ICSV13 - Vienna
The Thirteenth International Congress on Sound and Vibration
Vienna, Austria, July 2-6, 2006

NOISE AND VIBRATION DIAGNOSING OF TRIBOMECHANICAL SYSTEMS

Aleksandr Yavlensky*[1], Aleksandr Belousov[1],
Konstantin Chavoronkov[1], Aleksey Melnikov[2]
[1]Department of physics and mechanics,
St. Petersburg state university of cinema and television.
Pravda str.13, 191119, St. Petersburg, Russia
[2]J/S company "Vologda Bearing Factory",
Okruzhnoe shosse str.13 160028, Vologda, Russia
conpi@peterlink.ru

Abstract
Questions connecting the problems of the dynamics analysis, identification and diagnosing the systems with the problems of changing their during manufacturing and operation are considered. Theoretical aspects of this problem are presented as diagnosing the systems reodinamics. Simultaneous consideration of these questions allows to solve both the theoretical questions and the practical problems of improving the system manufacturing. The systems are the objects consisting of a great number of interworking elements such load-bearing ones including elements of construction, connection, transfer, engines, etc. Elements mutual interaction and their relative transfer cause vibrations which are significantly amplified if defects are available. It primarily concerns the systems with rotating details, for instance, reducers. Supports and gear wheels are the basic sources of vibrations in reducers. Vibration parameters and their spectral characteristics in particular, may serve as information signals about internal unobserved processes.

INTRODUCTION

Russian industry being integrated in the world economy, the essential feature required of competitiveness of domestic instrument-making products tends to increase. The dominant direction in the decision of this task is the high quality production at optimum expenses, and if can be provided for by further optimization of technological processes. Traditionally each stage of a general technological process is considered to be independent. In researches carried out in the sphere of improving upon elementary technological processes, primary emphasis is rendered to the optimum choice of the tool and its modes of operation.

To solve technological tasks connected with optimizing the high-quality production, new approaches accounting for technological heredity and individual changeability of elementary technological processes in time are submitted. The methods and means of controlling the present state of the technological process and forecasting the direction of its change in the future are considered. Identification and diagnosing the reodynamics of systems as a combination of methods and means of controlling the state of systems is one of perspective directions in creating up-to-date reliable devices.

1. THE REODYNAMICS OF SYSTEMS

The determination of the parameters of the object, or of its equivalent model, implies not only their estimate at a given moment but their changes prediction, too, thus allowing to use the results obtained for diagnosing the quality of systems functioning. Different methods may by applied for determining the model parameters, their choice being dictated either by an a priori information about the structure of the system or by an a posteriori information about the signals which characterize its state.

Much more effective methods which provide control over the state of the functioning system and allow to identify inherent disturbances are those of technical diagnostics aimed primarily at studying and giving proof of the ways of indirect measuring the latent devices parameters in accordance with their functional behavior. In fact, the existing methods of diagnostics are based on analyzing the objects basic operational parameters. The model of the object and the signals characterizing its state as a system element do not completely reflect inner processes and their changes, they only ascertain definite formal connection between the object input and output. It is impossible to diagnose the unseen inner processes within the limits of the model, that is why to diagnose the system technical state and parameters changes special methods are required.

To choose information signals and to establish interrelation between the models of the object as a system element and that of diagnosing optimal methods are required.

The greatest effect from utilizing the methods of identification and diagnostics is attained if they are used during all the stages of product’s active existence. The basic properties of the object as a system element are characterized by the operand $\mathbf{L}$, which not only connects input and output signals $\mathbf{U_1(t)}$ and $\mathbf{U_2(t)}$ but also accounts for dependence of $\mathbf{U_2(t)}$ on the $\mathbf{\Delta U(t)}$ posed by inherent inner processes

$$\mathbf{U_2(t) = L[\, U_1(t), \Delta U(t)].}$$

Technical state change may be controlled through the change of inherent vibrations $\mathbf{z(t)}$ which are caused by inner processes. The basic parameter linking $\mathbf{\Delta U(t)}$ and $\mathbf{z(t)}$ in the model structural scheme presented is $\mathbf{r}$. In systems $\mathbf{r}$ is determined by characteristics divergence from rated values as well as by technological errors and other fluctuations. Correlation between $\mathbf{\Delta U(t)}$, $\mathbf{r}$, and $\mathbf{z(t)}$ is established with the operand $\mathbf{T}$, and between $\mathbf{r}$ and $\mathbf{z(t)}$ with the operand $\mathbf{W}$:

$$\Delta \mathbf{U}(\mathbf{t}) = \mathbf{T}[\ \mathbf{r}(\tau), \mathbf{z}(\mathbf{t})\ ]; \qquad \mathbf{z}(\mathbf{t}) = \mathbf{W}[\ \mathbf{r}(\tau), \mathbf{t}\ ].$$

Correlation between the change (τ) and vibration is established by means of the operand $\mathbf{\Phi}$

$$\mathbf{r}(\tau) = \mathbf{\Phi}[\ \mathbf{z}(\mathbf{t}), \tau\ ].$$

Thus, there exit two types of characteristic processes in a generalized model: rapid ones (time $\mathbf{t}$), i.e. vibrations and fluctuations of operational parameters, and slow (time τ) parameters change. Rapid processes define the quality of functioning at a given moment of time while slow ones account for parametric system reliability. Changes in $\mathbf{r}$ are determined not only by processes of aging but by dynamic vibration effects as well; these changes are slow as compared to vibrations and fluctuations of basic operational parameters, they are reodynamics. The diagnostic signal should be chosen so that it might be informative enough for estimating vector $\mathbf{r}$, its changes and thus for estimating $\mathbf{z}(\mathbf{t}, \tau)$ and $\Delta\mathbf{U}(\mathbf{t}, \tau)$.

By monitoring the changes in these vibration properties, impending structural failure can often be detected before equipment has been damaged, personnel have been endangered, and costly machine downtime has been incurred.

2. PREDICTING THE QUALITY OF THE SYSTEMS

Principal approaches to predetermining durability of the friction systems are reviewed. The approaches to physical and mathematical simulation of estimations of durability for various modes of functioning are submitted. To predict durability the hypothesis of accumulation of damages at non-stationary modes of loading used. Modern theoretical approaches allowing to take into account the material weariness in the superficial layer are given. Great attention to technological processes of final processing and the influence of the quality of these processes on durability, the level of vibration and the stability of vibroacoustic characteristics is presented.

The deformation of surfaces during manufacturing is determined by the processes of friction and microdestruction in the superficial layer. To analyze these processes an equation describing changes in the elements size and form is dealt with. This equation is based on numerous investigations and observations which proved that the rate of destruction depends on dynamic parameters (dynamic loads caused by vibration $\mathbf{z}$ - $\mathbf{Q}(\mathbf{z})$), material properties (the intensity of wear-out $\mathbf{I}$ primarily) and time $\mathbf{t}$.

$$\frac{\mathbf{dr}}{\mathbf{dt}} = \mathbf{\Phi}[\mathbf{Q}(\mathbf{z}), \mathbf{I}, \mathbf{r}, \mathbf{t}]. \qquad (1)$$

This equation describes macro processes though it does not deal with micro processes causing destruction. Deformations are determined by the value of the acting factor $\mathbf{\Phi}$ which is a cyclic process for the systems considered. Let us represent this acting factor as superpositions of influences in each cycle, i.e.

$$\mathbf{\Phi}[\mathbf{Q}(\mathbf{z}), \mathbf{I}, \mathbf{r}, \mathbf{t}] = \sum_{\mathbf{i}=\mathbf{1}}^{\mathbf{N}} \mathbf{\Phi}_{\mathbf{i}}[\mathbf{Q}(\mathbf{z}), \mathbf{I}, \mathbf{r}, \mathbf{t}],$$

where $\mathbf{\Phi_i}$ is the acting factor for one cycle and N is the number of cycles.

When formulating the problem in this way dynamic load is considered to be a basic factor determining deformation.

$$\mathbf{Q} = \mathbf{k}\delta^{\mathbf{p}}\mathbf{e}(\delta)$$

where k is a constructive parameter; δ is the deformation in the area of the detail and the processing instrument interaction, and

$\mathbf{e}(\delta) = \begin{cases} 1, & \delta \succ 0; \\ 0, & \delta \le 0, \end{cases}$ (with $\delta>0$ it is deformation, and with $\delta<0$ it is a space between contacting bodies); and k, p are constrictive parameters.

Converging δ is determined by the trajectory of the cutting tool motion, the profile of the detail processed and radial relative displacements ($\mathbf{x}_D$ **-** $\mathbf{x}_I$)

$$\delta = \delta_{\mathbf{0}} + (\mathbf{r_D} - \mathbf{r_I}) + (\mathbf{x_D} - \mathbf{x_I}),$$

where $\mathbf{r}_D(\psi)$ is the detail profilegram and $\mathbf{r}_I(\psi)$ is the tool profilegram.

Combined masses being accounted for, the equation of vibration in the system ‘a detail - a tool’ looks like

$$\begin{aligned} &\mathbf{M_D}\ddot{\mathbf{x}}_{\mathbf{D}} + \mathbf{P}(\dot{\mathbf{x}}_{\mathbf{D}} - \dot{\mathbf{x}}_{\mathbf{I}}) + \mathbf{C}(\mathbf{x_D} - \mathbf{x_I}) = \mathbf{F}, \\ &\mathbf{M_I}\ddot{\mathbf{x}}_{\mathbf{I}} - \mathbf{P}(\dot{\mathbf{x}}_{\mathbf{D}} - \dot{\mathbf{x}}_{\mathbf{I}}) - \mathbf{C}(\mathbf{x_D} - \mathbf{x_I}) = -\mathbf{F}, \end{aligned} \tag{2}$$

where $\mathbf{M_{D(I)}}$ are a detail (a tool) masses with consideration for combined masses; **P** is the damping coefficient; **C** is rigidity coefficients and **F** is the disturbances resulting from defects in details and tools.

This data analysis proves that deviations in shape significantly influence the parametric rigidity while waviness effects disturbances in the high frequency range. Rigidity variation provides the possibility for parametric resonance occurrence, the latter being unfavourable for deformation.

In developing methods of individual prediction the most reasonable one is that of simulation used together with equations of technical state change. Such an approach allows to analyze a varied character of system behaviour in real conditions even at the stage of design.

The list of constructive and technological factors may be enlarged. At the same time it is necessary, when increasing the number of the factors analyzed, to take into account that the analysis of quality is the most efficient, if these factors and dynamic processes are studied in link-up.

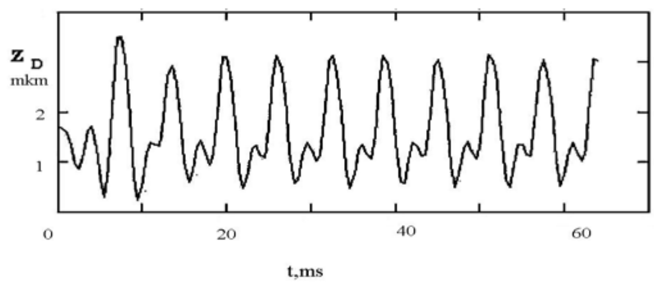

*Figure 1 – Vibration **Z**D of a detail at grinding*

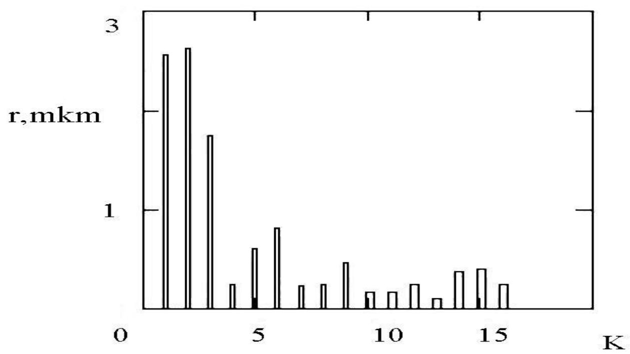

*Figure 2 – The harmonics amplitudes **r** - deformation of the detail*

Deformation simulation is possible as the result of simultaneous calculation of equations (1) and (2). These results allow to predict deformation processes with regards to initial geometry of details and tools, detail and tool wear-resistance and the modes of processing.

3. VIBRATION CONTROL AND DIAGNOSING

At present, there exist many technical means for vibration control, though there are no means for controlling destructive processes during exploitation. There are also no facilities for prognosing destruction in friction joints parts under frictional interaction. Mechanical systems are objects consisting of a large number of interacting elements. Interaction of elements and their relative movements cause vibrations, and defects, if available, significantly intensify them. This is primarily true of systems in which there are rotating parts. To increase the reliability of friction joints (moving mating parts) in mechanisms it is necessary to develop and improve methods and means of technical diagnostics. The main tasks in this sphere are the maximum use of mechanisms resources and reduction of energy and material consumption. Being part of technical diagnostics, the tribological one as a totality of means and methods of continuous control over frictional characteristics of moving mating parts plays a more and more important role in developing the theory and practice of friction, wear-out and lubrication. This role is conditioned by the general tendency in modern technology to develop closed systems with the so-called monitoring capable of changing their work in accordance with the programme preset and the environment. The functions of measuring (estimating) structural parameters in the tribosystem (TS), its continuous control and prediction of its technical condition, and automated regulation are realized in such a system. From a practical point of view one of the basic stages of tribodiagnostics is to develop a diagnosing complex which practically realizes the idea of detecting the TS state. This complex perceives characteristic signals from sensors and then, with the help of certain operations, forms a number of diagnostical indications in accordance with which certain TS states or the values of its internal parameters are defined and then a conclusion is given whether it is possible to exploit TS further on. The TS distinguishing feature is the irreversible and complex character of wear-out and a variety of its types dictated by environment and the parameters of the operating system. So if it is possible to realize diagnosing in the system of lubrication circulation by controlling pressure, temperature and lubrication characteristics in some friction joints with hydrodynamic lubrication, in systems operating without it or when lubrication is poor even the process of choosing basic parameters for diagnosing is not accomplished yet. At present, in order to get diagnostic information some parametric TS characteristics are measured: the coefficient of friction, the temperature in the zone of contact, the speed of wear-out, vibration values, acoustic vibrations, variable deformations and efforts. The most wide spread and effective methods of TS diagnosing are the current parameters control and the study of the wear-out products.

At present, the development of methods for diagnosing moving conjugations which work with lubrication or without it is considered to be one of the most important ways of significant increase in tribotechniques. All the methods described are being developed nowadays:

-the most labour consuming methods of physical and physics-chemical investigations are desirable for solving fundamental friction and wear-out problems;

-express-analysis methods realized as automated systems built into a mechanism general scheme are to provide for future technologies development.

The latter group of methods acquires a more and more growing significance in the context of intensive development of systems and facilities for information processing with PCs.

The most perspective devices from the view point of conducting express diagnosis are those ones based on the lubrication analysis by means of magnetic and electric fields or acoustic phenomena. The list of problems which should be solved for developing reliable diagnostic facilities is rather long. However, rapid development of instrumentation base for machines diagnosing as well as manufacture of simple miniature sensors of physical parameters and microprocessors allow to hope that they will be solved in the nearest future. That is why such tasks as elaboration of diagnostic criteria which adequately represent the wear-out mechanism and account for a variety of destructions processes and mass-transfer in friction are aimed at tribotechnical diagnosis development and becoming of primary importance nowadays [1,2]. The following problems are resolved:

-applicatition of express diagnostics based on analyzing the electric fields and acoustic phenomena;

-development of instrumentation base for diagnosing machines with simple miniature sensors for physical parameters and microprocessor systems;

-elaboration of tribotechnical diagnostics methodology, i.e. working out diagnostic criteria adequately representing the wear-out mechanism which would account for a variety of destruction processes and mass-transfer during friction.

By monitoring the changes in these vibration properties, impending structural failure can often be detected before equipment has been damaged, personnel have been endangered, and costly machine downtime has been incurred. To get more detailed information it is desirable to use multi-channel measurements. The vibration sensor is a traditional device, the lubrication condition sensor is based on an electro-physical method and it is an original one, the triboemission sensor is analogous to that of acoustic-emission but it operates in a specific mode. The principal novelty factor is a combination of measurements from three sensors into one information flow possessing definite synchronization. The diagnosing is conducted on the basis using "Wavelet transform". This method are gyved good result in case non-stationary signals.

The results of estimating the accuracy of diagnosing are presented in Fig. 3,4. The intensity of a diagnostic signal (envelope of a signal of triboemission on frequency of 150 KHz) is small - Fig. 2 for a joint in a normal state.

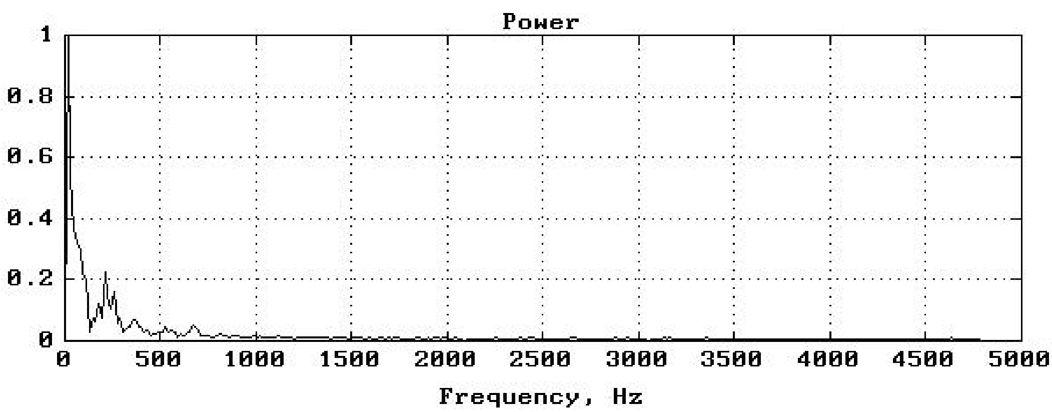

Figure 3 – Intensity of a diagnostic signal for a joint in a normal state.

The intensity of a diagnostic signal (envelope of a signal of triboemission on frequency of 150 KHz) for a faulty joint increases substantially - Fig.3.

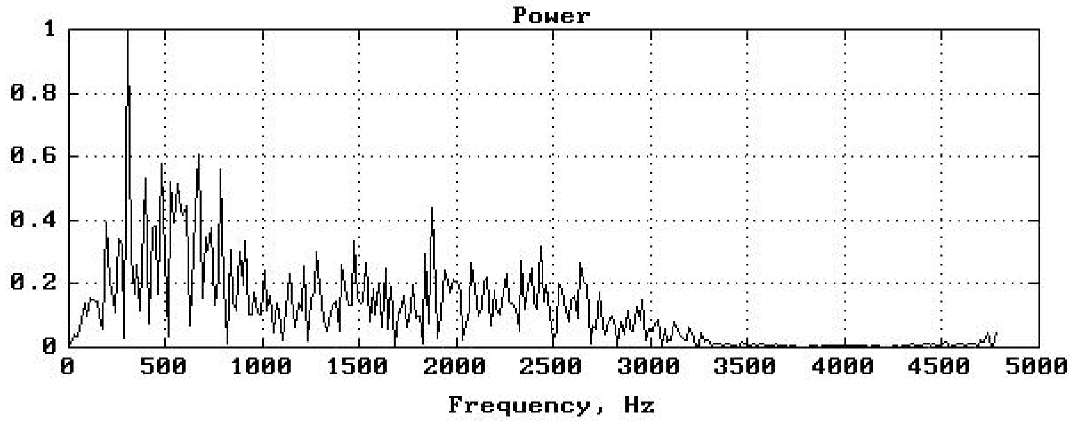

Figure 1 – Intensity of a diagnostic signal for a faulty joint

The benefit of applying the facilities proposed is that there appears a possibility to accomplish tribomonitoring which results in diagnosing the technical condition and thus in prognosing its changes so as to prevent emergency cases, to make operation more reliable and to reduce economic expenditures.

SUMMARY

The benefit of applying the facilities proposed is that there appears a possibility to accomplish tribomonitoring which results in diagnosing the technical condition and thus in prognosing its changes so as to prevent emergency cases, to make operation more reliable and to reduce economic expenditures. The diagnosing is conducted on the basis using Wavelet transform. This method are gyved good result in case non-stationary signals.

REFERENCES

[1]. Yavlensky A., Eiperin A., Talashov G., Diagnosing the reodynamics of friction systems, Editor Dr.S.Prof.A.K.Yavlensky, St. Petersburg “NAUKA”,1998.

[2]. Yavlensky A., Yavlensky K., Vibrodiagnostics And Prediction of Mechanical Systems Quality, Leningrad: Mashinostroenie (Leningrad Department), 1983.