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Research and application of methods of technical diagnostics for the verification of the design node

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ABSTRACT

Research and application of selected diagnostic methods for assessing the condition of the gearbox of machining center accrued from collaboration applied between our work location and the company Regada, Ltd. Prešov. The requirement of our partner was directed to identify the current state of the abrasive particles in oil, to assess the condition of the contact surfaces in the running-in period and to assess the condition of the lubricant. Implemented analysis of gear oils have been prefentially oriented to identify the wear particles produced during running-in period and in the first hours of operation of contact surfaces. At the same time the correlation between total content of Fe (iron) particles in oil and accrual of kinematic will in tooth meshing of toothed ring of the gearbox was monitored. In quantification of the content of ferrous wear particles the impact of the running-in processes on the contact surfaces (bearings, toothing), which can cause negative side effects, was assessed.

1. Introduction

The role of processes arising from implementation of technical diagnostics is based on objective knowledge of the technical condition of monitored objects and particularly in ensuring the capabilities of the technical system to perform a required functions under stated conditions. In the actual sense, the technical diagnostics represents discipline that follows the forms of manifestating of failures and developing of methods for detecting them [1].

The most important role of technical diagnostics consists in predicting the technical state of the system under review. One aim of the technical diagnostics is to predict the duration of trouble-free operation that means the time interval from the reference point to the time of failure. The role of forecasting failures rests in identifying the deterioration of system under review and determination of the moment when it is necessary to implement appropriate measures in order to prevent failures or damages [2].

Where the condition of the system under review is being marked with parameter S, it is represented by the time-dependent function of S(t). Through the known values of $S(t_i)$ for discrete time points $t_i (i = 0, 1, 2, 3, \ldots, k)$ at the time of commissioning the system until the moment of diagnosis t_k, it is possible to predict function values $S(t_k + 1)$, $S(t_k + 2), \ldots,$ $S(t_k + j), \ldots,$ $S(t_k + m)$ for time moments $t_{k+1}, t_{k+2}, \ldots, t_{k+\tau}$ (Fig. 1) [2].

The period of achieving the critical value can be determined by assessing the last two conditions, i.e. condition during diagnosing $S(t_k)$ and condition during previous diagnosing $S(t_{k-1})$. The failure occurs at the moment $t_{k+\tau}$, *i.* if $S(t_{k+\tau}) = S_m$ [2].

Determination of the time of critical value S_m can be determined from the relation [2]:

$$t_k + \tau = \frac{S_m - S(t_k)}{S_m} = \frac{(S_m - S(t_k)) \cdot (t_k - t_{k-1})}{S(t_k) - S(t_{k=1})} \tag{1}$$

Such a methodology is applicable in case of the existence of short diagnostic intervals. In the case of longer intervals that relationship may not represent the nature of wear, especially for reasons [2]:

- the rate of wear at the end of the technical life-cycle increases, i.e. failures may occur sooner, as it is clear from the above relationship
- with identical values of parameters $S(t_k)$ and $S(t_{k-1})$ there is a division by zero – the equation cannot be used (this may be the case if the metering device is not satisfactory, mainly because of the practical reading of values measured).

Abbreviations: ACC, acceleration; CCT IR, total amount of dirt particles in the process medium – Fe; ENV, Envelope acceleration; FFT, Fast Fourier Transform; gE, Unit of Envelope Acceleration; HFD, High Frequency Detection; PLP, Percent of Large Particles; PPM, Parts Per Million; PtP, Peak to Peak; RMS, Root Mean Square; RPM, Rev. Per Min; SEE, Spectral Emitted Energy; S(t), state of the system at time t; SKF, acoustic emission enveloping (AEE); WPC, Wear Particles Concentration.

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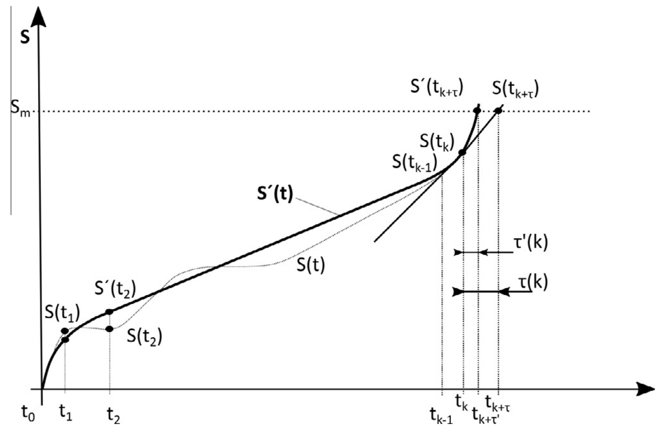

Fig. 1. The course of dependence of diagnosed parameter on time [2].

When determining the residual operational capability there is required for the above reasons to consider not only the last two values of real function $S(t)$, but the whole course of wear – all parameters from the interval $\langle S(t_1), S(t_2), \ldots, S(t_{k-1}), S(t_k)\rangle$ at the moment t_k and by correlation analysis to determine the functions $S'(t)$. In this case the failure will be predicted at the time $t_{k+\tau'}$, *t.j. ak* $S'(t_{k+\tau'}) = S_m$ [2].

Even at present, using modern tools of maintenance, the arising failure occurs often and very shortly before the outbreak of failure when maintenance is too busy to carry out repairs, because companies supplying spare parts, respectively providing repairs, often do not take into account the specific conditions of concrete operation.

To increase the reliability of the device is therefore necessary to carry out the following requirements [1–4]:

- increasing the time between repairs (the ability to be ready for operation),
- shorten repair time,
- early repairs to reduce the consequences of failure.

To meet these requirements there must be available information on what is the real condition of the device. This way can be removed also hidden, less serious errors, which may later develop into larger, often catastrophic failure. On the basis of this information we may intervene against failure in the most appropriate time and in terms of errors (error range and its process) and the impact on the production process (e.g.: during weekends, holidays, when production does not take place on the device). By the mentioned process, there can be removed not only the consequences but also early signs of failures and this way it is possible to significantly increase the lifetime of the technical system under review [1].

The fundamental requirement of modern maintenance is early diagnosis of failures. Even today there is a frequent occurrence of the fact that especially small businesses do not have the technical diagnostics established at all and the only diagnostic method is represented by subjective evaluation of machines, respectively by analysis of machine after failure. In the field of analysis of lubrication and lubricants, there are no tribotechnicians in such companies at all, so the lubricating of machines is thus represented by a random process. In large companies, the situation is different. Technical diagnostic is present in some form, but it happens often that the results are not well enough interpreted. This is often the issue especially of the human factor connected with a lack of data integration from different sources into maintenance management system [6–9].

Lubricants can bring considerable impact on the operation of machines and equipment, on their reliability which often depends on the proper selection and care of lubricants during their operation. From the literature data that are confirmed by the practice is known that up to 49% of gearbox damages are due to reason of bearing damage, 41% by reason of damage to the teeth and 10% are given as other reasons. The reasons must be found in the fact that it is a high-pressure systems (Hertz pressure) resulting in the formation of small fraction particles that cause bearing damage. It should be mentioned the new phenomenon of wear on the gear (micro pitting) generated on the tooth surface and causes a change in the profile of the tooth and leads to a higher noise level of gearing and causes the other fatigue wear (macro pitting, flaking, etc.). Micro pitting may also occur in bearings. The effect of the metal particles of oil degradation depends on the type of particles (Fe, Cu and others). We know that these particles may evoke a catalytic oxidation. One of the requirements is the regular inspection of the particles. It is a process which results from the monitoring of the friction parts, machine nodes and from the fact that the machine makes its own particles itself and therefore the requirement for periodic care of lubrication, in order to maintain a balance of particles present in the lubricating oil.

2. Application of methods of technical diagnostics by assessment of oil filling condition in the process of running-in of planetary gearbox

On the basis of cooperation applied between our work location and the practice, there arised the demand of implementation the analysis of the oil condition in the planetary gearbox of machining center type VB-715A. Specifically, the ZF is a two-stage planetary gearbox providing optimal torque at low and high spindle speed range.

The aim of the diagnostics of the system under review was:

- to identify the condition of the abrasive particles in oil (quantity, type, size)
- to assess the condition of the contact surfaces in the running-in process (analysis of wear particles)
- to assess the condition of the lubricant
- correlation, quantification of measured parameters – characteristics of the recommended limits.

Technical diagnostics assessed the gear machining center based on the principle of forecasting changes in the technical condition, i.e. prediction of time to failure under consideration of the technical system. The time to reach the critical value $t_{k+\tau}$ for the technical condition of S(t), which is in the specific case identified by size of the abrasive and adhesive wear (assessment of the condition of lubricant and analysis of wear particles) and the assessment of vibration and acoustic emissions can be estimated on the basis of the dependence presented in Eq. (1). The probability of estimation is greater if knowledge of the object and managing of the patterns in the process itself of diagnosis is greater.

3. Materials and methodology

Implemented analysis of gear oils have been prefentially oriented to identify the wear particles produced during running-in period and in the first hours of operation of contact surfaces. At the same time, the correlation between total content of Fe (iron) particles in oil and accrual of kinematic will in tooth meshing of toothed ring of the gearbox was monitored. In quantification of the content of ferrous wear particles the impact of the running-in processes on the contact surfaces (bearings, toothing), which can cause negative side effects, was assessed. Side effects may occur in the form of: