VIBRO-ACOUSTIC DIAGNOSTICS OF ROTARY TYPE MACHINES AND MECHANISMS

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ABSTRACT

In this paper, the method of vibro-acoustic diagnostics of technical condition of machines and mechanisms is presented. The method allows revealing defects of different rolling units in electric motors, generators, ventilators, turbines, compressors etc., without contact with them. Results of the analysis of the revealed defects allow to produce the practical references on their elimination and to establish a residual resource of equipment.

Keywords: vibro-acoustic, noise, spectrum, analyses, defects, diagnostics, reducer

I. INTRODUCTION

Vibro-acoustic diagnostics of rotary type machines and mechanisms are an independent scientific direction of technical diagnostics, which has arisen on a joint of acoustic dynamics of machines and theories of signals and recognition of defects [1,2].

The essence of technical diagnostics will consist of the theory, methods, and means of detection and search of objects' defects. The primary goals of technical diagnostics are: 1) definition of a technical condition in which there is an object during the present moment of time;

2) prediction of a technical condition in which there is an object during some future moment of time. For this purpose it is required to determine set of parameters which characterize a condition of machines and mechanisms, i.e. diagnostic parameters which majority is not electric sizes, namely: linear and angular moving, speed and acceleration of vibration, pressure, temperature, rotation frequency, etc.

The world practice shows, that diagnostics is necessary at all stages of the mechanism's life cycle: from designing and manufacturing up to removal from operation and the repair period.

Now methods of diagnostics of machines and mechanisms develop in four ways:

1) Diagnostics by the not destroying control method; 2) on vibro-acoustic signals; 3) the analysis of products concentration of wear process in oil; 4) by results of the exhaust gases analysis. The method of vibro-acoustic diagnostics [3,4] is the most effective among them for an estimation of technical condition of the complex equipment. It is connected by that, first, vibro-acoustic diagnostics allows not only to reveal breakages and to prevent catastrophic destructions, but also to find out developing defects at very early stage that enables to forecast an emergency, and also is proved to plan terms and volume of repair of the equipment, to carry out the analysis of the carried out works quality. Second, vibro-diagnostics is more sensitive to defects, in the third, provides the control of a technical condition of the equipment operatively and without demolition.

The basic distinctive feature of vibro-diagnostics is use as diagnostic parameters not static sizes such as temperature or pressure, but the dynamic parameters, such as speed, acceleration and moving.

Offered work is devoted to development the non-contact diagnostics technique of a technical condition of machines and mechanisms rotor type (as an example diagnostics of planetary reducer is taken).

II. THEORETICAL BASES AND EXPERIMENTAL RESULTS

The reducer is one of the most widespread mechanisms in machine units. The basic purpose of a reducer the coordination of frequencies of rotation of a shaft high-speeds the engine to slow-speed target shaft of installation.

According to numerous works [1-6] in normally working tooth gearings excitation of fluctuations is caused by display of two major factors: 1) periodic change of rigidity teeth on a phase of gearing and 2) errors of manufacturing and installation of cogwheels.

Basically it is possible to carry to defects of a reducer both defects of assembly, and defects appearing while in service. The unbalance, a deviation concern to them from concentric shafting, a wrong lateral backlash in bulkhead coupling and different gaps in a planetary reducer, a skew of axes, wrong position or reduction of a stain of contact in gearing, infringement of greasing.

The basis vibro-acoustic diagnostics is made with the analysis of the oscillatory processes, being direct results of interaction of details of a design of machines. For example, the basic sources of fluctuations in turbines, generators, pumps and reducers are unbalanced forces of inertia. Under action of these forces cross-section fluctuations of rotors at its rotation f_{rot}. and its harmonics $k\ f_{rot}$ (where κ=1,2,3.) are exited. Except for them poly-harmonious fluctuations of paddle –wheel frequencies such as $f = k\ f\ Z_{rot}$, where κ=1,2,3.., Z-number teeth's gear gearings and number of propeller blades (the fan, the compressor, the turbine).

The important feature of these fluctuations is that fact, that they have greater speed of distribution on designs and quickly fade at distribution from one unit of machines to another. These qualities at diagnosing allow revealing precisely defective unit within the limits of one machine, on the other hand quickly to define an emergency.

There are a lot of models of vibro-acoustic processes allowing establishing single-valued relation between the vibration signals characteristics and parameters of a technical condition of machine mechanisms. Among them the method of diagnostics on a spectrum of high-frequency signal's envelope [1] is most widely distributed.

For formation of diagnostic attributes the narrow-frequency range of the vibro-noise spectrum usually used, for example, in the one harmonic zone. In that case fluctuations of details and units are the most convenient for representing as peak modulation of high-frequency fluctuations which is described mathematically by expression [1]:

$$Y(t) = A[1 + m\,F(t)\,Cos(\omega_0 t + \varphi)] \qquad (1)$$

where ω is carrier frequency; A is an amplitude; m is a factor of peak modulation depth which varies in range from 0 up to 1 and is determined as

$$m = \frac{A_{\max} - A_{\min}}{A_{\max} + A_{\min}}$$

where A_{max} and A_{min} are maximal and minimal amplitude range of the promodulated signal; F(t) is modulating function which can be submitted in a general view by the sum of sinusoidal and cosineidal fluctuations

$$F(t) = \sum_{k=1}^{n} C_k Cos(k\Omega t + \varphi_k) \qquad (2)$$

In view of formulas (1) and (2) and also by decomposition to the sums of simple cosineidal fluctuations, resulting amplitude - modulated process will have the following kind bulkhead coupling

$$Y(t) = A[Cos(\omega_0 t + \varphi) + \sum_{k=1}^{n} \frac{1}{2} Am_k Cos[(\omega_0 + k\Omega)t + \varphi + \varphi_k] + \sum_{k=1}^{n} \frac{1}{2} Am_k Cos[(\omega_0 - k\Omega)t + \varphi - \varphi_k] \qquad (3)$$

For a planetary reducer

$$Y(t)_{\text{the plan.}} = A_0A_2/2\ \{\cos[(\omega_z - \omega_2)t + (\varphi_0 - \varphi_2)] + \cos[(\omega_z + \omega_2)t + (\varphi_0 + \varphi_2)]\} + A_0A_1A_2/2\ \{\cos[(\omega_z - \omega_2 - \omega_1)t + (\varphi_0 - \varphi_2 - \varphi_1)] + \cos[(\omega_z - \omega_2 + \omega_1)t + (\varphi_0 - \varphi_2 - \varphi_1)] + \cos[(\omega_z + \omega_2 - \omega_1)t + + (\varphi_0 + \varphi_2 - \varphi_1)] + \cos[(\omega_z + \omega_2 + \omega_1)t + (\varphi_0 + \varphi_2 + \varphi_1)]\} \qquad (4)$$

From the formula (3,4) it is visible that by decomposition of a vibro-signal spectrum on its frequency harmonics and by identification of these frequencies by known frequencies of the given unit it is possible to reveal diagnostic attributes of operational defects of the rotary machines' units.

Damages of bearings in operational conditions can be conditionally divided into the following groups: a) destructions from fatigue of material; b) damages from the increased deterioration; c) the destructions caused by change of clearance between the bearings details and rotor support; d) damages because of insufficiency or stopping of ubricant delivery.

The program which has been applied for diagnosing a technical condition of the reducer was developed by us.

For revealing and the analysis of kinds of defects, we develop the program of computer processing of results of measurements of the high-frequency acoustic noise, directly while in service working machines and mechanisms rotor type. Besides in the developed program for reduction of influence of casual vibrations the method of suppression of these vibrations by a choice of an optimum strip of frequencies of the analysis is realized.

The developed program has been applied to diagnosing a technical condition of the unit consisting from bulkhead coupling and a planetary reducer. From fig.1a it is visible, that the entrance shaft of planetary connection rotates by means of unsymmetrical teeth crown (2) wheel which is connected with unsymmetrical pinions(1). The kinematics scheme of planetary reducer is resulted on fig.1b.

We shall note, that depending on a way of fastening of a planetary reducer to the case one of parts of a reducer (c, d, H) should be stopped (in d diagnosed reducer the part is stopped).

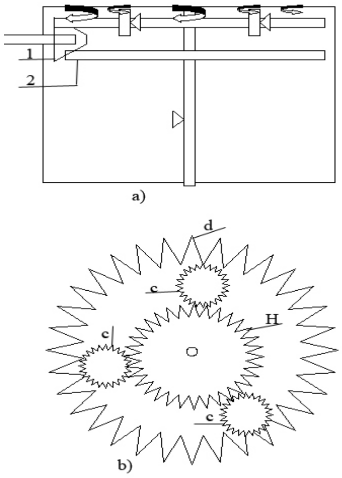

Fig.1.Kinematics scheme of the reducer.

On each support of the unit (fig.2) spectra vibro-noise on different frequency ranges have been removed. Then by means of the developed program defects which have arisen while in service the unit has been identified and degrees of the development, the revealed defects are estimated.

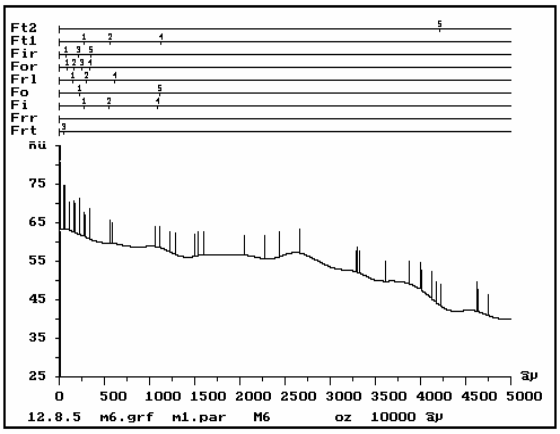

Fig.2. Vibro-signal spectrums.

As a result of the analysis of the measured spectra following defects of deterioration of the unit have been revealed: 1) the increased clearance at leaky planting the friction bearing, 2) cavities, flaws of inner ring, 3) Shifts of axes of joined mechanisms, 4) the unbalance of a rotor, 5) skewness of tooth gear shafts, 6) chipped spots non-uniform wears of rollers, 7) the non-uniform air backlash between a rotor and stators, 8) fatigue sapling of drive face of teeth, 9) infringement of a mode and quality of greasing.

We shall note, that by the analysis of the received results the reasons of occurrence and a way of elimination of the revealed defects also are specified. The detailed analysis of spectra specifies that the reason observable defect of a greater degree is encountering and misalignment connecting coupler between supports. Other reason is also non-uniform distribution vibro-moving on defective support (fig.4). From figure it is precisely visible, that at installation or while in service for whatever reasons the centers of connected shaft not precisely coincide with each other. As a result connected shaft at such defect represent them selves not a uniform shaft, and a shaft with defect in a junction.

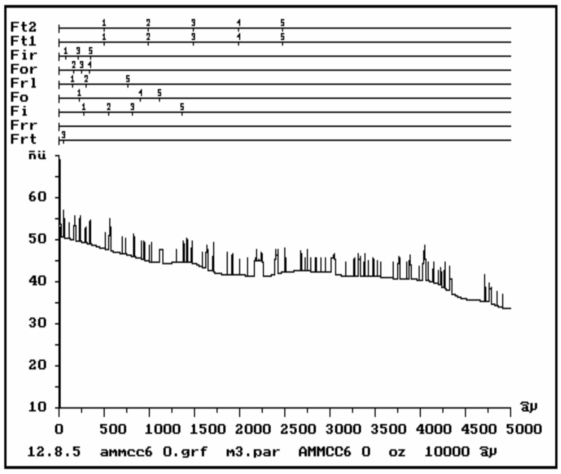

Fig.3. Vibro-signal spectrum.

It in turn leads to strong vibration of the equipment.

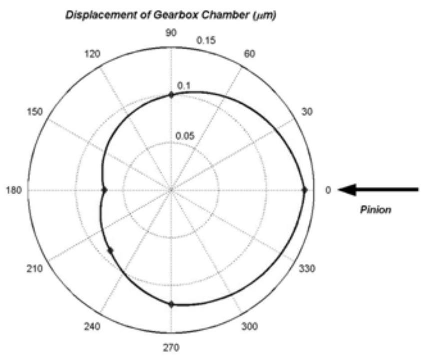

Fig.4. Allocation of vibro-displacement place of joint pinions with crown wheel.

We shall note, that the defect connected to a non-uniform air gap between a rotor and stator can result to disbalance of a rotor. And if to take into account, that magnetic force between a rotor and stator is proportional to value of a magnetic induction B (F ~ B), then this defect is so dangerous.

It is necessary to emphasize, that design features of planetary transfer in a reducer impose the certain print not only on character of excitation of fluctuations in a reducer, but also on character of distribution of these fluctuations from a source of occurrence up to a point of case construction design where the detector is established. Besides in planetary transfer cyclic moving of points of application of forces to gearing concerning the motionless detector established on the case of a reducer that creates additional difficulty at the analysis of spectra.

It has been by practical consideration established, that at size of factor of modulation m <6 %-corresponds to an arising defect (an early stage), at m <15 %-to advanced defect (is allowable), at m <40 % to take measures is required, m> 40 %- to strong (is inadmissible) defect of the bearing.

For qualitative carrying out of measurements of spectra vibro-noise, owing to essential attenuation of amplitude of high-frequency vibration in process of distance from an investigated reference point, it is necessary at record of spectra vibro-noise, vibration detector, transform mechanical fluctuations in electric signals, to establish as much as possible close to the location of the bearing. Besides it, for increase of accuracy of measurements, it is necessary to provide qualitative (dense, uniform on all working surface) of contact vibration detector to surface of the unit in an investigated reference point. With this purpose it is expedient to apply greasing.

III. CONCLUSION

The developed technique and the software allow to machines out processing vibro-acoustic spectra of vibro-noises from units and details of rotary type machines, and by means of it to reveal the inceptive defect, a degree of its development, to identify these defects and to establish the reason of their occurrence. The obtained results of the analysis of the revealed defects allow to develop concrete recommendations on their elimination and to establish equipment's residual service life.

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