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The problem of cooperation of a flat belts with elements of mechatronic systems

DOMEK Grzegorz[1, a], KOŁODZIEJ Andrzej[1,b] WILCZYŃSKI Michał[1,c] KRAWIEC Piotr[2,d]

[1]Kazimierz Wielki Uniwersity, Chodkiewicza 30, 85-064 Bydgoszcz, Poland

[2]Poznan University of Technology, Marii Skłodowskiej Curie 5, 60-965 Poznan, Poland

[a]gdomek@ukw.edu.pl, [b]a.kolodziej@pwsz.kalisz.pl, [c]mwilczynski@whm.pl, [d]p.krawiec@put.poznan.pl

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Abstract. A flat belt in power transmission and conveying systems cooperates with several elements consisting of timing pulleys, tensioners or guiding rails. Expectations concering coeficient of friction vary according to application. They depend strongly on characteristics of the process as well as the type of friction. In recent constructions, producers of belts are very much concerned about achieving as much slippery surface as possible. The work describes the problem of friction on different surfaces as well as its influence on gear lifetime. Research results confirm that on many surfaces bigger coefficient of friction is expected.

Introduction

A part of the system fulfilling at the same time the role of a transmission and a coupling – is a flat belt transmission. Mark Twain once said: "the reports of my death have been greatly exaggerated". Similarly, the following phrase can be reformulated: use of flat belts in advanced structures of machines is unjustified and firmly obsolete. Transmissions with flat belts were among the first flexible link transmissions and after introduction of other types of belts for the torque transfer, their role has been limited to a belt conveyor belts. They were called conveyor belts and process belts, which was a bad translation from the German language and it seemed that their function is very simple. Transfer of a product from point A to point B, or being a component of the manufacturing process (Fig. 1). Over the last years their functions and quality have started to significantly change as structures which may fulfill the strictest requirements of modern machines have been developed. In some machine drives they reach highest speeds which are unavailable for other belt types. They are also used in presses, where wooden or plastic plates are pressed under high pressure. Flat belts are also used in drives with the highest torques [1].

Fig. 1 Conveyor belt system in PU foam plant

Flat belt operation problems

A fundamental feature of belt transmissions is the ability to transfer torque to significant distances. This task can also be accomplished by other flexible link transmissions and drive shafts. Belts are used because they are lightweight and the transmission does not emit excessive noise. "Heavy" solutions cause loss of energy, but users consider them to be more durable. This is incorrect thinking, because the durability problem is solved by selection of an appropriate material also in the case of other transmissions. The conveyor belt and drive belt life depends on both volumetric and energetic wear. Belt transmissions are usually made of artificial and natural polymers, whose consumption of energy of bonds between chains of polymers causes material structure weakening and, as a consequence, cracking. Belts are also made from crystalline materials, like for example steel belts, and in this case material fatigue may occur after some time [2,3]. Volumetric wear is mainly caused by the abrasion, although there is also crushing of the material. Crushing of polymer belts occurs in the first cycles of belt operation, and of course after a long period of time due to material creeping. Abrasion occurs in all drive belts and conveyor belts and it results from the friction or combined form-fitting and friction coupling between the belt and pulleys. In a real belt transmission, the belt slip over the pulley is associated with the compensation of the driving strand extension in relation to the slack strandextension. Thus, since there is slipping in each transmission then also abrasion occurs there. Belts and pulleys are chosen so as the belt-pulley friction couple ensures maximum efficiency of the transmission, and the wear resistance is the second most important design factor. Pulleys highly resistant to abrasion are selected first, then the belt made of material resistant to abrasion, but the priority remains the friction factor. It often seems to designers that the friction factor is directly proportional to the abrasion resistance, but unfortunately it is not. Similarly, the hardness of the belt and the pulley does not directly translate into abrasion resistance as this is related to the internal structure of the material (Fig.2).

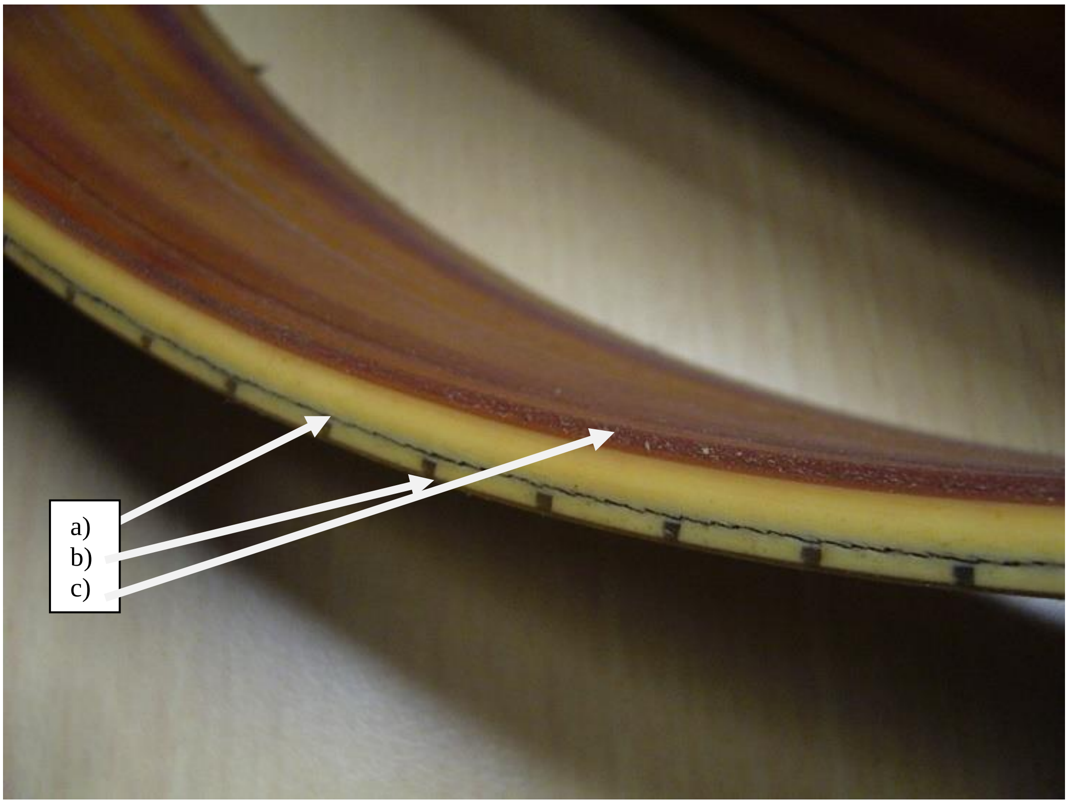

Fig. 2 Flat belt used in the floor panels machining process: a) steel cord, running sid, c) back side with abrasion resistant covering

The first flat belts were made of leader, and then this material was abandoned as flimsy one. Currently a number of belts which are built on modern matrix are covered with leader as this material is very resistant to abrasion. Presence of permanent slip on pulleys does not damage the belt and, upon reduction of the peripheral force, the belt can be further operated. Belts of such structure are used in the heaviest chippers in plants manufacturing wooden plates. Material abrasion is a phenomenon to which special attention is paid in the case of tires on the wheels of motor vehicles - rubber, industrial vehicles - polyurethane and railway rolling stock - steel. Similarly, in the case of belts working in extreme operating conditions different types of rubber are selected, while polymers are selected for indoor facilities and steel in the case of enormous pressures and very difficult operating conditions. Belt operation circumstances are often very complex. For example, belts dispensing banknotes in atms must not fail, although the ambient conditions between the winter and summer change diametrically [4]. The same applies to belts working in explosion hazard environments or chemically aggressive environments. In cigarettes production systems, the belt material penetrates the tobacco and is combusted together with it, therefore the range of materials for such belts is very limited. Conveyor belts in sugar production industry are subject to very intense abrasion, i.e. half of the belt thickness is abraded after two years of operation. There is abrasion product in the manufactured goods and its quantity amounts to hundreds of kilograms. The material of the belt must hold a food grade (be certified for contact with food) and already for several years the European Norms regulate the amount of material that can migrate into food from the belt.

Coupling between a belt and a pulley

The friction coupling of a weightless thread with a pulley was described by Euler it his papers and although this issue has been later addressed by many authors, the extension of the Euler's formula allows to understand phenomena occurring in the flat belt transmission. In the actual transmission one should indicate the phenomena occurring between the belt and the pulley and between belt material and the cord [6,7]. Modern types of fibers used in the carrier layer of the belt are characterized by better and better mechanical properties. The driving strand to slack strand extension ratio gets closer and closer to unity. The coupling quality depends on the belt on pulley friction factor μ_z and internal belt friction factor μ_w. The coupling of the transmission can be considered as follows:

$$\frac{dS_1}{dS_2} = e^{\beta\mu}, \quad (1)$$

where:

$$\mu = \mu_z + \mu_w \quad (2)$$

while –β is the contact angle between the belt and the pulley in radians. Higher tension resistance of the belt load-carrying layer improves the running surface operating conditions. Its elongation is smaller and fatigue damages are avoided. The problems of the modern belts include rheological phenomena and cohesion of the cord and belt material as well as the belt linear velocity. If the driving strand extension ΔL_C to the slack strand extension ΔL_b ratio approaches unity, one should consider material strain below the load-carrying layer consisting in its compression and horizontal displacement in relation to the cord. Thus, if:

$$\frac{\Delta L\, c}{\Delta L b} \gg 1 \quad (3)$$

then a coupling in the flat belt transmission gear:

$$\frac{dS_1}{dS_2} = f(\sigma, h, D, F_r, F_o) \quad (4)$$

is the function of the belt material -σ, contact surface with the pulley –*D*, peripheral force $F_o$and the pre-stress force F_r as well as the belt layer height *h* below the load-carrying layer.

Guiding the belt run on pulleys

The major problem seems to be flat belt slipping over the pulley as this caused abandoning of that kind of transmissions (Fig. 3). However, that problem was solved many years ago. A belt pulley, at least the driving one, should be of a barrel shape. It is possible to provide the running track side of the belt with wedge-shaped profiles cooperating with an appropriately shaped pulley. Mechanical systems correcting the belt running direction are also used in many transmission systems [5].

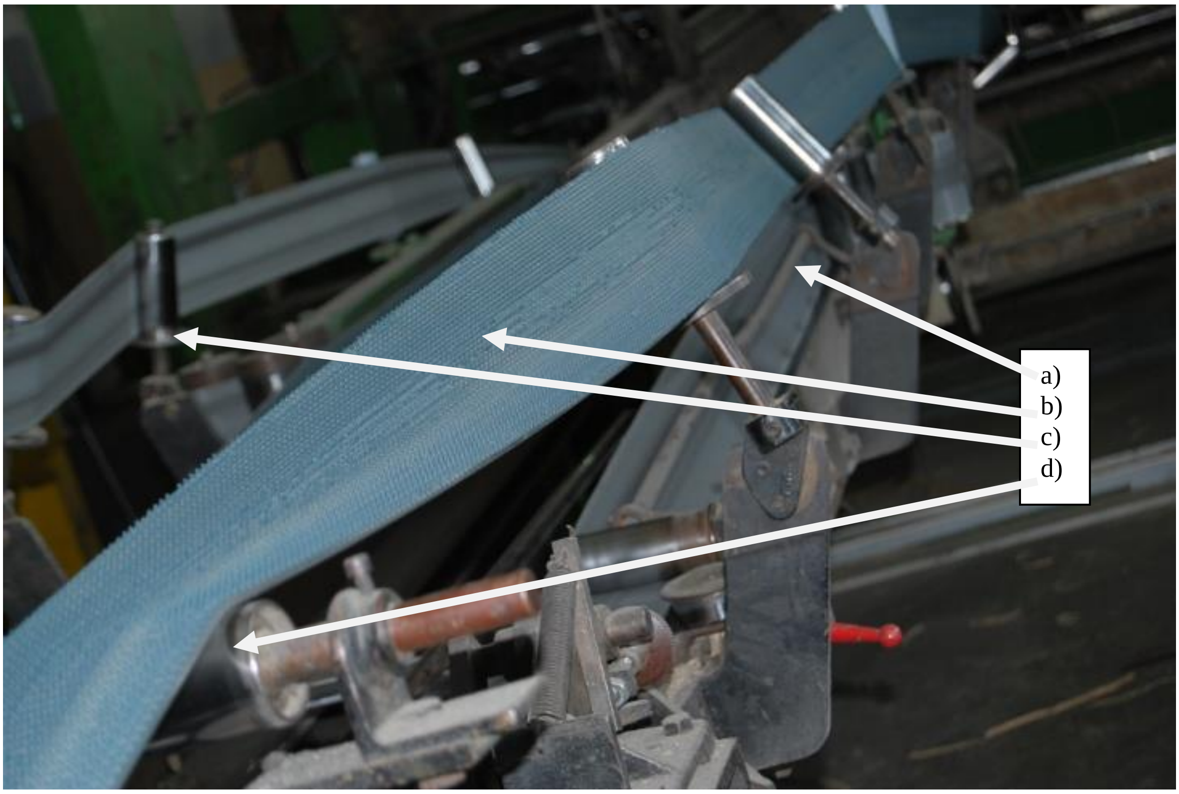

Fig. 3 Belt system in paper packaging manufacturing plant: a) back side with v- guide, b) top side with special structure, c) guide roll for top side, d) guide roll for bottom side, with gap.

Those systems compensate the effect of changes in the force acting over the belt width as well as installation and structural errors of mechanical systems. The manufacturing accuracy of machines where belt transmissions gears are mounted is also a cause for damage of other belt types.

Selection of the drive drum diameter and the belt bending problem

Designers have been using calculation software provided by belt manufacturers to select belt transmission components for many years. Such software includes a number of implemented limits and constant values. Obtained results do not coincide with those achieved from own calculations. The software excludes too extreme calculation results, too narrow belts, too small pulley diameters, and additionally provides a number of parameters defining properties of a belt. By putting those parameters in a complex software, a manufacturer prevents this knowledge from dissemination. Sometimes the best way to select the belt to pulleys is belt selection according to the minimum pulley diameter over which the belt can run. Thus the "strongest" belt that can cooperate with a pulley of a given diameter is selected. The belt is probably often over-dimensioned, but it certainly fulfills its function and shall not break over the pulleys.

Summary

In modern flat belts the load-carrying layer is made of materials ensuring the lowest possible elongation while maintaining flexibility over small diameter pulleys. A cord made of carbon fiber or highest grade steel provide high stability of flat belt load-carrying layer. Thus the coupling with pulleys depends to a large extent on the material used on the running side. Like in Euler's formula, it was possible to approach an unstretchable cord, but the problem of the strand weight and thickness remains unsolved. That is why materials of the belt running side ensuring high friction factor over a pulley material are used, but also those materials that are unstretchable and light and for which this layer is thinnest one. Like in glued joints, the thinner the running layer the higher the efficiency of the transmission. Many new studies on flat belt transmissions were prepared in recent years and transmissions of that type still have many successful applications ahead.

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