Wear

WEAR AS THE CRITERION OF MECHANICAL TRANSMITTERS WORKING LIFE

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ABSTRACT

Working capability of machine systems is capability for maintenance of systems function at changeable exploitation condition and capability to return in function after its cessation. Working life is the measure of machine systems working capability and result of quality design, production and maintenance.

This paper is analysed the connection between definition of working life and tribological condition of mechanical transmitters elements (gear transmitters, chain transmitters, friction transmitters). Research results show that the wear is the basic criterion for definition of the working life of mechanical transmitters.

Keywords: working life, wear, mechanical transmitters.

AIMS AND BACKGROUND

Working life or work cycle is the term representing complete collection of all activities and events in the life of machine systems. It is starting from the definition of the concept and global concretisation up to production documentation, production and setup, exploitation (use) and maintenance, expenditure and write-off, that is, up to the withdrawal from service.

Within this time frame, activities and events occurrence, special emphasis is given to the exploitation and working life of machine systems as parameters for evaluation of preceding events and also important from aspect of future events forecasting[1].

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Exploitation in its broadest sense comprises every way of utilisation to the end of available resources or previously determined limits.

Exploitation of machine systems also represents a way of industrial products utilisation, but within the limits of working capability. The system state is working capable when values of all parameters that characterise system capabilities to perform the given function correspond to demands of normative-technical and/or design documentation. At the same time, it represents the capability to sustain the system functions at changeable exploitation conditions and capability to return in function after its cessation.

Interdependence of the quality of design and quality of the new product is referentially evaluated during exploitation. Exploitation represents a period of the working life of the new product when all results of its design, production and installation are compiled together.

The working life of machine systems is time measurement of exploitation within whose limits all activities of the system are performed. It is a determined time frame when system is capable to perform requested function but also to preserve that function under all conditions of designed exploitation including capability to return in function after its cessation. Working life duration is transparent parameter for evaluation of exploitation cycle but also for working life of machine system.

Analysis of the working life or working cycle of machine system, where complete range of all activities and events in system life is contained, shows that more than 80% of machine failures are due to wear of its tribomechanical systems. Wear as a process of destruction and separation of material from contact surfaces and (or) accumulation of remaining deformations resulting in gradual change of dimensions and (or) body shape, is the main cause of the working capability loss of different intensity. Final loss of working capability is necessity that can be more or less postponed, but can not be prevented.

Direct dependency between wear and working life of machine systems can be established by recording wear as native process that accompanies exploitation of machine systems and by accepting working life as a time measure of exploitation. Working life is bounded by the wear rate of the tribomechanical systems whereat the start of the working life is within a running-in period and its end at the beginning of the catastrophic wear period.

Analysis of a large number of different mechanical transmitters shows that the dependence presented in Fig. 1 can be established between wear and working life. Defining wear as catastrophic, medium and low wear is more or less approximate and it mostly comprises intensity as ratio of wear to distance over which tribological processes happen. Wear curves are not determined by mechanism and type of wear.

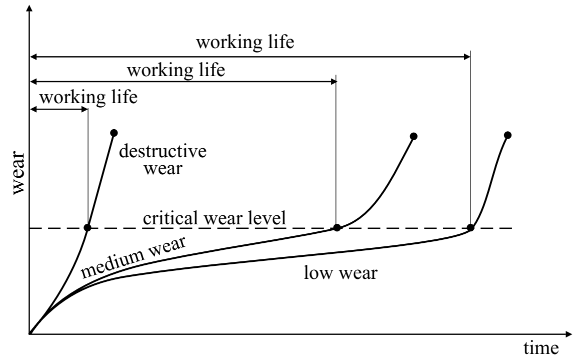

Fig. 1. Diagram of dependence of wear and mechanical transmitters working life

Characteristic variable for definition of the working life of mechanical transmitters is critical wear rate, most often defined by type of wear. Appearance of the certain type of wear at contact surfaces of mechanical transmitters is the signal for the end of the working life and warning to withdraw it from use[1,2].

WORKING LIFE OF THE MECHANICAL TRANSMITTERS

According to statistical data about existing power transmitters, gear transmitters (cylindrical transmitters above all) have the widest use of all transmitters with constant transmission ratio. Share of mechanical transmitters is significantly lower.

Gear transmitters can work in different areas of wear development, depending on the system function, design characteristics and exploitation conditions. Typical diagram of characteristic areas of wear development as a function of relative sliding velocity and normal force in gearing is given in Fig. 2 (Ref. 3).

The largest number of gear transmitters work in area of medium wear. Critical wear level is defined by fatigue and occurrence of pitting.

Calculation of gear bearing capacity according to criterion of gear flank durability is actually calculation of pitting resistance. Characteristic variable in calculation is permanent dynamic flank durability ($\sigma_{H\lim}$) experimentally obtained by testing gear couples under precisely defined working conditions. The number of load changes (N_{HD}) that corresponds to permanent dynamic durability is within range from 2×10^6 to 10^9 and depends on material type and gear application.

Working life of gears that work under conditions of medium wear can be defined by theory of accumulation of damages and it is mostly ended by appearance of initial crack. On the other hand, working life of gear is defined by the level of the working capability whereat rate of loss depends on large number of parameters. Very important question that can be asked here is determination of criterion and evaluation of the working capability of gears[1].

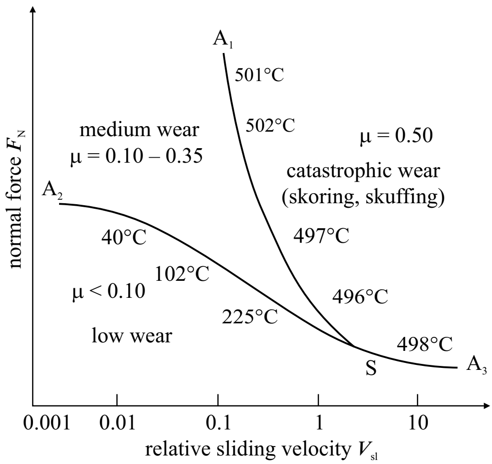

Fig. 2. Characteristic ways of wear development for gear transmitters

There is no unanimous opinion in technical community on what the limits of the working capabilities are and when the gear is ready to be withdrawn from use. According to many papers (Trubin, Setinin, Stepanov, Belanin, Zablonski, Kalacert, Nimman, Rihter, etc.) (Ref. 1), the suggested level of active surface damage, as a mean to evaluate working capability, lies in the range 0.6–50% from total active surface. Our investigations of gears according to which, development of pitting goes through 6 (six) phases limited by material stretching and appearance of initial pits as the first phase and complete failure of the contact surface as the sixth phase, as the criterion for working capability and working life suggests V (fifth) phase of the catastrophic wear, i.e. appearance of large pits above already formed destructive wedge.

Modern directions in design and necessity for machine systems to work also under extreme conditions of exploitation are again promoting gears whose development of wear corresponds to the catastrophic wear curve (Fig. 1). These are gears that work under conditions of high loads, high temperatures and high sliding velocities (Fig. 2). Critical wear level is defined by adhesion as a mechanism, adhesive wear as a type and scoring or scuffing as a wear type. The main cause of the gear scoring during transmission of high loads and high sliding velocities is considered to be the significant increase of the friction coefficient during sliding that provokes significant temperature increase in contact what further leads to destruction of the lubricating layer and pure metal on metal contact[4]. Scoring process is realised in three phases: destruction of the lubricating (EHD) layer, destruction of the secondary structures (boundary layer), formation of adhesive bonds with transition to their critical number and appearance of scoring as a wear type. It is confirmed that scoring at the gear contact surfaces occurs under certain current contact temperature (temperature flash) that is in consistence with experimental and theoretical findings of Blok (Ref. 1).

Determination of the minimum endurance zone of the gear where the beginning of the scoring is expected is tightly connected to the contact surface area where critical temperature is expected to appear. Diagram of the temperature distribution over active tooth surface is shown in Fig. 3, where the distribution is calculated according to the following equation[5]:

$$T_{x,y,z} = \frac{1}{2\pi(\lambda_1 + \lambda_2)} \iint_{S_p} \frac{Fv\tau}{R_p} \mathrm{d}S \qquad (1)$$

where λ_1, λ_2 are the coefficients of thermal conductivity of materials; F – load, dS – elementary area; v – contact velocity; τ – contact time, and R_p – distance between point loads and control point.

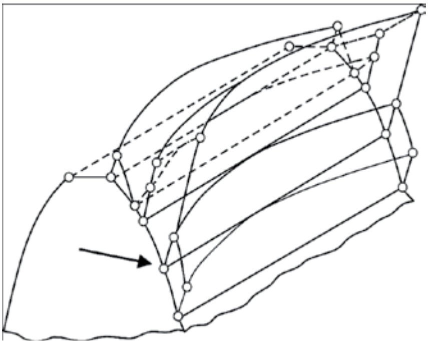

Fig. 3. Diagram of the temperature distribution over active tooth surface

Calculated diagram of the temperature distribution and area of initial scoring occurrence coincide in large extent with experimental investigations.

Working life of the gears, as well as of other transmitters whose wear development corresponds to the catastrophic wear curve is unallowable short.

New directions in design takes under consideration attempts to increase the working life of such systems, that is to eliminate the threat of scoring occurrence. Beside traditional and already established possibilities (higher viscosity, anti-scoring additives, selection of rational gearing parameters, etc.), some additional considerations are valuable.

Appearance of the critical temperature corresponding to the zone of minimum durability can be successfuly prevented by progressive management using technological methods of radiating thermal machining (laser, electro-arc). Management of processes consists of special program strenghtening of those areas of contact surfaces where maximum temperatures and initial scoring are expected.

Another option to fight against scoring is to achieve the relation $t_k < t_a$, that is to establish working conditions for gears in such a way that the unit duration of real gear contact (t_k) is shorter than duration (t_a) of maintaining molecules of the lubricating layer in adsorbed state. It means to achieve such conditions that duration of adsorbed layers does not enable temperature flash to destroy lubricating layer and to generate pure metal on metal contact.

Duration of maintaining molecules in adsorbed state is calculated according to the Frenkel equation[5]:

$$t = t_o \exp(E/RT) \qquad (2)$$

where t is duration of maintaining molecules in adsorbed state; t_o – coefficient of adsorbed molecules fluctuation period; E – desorption activation energy; R – universal gas constant, and T – absolute temperature.

Working capability of chain transmitters that operate in normal conditions, conditions of abrasive pollution or conditions of low lubrication is limited by wear of joints. Wear inevitably leads to increase of the pitch, decrease of toughness

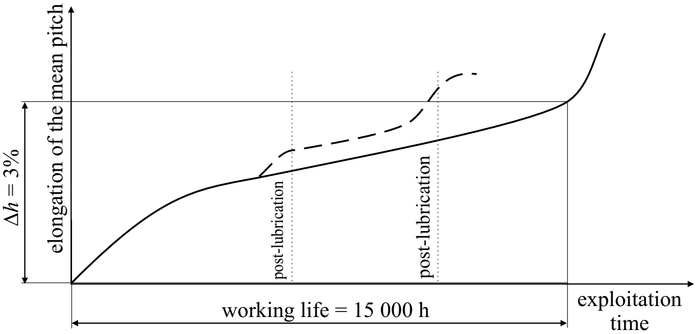

Fig. 4. Diagram of chain wear

and functioning uniformity, as well as violation of normal conditions of coupling between chain and sprocket[6].

Chains operate under conditions of medium wear whereas the critical wear level is defined by the elongation of the mean pitch (Δh = 3%) at normal working life of 15 000 working hours (Fig. 4). The most common type of wear is abrasive wear, where abrasion is conditioned by specific structure and design of joint.

It should be noted that the homogeneous trend of the wear curve (full line in Fig. 4) is valid for conditions of good lubrication. In other cases, the wear process can have a trend of the catastrophic wear that shows that the given working life can be maintained only under conditions of good and timely lubrication.

Transmission where torque moment is transmitted by friction (frictional and belt transmission) has a special place in scope of possible mechanisms of power transmission. Mechanism of power transmission by friction is based on characteristics of 'friction at standstill' and the whole process of coupling is realised under very specific conditions. External friction at standstill is realised within the zone of preliminary displacements, i.e. transition from standstill state to sliding is realised during appearance of small relative displacement.

Specific characteristics of power transmission and significance of friction for realisation of given function demands somewhat different approach in definition of the working life of these transmitters. It is appropriate to introduce friction – wear characteristics and friction – wear level, instead of the critical wear level. Obtained and confirmed experimental investigation of friction – wear characteristics would represent kind of synthesis of friction coefficient stability, certain type of wear and working life as time measure of exploitation.

The timing belt drives are relatively new concept of power transmission, which originated in the 1950's. The largest amount of motion and power is transferred by shape, while only a small amount is transferred by friction. The influence of friction must not, by all means, be neglected. Appearance of friction in timing belt drives and its consequences have not been thoroughly explained. In contrast to other transmissions of power and motion (gears, chain drives, cardanic

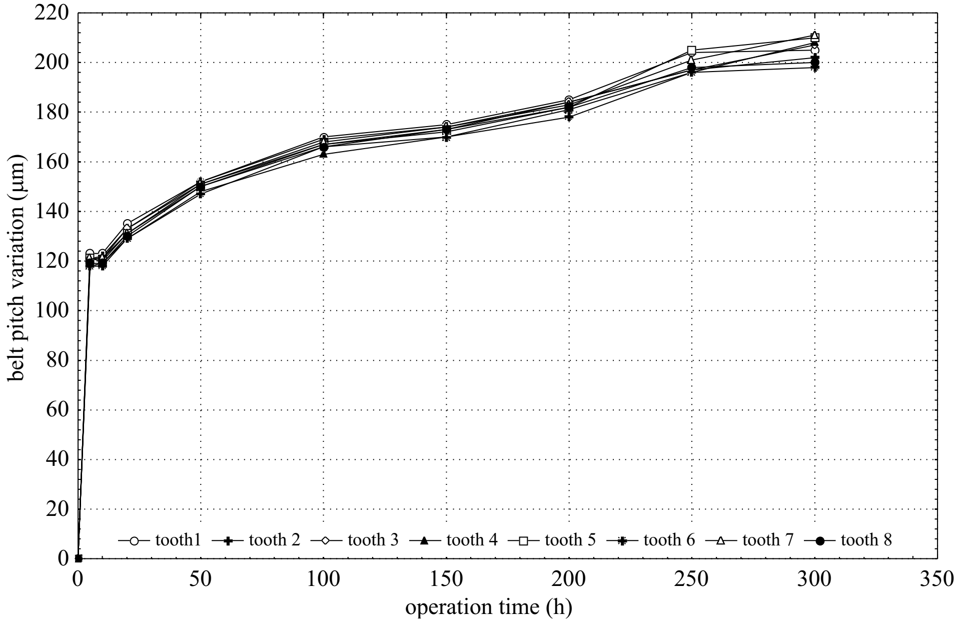

Fig. 5. Belt pitch variation during exploitation

transmissions, etc.) in which friction mostly occurs in the contact of the two metal surfaces, in timing belt drives, there are one metal and one non-metal surface or two non-metal surfaces in the contact.

The basic tribomechanical systems in the timing belt drives are: belt tooth – belt pulley tooth, belt face – flange and the belt groove – apex of the belt pulley tooth.

Measurement of geometrical values of timing belts was conducted on 8 belt teeth. The following values were measured: belt pitch (t), belt width (b), belt groove thickness ($h_b = h_s - h_t$) and belt total height (h_s).

The following diagram shows variation of the belt pitch during the testing (Fig. 5).

In the period of working out, there is a sudden increase of belt pitch. This increase originates from plastic deformation of the belt and from wear of teeth flanks. Roller wear (a special form of elastomeric wear) is specially emphasised there and the consequences are removal of material from belt teeth and increase of pitch.

The belt pitch increases for approximately 0.2 mm, which leads to the increase of the belt length. Total elongation of the belt is approximately 23 mm. Large portion of this elongation is due to plastic deformation of the belt, that is the elongation of tractive element. However, wear of side surfaces of teeth provokes 30% of variation of belt pitch. Elongation of pitch is the greatest in the period of working out and amounts to approximately 60% of total elongation. During this period, mostly plastic deformations occur. At the end of the period of working out and during period of normal wear, the belt pitch changes mostly due to roller wear of teeth side surfaces (Refs 7–9).

CONCLUSIONS

Working life and duration of working life are significant parameters of mechanical transmitters resources. They are, at the same time, transparent parameters for evaluation of exploitation cycle within which results of design, production, assembly and maintenance are comprised.

Direct dependencies established between wear and working life of mechanical transmitters, as well as definition of critical wear level enable designer to realise not only more reliable design, but also offer possibilities to access the corrective measures in phases of monitoring and exploitation.

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