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VIRTUAL STANDARDS OF VIBRATION-BASED DEFECTS DIAGNOSTICS IN RAILWAY INDUSTRY

Summary. The issues related to testing the functionality stated by producers of vibration-based diagnostic equipment have been considered. The introduction of virtual standards of defects found in bearing and geared assemblies of rolling stock is offered. The variants of virtual standards realization have been considered.

ВИРТУАЛЬНЫЕ ЭТАЛОНЫ ДЕФЕКТОВ В ЖЕЛЕЗНОДОРОЖНОЙ ВИБРОДИАГНОСТИКЕ

Аннотация. Рассмотрены проблемы проверки заявляемых производителями функциональных возможностей вибродиагностического оборудования. Предлагается введение виртуальных эталонов дефектов для подшипниковых и редукторных узлов подвижного состава железных дорог. Обсуждаются варианты реализации виртуальных эталонов.

1. VIBRATION-BASED DIAGNOSTICS IN RAILWAY INDUSTRY

Recently the vibration-based diagnostics equipment has been increasingly applied in railway industry. According to preliminary assessments nearly 1000 of such devices are used by Russian railways. According to the Russian regulations [1, 2] the procedure of vibration-based diagnosis is obligatory during maintenance service and repair of locomotives. The purpose of technical diagnosis is the „maintaining the designated level of reliability, provision of safety and effective use of the devices" [3]. Generally diagnosis is aimed to solve the following problems [3]:
– definition of technical state type;
– identification of failure or defect location;
– forecasting of technical state.

The most crucial rotor-type mechanic engineering units, the wheel motor assemblies (WMA), are the most frequent ones under vibro-diagnostics tests in railway industry:
– axle equipment bearings;
– traction motors bearings;
– speed transformers bearings;
– toothed wheel gearings.

Rotor-type mechanic engineering units vibration-based diagnostics enables:
– to prevent the defect growth and lower the expenses related to the assembly restoration;
– to identify the restoration procedure;
– as the result of sound diagnostics - to forecast the residual life (to assess trouble-free operation time).

2. METROLOGICAL CHARACTERISTICS AND FUNCTIONALITY

It is the sound diagnostics that appears to be the most valuable and informative. The use of vibration-based diagnostics equipment on the expert systems level allows to gain the greatest economic effect.

Development engineers and producers of such equipment claim the possibility of detection of separate defect types and the degree of their growth. But the standard documentation accompanying these products does not contain the procedure of verifying the claimed capabilities. The metrological gauging neither test nor confirm these properties. Such metrological characteristics as the dynamic range, the pass band, the frequency resolution at spectrographic analysis, the minimum input signal level and others are tested.

The confirmation of solely metrological characteristics cannot convince the consumers of the equipment efficiency. It is quite understandable, since the metrological characteristics values indirectly characterize the potential possibilities of the hardware. Good metrological indexes do not guarantee effective and reliable defects identification in tested units. This is mandatory but not sufficient condition of the diagnostic equipment effective operation.

Efficiency is in many ways defined by the applied vibration signals and rotational speed processing methods and analysis. The defects identification is carried out by using rather complicated algorithms. For example, to identify each of the designated defects in a bearing part the „Rpognoz-3" diagnostic complex checks the conformity to 400-450 rules and conditions. These checks are controlled by special recognizing part of the program, which is different for each manufacturer.

In is there that the most active rivalry among the development engineers and producers is taking place. The used signal processing methods and analysis as well as the algorithms of defects identification are very hi-tech aspects, the "know-how". The cost of the software providing automatic diagnosis of rotor equipment can be as high as $ 10,000 [4].

The user in the long run has little interest in numerical values of metrological parameters. He/she must be aware that the equipment will accurately accomplish its mission of defects identification and determination of their degree of growth. In this connection the serious question comes to mind: what should be the claimed capabilities conformity check procedure look like?

Such a check can be carried out in multiple ways. Let's briefly consider each of them.

3. WAYS OF CHECKING THE CLAIMED CAPABILITIES

The first and the most obvious one is the analysis of diagnostic equipment performance check, i.e. the comparison (on the basis of hundreds experiment) of the resulting diagnoses and actual condition of the inspected assemblies which can be determined after their disassembling. But in this case there is another problem - subjectivity of actual assembly assessment as well as subjectivity of the comparison procedure itself. In order to avoid this problems it is necessary to specify both of the procedures which in turn is quite complex.

The second way is to organize a number of active experiments. The experiments are to be as follows. In order to obtain a representative sampling it is necessary to expose sufficient number (from hundreds to several thousand) of same type assemblies to diagnosing. According to the sample calculations carried out jointly with the Institute of Mathematics of Siberian Branch of the Russian Academy of Science aimed to gain comparative estimation of two diagnostic devices overall performance and receive acceptable accuracy (about 10 %) it is necessary to carry out at least 120 active experiments. After diagnosing the assemblies are to be disassembled and examined by special commission, i.e. register their real technical condition. Further it is required to compare the results of

the corresponding assemblies diagnosing with their actual condition. The comparison results then are to be used for diagnosing parameters reliability calculation. In order to carry out the above mentioned procedures, as well as in the first case, it is necessary to develop the orders of assessment and comparison of the gained results. In addition it is required to collect a great number (dozens) of rotor assemblies having various defective parts. Besides, the same defect types must have various growth degrees.

The third way is the creation of defects standards which could be used check various diagnostic equipment for their compliance to claimed capabilities. Such standards are to possess the following mandatory properties:

– reproducibility and repeatedly;
– precisely stipulated and checkable numerical values, ranges and limits of the reproduced physical quantities;
– possibility of duplication;
– ability to save the properties and characteristics for prolonged periods of time (with observance of the agreed exterior conditions).

Full-scale specimen of wheel motor assemblies with known classified and assessed defects cannot be used as such standards since the requirements to the standards set forth above are not applied to them.

4. VIRTUAL STANDARDS OF DEFECTS

The offered solution is to introduce the virtual standards of defects (VSD). On one of the definitions runs – a virtual standard is a soft hardware which uses informational by its nature highly stable representation of a measured physical quantity [5]. Virtual standards have already found the application in the theory of spectral analysis of materials [6].

As it has been mentioned, virtual standards of defects can be realized in the form of specialized soft hardware or on the basis of a PC with corresponding interfaces.

Let's consider one of the possible variants of VSD construction and the way it interacts with vibration-based diagnostics equipment. Fig. 1 shows VSD function chart (position I) of interacting with soft hardware vibration-based diagnostics complex (position II).
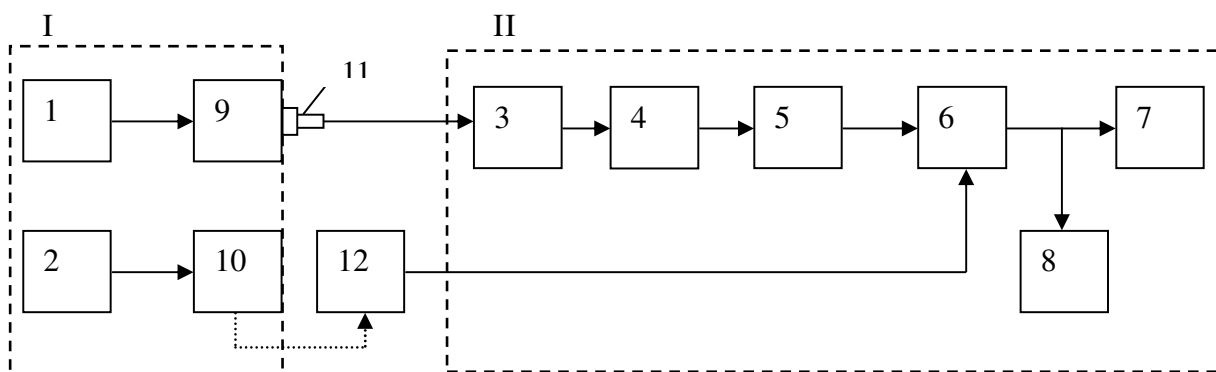

Fig. 1. VSD function chart of interacting with soft hardware vibration-based diagnostics complex, where: 1 – simulator (data carrier) of vibration signal; 2 – simulator of rotational speed signal; 3 – amplifier; 4 – filter; 5 – analog-to-digital converter; 6 – programmable processor; 7 – indicator; 8 – logger; 9 – vibratory table; 10 – controlled reference electric drive; 11 – vibrator inverter (vibration transducer); 12 – rotational speed sensing transducer

Рис. 1. Функциональная схема ВЭД во взаимодействии с программно-аппаратным вибродиагностичес-ким комплексом, где: 1 – имитатор (носитель информации) сигнала вибрации; 2 – имитатор сигнала частоты вращения; 3 – усилитель; 4 – фильтр; 5 – аналого-цифровой преобразователь (АЦП); 6 – программируемый процессор; 7 – индикатор; 8 – регистратор; 9 – вибростолик; 10 – образцовый управляемый электропривод; 11 – вибропреобразователь (вибродатчик); 12 – датчик частоты вращения

In the chart the key role is played by the unit marked by 1, simulator (data carrier) of vibration signal. It is this unit that stores the information on physical quantity modifications (vibration acceleration, vibration velocity or vibration displacement) during rotor mechanical assembly with defective parts operation. As a rule, diagnostic equipment uses the information on RPM as well (unit 2). How can the information be placed into the simulator 1 be obtained? Theoretically such information can be gained in two ways.

5. OBTAINING INFORMATION FOR STANDARD CREATION

The first way is artificial synthesis of a complex signal on the basis of theoretical and empirical data. This alternative is characterized by a small number of diagnostic indications present in real signal.

The second is to record the signals from real units (wheel motor assemblies) whose parts (bearings and reductors) have various defects and same type defects of different sizes. It is quite obvious that the recording of such signals is to be made by reference equipment in matching modes and conditions.

Generally it is necessary to have a variety (set) of standard samples of defects with various defects growth degrees. Figs. 2, 3, 4 shows the example of characteristic defects in axle bearing which can be used for creation of virtual standards.
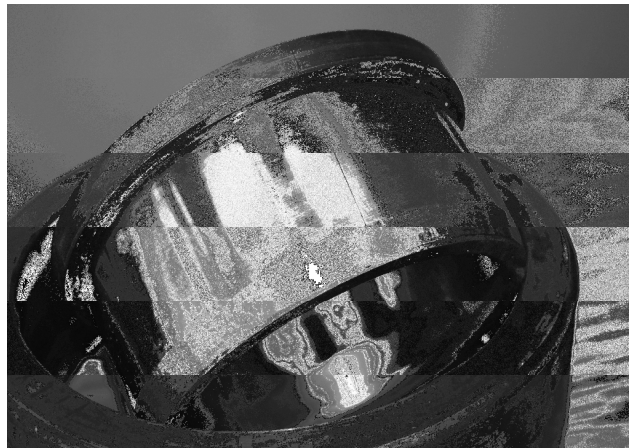

Fig. 2. Inner ring flaw
Рис. 2. Трещина внутреннего кольца

Fig. 3. Flaws, corrosion and an electro burn on cam bowls
Рис. 3. Трещины, коррозия и электроожог на роликах

Fig. 4. Inner ring cavity
Рис. 4. Раковины внутреннего кольца

The selection of such samples is quite complex. The records of standards are to be classified, i.e. be divided into classes and groups. As it has been mentioned, it is necessary to use reference equipment for the purpose of signals recording. Generally it is to contain the following elements:
– transmitters (vibration transducer and rotation velocity sensor);
– anti-vibration cable;
– amplifier;
– analog-to-digital converter;
– microprocessor-based device or personal computer.
  A CD can serve as data carrier.

6. VIBRATION REPRODUCTION

The chart of virtual standards of defects realization was partially shown in fig. 1 (position I). Generally, VSD is to contain the following elements:
– data carrier, for example, a CD;
– PC-based reproduction device;
– digit-analog converter;
– amplifier;
– vibratory table.

The equipment by Bruel & Kjaer, the system of automatic gauging of accelerometers of VibraCal 3629 type and PULSE 3560, the system of multipurpose analyzer can be used, for instance, as the reference equipment for recording and reproduction of vibration signals.

During the gauging or checking each of the tested vibration-based diagnostics equipment samples can be classified accordingly (control equipment, diagnostic equipment, expert system etc.) depending on the sensitivity it displays in the course of the tests.

The signals, which have been recorded from real objects by means of the reference equipment, were not reproduced yet. The math modeling results confirm the possibility of the defect's virtual etalons realization. Experiments of reproducing the etalon signals were planed. It is proposed to use the equipment by «Bruel & Kjaer», particularly signal amplifier 2706, vibration tables 4809 and 4801, spectrum analyzer 2034, generator 4901, accelerometer 8305.

It is planned to form experiment results as a separate publication.

7. CONCLUSIONS

An attempt to show the new idea in the vibrodiagnostics was made in this publication. The idea is in creation of bearing's defect's virtual etalons. Possibility of virtual etalons realization by means of the specific equipment was demonstrated. This idea was approved by RZD locomotive economy department.

Implementation and confirmation of virtual standards of defects by corresponding official bodies or standardization authorities will enable:

to carry out objective assessment of claimed capabilities of vibration-based diagnostic equipment resulting in optimum choice of such equipment, for example, for centralized supply to the railway network;

– to organize the diagnosing procedure during maintenance and repair of locomotives more rationally;
– to check the correct operation of diagnostics tools before work (at shift start);
– to replace the labor-consuming procedure of gauging (on separate metrological parameters) with complex test by means of using the mentioned standards (or to prolong the interval between gaugings).

All above-mentioned conditions will increase the effectiveness of using vibration-based diagnostic equipment and, in the long run, lower expenditures related to provision of transportation quality.

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