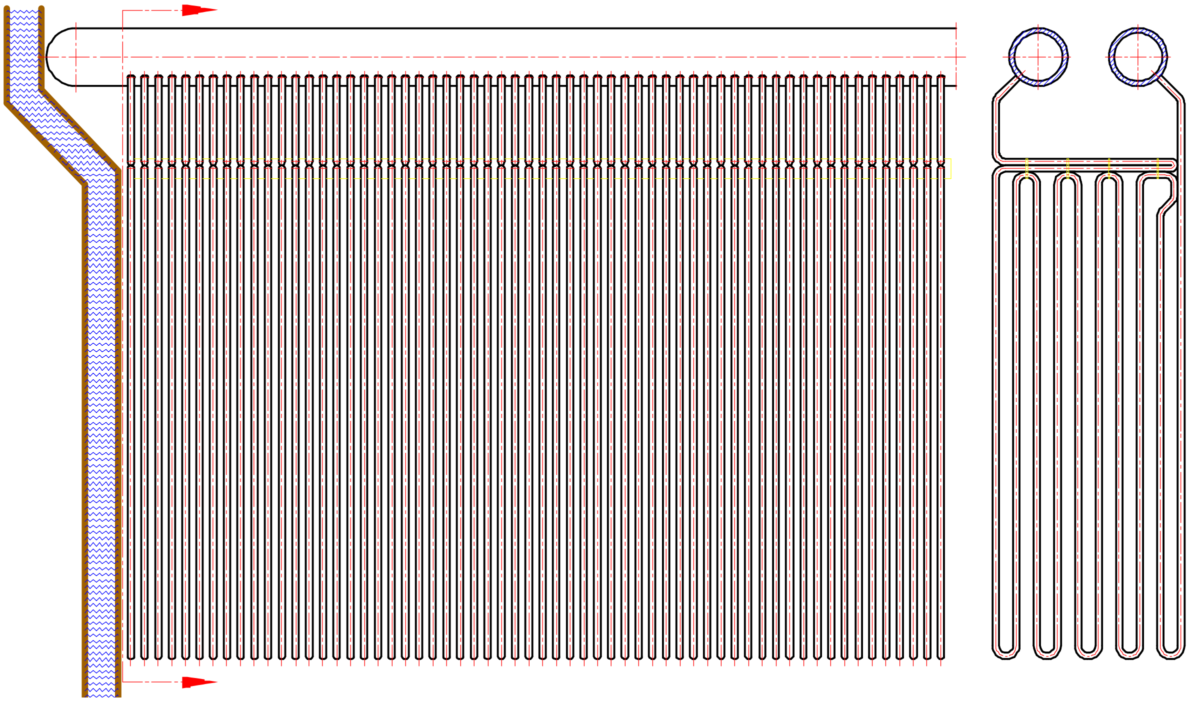

Figure 8.10 Tube structure of a waste heat boiler

In the beginning of the 1970 a waste heat boiler was delivered to a cobalt factory in Kokkola. It should have taken full advantage the heat from the exhaust gas into the bundles of tube loops hanging inside the boiler. There were thousands of the tube loops. However, the exhaust gas contained much soot and ashes, that stuck to the tubes filling the empty space between them. Finally there was only one open channel through the boiler and the yield of heat was almost zero. All kind of shakers were used, even high power sound vibrators, but the cleaning of the tubes was an unsoluted problem.

The high power sound was an effective cleaner, but always some of the tubes were in resonance with the sound frequency and they broke down now and then. The boiler had to be run down and cooled for some days before the repair was possible. The situation was so desperate, that the disassembly of the boiler was discussed and the cancelling of the whole business as well. I got the task to design a cleaning method, which could keep the boiler continuously in good operating condition.

I got the possibility to see the boiler, when it was cooled down, but the soot and ashes still were between the tubes. All spaces were completely filled except a channel of diameter approx. 2 m. When the exhaust gas flow through this channel, the speed was very high and the time for efficient heat transfer was too short. I hit one of the tubes with an ordinary carpenters hammer with the consequence, that several tons of ashes dropped down. Then I measured acceleration on the tubes and found out that the acceleration value, caused by an impact, advanced through the bundle of tubes, almost without any damping, from one side of the boiler over to the opposite side. Such an impact dropped down all ashes from that particular tube bundle.

The use of the impact seemed to be an appropriate method for cleaning. However, the designers of the previous shakers told me, that in the high temperature the ash is so tough, that no impact is able to drop it down. They presented me shakers, which stroke the loops against each other using pneumatic cylinders. Even the stroke was approx. 40 mm, the ash did not drop. I tried to measure the advance of the impact from these shakers in high temperature, but the measuring was not successful and we did not get any results.

However, the impact was the most promising method to clean the tubes. To search for the best impact method, we build up in the back yard of the workshop a model to simulate one of the tube bundles. The hanging loops we connected together with a long impact tube. The acceleration pick-up was fixed along the impact tube of the bundle and a fitter started to hit the front end with a sledge hammer with steady pace and uniform force. The vibration advanced without any significant damping through the bundle and the sound was clear and strong like sound of a church bell.

After that we started to put steam through the bundle and we followed the acceleration continuously with the rising temperature. When the temperature was about +150°C, the sound completely changed, to that resembling the striking of a sunken log. The hitting point at the end of the impact tube started to swell plastically and no vibration was left at the opposite end. Only at a frequency of 1000 Hz were some rests of vibration detected, while the maximum acceleration in cold temperature was measured at 4000 Hz.

I had to ponder the reasons for that phenomenon. The static strength of the steel is only slightly changed with this rise in temperature. Why did the hitting point start to swell and the clear sound of a bell is shut down? Does ordinary mild steel possess the same kind of characteristics as Teflon, which stands high dynamic loads, but flows plastically with almost any static load? If this characterisation is correct, it could prove many mysterious phenomena. For example, stainless steel is very sensitive to dynamic vibrations, but the weldable mild steel does not suffer at all. The same relationship is also true between high strength weldable steels and mild steel, too.

The main problem was to get the vibrations to advance through the tube bundle. All impact energy seemed to be killed by the energy of plastic deformation at the end of the impact tube. Would it be possible to use only one frequency in the impact? With this thought I had an idea. We could use a spring between the hammer and the impact point. The spring should be so dimensioned, that the impact would cause a sinus formed push against the impact tube. The vibration would have only one frequency responding the time of the push.

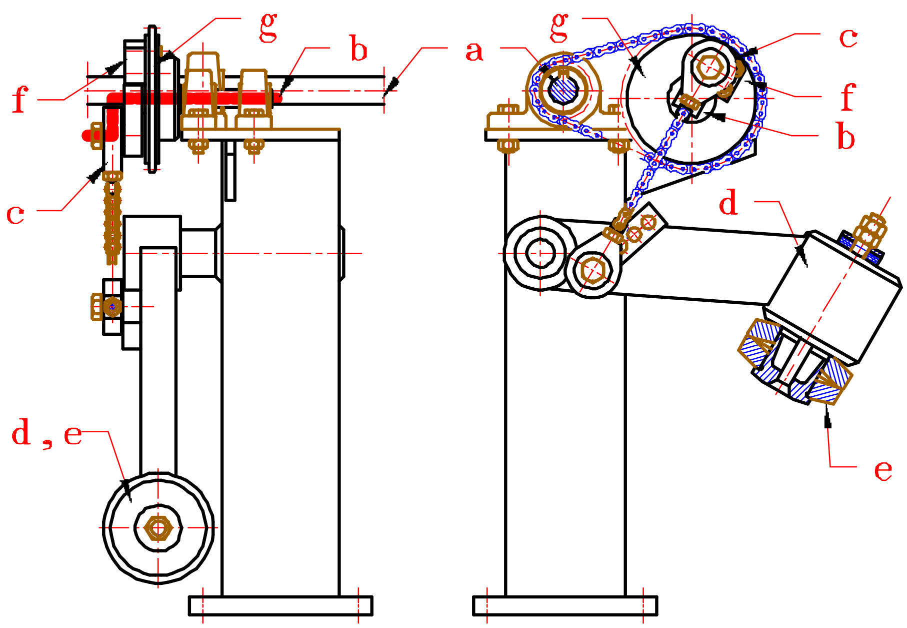

Figure 8.11 Spring hammer

The interval between the impacts could be approx. 5 min, even longer. There is no reason to increase this pace as there is no need to load the tubes unnecessarily. If we have only one impact at a time, no resonance can be build up, thus this method should be safe. In the practice the construction was not easy, because we did not want to have any electronics for the pace setting. The circumstances at the boiler do not favour very sophisticated solutions.

Figure 8.11 demonstrates the final structure. The hammer (d) has two disc springs (e). The combined stiffness is dimensioned for a push, which fits into the curve of 1000 Hz vibration. The hammer hangs linked to the body. It will rise and drop once every 5 minutes. All hammer units are connected together with a long shaft (a), which is driven with a speed of 0,2 r.p.m. Each unit has a crankshaft (b) which is driven with a chain drive (g). The elevating link (c) is pillowed at the end of the crank. A lifting coupler (f) is attached to the front of the bigger chain sprocket. During every turn this coupler takes the crank (b) along and elevates it slowly until it reaches the upper position. At this upper point the crank may turn freely forward and the hammer drops down against the impact rod.

In the testing of this new hammer I first noticed that the hot impact point did not swell any more. The vibration of 1000 Hz advanced through the hot tube bundle effectively with only slight damping. To be sure, we arranged water cooling through the impact tube in the boiler. The final assembly in the boiler worked perfectly, and no soot or ashes gathered on the tubes any more. The idea is patented all over the world and thousands of units have been delivered since then.

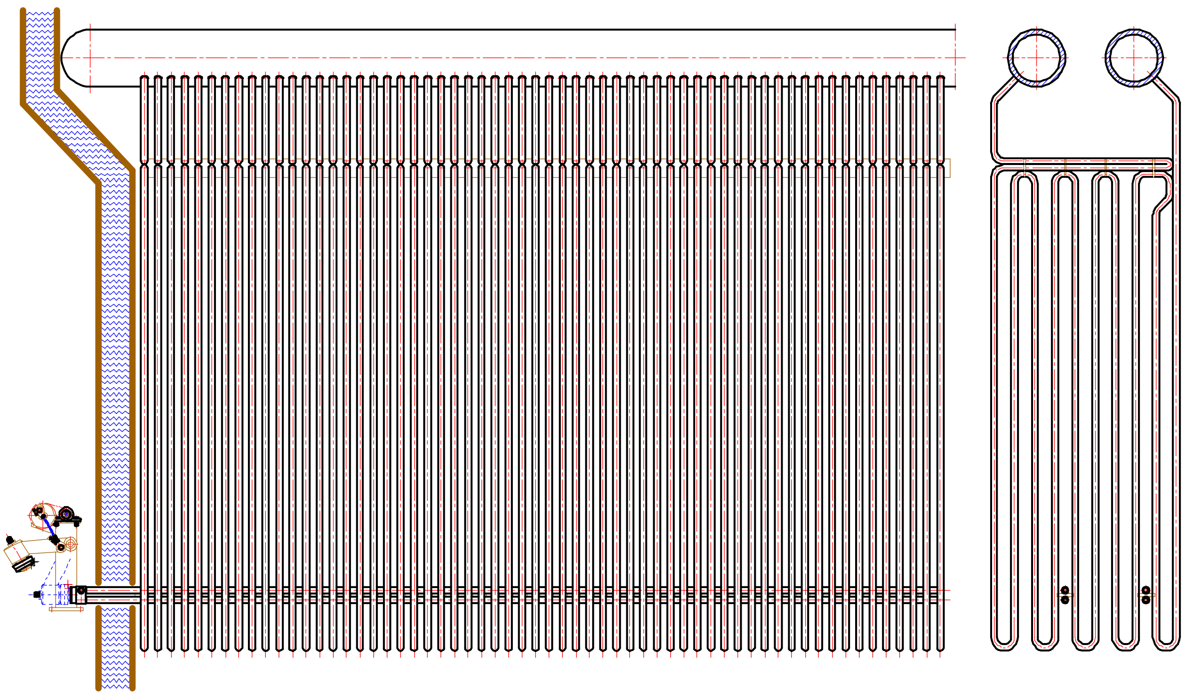

Figure 8.12 Final arrangement of spring hammers

That insight of using only one low frequency was a perfect success. Where did it come from? Sophisticated measuring technics were one starting point. They gave the possibility to analyse the advancing vibration in different points of the tube bundle. But it is not enough to explain the birth of the idea. The idea is so exceptional, that the patenting authorities were reluctant to believe my explanation and they accepted it only after the excellent results in the field. Since then this idea has got, as its follower, at least five derived US-patents from other inventors.

During the development I did not knew any single dualistic application, which could be a source for this one. Later on I remembered, that the boxers use soft gloves in purpose to save the face tissues of their opponents. Perhaps there is in background knowledge, that this could enhance the damage to the brain (knock out), which is the primary aim of the boxing. But this grotesque image came later to me, thus it cannot be the source.

But somehow this idea come into use. If not, my work had proved me to be a genius, which is not true. Many years later, a story came to me, and now I believe, that it was the background for this invention, as well as for my interest in impact in general. It has really had a far-reaching influence on me. At the end of part I, I would like to tell that important story of my life:

Death Bells of the Czar

The Russian Czar Alexander III died AD. 1896. It was ordered that in the whole empire the death bells should be rang during the whole month every night between 6 and 7 pm. This order was valid in Finland too, because Finland belonged to Russia as a grand duchy. Our ruler was not called grand duke or czar, but in common language he was Caesar.

It happened to be winter and a very cold one. Ringing the bells was quite a heavy task for the church verger, hence this duty was shared by some farmers around the church, one week for each, as it happened at least in Evijärvi. This was not any unpleasant duty for the farmers, and in the first evenings the farmers themselves climbed up to ring the bells. At the end of the week they were tired of that and the young boys of the farm got the job.

At the same time there was a story among the people. According to it the church bell might crack, if in the cold weather the clapper was covered by a knitted glove. In the last evening the boys could not avoid the temptation and for the last clapping they put the glove on. The bell really cracked! The boys were terrified because of the damage they had accomplished and they promised to keep their mouths closed of the reason. However, they were so afraid of what happened that in the next spring all of these three boys moved over to USA as immigrant.

In 1945 or 1946 there was an American letter published in our local newspaper. In this story an old man told that story on purpose to lighten his heart before he past away. I read it and the paradox of the happening started to haunt in my head. The mystery was still stranger for me, when at the same time I saw in Pedersöre church deep marks at the mouth of the biggest church bell, caused by an axe. These marks date back to the time of the Great Northern War approx. 1714, when the Russian soldiers tried to split the bell for the easier transport as plunder. The people from the grave yard came to attend that and the Russians got a fast start. The bell did not break even the deep marks were made at it.

8.4 Summary

The main content of creative engineering design has two major items. The first of them is **the basic knowledge of all materials, structures and components.** This knowledge should be stored in one's subconsciousness and it should include one's own experience of this material in use. Thus, it is not possible to reach the adequate standard of knowledge by studying and research alone. The second part of this book tries to give some samples of the content of this knowledge. As examples, only some materials and structures are exploited. The second major item consists of the **method**, which helps us **to activate** this static but enormously powerful and resourceful **subconsciousness** in the use of creative working.

The value of the creative engineering method is lower than the value of the understanding of these two major items. The only universal advises are the building up of tension aimed to a goal, the heuristic way in developing and the avoiding of the alternatives produced by the ideation, only. We must remember the monolith structure of realised solutions and the need of penetrative analysis. Otherwise the method I presented is only one model, which suites only some of the designers. It must be revised for the personal needs of the reader. We have always to keep in mind, that any systematic step-by-step procedure of creative design does not exist.

8.4.1 Basic Knowledge

The basic knowledge should go still deeper, than only into details of all characteristics. It should include the understanding of the whole influence of this material on the development and the possibilities in the whole area of engineering design. When new structures and possibilities appear, the designer should be able to put them in harmony with the old ones to complete them, not to replace them. Examples of these new structures and materials could be box beams, cheaper electro-motors, extruded profiles, hydraulic actuators and today the programmable controllability of the machines. The adapting of the last items is still going on.

The basic knowledge, as it turns out, is clearly subconscious knowledge which is flexible and quickly usable whenever needed. The subconscious knowledge alone, however, is static, apparently only some kind of subconscious data storage. Despite of that, it is irreplaceable for the creative activities.

8.4.2 Taking Advantage of the Subconscious Mind

In the first part of the book we have already discussed this item using several descriptions and examples. In the summary we have to define it with clear concepts.

a) **Attribute structure** *is the result of one's acquaintance with the task. It is a set of attributes and other epithets, which are connected with the details of the task, with its materials, structures and components. Furthermore, it* *includes the attributes of the conditions and manners of use. The attribute structure precedes the* **technical structure** *(= solution) and it is in certain ways opposite to it. After the technical structure is completed, its attribute structure tends to be forgotten quite quickly.*

b) **Penetrative analysis** *is the process by which the attribute structure is created. When it is focused on an older or a competing solution, it reveals the basic characteristics of the materials and structures, which were the basis of that particular solution. It is an extremely valuable process, because it reveals us the experience used with the former solution. At the same time it dispels the old technical structure. The penetrative analysis is logical conscious work, but its results should be directed towards the subconsciousness. It should be pointed out, however, that creating a new technical structure does not mean copying, even though the result has some completely identical details with the competing structure.*

c) **Creativity** *is never a conscious action, but completely subconscious one. Because of the static nature of the subconsciousness, a* **tension** *is needed to activate it. The tension is created by the task and by the conscious desire to reach a solution. When the tension is combined with penetrative analysis and growth of subconscious knowledge, it will effect the subconsciousness as well, and it will cause activity even during moments of rest, during other forms of work, and even during sleep. The subconscious tension can be called* **intuitive tension**.

d) **Intuition** *is the transfer of the crucial thought from the subconscious to the conscious mind. Most people feel the intuition as an incidental, even mystic experience. Moments of intuition follow the fixed schedule surprisingly well and the timing seems to have no limitation. In an emergency situation an intuitive solution surfaces immediately, provided that subconscious knowledge is available.*

e) **Idea** *is an intuitive contributory factor, which can pop up propelled by a usual association. The birth of an idea indicates an ability of communication between the conscious and the subconscious mind. The ability of ideation can be developed by a convenient computer program, brain storming etc. There is, however, only limited advantage in this.*

The most common mistake is to develop the idea in the conscious mind using systematic methods, which leads inevitably to constrained solutions. Once the method of ideation is learned, the concretisation of the idea should be avoided in the practical design work. This is to say, that the idea must remain as an active subconscious factor. This way the idea will not bind nor freeze the process.

f) **Communication between conscious and subconscious minds** *is the key to the effective creative work. The ability of ideation indicates already this communication, and it can be trained and developed using several methods. The virtuosity in creativity calls for avoiding the short span ideation and for transferring the process into the subconscious mind. Only prior to the end solution the subconscious material is allowed to come into the conscious logical world.*

A common characteristic for the creativity in all branches is, that the communication between the conscious and subconscious minds is not directly possible using spoken or written language. Discussions are naturally beneficial, but only when they generate images. In other words, powerful communication between the conscious and subconscious minds calls for the use of senses. When senses and images are used, even communication between the subconsciousnesses of the individuals in a team becomes possible. Consequently, there is not a lot of discussion in a good working team, but everyone follows the struggles of the others.

In order to promote the communication between the conscious and subconscious minds in the field of engineering design, the method I have described in this part can be used. The language for this method is based on scetching details, e.g. on the use of ***heuristic points***. I have previously used two aphorisms from Umberto Eco, written in Latin, from medieval time. They can be interpreted as description of the power of figures. I would like to add a third one from the same source. It gives us ”the grammar” for this language:

Motto III

Omnis ergo figura tanto evidentius veritatem demonstrat quanto apertius per dissimilem similitudinem figuram se esse et non veritatem probat.

Therefore every figure indicates the truth, the more obviously the more openly it shows the unlike similarity; so that it is the picture in the first place, not any truth.

(Umberto Eco: Il nome della rosa)