Selecting a Flat Belts for the Model of Coupling with Flat Belts

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Abstract. Mechanical gears with flat belts are currently the most intensively developing group of mechanical transmissions. This is due to the need to increase the speed of moving elements of machines and to transfer torque over considerable distances. This intensive development has enabled the development of materials engineering and the emergence of modern materials in the production of belts. An example would be the use of Kevlar and modern Carbon fibers. Analysis of the latest flat belt designs against the background of the whole group of these gears allows to indicate how to choose a belt for the gear so that coupling with the wheel is optimal. For this purpose, the model of coupling was analyzed again for modern drive. Modeling of this process is a solution to the age-old problem of choosing the right belt for a belt transmission.

1 Introduction

Flat belt transmissions are currently the most intensively developing group out of all kinds of mechanical transmissions. This is likely due to the ever-increasing need for faster transportation of elements, as well as the accompanying it need for torque to be transmitted over longer than ever distances. The extensive development of flat belt transmission contributed not only to the robust development of the field of material engineering but also led producers to use modern materials in the production of belts. Examples of that can be seen in Kevlar belts, and innovative carbon-fibred types of belts – Carbon[1]. The contemporary materials alongside parameter advancements call for a new approach to be taken when modelling the phenomena occurring in the process of coupling the belt with pulleys[2,4]. Moreover, when the phenomena are at last modelled correctly, the problem of selecting the right belt for a belt transmission becomes quite uncomplicated.

2 Design of flat belt and pulley

A typical flat belt consists of: a carcass (load-bearing layer), covering of the running side (running layer), and covering of the dorsal side (back layer) (Fig. 1).

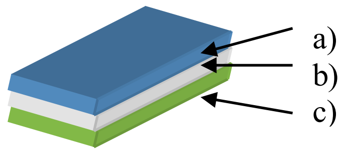

Fig.1. Construction of a flat belt: a- back side, b- load-bearing layer, c- running side.

Firstly, it is important to notice that belts with both running sides (used to drive a plurality of shafts or in a tangential drive) often have these layers made of the same material. Some belts are built only of the supporting layer, such as steel belts - polyamide belts made of oriented polyamide - or various types of fabrics, ranging from natural, through mineral, to synthetic. Such a construction can be seen as disadvantageous as the matrix subjected to abrasive wear changes its properties, which leads to a rapid degradation of the belt. To prevent this, various types of surface finishing methods are used. Most flat belts have a warp covered with additional layers, that is elementarily responsible for transmitting circumferential force, thus, as the layers constitute for the foundation of the belt, they are responsible for its coherence [8,9].
Nonetheless, there is not just one type of a belt warp, many modern materials proved to be effective solutions to the construction of flat belts, which are be divided into three groups: solid, fibrous, and composite. However, materials such as Polyamide, Polyurethane, Polyester, Steel, and other metal alloys dominate amongst solid bearing layers. On the other hand, fibrous materials (mainly fabrics and threads made of mineral, synthetic, and metal alloys) are not as commonplace. Yet when it comes to the composite carrier layer, a combination of the aforementioned materials is used most often [6,7].
New types of warp in the belts are aimed at improving their mechanical properties. Oftentimes an inextensible cord is used for the transmission process to approach the Euler model. Nonetheless, it is important to notice that the cord should be flexible enough so that the belt can work on small diameter pulleys.
The shape of the pulley can prove to be a significant problem in the transmission with a flat belt. The pulley should be shaped in such a way that the belt remains entirely on the pulley track. A larger diameter in the center of the pulley causes the linear speed of the belt to be greater in this area which subsequently pulls the belts from the area of the pulley with a lower linear velocity. One solution to this problem is engraving a groove on the pulley which by cooperating with the wedge profile of the belt helps to keep it aligned. However, this solution is less efficient and durable. Therefore, it is used in heavy-duty transmissions where belts travel only a short distance or at low speed [12].
In modern transmissions, attention should be paid to the surface condition of wheels and belts. It is of course conditioned by the materials selected for their production; however, the production technology is of equal importance. In a modern transmission, the condition of the contatct surfaces must be designed so it meets the conditions of the coupling model.

3 Model of coupling, modern flat belt with pulley

For proper operation of the system, an important factor is the correct geometry of the transmission and the appropriate pre-tension force of the belt. The value of this force should be selected so that the passive tendon remains under tension during the transmission of the maximum circumferential force F_U ($F_2 > 0$). The basic principle of the frictional coupling described by Euler by the equation in which stresses can be replaced by forces will be fulfilled then given that:

$$\frac{F_1}{F_2} = e^{\mu\beta} \quad (1)$$

Force in an active cable F_1
The force in the passive cable F_2
Belt-pulley friction coefficient μ
Wheel wrap angle β
The base of the natural logarithm e

The value of the circumferential force can be obtained from the previously indicated equation by substituting in the belt drive parameters. Unfortunately, the formula does not take into account the dynamic loads that may occur in the transmission, e.g. blockage of the drive system[11].

The maximum circumferential force is often difficult to predict or calculate. In this case, an adequate force estimate is determined from the mechanical properties of the belt, such as bending resistance, and tensile characteristics (elastic strain range, tensile strength, creep, and stress relaxation). The minimum diameter of the pulley for flat belts is determined based on a multiple bend test at the lowest temperature allowed for the material that the belt is made out of. Thanks to the tensile tests it is possible to determine forces required for 1% or 2% elongation and their values are given as the maximum permitted value of the circumferential force. In recent years, most manufacturers have adopted a new parameter to calculate this force (usually provided in their catalogs) which is simply the relationship between the force needed for the belt to be elongated by 1% and the unit belt width. In a situation where a belt is selected for an already existing structure with no information about the forces that may occur in the transmission provided, it is advisable to use a belt that can transfer the greatest possible circumferential force. Subsequently, the only vital information left (that would affect the choice of the belt) would be the minimum diameter of the circle.

It is also important to take into account the plasticity of the belt. For instance, using belts which do not deform excessively while working in drives, can increase the durability of the whole system, as no microcracks occur within the structure of the belt. Therefore, by using more rigid belts it is possible to curb the pace at which the covering material wears off, thus making the belt more durable[10].

However, when a flat belt is used for transport, the circumferential force depends mainly on the weight that the belt is to carry and the system that supports the belt throughout the transport process.

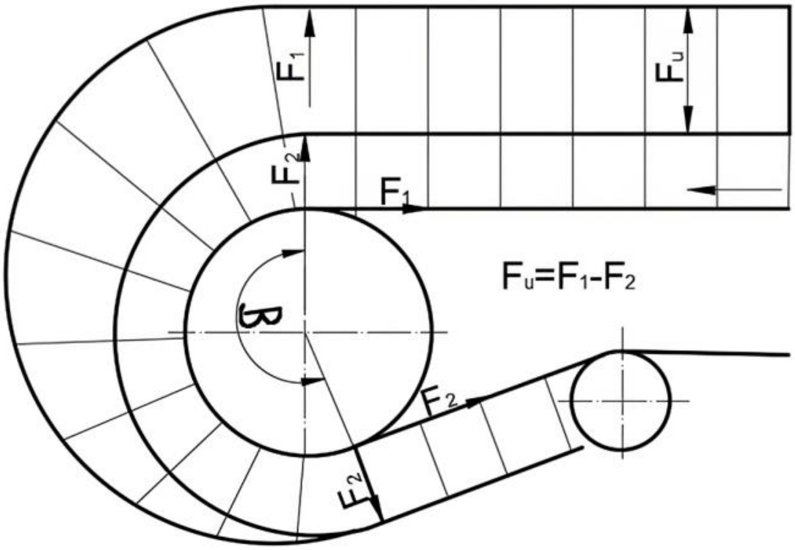

Fig. 2. Loads in gear with flat belts.

The circumferential force must overcome the friction force, $F_U > F_t$. For sliding friction the simplified Coulomb formula is used, $F_t = \mu_A F_n$, and for rolling support $F_t = \mu_R F_n$. (Fig.2) $F_U > F_t$, where we use Coulomb's formula, $F_t = \mu_A F_n$, In case rolling support $F_t = \mu_R F_n$. When dealing with "long" belts where the material transported is not evenly distributed, it is advisable to choose a belt suitable for a transmission of forces which value is several times greater than the originally calculated force. This measure will prevent the belt from lengthening at the beginning stage of work. That is because an uneven load causes unit elongation of the belt in the area of the active tendon just behind the driving pulley.

4 Testing of the vulcanization process of the rubber covering of the running side

In the case of coupling a flat belt with steel pulley, the most important for the process are the properties of belt. The quality of surfaces has primary influence on friction coefficient, but one of equally important are the mechanical properties of running side material. This properties are dependent from type of used rubber and quality vulcanization process (Fig.3,4). Material samples are usually taken for testing in the process of preparing the polymer mixture. Tests are then subsequently carried out during the vulcanization process. Examples of such tests of materials most often used in the production of flat belts, (HNBR and EPDM rubbers) are presented in the following figures. Figures 3 and 4 show the parameters of the vulcanization process, cross-linking, and hardenings.

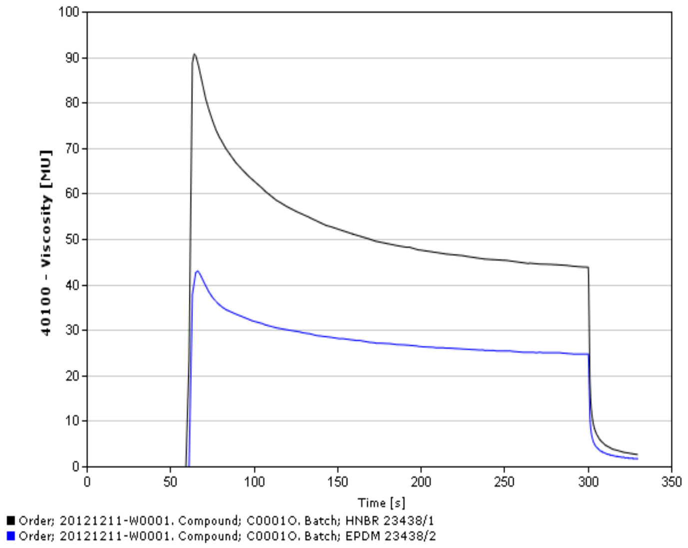

Fig. 3. Cross-linking of polymer chains in %.

The correct course of the polymerization process has an impact on the surface properties of the belt, especially the specific coefficient of friction. In the case of sliding friction, the grip related to the adhesion of the material and the belt to the pulley must be taken into account. It also affects the durability of the belt (Fig.3).

The research conducted jointly with one of the leading producers of rubber mixtures allowed to establish a number of parameters influencing the mechanical properties of belts made of these materials. It is impossible to mention all of them in this material. Another important measurement was the measurement of the rubber hardening process in the vulcanization process.

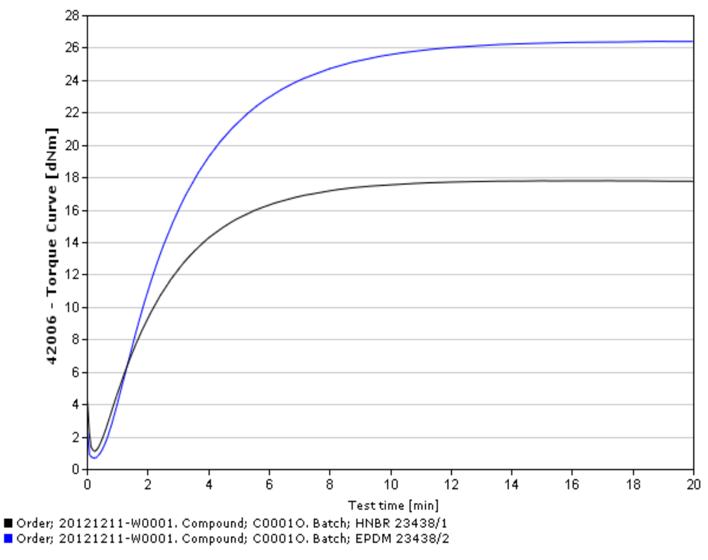

Fig. 4. Hardening in the process of vulcanization.

Hardening of the belt surface has a positive effect on abrasion resistance, but through-hardening causes cracking and premature failure of the belt. Therefore, a high value of this parameter is not favorable for the friction phenomena occurring in the flat belt and on the wheel surface.

5 Conclusions

When choosing a belt from a group pre-existing belt structures, it is important to differentiate that the belt is merely fitted for the needs of the construction, contrary to common belief it is not designed for it.

$$\frac{F_1}{F_2} = e^{\mu_A \beta} \qquad (2)$$

Such selection is based on a thorough analysis of the conditions in which the designed gear is to operate. First and foremost, it should take into account environmental conditions, such as temperature, humidity, lighting, explosive environment, contact with food, or special chemical conditions. Secondly, it is essential to determine the geometric conditions of the space in which the gear is to be placed. This restricts, for example, the value of the pulleys' diameters, and the width of the belt that is to be used in the process of transmission. Only having taken into account the former, one can begin to calculate the values of the forces, ratio, and selection of the most durable and operational belt.

Designing gears with flat belts may seem simple due to the large selection of ready-made solutions. Furthermore, their operation is undemanding and has been used and tried in the industry for hundreds of years. What creates a significant challenge is, however, designing appropriate disposal of used belts. Depending on the material from which they were made, the utilization of the belts should be carried out together with products made of the same materials, which is an often-disregarded issue.

Therefore, it can be said that the most important stage of belts' lives is the period of operation for which they are designed. Nonetheless, the method of monitoring the condition of the belt and pulleys, thus forecasting their lifespan is quite imperfect. Generally, this period is determined experimentally or depends on other elements of the drive system which makes it highly fallible.

Hence, supervision over the technical condition of the belt is of utmost importance. It should be carried out regularly by inspecting the technical condition of the running side, measuring the belt thickness, or measuring the natural frequency of the tendon. The latter method makes it possible to observe whether the belt has experienced stress, relaxation, or creep processes. The method is moreover is used when introducing the pretension force.

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