Modeling the damages of belt gears

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Abstract. This paper looks into the problem of choosing a driving belt for a drive. The previously developed selection of algorithms was subjected to another evaluation that helped us recognize the need for changes indicated in developing new designs of drive belts. The new algorithm will be tested by simulating the operating conditions of the transmission, to which the right belt must be selected. Damage assessment after operation and belt selection allows for the identification of a new coupling model. By presenting the relationship between specific failure cases and the parameters of the coupling model, we can see the functionality of the selection algorithm. There may be multiple belt transmission damages. The feed may be broken; the surface may be damaged; the same applies to the edges. Furthermore, the wheels and bearings may be damaged too. The belt can have many additional functions that affect its operating parameters. Next to the drive function, the belt often performs conveyor and control functions. Thus, additional types of damage occur in belts with additional functions. The number of causes of their occurrence is also growing. For example, any damage to the sling in the passenger elevator can endanger the life of the passengers. Intensive research is being carried out on the real-mode damage monitoring systems. Specific failures are being monitored, and appropriate systems are being designed for them. Therefore, it is important to investigate the damages to belt transmissions, modeling their course of progression and causes.

1. Introduction

Durability is the fundamental problem for designers and users of mechanical transmissions, as it depends on many factors, which determine the choice of a belt used. The choice is the more important, as it directly affects the quality of operation, the degree of belt wear, and the damage to the transmission. By analyzing these parameters, it is possible to propose a selection model that would consider the consequences of exploitive issues to indicate the directions of subsequent research into developing even better belt structures.
Figure 1. Flat belt made of polyurethane with a steel cord (running side with a visible cord and technological slots).

Over the years, two trends related to production technology have developed: polymer belts and belts made of elastomers. In recent years, we have observed a merger of the constructions obtained in these two technological trends, which offers belt designers many choices for the structure. Nevertheless, the currently accessible computer programs supporting this choice are still mainly created by manufacturers, influencing the designer's choice and making them inherently partial to only one specific group of transmissions. The selection algorithm, of course, requires creating a pervasive database of toothed belts and materials used in production. Therefore, manufacturers or traders should not be tasked with creating a belt selection program to be used for construction and design purposes, as their goals are aligned with the ones of the world of academia, as they are driven by profit-maximizing decision-making. Instead, a suitable algorithm should aid the design of the best solution for the operating conditions. Before starting this project, we had discovered a gross lack of algorithms that could be used to determine the selection of a specific belt transmission. Therefore, we would like to highlight that the investigation of an appropriate toothed belt gear selection algorithm will allow it to be included in the overall belt transmission selection algorithm, thus aiding its further development. However, as shown in this study, the belt transmission selection algorithm still has several development elements.

2. New functions of belt transmissions

One of the directions in which belt drives are developing is the use of belts as a driving element and the main driving tool of transportation and system control. At the stage of belt production, the running side of the belt is formed correctly, and the dorsal side or a particular arrangement of the cord in the supporting layer is made. Different versions of the same batch produced can be made separately or simultaneously (Figure 1). After production, the belt may undergo additional machining or other types of treatment [5]. Later, such a finished "universal belt" can be adapted by the user to his conditions of use without generating waste and unnecessary belts with each change of the production technology or use of the machine. In the latest designs, the increase in functionality is associated with the placement of sensors in the belts that monitor the drive system's technical condition and information carriers. In addition, a whole range of universal elements is developed that can be attached to the belt. Universal bolts and elements connecting the ends of the belt are being manufactured. Work is underway on solutions that allow the belt to be driven with a magnetic field to obtain higher speeds, accelerations, and decelerations.

The next direction of belt construction development is much less developed but has much broader prospects, especially in thermoplastic belts. An example of such structures, already present in some devices, is the placement of electric cables in the belt's supporting layer, allowing for electricity supply or a signal control of the motor (manipulator) located at the end of the belt. This solution, of course, applies to belts produced in ribbons in which the cord is placed in parallel. Elements that can be placed
in this way can be any wires placed in the axis of the cord, not causing a significant change in the belt's stiffness and flexible enough not to be broken on the pulleys. Data carriers that can be read either magnetically or optically can also be mounted in the carrier layer. The main problem with making this type of belt is to position the controls so that the geometry of the belt is not damaged. Excessive heating when placing the wires, excessive perforation, or overloading the belt with elements placed on the dorsal side can cause the belt to fall out of synch with the pulley, making this type of belt unsuitable for this type of application. Note that steering belts are manufactured with a pre-tensioned cord, and excessive belt overheating may lead to tension relaxation or creep between the belt material and the cord. It may cause the belt to buckle, which will result in the belt not working correctly on the pulleys. Leaving the space in the load-bearing layer without a cord reduces the breaking strength of the belt. Therefore, in this type of belt, the cord with the best mechanical characteristics is used. A properly selected type of cord, even unevenly distributed, ensures that in cases of belt overload, the running layer detaches from the bearing layer. There are cases of belt breakage at the mounting brackets due to over-tightening of the bolts, similarly to the self-clamping jaws of a testing machine in the case of poorly prepared samples. New solutions have been developed - belts made of fabric, mostly polyester, covered with polymers, thermoplastics, or thermosets, with mechanical parameters even better than the existing belts, usually based on a polyamide matrix. The belt material is adjusted to specific speeds, and the belts are made with an unevenly spaced mass or contour of the running side to avoid excessive vibration at certain speeds.

3. Algorithm of the computing program of the belt transmission

When starting to design a belt transmission, it is necessary to determine what functions the designed transmission is to perform, of course, bearing in mind the limitations and possibilities of this type of transmission. Proper use of the available functions allows for a number of elements of the designed device to be reduced. For the available possibilities, an algorithm (Figure 2) for calculating the gear used to transfer the drive between two shafts has been developed (Figure 3). The directions of activities marked with letters: A, B, C, D, due to the limited scope of this study, have not been included. The directions of the algorithm’s operation, marked with the letters: X, Y, Z, V, consist of separating complex belt functions and carrying out separate interactions.

After going through a series of first queries, the belt design begins with selecting the appropriate cord. The first criterion chosen is the flexibility of the cord. There is a design method by selecting the stiffest cord that can work with pulleys of a specific diameter. However, in the case of the algorithm, this would significantly limit the choice of the optimal belt. Therefore, starting with very flexible cords still leaves a wide choice of belts.
Will the belt act as a drive?

Will the belt serve transportation purposes?

Will the belt serve control purposes?

Does the gearbox convert rotary motion to linear motion?

Does the gearbox contain more than two shafts?

Are you looking for a transmission with a multifunction or special belt?

Are you looking for a belt for different forms of drive?

The belt is used for drive and control?

The belt is used to fulfill more functions in special environmental conditions

Enter the minimum D1 and maximum D2 the diameter of the smaller wheel and the maximum width of the gear B

From the database of available cord types, select the “first” K sorted by starting with the most flexible

From the P series of types of belts, select the first available for the selected pulley diameter

Does the selected belt satisfy the conditions of the following function?

Does the selected type of cord exist?

Can the selected type of cord work on wheels with a diameter of D2?

Is the selected belt with the selected K cord?

Figure 2. Drive belt selection algorithm, central part.
Figure 3. The flat belt on the belt arc of a pulley.

4. Drive belt selection model

The users' expectations demand from the designer to be determined the time-life of a belt, taking into account the main parameter of belt durability \(D\). That criterion is material aging - factor \(M\); another criterion could be material exhaustion \(F\).

\[
D(t) = M(t)
\]  

(1)

When designing the operation of the transmission, the abrasive wear of \(V_p\) belts and \(V_B\) pulleys is considered. However, it must remain related to the maintenance and replacement schedule designed in operation. In addition, it is not accounted for damage caused by other system components such as bearings, couplings, etc.

\[
\begin{bmatrix}
D(t)
\end{bmatrix} = \begin{bmatrix}
M(t) \\
F(t) \\
V_B(t)
\end{bmatrix}
\]  

(2)

Even though belt transmissions allow for the cooperation of misaligned wheels (not lying in one plane), the quality of the wheel mounting is crucial for the durability of the transmission. Wheel runout or eccentric mounting may lead to the belts' premature wear. Gear geometry errors often lead to belt distortion, edge damage, or breakage. An improperly selected belt for loads may undergo plastic deformation, and the phenomena of creep and stress relaxation occurring in belts made of polymers.

The proposed algorithm for selecting a gear with a toothed belt implements the previously proposed general model of coupling the toothed belt with pulleys:

\[
\frac{s_1}{s_2} = e^{\mu \alpha} = f \left( \sum_{v=1}^{\nu} \frac{\Delta v}{p} \right)
\]  

(3)

Where total deformation of the unit elements of the running layer (on the arc of contact with respect to the volume of this layer) determines the value of the ratio of active to passive tension. The ratio of these stresses is related to the elongation of the bearing layer. The smaller elongation causes the lower deformation of the teeth on the arc of contact bearing layer, and the smaller the elongation, the lower the deformation of the teeth on the arc of contact.

The weakest place of the selected drive belt is the connection point. As a result, there is often damage to the belt when the transmission operates under extreme conditions (Figure 4).
5. Conclusion

To conclude, it should be emphasized that the proposed method of gear selection puts the primary emphasis on the materials used in production. The presented sequence of selecting the design features of the belt transmission allows avoiding randomness in belt selection. It allows the designers to make their own decisions based on the mechanical properties of the belts rather than following the suggestions of profit-maximizing manufacturers. After answering the first few basic questions about the different functions of belt transmissions and their possibilities, the appropriate support layer is selected.

A belt for a structure can be selected from among the already available solutions based on the parameters determining the suitability of the belts for the given structure. Unfortunately, it is necessary to research to collect information about the modifications of the basic types of belts and the properties of the available materials.

Creating a computational program based on the proposed algorithm, accompanied by the designers' expertise, would enable unbiased belt selection processes to be made, independent of the incomplete information provided by belt manufacturers. Only then would the designed gears meet the operation model and be optimal in terms of technical parameters. Unfortunately, the prices of belts do not always correspond to the production costs and technical parameters. A prime example is the ratio of the production process duration of a 600 mm wide belt to its price. It takes about 1 hour to produce a rubber belt of such dimensions, and it takes a whopping 12 h to produce its polyurethane counterpart. While the former takes significantly less time to be produced than the latter, the prices of the belts are inversely proportional to the time difference in their production process.

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