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What characterises an attractive machine element?

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Abstract

An attractive product is one that functions well, is easy to use and has 'it'. Both technical and interactive functions are important. In this paper, the functional surfaces of a product and of its elements are regarded as carriers of functions. Some general principles are outlined starting with these concepts. Initially standard vehicle wheels were studied to find out what makes machine elements attractive.

One difference between an individual machine element and a machine element acting together with other elements in a product is the often hidden interfaces between elements. An interface is defined as an interaction relation between two functional surfaces belonging to different elements. Some machine elements are also covered by others in order to prevent harmful effects from or on the environment. Some classic machine elements are covered by styled elements, whose functions are mainly interactive.

The conclusions drawn from this study are that future machines will probably have more attractive covering elements than today, the attractiveness of machines is often increased when the performances of some classic machine elements are improved, new technologies such as drive-by-wire and/or new propulsion systems will probably improve the attractiveness and performances of vehicles, the attractiveness of a universal joint is mainly related to how well the technical functions are fulfilled during its life, gears will continue to contribute indirectly to the attractiveness of many types of machines by their technical behaviours and performances and they are seldom visible but can be made visible if alternative lubricants are used and/or if lower performances are accepted, rolling bearings are normally regarded as high performance elements, bushings for different types of sliding bearings are styled in order to attract engineers and others before being assembled in a product and finally education in Machine Elements should be supplemented by an education of styled covering elements.

1. Introduction

The word "attractive" can mean many things, depending on the situation, by whom and when the word is used. In this paper, the author will use the definition of the word used at KTH for the Design and Product Realisation programme. The goal of the programme is to teach students how to develop and produce attractive products, which means products that:

- function well
- are easy to use and
- have 'it'.

The program follows the European principles outlined in Bologna, which means an initial candidate period of three years and a second master's period of two years.

Similar functional principles are probably valid for individual machine elements as well as for whole products. What then is the difference between an attractive product and an attractive machine element? Of course, there is no difference if the product consists only of one machine element. If a product is built up of more than one element, the difference is mainly that some surfaces of the individual elements are technical functional surfaces interacting with corresponding surfaces on other elements. The interacting surfaces define interfaces that are often not visible. Another difference is that more and more classic machine elements are covered by other elements in order to protect humans and the environment from the product and vice versa. It also facilitates styling the product.

In this paper the author present the results of a study of some machine elements. The goal has been to find out to what extent classic machine elements can be made more attractive and also to determine what modifications should be made to education in machine elements.

2. Function

The function of a physical product is often defined as what it does or is intended to do. The word 'function' is used in many different situations and with many different meanings. This paper uses the definition accepted by the Swedish national program in engineering design, Endrea [1], which defines function as 'what a product or an element of a product actively or passively does in order to contribute to a purpose, by delivering an effect'.

One way to consider functions is to formulate the technical functions as storage, transformation, and division of flows and efforts within a product and its elements. However, the same technical functions can be formulated in different ways. For example, the same function may be described as 'heating water' or as 'storing thermal energy in water'. Regardless of how the initial function is formulated, the use of a systems approach enables most products to be satisfactorily defined technically by gradually building up the functional structure during product development.

A product is always perceived by someone. In his doctoral thesis Lange [2] stated that ‘a product is designed by someone to be perceived by someone’. By that he meant that humans are involved in the whole product cycle. The involvement of humans is of particular importance when considering the attractiveness of a product. Warell [1] uses the concept of function for this purpose. In his dissertation, he proposed that in addition to considering the traditional technical functions, one may also consider the interactions between humans and physical products that he called interactive functions.

Interactive functions are associated with users and observers. These functions are sometimes referred to as human or user demands or non-technical demands. According to Warell [1] interactive functions can be divided into ergonomic functions, semantic functions and syntactic functions. Semantic and syntactic functions are sometimes difficult to separate, and the term ‘communicative functions’ conveniently covers both uses. By combining interactive and technical functions with a systems approach, Sellgren and Andersson [3,4] have shown the advantage of the expanded system representation in completely defining a product. The expanded system representation includes a technical system (the technical product), an environmental system (which can have a technical or interactive function) and a human system. This is good way to structure models of a product and their interrelation with other models and interaction with other parts/systems and users/observers.

3. Functional surfaces

Sellgren and Andersson [3,4] use the term ‘functional surfaces’ to refer to technical and interactive functions as well as interfaces. They define an interface as an interaction relation between two functional surfaces. They also assert that there are advantages to considering functional surfaces as carriers of technical and interactive functions. If we use the enlarged functional representation concept, all surfaces on a product or an element are functional surfaces. They can be both technical and interactive surfaces at the same time, and quite often they are interactive constrained functional surfaces.

A surface can also be divided into more than one functional surface, as in the example shown in Figure 1. This simple concept model of a bottle opener was used in [3,4]. The opener is made in one piece, but can be seen as having three parts with different functional surfaces. The front end (a) is characterised by a technical functional surface, the mid part (b) is characterised by a communicative functional surface, and the rear part (c) is characterised by an ergonomic functional surface. The middle part must be strong enough to transmit forces and torques generated at the end parts and forces generated internally due to its shape. As long as the strength of the middle is adequate, the designer has full freedom to shape the part.

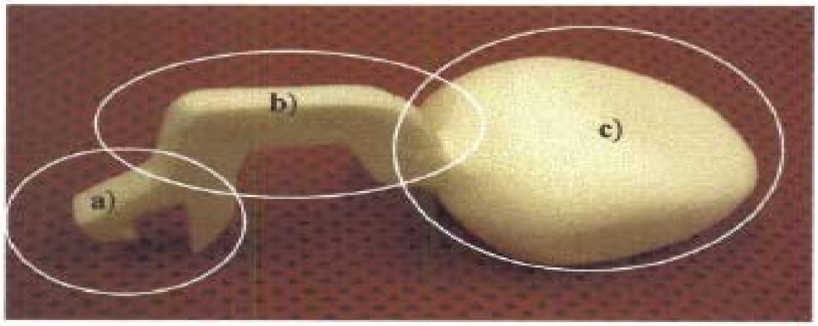


Figure 1. Model showing three functional surfaces of a bottle opener:
a) a technical functional surface, b) a communicative constrained functional surface, and c) an ergonomic functional surface. Photo: C.M Johannesson.

4. Wheel rims

Much effort is expended in the styling of products in order to please as many customers as possible. Cars are a typical example Not only are car bodies styled but so are other visible parts, such as the wheel rims.

The styling of car wheels can easily be observed. It was, in fact, the inspiration for this project. Tyre shapes may vary, but not as much as the wheel rims. Every car manufacturer seems to strive for a particular style in order to entice potential customers. Figure 2 shows the wheels of some cars parked close to the author's home, and they are all different. Some wheels may directly be associated with a particular car.

Figure 2. Car wheels photographed in a car park close to the author's home

The basic characteristics of all wheels are shown schematically in Figure 3. The functional surfaces of the wheel can roughly be divided into two technical functional surfaces and one technically constrained communicative functional surface. The outer technical functional surface is defined together with a tyre in order to form a reliable wheel–tyre interface. The outer technical functional surface (A) of the wheel rim must therefore have the correct shape, reasonably small deformation and good strength. The inner technical functional surface (C) is pressed against the corresponding surface of the hub of the vehicle in order to allow forces and torques to be transmitted between the wheel and the hub. The technical functional surface must therefore be shaped to fit the corresponding surface on the hub. It must also be made to withstand the forces and torques it has to transmit. In joining the wheel to the hub with bolts, both the position of the holes and the design of all the contact surfaces related to the holes are important.

The third part (B) can be considered a communicative functional surface with constraints between the two technical functional surfaces. It can be shaped quite freely provided it has adequate strength and stiffness. It may also have to satisfy some additional constraints, such as those posed brake ventilation.

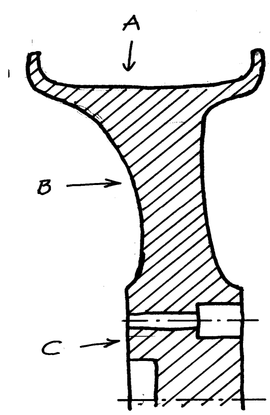


Figure 3. A principle picture of the functional surfaces of a

These observations may be summarized as follows:
A vehicle wheel rim can be represented by three functional surfaces, where

- the outer technical functional surface (A) interfaces with the tyre,
- the inner technical functional surface (C) interfaces with the hub of the vehicle and
- the constrained communicative functional surface (B) interfaces with both the outer and inner functional surfaces.

Since a car rim can be considered a machine element, one may ask whether other machine elements could also be designed in a similar way to make them more attractive. It is obvious that some high performance machine elements contribute indirectly to the attractiveness of a product. It is, however, not clear whether all machine elements contribute directly to the attractiveness of a product. Therefore, some classic machine elements were studied.

5. Universal joints

Universal joints were the first classic machine elements studied. Figure 4 shows an illustration of the rear of a truck. The design is rather traditional and most of the machine elements illustrated are classic elements. In the figure you may find springs, hubs, wheel rims and tyres. There are also shafts and gears as well as a universal joint used as a shaft coupling. The components of the universal joint are shown schematically in Figure 5. The universal joint allows some misalignment between the connected shafts. The form of the coupling is defined mainly by the technical principles and performance of the coupling parts. A universal joint consists of two forks joined by splined short shafts. The forks interface with a cross via bearings within which the interacting technical functional surfaces are sealed from the environment. The dimensions of the bearings are probably determined using a bearing design guide from a bearing manufacturer. The shape and size of the forks are determined by their strength. In the truck application, the visible surfaces not in contact with other surfaces must be properly protected against corrosion. The technical interacting surfaces must be properly sealed so that the lubricant will neither leak out nor be contaminated.

Is it possible to modify a universal joint in order to make it more attractive? The answer is both yes and no. In the example, the attractiveness of the universal joint in a truck relates mainly to how well it fulfils its main technical function, since it will most likely be covered by other elements. The interactive functions are mainly important for observers and persons handling the coupling before and during assembly, service and repair of the product. Those who observe or come into contact with this machine element will probably not accept any degradation before the coupling is assembled. The couplings should also not degrade during use. Thus the attractiveness of this type of machine element is closely related to its technical performance over its entire lifespan. The ease of installation and removal is also an important facet of the attractiveness of a particular coupling. This is closely related to the shape and the tolerances of the functional surfaces and the ergonomic properties of the element.

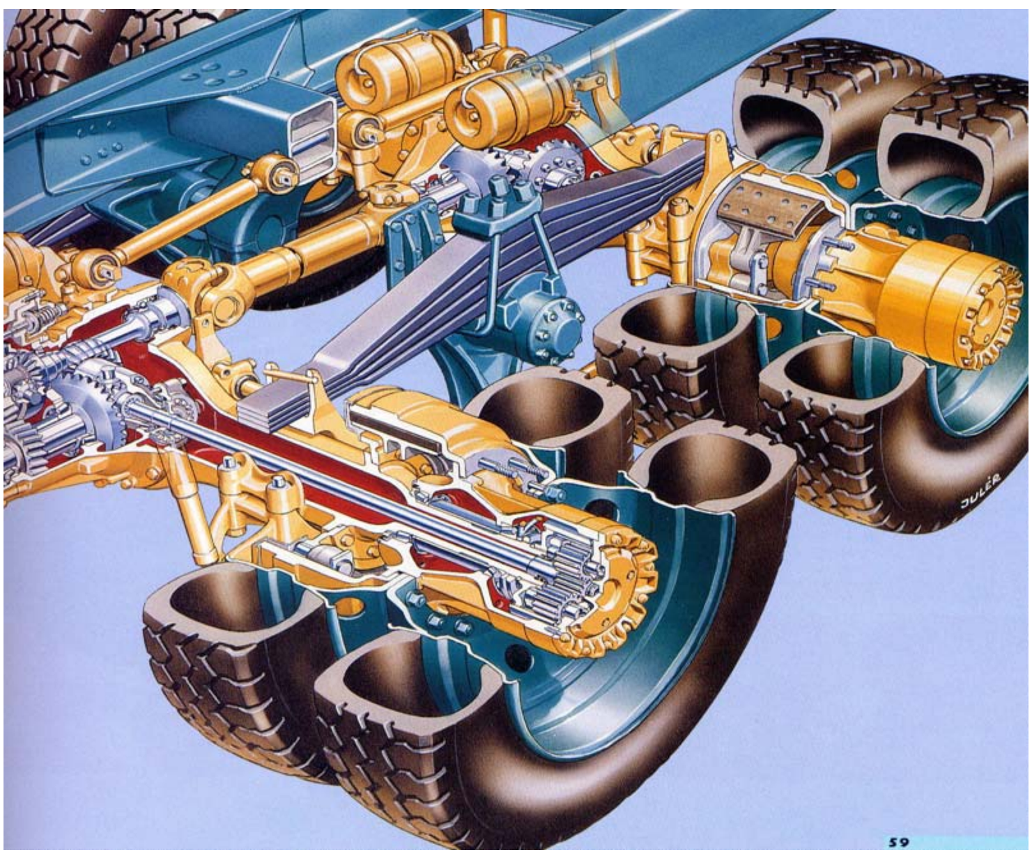


Figure 4 Illustration of the rear of a Scania truck

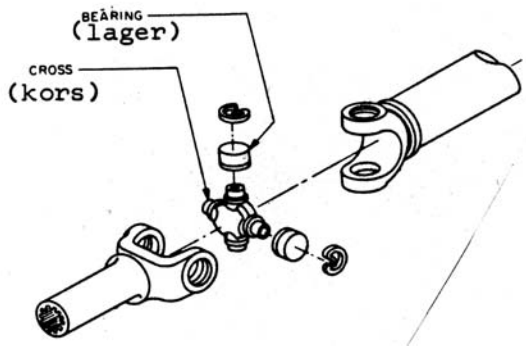


Figure 5 Universal joint

6. Gears

Gears such as those shown in Figure 5 are the next class of classic machine elements. Gears will always be used in high performance machines because of their efficiency. Since high performance gears are lubricated, they are normally covered by a housing which contains the necessary lubricant for the gear tooth contacts. The lubricant is often some sort of mineral oil, synthetic oil or grease. Lubricants often have a rather dull color. Due to the splashing of the lubricant when the gear teeth interact it is also difficult to see gear wheels in action in a gearbox. This is unlikely to change because dry lubricants only work for a limited time and are not suited to high performance gears.

Although gears are fascinating machine elements and have some similarity with car wheel rims, they are seldom or never styled in the way that most car wheel rims are. The reason is partly tradition but high performance and low costs are probably more influential.

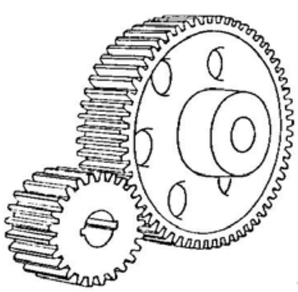
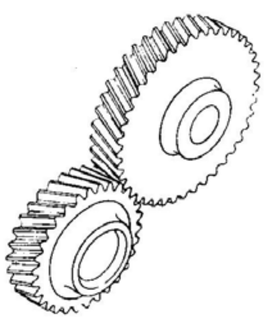
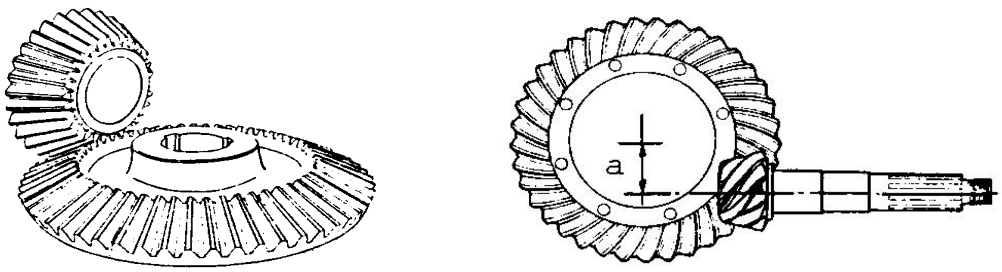
a)  b) 

Figure 6. Cylindrical gears with parallel shafts: a) Spur gears, b) Helical gears



a) Straight bevel gears b) Hypoid gears

Figure 7. Bevel gears

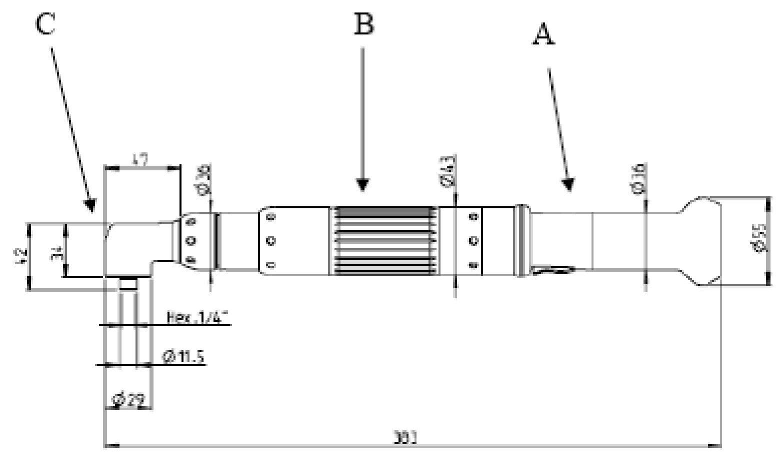


Figure 8. Motorized screw driver

Gears also play an important role in computer-controlled hand-held motorised screw drivers (Figure 8). Such tools must be ergonomically shaped. The pneumatic or electrical driving motors (A) are integral parts of the tool and must be adapted to the users. The tools are therefore designed with high speed motors in order to reduce the outer diameter of the motors. However, the high rotational speed must be reduced at the front to produce adequate torque for tightening screws. The speed reduction is done with a set of modular planetary gears (B) and bevel gears (C). The outer diameter of the planetary gears must also be determined by the size of a typical user hand. The outer surface of the planetary gears is therefore both an ergonomic and a communicative functional surface. In this case one can conclude that for ergonomically designed machines, the size, weight and compactness of the machine are important.

Figure 9. An industrial robot (Photo ABB)

Gears also play an important role in the attractiveness of industrial robots like the one shown in Figure 9. The many gears in this robot are all covered and thus not visible. That is acceptable because the attractiveness of an industrial robot is not related to the display of classic machine elements but to accurate, fast and cheap performance. In some types of robots, however, the attractiveness of the robot might be improved by improving the behaviour and performance of gears or by making the gears visible. This would involve the gear housing or part of the robot being made of a transparent material. The commonly used lubricant would also have to be replaced with a 'clean' and probably transparent lubricant.

The conclusions from the studies of different gear applications can be summarised as follows:

- Gears are often covered.
- Gears contribute indirectly to the attractiveness of many types of machines by their performance.
- Gears can be made visible if lower performance is acceptable and provided different lubricants are used.

7. Bearings

The next type of classic machine elements studied was bearings. Rolling bearings of different types are used in many high performance machines. They can be found in Figure 4 if you know where to look. Although bearings are perhaps the most technically advanced elements in modern machines, they are often rather difficult to see. Their characteristics include nonconformal contact surfaces as well as good form and smooth hard surfaces. Consequently they produce good performance with good predictability. Rolling bearings are normally not coated, but are nearly always lubricated with grease or oil, which also provide some protection against corrosion. The styling of rolling bearings is limited. Since such bearings are often placed inside a product and are sealed off from the environment, they are normally not visible. Good seals are necessary to prevent contamination of the lubricant and to prevent the lubricant contaminating the environment. The handling of the bearing before assembly is also important and therefore they are often carefully covered with a special material and kept sealed as long as possible.

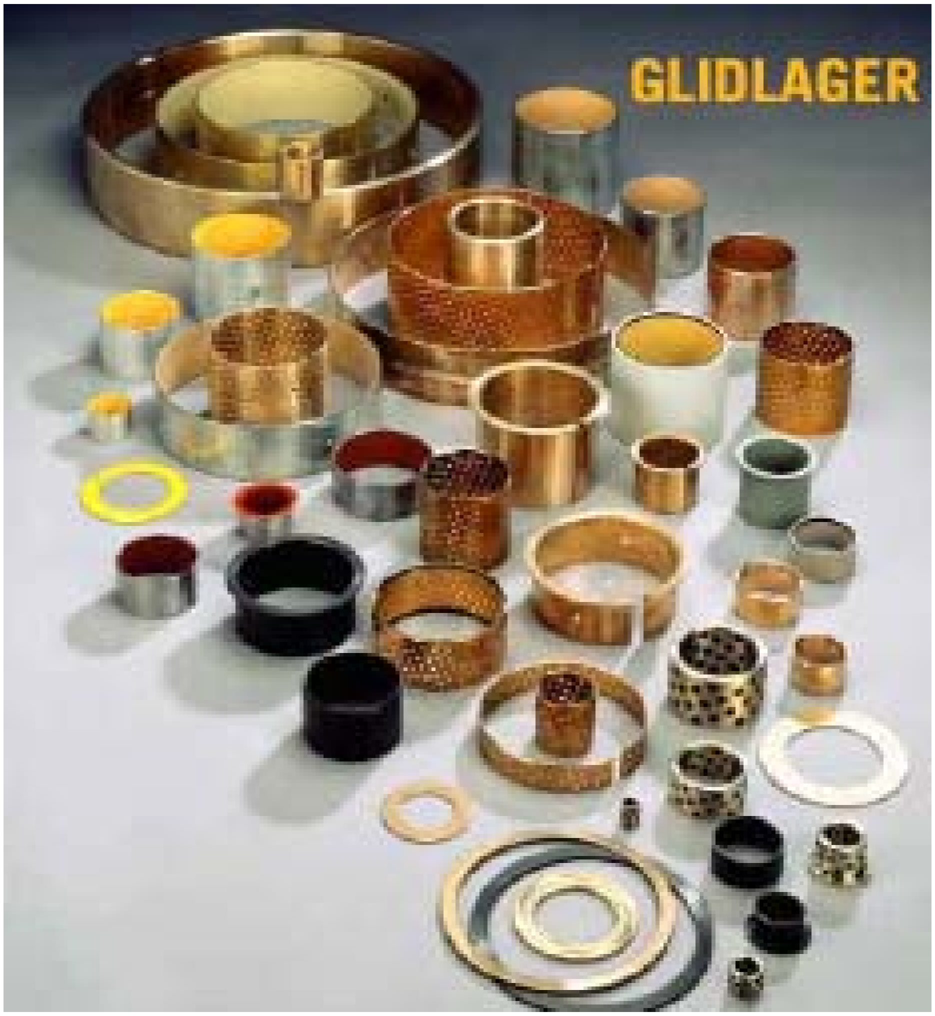


Figure 10. Bushings

Bearings can also be of a sliding type. Figure 10 shows bushings intended for use as part of boundary lubricated or dry sliding bearings. Interestingly, the producers of the bushings have put effort into the appearance of the bushings, even though the bushings will not be visible in use. The producers have judged that the time before the bushings are assembled is important.

The following conclusions can be drawn from these studies:

- Rolling bearings are normally considered high performance elements.
- Bushings for different types of sliding bearings are styled in order to attract engineers and others before being assembled in a product.

8. Trends and discussion

We will use a photograph of a scale model of a concept truck (Figure 11) to illustrate what we see as the trends regarding machine elements.

Figure 11. A photo of a physical model of a future concept truck from Scania

Looking at the figure reveals some trends. One is that the wheel rims of the truck are styled in a similar way to the wheel rims of today's cars. Another is that most of the technical solutions are concealed behind the outer covering. It seems reasonable to conclude that the shape and the appearance of the outer surfaces will be important and that producers will put considerable effort into the visible parts. From other sources we know that by using new concepts such as drive-by-wire the driver's space can be improved considerably. This cannot be seen in the picture. The loading space and the structure of the truck will probably also be improved from both a human and a technical viewpoint by using new propulsion systems and other ways to build trucks. That might also influence the use of classic machine elements.

The attractiveness of a vehicle is connected to its function, ease of use and how well it is perceived in general. In the future, just as today, the classic machine elements will contribute to the attractiveness of a vehicle mainly through their technical functions and performance. It is unlikely that high performance machine elements will be visible. The trend is rather towards a separation of the styled covering parts and the mechanical functional parts such as shafts, gears and couplings. Thus it is probable that there will be more sophisticated styling of the coverings of machine elements in the future. If the classic machine elements are developed, it is likely that the performance will be improved in the future.

This trend should also influence education in the design of machine elements. More emphasis should be placed on styled covering elements than before, but design education regarding high performance machine elements should be at least at the same level as today. The results of this study therefore have some consequences for engineering education, particularly as regards machine elements and related subjects. If we consider the well-known Axiomatic Design Theory it seems as if the first axiom (the independent axiom) will be a dominant trend for future trucks at least, but probably also for many other applications.

9. Conclusions

The following conclusions can be drawn from this study of different machine elements:

- Future machines will probably have more attractive covering elements than today.
- The attractiveness of machines is often increased when the performance of some classic machine elements is improved.
- New technologies such as drive-by-wire and new propulsion systems will probably improve the attractiveness and performances of vehicles.
- The attractiveness of a universal joint is mainly related to how well its technical functions are fulfilled over its entire life.
- In the same way as today, gears will indirectly contribute to the attractiveness of many types of machines by their technical behaviour and performance.
- Gears are seldom visible but can be made visible if alternative lubricants are used or if lower performance is accepted.
- Rolling bearings are normally regarded as high performance elements.
- Bushings for different types for sliding bearings are styled to attract engineers and others before being assembled in a product.
- Education in machine elements should be supplemented with education in styled covering elements.

10. References

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