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Mechanism of friction generation and different types of wear – influence of tribomechanical factors

TRIBOMECHANICAL SYSTEMS IN MECHANICAL POWER TRANSMITTERS

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ABSTRACT

In this paper, the detailed analysis of tribomechanical systems for transmission of power and movement in mechanical transmitters is presented. The basic tribological characteristics of tribomechanical systems are friction and wear that are the main causes of systems structures alterations, energy loss and losses of material. As natural processes, the friction and wear, depend on a large number of different factors: systems structures, exploitative conditions (speed and load), mechanical-chemical properties of materials, characteristic of lubrication, aggressiveness of environment, temperature, topography of contact surfaces, mechanical processing (pre-processing and final processing), etc.

On the basis of the relevant information, the classification of basic tribomechanical systems is done. By the analysis of specific tribomechanical systems in certain mechanical transmitters, the identification of common wear modes, theirs causes and recommendations for avoidance are done.

Keywords: tribomechanical systems, friction, wear, mechanical power transmitters.

AIMS AND BACKGROUND

The tribomechanical systems, as dynamic executors of basic functions, act in conditions of friction contacts and in conditions of relative movement of theirs elements. In the zone of friction contact, the complex non stationary physico-chemical and mechanical processes are induced that are followed by friction and wear of contact surfaces.

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The number of influential factors and complexity of their interactions in which variation of one parameter caused chain alterations of different parameters complicate the quantification of theirs influences. This is the reason for present insufficiency of systematic information about tribological characteristics of tribomechanical systems.

The tribological processes occur at basic tribomechanical systems that are composed of 2 elements in contact in the presence of the lubricant as the third element. The existing environment may, but must not, affect the tribological processes in basic tribomechanical systems.

The number of tribomechanical systems in certain industrial systems may be more than several tens of thousands. In order to simplify the analysis of tribological processes at contact surfaces, those tribomechanical systems can be classified in 4 major groups[1–10]:

- Tribomechanical systems for motion transmission:
  - tribomechanical systems for transmission of rotation in transverse direction,
  - tribomechanical systems for transmission of rotation in longitudinal direction,
  - tribomechanical systems for transmission of linear motion ,
  - tribomechanical systems for motion braking;
- Tribomechanical systems for power transmission;
- Tribomechanical systems for transmission of information:
  - tribomechanical systems for production of information;
- Tribomechanical systems for movement and processing of material:
  - tribomechanical systems for material movement,
  - tribomechanical systems for material forming,
  - tribomechanical systems for material processing.

TRIBOMECHANICAL SYSTEMS FOR POWER TRANSMISSIONS

Tribomechanical systems for power transmissions, which are known as mechanical transmitters, are used for transmission of mechanical motion energy on distances, so as for transformation of its parameters. Those transmitters simultaneously transmit the rotary motions.

The general use of transmitters is highly related to executing the elementary functions with major characteristic that are, among them: energy distribution, reduction or increasing of speed, alternation of motion type, regulation of speed, starting, braking, direction changing, etc.

The transmission of power and mechanical motion can be done in many different ways and by different transmission mechanisms, so the mechanical power transmitters can be classified in 2 major groups: power transmitters with transmission by form, and power transmitters with transmission by friction.

The power transmitters with transmission by form act on the specific form of triboelements and related principles of meshing of contact surfaces. The following transmitters are classified in this group of mechanical power transmitter: gear transmitters, chain transmitters, timing belt transmitters, worm transmitters, thread transmitters, planetary gear transmitters, Cardan transmitters, and variators with meshing.

In the process of power and motion transmission, the molecularly-mechanical nature of friction is involved. The mechanical transmitters that act on the basis of this principle are: belt transmitters, flat belt transmitters, friction transmitters, planetary friction transmitters and friction variators.

According to statistical data about produced power transmitters, the most commonly used, in area of continuous transmission ratios, are the gear transmitters (cylindrical, at first). The share of friction transmitter usage at mechanical power transmitter in usage is significantly smaller than the share of usage of power transmitters that transmit power by form connection.

The present usage of mechanical power transmitters is highly related to development of mechanical transmitters with continually variable transmission ratio, accurately, with continual speed regulation. The share of mechanical power transmitters in global production of continual transmitters is the biggest and, from that aspect the process of power transmission by friction, has bright perspective.

Power transmitters are classified in the group of widely used tribomechanical systems that are necessary for functioning of mechanical systems of higher levels. Furthermore, the qualities of power transmitters are the major influential factor to quality of the whole construction[1,11].

MECHANICAL POWER TRANSMITTERS WITH FORM TRANSMISSION

In the zone of friction contact at mechanical transmitters and interactions of system elements, the complex non stationary mechanical and physicochemical processes are induced, so as the processes of friction and wear.

Processes of friction and wear in mechanical transmitters are defined by structure and general function of the system. As the general function of the system at all mechanical transmitters is the same (transport of energy on certain distance), it is implicated that those processes are highly defined by system structure.

At the mechanical transmitters that work on the basis of geometrical form connection of elements, the external friction is present. The friction is present at contact zones of elements due to relative motion: impact, rolling and sliding.

Kinematical analysis of meshing at cylindrical gears implicates that components of current speeds at some contact point on common tangent line to side surface of teeth of mashing gears are not and must not be in equivalence. That means that side surface of teeth of mashing gears slides on each other. The sliding is not present only when contact is at central point and in that case only rolling is present (Fig. 1).

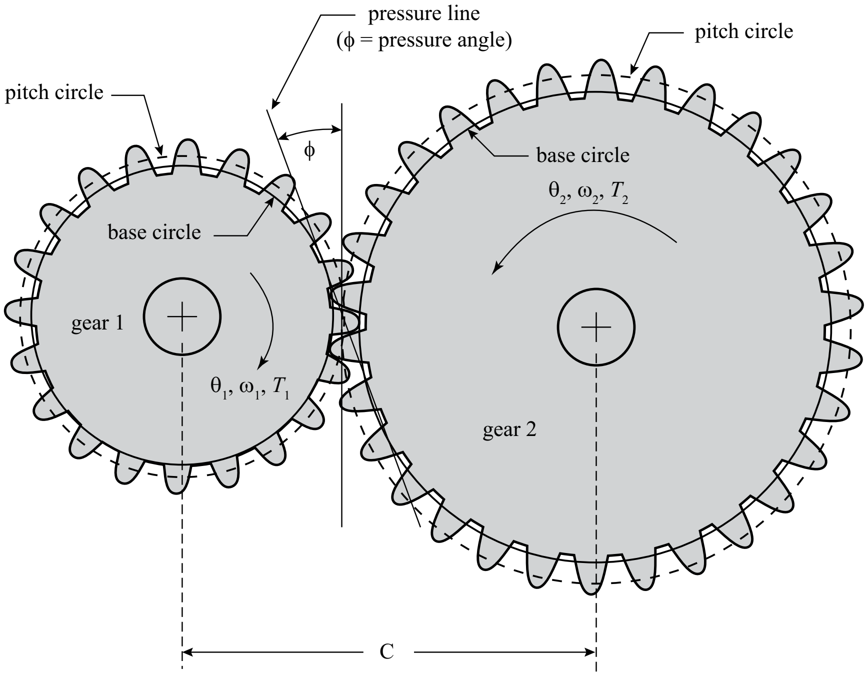


Fig. 1. Gear power transmitter

External friction that is present at meshing of gears is resultant of sliding friction and rolling friction. As the directions and values of sliding speed are altering during meshing period (in interval of time from enter in contact to exit from contact of teeth), it is logical that friction is also altering during that interval. The current values of force and friction coefficient, that are present, are in function of current contact of meshing tooth[12–17].

The defining of current value of friction coefficient at every contact point during the period of meshing is very complex. The basic parameters that influent on friction coefficient and sliding speed are changeable in direction and value during the period of meshing. From that reason, it is sufficient to use the average values of friction coefficient that are presented in many systematic information, at conceptual procedure of construction process.

Worm transmitters, as hyperboloid gear set with axes that intersects are characterised by linear contact of triboelements (worm-worm wheel). The linear contact is followed by relatively high level of sliding at mashing elements, but also with forming of sufficient layer of lubricant as the third element of tribomechanical system. The sliding friction can be high, so it can induce the low degree of efficiency, lower than 0.5 at multiplicators. In case of worm transmitter application at reductors it is possible to increase the degree of efficiency to over than 0.9 by construction solutions.

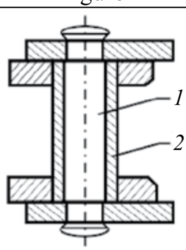
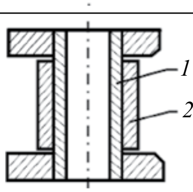
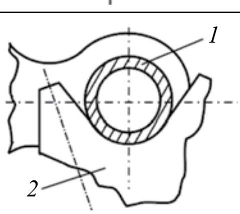
Chain transmitters are mechanical transmitters which transmit power and motion by flexible element – chain. From the aspect of analysis of the tribological processes, the chain transmitters belong to the tribomechanical systems with complex structure[18]. Chain consists of several basic tribomechanical systems: pin–bush–lubricant; bush–roller–lubricant; side surface of pin link plate–side surface of roller link plate–lubricant, etc. Some tribomechanical systems at chain power transmitter are presented in Table 1.

The friction as process that opposes to motion is very intensive during phase of entering in contact of sprocket and chain and in the phase of descent of the chain element from the sprocket.

During the entry phase of contact of chain element and sprocket, at first, the roller hits to the teeth of sprocket, and after that, bush and pin hit to the roller as elements of joint. Impacts produce destruction of the chain and its elements, tooth of the sprocket and produce the noise and impact-cyclic destruction of chain elements.

The constructional shape of the sprocket teeth and its interspaces, during the normal meshing provide the normal positioning of the joint on active part of the teeth profile. After the impact, the rolling with sliding of roller, at roller chains, is induced or sliding on bush, in case of bush chains is induced. By that, the presence of roller decreases intensive wear of tooth sprocket due to sliding.

Table 1. Tribomechanical systems at chain transmitters

No	Tribomechanical system		Element of system	Type of motion
	figure	nomenclature		
1		pin–bush	*1* – pin 2 – bush	impact sliding
2		bush–roller	*1* – bush *2* – roller	impact sliding
3		roller–sprocket teeth	*1* – roller *2* – sprocket teeth	impact sliding rolling

Simultaneously, the sliding between bush and pin is present, so as sliding between the roller and bush with press fits to bush link plate.

Analogue process of relative motions at tribomechanical elements is present during the ending phase of contact, but without impacts and their distraction effects.

Relative motion at joint is followed by resistance to this motion, so different friction processes at contact surfaces are induced (impacts, rolling and sliding). Those processes are the main cause of losses of energy in transfer, so as the causes of different types of wear.

Timing belt transmitter, as relatively new concept at power transmission, uses flexible element (toothed belt) for realisation of main function. The combination of the chain, gear and belt transmission brings a variety of the motion in tangential, radial and axial directions. This is especially significant at the phase of entering at contact of belt and pulley.

The basic tribomechanical systems at timing belt transmitters are (Fig. 2):

- belt tooth–belt pulley tooth (position *1* in Fig. *2*),
- belt face–flange (position *2* in Fig. *2*),
- the belt groove–apex of the belt pulley tooth (position *3* in Fig. *2*).

Types of motion that occur in these tribomechanical systems are given in Table 2.

The initial contact of timing belt teeth in the entering phase of contact starts

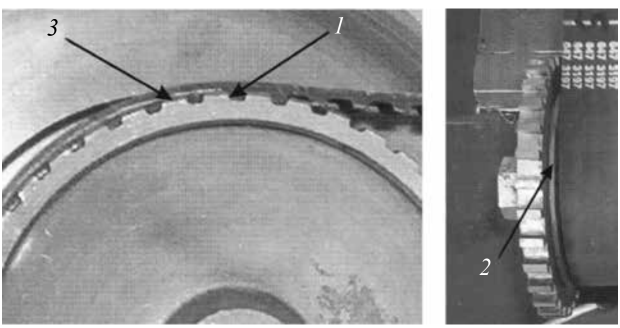


Fig. 2. Tribomechanical systems in timing belt drives

Table 2. Tribomechanical systems and types of motion in timing belt drives[19–21]

Tribomechanical system	Type of motion
Belt tooth–belt pulley tooth	impact sliding rolling
Belt face–flange	impact sliding
The belt groove–apex of the belt pulley tooth	sliding rolling

Table. 3. Common wear type at mechanical transmitters

Type of wear	Mechanical transmitters	Cause	General recommendations for avoid and minimising the making of the process
Fatigue wear (pitting)	✓ gear transmitters ✓ timing belt transmitters ✓ planetary transmitters ✓ cardan transmitters ✓ friction transmitters (lubricated) ✓ belt transmitters (belt) ✓ flat belt transmitters (flat belt)	¤ cyclical loads in prolonged period of exploitation ¤ overload and stress concentration ¤ inclusions in material ¤ insufficient lubrication ¤ improper final technology process (technology heritage) ¤ improper parameters of chemical-thermical treatment (technology heritage)	• reduction of contact stresses and frequencies of cyclic load • reduction of load • using of material with improved resistance to wear due to fatigue • using of lubricant with higher viscosity and with EP additives • using of optimum parameters of technological processing • using of optimum parameters of chemical-thermical treatment
Abrasive wear	all mechanical transmitters	¤ abrasive-aggressive environment ¤ overload ¤ insufficient hardness of contact surfaces	• removal of pollutants sources • improve sealing (use of sealants) • reduction of load • decrease of hardness of contact surfaces • decrease of thickness of lubricant layer
Corrosion wear	✓ gear transmitters ✓ chain transmitters ✓ timing belt transmitters (pulley) ✓ planetary transmitters ✓ cardan transmitters ✓ friction transmitters ✓ belt transmitters (pulley) ✓ flat belt transmitters (pulley)	¤ aggressive environment ¤ moisture ¤ insufficient lubrication	• improve sealing • using of lubricant with corrosion inhibitors • using of material with resistance to corrosion
Scoring	✓ gear transmitters ✓ planetary transmitters ✓ cardan transmitters ✓ friction transmitters (lubricated)	¤ overload ¤ boundary lubrication ¤ inproper lubrication ¤ insufficient lubrication ¤ absence of break-in period	• reduction of load, speed and temperature • use of compatible materials • increase of lubricant quantity • cooling of lubricant • using of lubricant with higher viscosity • using of high pressure additives • using of tribology coatings
Fretting corrosion	✓ chain transmitters (chain) ✓ cardan transmitters (telescope)	¤ vibrations ¤ insufficient strength of assemblies ¤ aggressive environment	• elimination or absorption of vibrations • using of absorbing materials • increase strength of assembly • protect contact surfaces from corrosion-fatigue processes • improve sealing • using of lubricant with corrosion inhibitors

with contact of side surfaces and with special interference of timing belt teeth that interferes to side surface of the timing belt pulley teeth. Due to elasticity of the belt and rigidity of pulley, the initial contact is followed by the deformation of the timing belt teeth. The rotation of the pulley moves the contact surface from the top of the pulley teeth to its basis and it is followed by relative sliding of side surfaces of the pulley and teeth, during the entering phase of contact, means sliding friction. Further movements of the belt along the circumferential angle are characterised by flexion of timing belt teeth, small sliding speeds of side surfaces of teeth, but, also, with moving of the first layer in the contact of the top surface of the pulley teeth and interspaces of teeth of timing belt. The intensity of friction is very small in this period till the end of contact. The characteristic of the timing belt and timing belt pulley with side rings is to compress and to push the air at high speeds during the entering phase of contact and by that alter the general characteristic of friction of timing belt transmitters.

The presence of axial forces, caused by construction of the belt and by helicoidally thread of puling element, produces running of the timing belt on the side ring of the pulley. Relative motions of face surface of belt and side ring of the pulley are the causes of sliding friction that is significantly high at the beginning of the contact and at the end of contact.

The wear types at mechanical transmitters that are common in exploitation are presented at Table 3. By choosing the executors of elementary functions, in the conceptual procedure of design process, the designer also takes obligation to minimise the wear processes, further through design, that are unavoidable in exploitation. Large number of possibilities collected in systematic information can be used, but also own creative experience can be used.

CONCLUSIONS

The analysis of the tribomechanical systems for power transmission by form connection implicates that realisation of the main function is influenced by all components of the system structure (elements, properties, interactions). The differences in geometrical shape of triboelements, complex and different kinematical motions, presence of lubricants and other factors cause different mechanisms of friction generation. Every type of transmitter has own specific functioning, but, also, own characteristics of friction processes. This is specific for the tribomechanical systems with complex structure that consist of several tribomechanical systems and in which realisation of function is related to resultant in motions, and the resistance to those motions is far more complex.

The wear is natural, progressive process of material lost from the contact surfaces that can not be avoided and that follows every tribomechanical system at power transmission in exploitation. The influence of factors and their complex interactions produced different types of wear processes at contact surfaces of tribomechanical systems. Those processes are different due to its causes, intensity and due to significances to influence the duration of exploitation period of realised constructions. Wear can not be completely eliminated, but it can be minimised to acceptable levels.

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