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Meshing in Gear with Timing Belts

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***Abstract*—The work treats about problem of designing of gear with timing belt depending on expected character of exploitation. There are many different elements of meshing model connecting with exploitation conditions. Analysis of this problem will let for wider use of this type of gears.**

***Index Terms*— mechanical gears, timing belts.**

I. Introduction

Easy production technology of pulleys without necessity to maintain high workmanship accuracy, is one of the advantages that contribute to development of belt gears. In modern gears, it is important to take the production accuracy of pulleys into account, but also a state of surface, as in most cases frictional steam of belts and pulleys occurs. Gears with timing belt have been recognised and still mistakenly are as gears, where only profile coupling occurs [1]. The frictional and profiling character of the coupling have not been taken into account. In case of gears with timing belts, operation tests have shown a huge significance of not only conditions of pulleys, but also the technology of their working. Application of these experiences on gears with timing belts contributes to another quality progress in intermeshing of belts with pulleys[2]-[3]. Series of pulley production technologies, the new machine tools and a broad selection of materials applied in production contribute to it. Pulley teeth may be located freely along a pulley, width an axially placed guiding wedge starts to be applied more often. The difference in production technology makes the belt pulleys of the same type and the same producer difference in dimensions and surface conditions[4]. One of most precise drive with timing belt is used in high efficiency bottle filling machine(Fig.1). By shaping belt pulleys, the design engineers applied experiences obtained in other gear types. Structures of chain, toothed, cylindrical and other gears were developed. A pulley had to assure staying on track and proper ratio and coupling in a gear. Round belts, V-belts, and Poly-V belts have got no problem with staying in track. The problem required a solution within flat belts and timing belts.

II. Gear with Timing Belt Problems

There are three structures that can be distinguished, out of which each makes up a solution to this problem, they are however adapted to specific operating conditions in a gear. Production of a belt pulley in a profile of a barrel, generates various linear velocities on a pulley surface. The points of contact on a surface with greater diameter move faster, what pulls a belt always into the pulley centre. Special profile of the running side, e.g. application of a guiding wedge allows placing the belt on the pulley basing on special slot. This is a good solution for belts moving with low linear velocity, on pulleys with a diameter not causing an excessive bending of a belt with a wedge. There is also a possibility to apply edge discs and belt work-rests, however this solution often causes mechanical damage of a belt. One may come across automatic adjustment systems in case of slow-moving belts, used in control systems. These systems are applied in gear structures, where the cost of instrumentation is not considerable in comparison with the cost of the project. Belt gear ratio may be: fixed, variable or non-uniform and may cover reduction and growth of revolutions of intermeshing drive-shafts. A belt may intermesh with one pulley, most often with a pair of pulleys, but also with numerous pulleys of different coupling character. In case of gears with fixed ratio, various profiles assure various instantaneous and average efficiency. Gears with a variable ratio mainly include wedge gears and wedge-toothed gears. In these structures, ratio change is obtained through approaching and moving away of surfaces intermeshing with belt sides. Intermeshing with a pulley at different diameter allows obtaining different ratios. Gears with non-uniform ratio are the gears, in which pulleys are placed eccentrically or their external profile is not a pulley[5]-[6].

Fig.1. Drive in bottle filling machine with “special made” double sided timing belt

By shaping belt pulleys, the design engineers applied experiences obtained in other gear structures, like cylindrical and other mechanical gears. [7]-[8](Fig.2).

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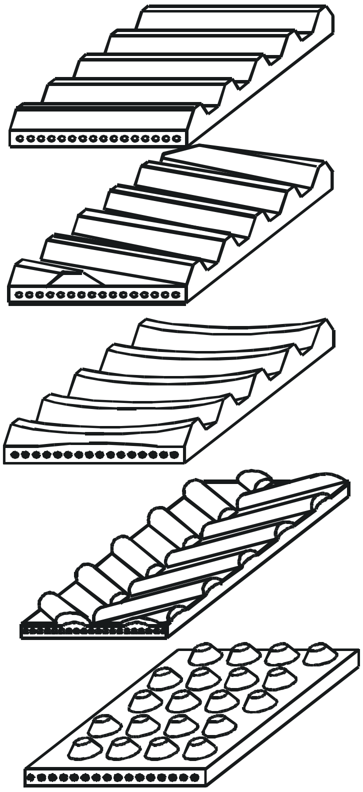

Fig.2. Different types of timing belts

Location in this type of gears changes during one shaft revolution. Series of parameters essential for belt coupling with pulleys may be distinguished here, such as: profile of belt and pulleys, surface state, barrel profile, whip and parallelism of shafts. The profile of belt and pulley has a significant impact on coupling in gear with V-belt and timing belt. Modification of belt profile is a problem, because such belts have been produced in large numbers and have created great confusion among users. Necessity to apply mechanical characteristics of belt material as well as belt bending on pulleys has been documented in many works [9]. Taking essential changes into account is possible in structure change of pulleys, which are produced in shorter series and often on individual design engineer's demand. The surface state and structural features, often omitted, such as gear tooth and tip rounding radius is dependant on a production technology. Pulley setting on shafts is considered here however, the solutions, such as bearing adapter sleeves or collets considerably improve repeatability of pulley setting[10].

Cutting teeth according to the profiling method is the most frequently applied method in the production of belt pulleys, what causes a low pulley make quality observed in the tests. Unfortunately, the number of mills used for a production of an entire range of teeth is limited and not all pulleys are provided with an optimal tooth profile. The structure of pulleys with teeth irregularly distributed at width should cover deformation of the central belt caused by maintaining a belt on track. Analysis of also these kinds of barrel-shaped pulleys is purposeful here. Problem of belt's tooth shape change is still left unsolved although several attempts to deal with it hale been made. Similarly as in case of V-belts bending described in literature, producers still avoid fading mathematical model of his phenomenon. Escaping into composite solutions or non-uniform teeth placing on the belt is only a change of covering factor. Similar effects can be observed in belts with uniform teeth where cord more resistant to elongation was used, increasing pitch at the same time.

III. Meshing in Gear wit Timing Belt

Accuracy and wear out of pulley make is a substantial problem of a gear structure. Series of measurements have been conducted on belt pulleys, the most important of which include: roughness, pith accuracy and rectilinearity of teeth. Single and total deviations of left and right side of belt pulley as well as radial run-out deviation have been presented on the measurement result sheet. An extra changeability of coupling conditions [11,12], contact stresses shall be different in belt pulleys as well as their distortion. Adopting this in average coupling formula, it gives us:

$$\frac{S_1}{S_2} = f\left(\sum_{z=1}^{z_o} \frac{\Delta lz \pm \Delta p_k}{p}\right), \qquad (1)$$

where: S_1, S_2 – stresses in wrapping connectors, z- tooth number on pulley arc of contact, p- pitch, Δpk- pulley pitch error, Δlz- belt tooth distortion.

The features, which have been taken into account in measurements, also include: deviation of adjacent pitches, irregularity of pitches and total deviation of pitches. The last feature has been considered in the studies on belt pulley diameter amendment. The term total pitch in case of a toothed belt is important for changes made in relation of a toothed belt pitch to a pulley, it is also important when totaling pitch errors of pulleys with a large number of teeth.

$$p = 2\frac{\pi\left(R_o + h_o + \dfrac{k}{2}\right)}{z_o} \pm \frac{\sum_{z=1}^{z_o} \Delta p_k}{z_o}, \qquad (2)$$

where: R_o- pulley(roots) radius, h_o- belt tooth height, k- height change of cord axis.

The different accuracy and wear of pulley is essential important in parallel conveyor(Fig.3). This difference is not caused by a tooth profile as it does not have an impact on the pitch accuracy. These pulleys were made of different materials, what has a huge importance for the surface state of these pulleys, as well as in most cases determine a working technology. Steel pulleys, such as the tested HTD pulleys are made by hobbing, yet aluminum pulleys (the tested AT pulleys) are made by profile milling. Such method selection is not imposed by a desire to obtain specific accuracy of make, but by economic reasons. It has been accepted that a hop would be a better steel working tool than a profile miller. It should be emphasized here however that this type of division is not fulfilled, particularly when it cymes to small producers of pulleys, who are provided with machine tools of one type. Producers of pulleys often try to engage all machine tools in a production. Different production technology also leads teeth differing in structural details. Produced pulleys have various roughness, tooth rounding at tip and root of different radiuses, tooth contour line is not the same.

Fig.3. Parallel conveyor for glass plate cutting

Measurement of tooth line show considerable irregularities in this part of a pulley tooth, which has a first contact with belt in the coupling process. HTD type steel pulleys feature greater irregularity, profile errors in this field determine a considerable volume wear of belt teeth and at the same time worsen coupling conditions in the entire utilization process. The belts with teeth irregularly distributed at a belt width are one of the last structures. These structures try to imitate toothed cylindrical gears, so as to transfer their advantages to belt gears. Belts of the following teeth are produced: curved, canopy, diagonal and conical. Tooth profile in transverse cross-section to a tooth side has not been changed and in case of curved teeth, this is AT profile, canopy teeth –HTD, diagonal –CTD and conical –AT(Fig.4). Space profile of belt pulleys reflects the same profiles of teeth without considering torsion and upsetting of teeth on the arc of contact. Proper belt structure taking the properties of polymers applied in a production of belts into consideration is a problem for producers. Internal friction inside upset teeth causes dissipation of a considerable part of energy. A material in an increased temperature is imposed to greater deformation caused both by pressure as well as bending. Belt expansion is added to this type of belts, what causes deformation of teeth at width. The problem of deformation of teeth is being solved by using composite fibres in teeth, covering fabrics or excluding the central part of a belt from profiled coupling using a guiding wedge as in the case of BATK type belts. Partially the problem is solved by increasing a gap between belt teeth and pulley, what worsens however the coupling conditions. In effect, the belts with irregularly distributed teeth at width do not transfer greater torques. The gears of this type are working emitting less noise. Thanks to the increase of cover ratio, a greater number of teeth is taking part simultaneously in the coupling process, and the points of belt teeth are not striking the points of pulley teeth.

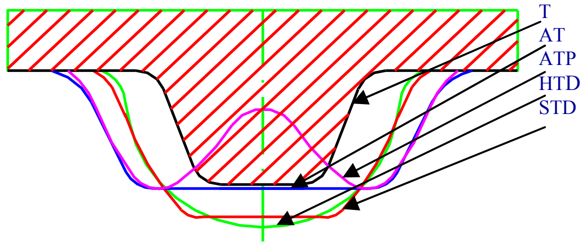

Fig. 4. Geometrical form of belt teeth

Exploitation wear is basic connected with internal and external friction of timing belt. Increase of temperature also influences mechanical characteristics of material which results in worse meshing on central part of the belt. Material with increased temperature is more deformed because of squeezing and bending. The result is streching of the belt followed by deformation of teeth on belts' width. Problem of deformation of timing belts teeth is meant to be solved by usage of composite fabrics, covering fabrics or by excluding central part of the belt from meshing putting a V-guide like in belts type BATK. On the other hand the producers do not take into consideration problem of guide bending on the arch of contact. In this case deformation of the guide is significant as it is placed below the cord and exposed to squeezing stresses. Partially it may be solved through increase of backlash between belt's and pulley's teeth but it makes conditions on coupling worse. As an effect belts with non-uniform teeth do not transfer higher torque moment. The gears emits less noise and thanks to increased covering ratio more teeth takes part in coupling and no impact is made between heads of belt teeth and heads of pulley teeth. Dissipation of energy in timing belts is problematic with timing belts where teeth are not straight on belt's width. Bending of the belt causes twisting of belt's teeth and serious increase of internal friction. The loss of energy of bonds in polymer chains and loss of tooth volume change meshing condition up to the moment when switch cooperation between belt and pulley. In result gear is very quickly damaged.

IV. Conclusion

The proposed by the author model of the coupling in gear with timing belt, lets better to describe and to study phenomena with this connected. This is one of proposed models about various degree of complexity.

$$\frac{S_1}{S_2} = f\left(\sum_{z_o=1}^{z_o} \Delta z\right) \tag{3}$$

He pays the attention to the basic dependence of the coupling from the deformation of teeth on arc of contact between belt and pulley from first tooth z_o to last burdened tooth. This dependence is different for the various types of belts, made from various materials. The most important this jet, that the different coupling defines for active wheel and passive wheel.

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