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PART SYNTHESIS USING PHYSICAL LAWS AND ALLOCATION OF WIRK ELEMENTS

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Abstract

No natural or technical system can function contrary to physical laws and thus, every technical system can be described by one or several but a finite number of physical laws [1]. We will further develop a method that uses physical laws in order to conceptualise or upgrade the existing technical systems, where the main focus will be on their synthesis.

Each physical law has its complementary basic schematic, whose smallest building block is represented by a wirk element. Wirk elements are identified from physical laws and basic schematics. Procedure of formalizing the transition from physical law to a schematic of a future technical system is indicated.

Keywords: part synthesis, physical law, basic schematic, wirk element

1 Introduction

Potential of using physical laws as a source of new ideas or for generating innovative alternatives to the existing technical solutions has been recognized by several authors [2, 3], and has been part of the active research. Several software tools, using this method, have been developed, either to optimise structure sharing of the existing concepts [4] or to search for possible concepts that would fulfil the desired functions. The software tools support generation of a greater number of alternatives and better management of growing complexity of parts, although the transition from a physical law to the embodiment is not sufficiently transparent.

In order to reduce the gap between the abstraction of physical laws and the embodiment, the use of basic schematics that represent the complementary part of physical laws, was suggested [3]. Each law is represented by only one basic schematic that may take many different forms at the end of the embodiment process (Fig. 1).

A problem that arose was the transition from physical laws and their basic schematics to the embodiment of a future technical system, which had to be performed by an experienced design engineer. It is our assumption that transition could be performed formally via decomposition of basic schematics into wirk elements. Part synthesis (i.e. embodiment) would then be performed by means of allocation of wirk elements, using an appropriate allocation mechanism and structure sharing.

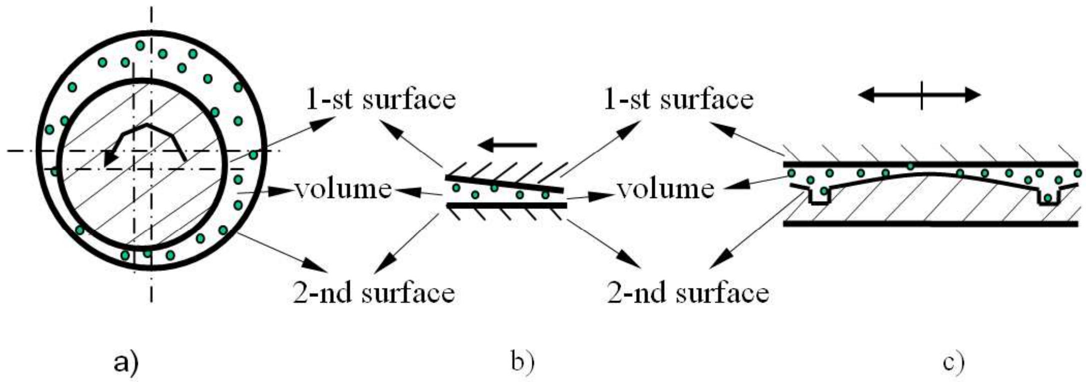


Figure 1. a) Cylindrical bearing, b) basic schematic and c) sliding plate.

2 Method

During the conception phase of the design process, the method suggests the procedure, shown in figure 2. The purpose of each technical system is to fulfil some desired function. From the main function, the initial variable is extracted, by means of which appropriate law or chain of laws and basic schematics are sought. The chain of basic schematics represents the necessary geometrical form to fulfil the law. At this point, the final shape of the technical system still has to be done by the designer, which is an advantage in case of an innovative design, since it does not suggest an existing technical solution.

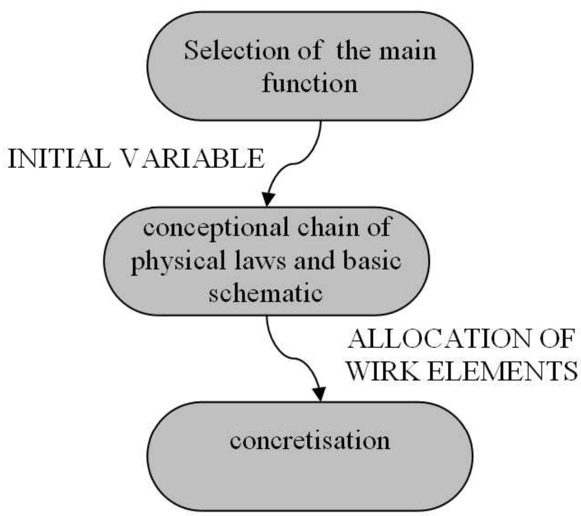


Figure 2. Activities in conception phase of a design.

2.1 Selection and chaining of physical laws

For the purpose of searching and creation of chains of physical laws we used a programme, developed at the Faculty of Mechanical Engineering, University of Ljubljana. This programme uses a database of 138 physical laws and their variants. With an additional set of laws, the number of possible solutions would be even bigger (Koller and Kastrup gathered a set of 161 laws [1]) but studies have shown that an explosion of solutions does not appear. The conceptual design tree of chains is shown in Figure 3. The conceptual design tree represents possible solutions for the initial variable.

Initial variable (X) was selected from the main function. In the first step, X represents the independent variable, connected with the dependent variable Y through the physical law. In the next step, Y is the independent variable, connected with the dependent variable Z. If the dependent variable is a geometric, material or base variable (N), such as length, time, mass, electrical current, temperature, amount of substance and luminous intensity, the chain ends. Programme algorithm is described in details in literature 5.

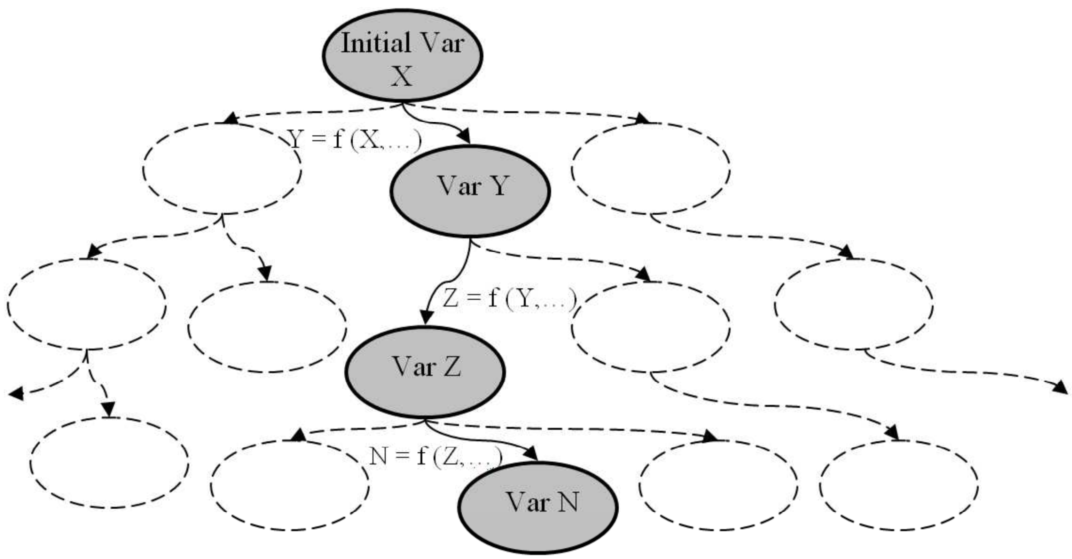


Figure 3. Conceptual design tree with a highlighted conceptual chain.

2.2 Identification of wirk elements

At first, it was presumed that the synthesis could be done by means of the existing schemes that describe technical solutions (Figure 4a) [6], [1]. This was a step towards formalization of the synthesis process but at the same time it was recognized that some structure merging can occur, which can easily be overlooked if only formal schemes are used (Figure 4b).

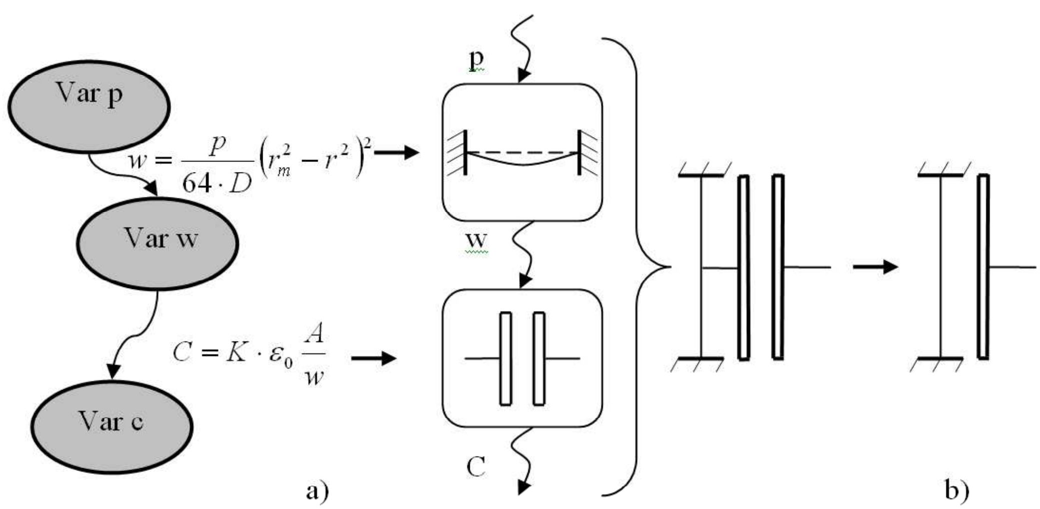


Figure 4. a) Schematic of chaining conceptual design chain and its concretisation [6]. b) Structure merging.

This leads us to further investigation of elements that are common to schematics, representing technical solutions. These common elements are called wirk elements and they represent places where function is realized. For the purposes of this procedure, wirk elements will be defined as a point, line, surface or volume. Basic schematics are built from several wirk elements that are necessary for realization of physical laws. In many cases, the setting of wirk elements is also essential.

Two recent approaches to part synthesis with the use of wirk elements were made by Jensen [7] and Matthiesen [8]. Jensen defines wirk element (point, line, surface or space of continuous geometry and uniform material) as the lowest level of resolution in the organ domain, where organ is a structural design element for the complete realization of a given function. Some organs consist of only one wirk element (helical spring, spiral spring, cantilever...). On the other hand, Matthiesen defines wirk elements only as a surface in contact with another surface through which energy, material and information are transported. Distant influences, such as gravity forces between bodies are explained as a surface contact between gravity fields. These surfaces are then mounted onto the supporting structures.

In this article, the focus will be mainly on the shape characteristics of the wirk elements that are relevant for the final embodiment. To do this, several things should be agreed on:

- Working effect is always transmitted between two identical wirk elements. If surface is one wirk element in contact and point is the other element, then the working effect would be transmitted through the simplest shape wirk element in contact which would be a point in our case.
- Although one could argue that every point has an infinitely small surface, a wirk element, such as the point, exists theoretically, however, by its nature it is part of wirk elements of a higher complexity, such as the surface (Figure 5.b). For example: if we consider static friction (Figure 5.a), there are no geometrical units in the static friction law, but it appears only if one body/fluid is in contact with another body/fluid. Only compatible wirk element that would be able to receive the effect of this law would thus be a point.

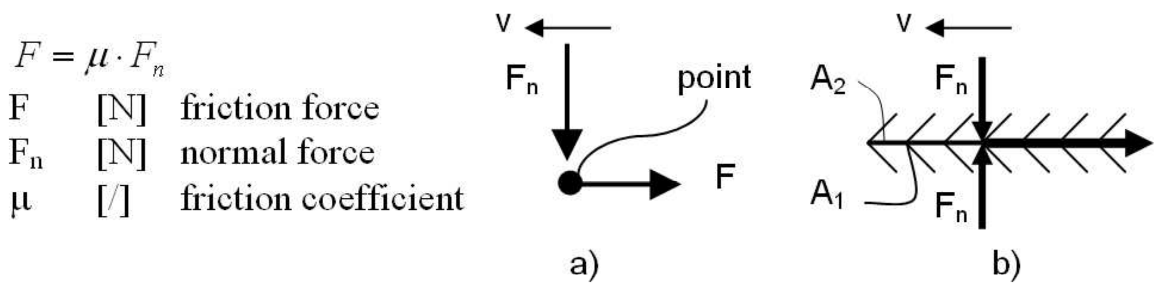


Figure 5. a) Point identified as wirk element from the physical law of friction and b) suggested basic schematic.

- When considering a line, we again have the same reasoning as with the point. Wirk element that is represented by the line is much bigger in one direction than in the other two directions. Line would also represent a beam of light (Figure 6).

$$\frac{n}{n_0} = \frac{\sin \alpha_0}{\sin \alpha}$$

n_0	[/]	refraction coefficient of first substance
n	[/]	refraction coefficient of second substance
α_0	[°]	angle of a light beam in first substance
α	[°]	angle of a light beam in second substance

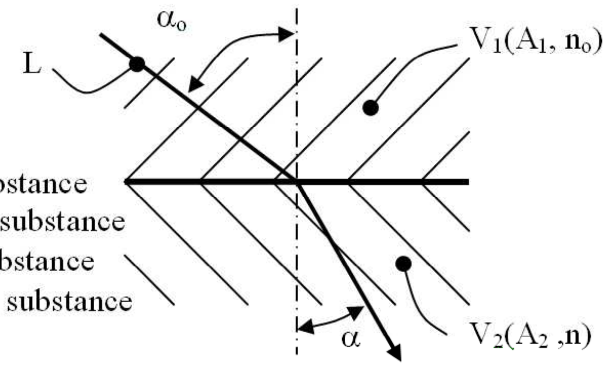


Figure 6. Refraction of a beam of light.

- Velocity or acceleration does not include geometrical or structural characteristics, so they are not used indirectly for part synthesis.

$$F = \frac{\eta \cdot A}{h} \cdot \frac{\Delta l}{\Delta t}$$

$$v = \frac{\Delta l}{\Delta t}$$

F	[N]	viscosity force
v	[m/s]	velocity
A	[m^2]	surface
η	[Ns/m^2]	viscosity
h	[m]	hight
l	[m]	path
t	[s]	time

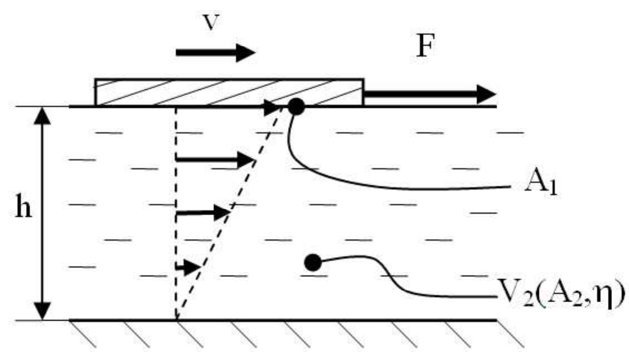


Figure 7. Viscosity force.

- At the end of the concretisation process, all wirk elements will be located on structural elements that have some volume. In many cases, volume has the role of a supporting structure, but in others, volume carries information about material, field etc.

$$F_g = \rho_1 \cdot V_1 \cdot g$$

$$F = \rho_2 \cdot V_1 \cdot g$$

F_g	[N]	gravity force
F	[N]	buoyancy force
V_1	[m^3]	volume
ρ_1	[kg/m^3]	density of volume 1
ρ_2	[kg/m^3]	density of volume 2
g	[m/s^2]	gravity acceleration

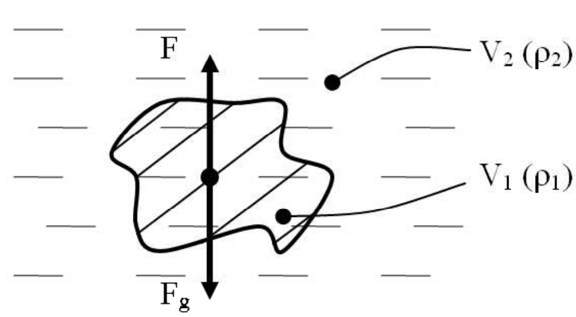


Figure 8. Buoyancy force.

2.3 Allocation of wirk elements

Wirk elements are identified directly from the physical laws and its complementary basic schematic is shown on the following example of fixation of a tube to a wall (Fig.9). We are observing only the clamp part of the joint. Loading force is transmitted from the tube onto the clamp part through the surface A_I. Half of the load is then transmitted through the surface A_{II} on each of the screws and then further onto the fixed part of the joint.

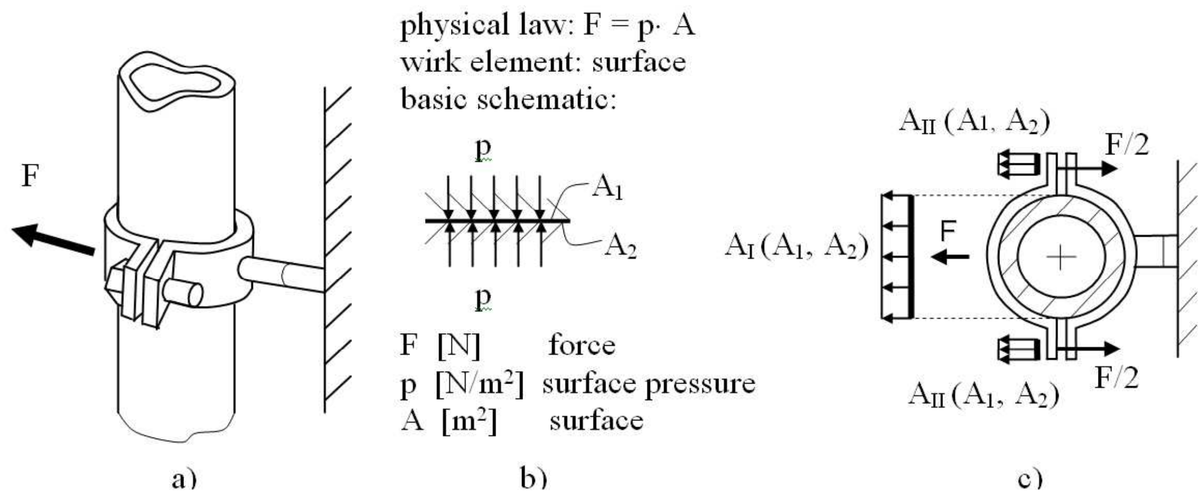


Figure 9. a) 3D model of a tube joint and b) basic schematic of the physical law and c) cross section with loading of the clamp part of the joint.

On all contact surfaces, the same physical law was observed and the same basic schematic was used. We will continue with the same physical law and basic schematic but the wirk element (surfaces) will be relocated, which will thus generate alternative solutions (Fig. 10).

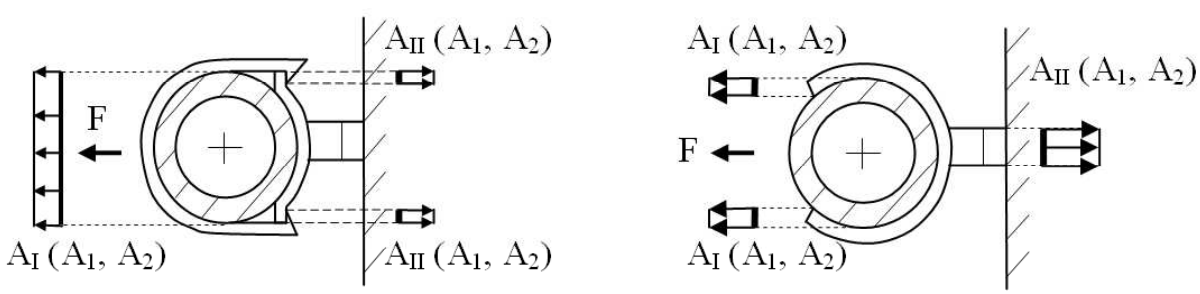


Figure 10. Two alternatives of a tube fixation with the use of the same physical law and basic schematic as in Fig. 9 but with relocation of wirk elements.

Further alternatives can be generated with the use of different physical laws: static friction (stick-slip effect) (Fig.11.a), magnetic force (Fig.11.b) and shear force (Fig.11.c). Although the basic schematic changes every time when the physical law changes, this does not necessary mean that the wirk element would also change, since all basic schematics are built from only four types of wirk elements (point, line, surface and volume).

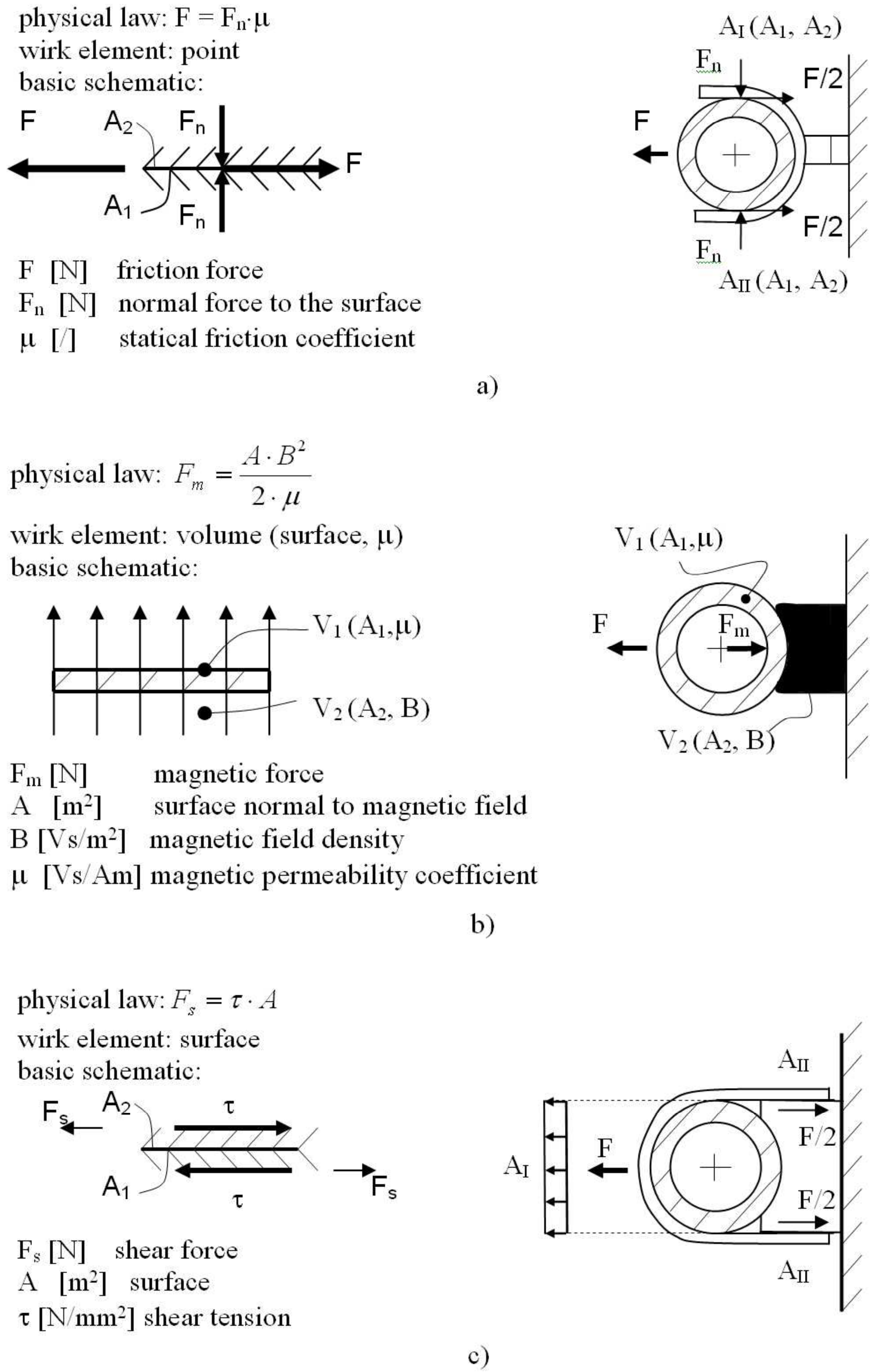


Figure 11.Tube joint with the use of a) friction law, b) magnetic force law and c) shear force law.

3 RESULTS

We used this method in order to search for solutions of fixing a vacuum cleaner motor (VCM) in a fluid. Because the visibility and free flow are required, the motor should be fixed in such a way, that there would be no obstacles at inlet, outlet or through the flow path of the VCM. Fixation should be carried out in such a way that it could be possible to remove or replace the VCM. Housing of the VCM is made of a plastic material. This is the reason why we decided to make transmission of the mass load with the use of static friction law. Static friction will be set on the flat surfaces of the casing (Figure 12).

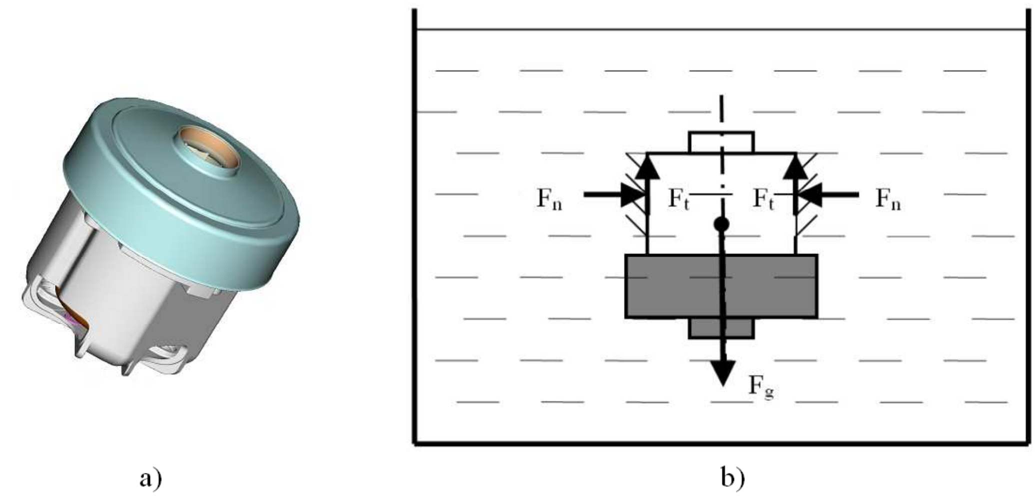
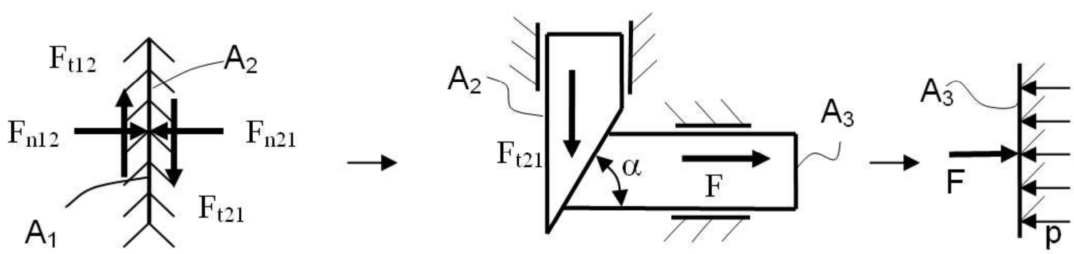


Figure 12. a) Vacuum cleaner motor and b) fixation of a vacuum cleaner motor in a liquid vessel.

One of the solution chains is shown in Figure 13. Every physical law from the chain is also represented by its complementary basic schematic. Merging of the wirk elements in contact gives us a basic schematic solution (Figure 14).



$$F_{t12} = F_{n12} \cdot \mu \rightarrow F_{n12} = F_{n21} \rightarrow F_{n21} = \frac{F_{t21}}{\mu} \qquad F_{t21} = F \cdot tg\alpha \qquad F = p \cdot A_3$$

$$F_{n12} = p \cdot A_1 = p \cdot A_2 = F_{n21}$$

$$A_1 = A_2$$

Figure 13. a) Solution chain of physical laws and their basic schematics.

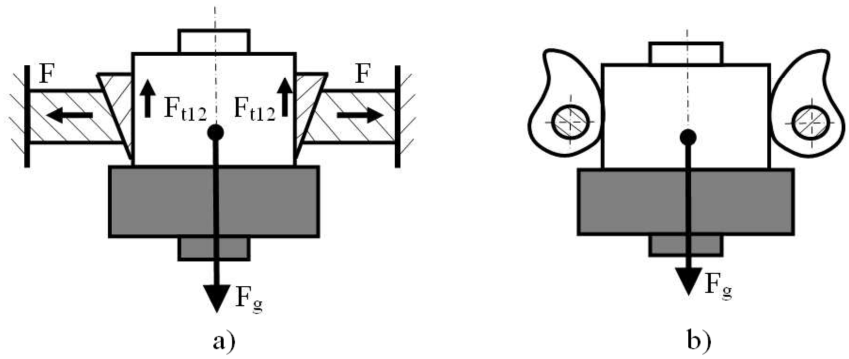


Figure 14. a) Basic schematic solution and b) final concretisation.

4 DISCUSSION

After the creation and analysis of the physical law and basic schematic chains, we found out that only a small number of suggested solutions were suitable to fulfil the desired function for the given conditions. It was also noticed that the bigger the law chain the bigger the chance that there will be some physical law in the chain that does not fulfil the required conditions (material is not suitable (magnetic or electric characteristics are required), some laws have the same variables, but their direction of action or magnitude is not suitable, etc).

Some of the mentioned shortages were eliminated by the use of complementary basic schematic, where the direction of action is indicated and the necessary characteristics of the material are included in the volume wirk elements. Further decomposition of the basic schematics into wirk elements and their allocation enable the creation of a wider scope of solutions and they also support an innovative design, since they do not use the existing solutions from design catalogues. Concept of decomposition of basic schematic into wirk elements is shown in the chapter *Identification of wirk element*s and their allocation in the chapter *Allocation of wirk elements*.

Authors admit that the last step from the basic schematic solution (Figure 14a) to the final solution shape (Figure 14b) was made on the basis of experiences, but the solution was strongly indicated from the basic schematic. The step from the basic schematic solution to the final concretisation form of the product still has to be made by the designer, since the method does not include production facilities, esthetical values, material costs, etc.

5 CONCLUSION

The described method supports a designer in the conceptual phase of the design process, where solutions are sought by means of chaining of physical laws and its complementary basic schematics. Our goal in this research was to formalize transition from physical laws to the embodiment of a part or the technical system. The first step was the introduction of basic schematic with identified wirk elements and their allocation. Basic schematic also proved to be applicable at the preliminary evaluation phase, where some non-feasible solutions were excluded, because vector or material characteristics that had been included in the basic schematic were not fulfilled. Currently, the method is performed manually and it is only the part of chaining of physical laws that is supported by the software tool.

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