Method of diagnostics of the state of rolling element bearing on the basis of the theory of active perception

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***Abstract*—In this work is considered vibration-based diagnostics method the state of rolling element bearing on the basis of the theory of active perception. The experimental researches of the method are given according to the data presented by Case Western Reserve University Bearing Data Center. According to the research it can come to the conclusion that the proposed method ensure a high precision the state's classification of rolling element bearing by vibration signal.**

Keywords—digital signal processing; theory of active perception; vibration signal; rolling element bearing; fault diagnosis

I. INTRODUCTION

One of the important problems which related to ensuring the normal operation of machines and mechanisms is timely detection and prevention their failures. Scientific discipline that studies and determinative defects' sings of technical objects, as well as methods and facilities for the detection and search (indicate the location) defects is called technical diagnostics [1].

Vibration diagnostics – one of the part of technical diagnostics, which is consecrated on the development and practical realization algorithms for estimation parameters of technical state of the diagnosis object without its disassembling in operating conditions, by vibroacoustic processes accompanying its operation [1]. Vibroacoustic diagnostics methods can not only identify developed a fault but also to detect developing defect at an early stage.

Vibration diagnostics is used in gas and oil transport industry, railway traffic, food, chemical, gas and motor industry, energetic, metallurgy.

In various equipment used in the described industries, are often used rolling bearings [2]. The damage of rolling element bearing can cause failure of the whole mechanism. Therefore, urgent task is diagnostics of rolling element bearing by its vibration signals, may be performed without disassembling mechanism.

This paper is devoted the description of solving problem of vibration diagnostics method on the basis of the theory of active perception [3].

II. METHODS OF VIBRATION SIGNALS' CLASSIFICATION

A classification system of the bearing's condition by its vibration signals can be represented as a system of image recognition. From the aspect of system analysis the problem of recognition (to wide extent) is a scope of three stages: preprocessing, calculation features and decision-making (see. Fig. 1).

Consider the methods which used at different stages of recognition problem [2, 4-11]:

- preprocessing stage usually consists in filtering the vibration signal. Considering that the recognition problem is solved in the a priori uncertainty conditions, i.e. is not known any information about hindrance, select a suitable filter is difficult [5];
- for making a vibration signal description is used the following features: Fourier coefficients spectrum, wavelet spectrum coefficients, mel-frequency cepstrum coefficients, etc.;
- at the stage of classification by existing features is executed the assignment of input signal to one of the known classes. For that is usually used: hidden Markov model, Gaussian mixture model, neural network, Support Vector Machines. Application of these models assume their pretraining and selection their parameters which in the conditions of a priori uncertainty is not a trivial task.

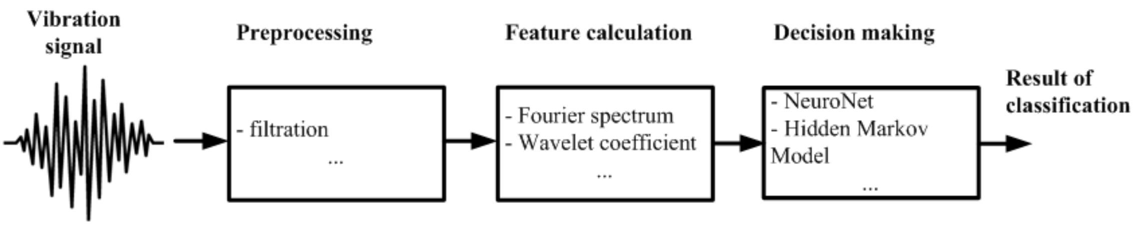

Fig. 1. Stages of vibration signal's recognition

There are known problems which linked with application of existing methods of pattern recognition [3]:

- the problem of initial description formation: this problem attributes to the fact that the existing models and methods of recognition are adapted to a particular class of applications and required a priori knowledge of analyzable signals' features;
- the problem of feature's system formation links to choice of a finite set of features, providing uniqueness of solution of classification problem at the stage of recognition and respondent to the requirements of necessity and sufficiency. Select stage of system's features is required to reduce the dimensionality of the input description. In consideration of the problem of dimensionality reduction is optimization problem, then solving it is necessary to use the criterion of information content. The lack of a priori model uncertainty and model its disclosure had generated a large number of methods in selection of criterion of information content which by-turn generate a large number of possible sings [3];
- problem of decision making under uncertainty a priori. Step of decision making consists in comparison with existing standard of feature descriptions analyzable vibration signal. It is assumed that the standard corresponds to a compact set of points in the system of features. However, noise, structural changes of the same class representative lead to overlapping classes. Therefore the problem of decision making is closed to problems of system features' formation, allows to form a standard that has a compact conception.

The theory of active perception proposes a solution the described problems [3]. This paper deals with the application of this theory to the analysis of vibration signals.

III. Vibration-based Diagnostics Method on the Basis of Theory of Active Perception

Consider the implementation stages of the recognition system in the TAP's terms.

A. Calculation of features

The proposed method of calculating the feature descriptions of the vibration signal consists in the following:

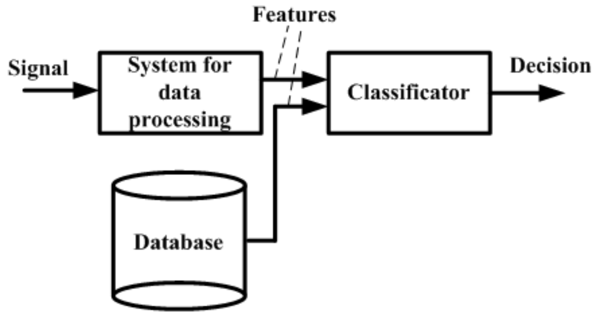

Fig. 2. The Received Signal Classification

- vibration signal readings are divided into a multitude of segments $S = \{s_k\}$, k=1:N, where N – number of segments;
- to each segment s_k is used U-transform (U-transformation is a basic in the theory of active perception), consequently forming a spectral representation of each segment: $u_k = U[\, s_k\,]$, $\boldsymbol{u} = \{\, u_k \}$, where U - operator calculating of U-transformation;
- by calculated spectral presentation $\boldsymbol{u_k}$ of s_k segment determines a closed groups: $p_k = P\,[\, u_k\,]$, $\boldsymbol{p} = \{\, p_k\,\}$, where P - calculation of closed groups' operator;
- calculated histogram of closed groups: $d_{ij} = H\,[\,\boldsymbol{p}\,]$, where H – operator of forming a histogram of closed groups, which is indicative of the description field G_{ij}. Number of closed groups are used to describe features of vibration signal, is 840.

B. Decision making (classification)

Stage of classification is based on the method of template matching (see. Fig. 2, is used measure of proximity - Euclidean distance):

$$a(e) = \arg\min E(d_{c,\,i},\, e), \qquad (1)$$

where a, b – indicative description of the comparison objects, i – serial number of sing, C **-** classes set describing the bearing state (normal state, the defect in the rolling body, a defect in the inner track to the outer track defect), $d_{c,\,i}$ – features of the i-th standard appurtenant to c-class, e – features calculated from the input signal, E – calculating operator of Euclidean distance.

As a resultant class is chosen the class of that standard, to which the distance from input signal was the least.

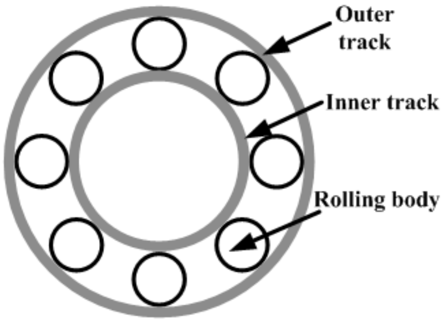

Fig. 3. Bearing Scheme

IV. COMPUTING EXPERIMENT

A. Description of test data

Computing experiment was carried out on basis of database of vibration signals, as described in [5]. This database contains records of vibration signals of rolling bearings with defects (on outside, and inside track on the rolling body, see. Fig. 3), and without defects. The size of defects are 0.007, 0.014, 0.021, and 0.028 inches in diameter. Defects of the outer track are stationary, so that the position of the defect relatively to the load zone of the bearing affects to the vibration signal generated by the bearing. To investigate the influence of this effect on the outer track defects were applied in three positions.

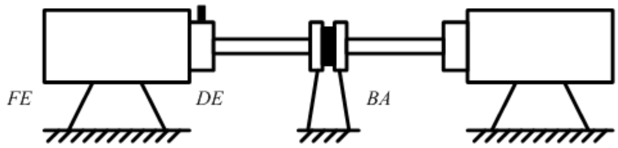

Fig. 4. Stand for registration vibrosignals

Thus, within the available databases can be categorized twenty one bearing condition: 1) is normal; 2-5) defect of rolling body; 6-9) inner track defect; 10-21) outer track defect.

Stand scheme to record vibration signals is shown in Fig. 4. The test bearing is fixed on the motor shaft. Accelerometers are used to register vibration signal which are placed on the engine case on the connection load (DE), next to the fan (FE) and on the supporting device (BA). Vibrosignals' recording is performed with a sampling rate of 12 kHz and 48 kHz.

B. Test Results.

Results of testing of existing classification methods rolling bearing status are shown in Table 1. Table 2 shows the results of the research of the proposed method on vibration signals which recorded in different parts of the stand.

Computing experiment was executed on a laptop Asus K70AD, CPU – AMD Turion (tm) II Dual-Core Mobile M500, 2200 MHz (dual-core), the amount of RAM – 4GB.

TABLE I. RESULTS OF TESTING VIBRODIAGNOSTICS METHODS

Reference	Features	Number of Features	Classification Method	Number of classification states	Recognition Accuracy (R, in %)
[5]	Mel-Frequency Cepstrum Coefficients	16	Hidden Markov model	4	99
[5]	Mel-Frequency Cepstrum Coefficients	16	Gaussian mixture model	4	94
[7]	Wavelet Packet Expansion Coefficients	32	Support Vector Machines	21	99.3
[7]	Statistical Features	26	Support Vector Machines	21	92.88
[7]	Spectrum of Complex Envelope	72	Support Vector Machines	21	85.47
[7]	Wavelet Packet Expansion Coefficients	32	*K* Nearest Neighbors	21	97.76-97.35
[7]	Statistical Features	26	*K* Nearest Neighbors	21	96.64-95.69
[7]	Spectrum of Complex Envelope	72	*K* Nearest Neighbors	21	99.83-99.92
[11]	Features of wavelet coefficients	5	Network of Radial Basis Functions	4	72.1
[11]	Features of wavelet coefficients	5	Multilayer Perceptron	4	100
[11]	Features of wavelet coefficients	5	Probabilistic Neural Network	4	97.5

TABLE II. DEPENDENCE OF RECOGNITION ACCURACY FROM THE LENGTH OF VIBRATION SIGNAL

The Length of the Signal (in Reference)	Recognition Accuracy (R, in %)		The Length of the Signal (in Reference)	Recognition Accuracy (R, в %)		
	Sampl. freq.: 48 kHz			***Sampl. freq.: 12 kHz***		
	DE	***FE***		***DE***	***FE***	***BA***
60000	100 (14)	100 (14)	60000	93 (16)	92 (14)	100 (13)
30000	92 (14)	100 (14)	30000	93 (16)	85 (14)	84 (13)
15000	92 (14)	92 (14)	15000	81 (16)	71 (14)	84 (13)
10000	78 (14)	78 (14)	10000	56 (16)	71 (14)	84 (13)

Material for forming the base of vibration signals standards set in multitude of Z_{teach}, which comprising of training implementations ("training sequence"). To check the quality of the recognition method is presented another array (Z_{contr}) data ("control sequence").

Accuracy of recognition (R) is calculated as the ratio of the number of correctly recognized states bearing (W_{corr}) to the general conditions (W_{all}):

$$R = W_{corr} / W_{all}. \quad (2)$$

In Table. 2 in brackets, near the value of recognition accuracy, indicate the number of classified states, as owing to lack of data number of bearing states is not always equal to 21.

We can explain the deterioration of results when reducing the size of the signal that in order to accurately construct a histogram is required enough amount of data. Consequently, with decreasing volume data by which the histogram is constructed, is lead to reduce the accuracy of the feature signal description.

Table. 1 and 2 shows that for twenty-one class of possible states of bearing one hundred percent classification accuracy is only achieved by using the proposed of recognition method.

SUMMARY

Paper is devoted to solving the problem of diagnosing of the rolling element bearing state by vibration signal, which generates the bearing during operation. The proposed method of vibration diagnostics is based on the theory of active perception. In the capacity of feature description of vibration signal is used the closed groups' histogram on stage of classification - Euclid distance. Testing method on the basis of rolling bearings' vibration signals has shown absolute accuracy of the method.

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