Application of the VIBROT Software for the Diagnosis of Rolling Bearing Failures

R. Tomović, D. Bratić, A. Tomović

***Abstract*— The aim of this paper is to present the possibilities of using the VIBROT software for diagnosing failures that may occur in rolling bearings. The VIBROT is complex software for the diagnostics of rotary machines that was developed in the Laboratory for Mechanical Design at the Faculty of Mechanical Engineering in Podgorica. The software was developed inside the LabVIEW™ development environment, with the support of MATLAB®, which are the two most significant tools for signal acquisition and processing. The developed software was tested using an experiment. Real vibrations, that originate from faulty rolling element bearings, have been used in order to test the efficiency of the developed software. The obtained results suggest that vibration diagnostics of rolling element bearings could be performed efficiently with the use of signal processing techniques of VIBROT software..**

***Index Terms*— VIBROT, software for vibro diagnostics, rotation machine, rolling bearing, Fourier transform, Envelope analysis, Cepstrum analysis, Spectral Kurtosis**

I. Introduction

The analysis of the operation of rotating machines is one of the most important areas of engineering practice. The rotating elements are widespread in machine systems and perform a wide spectrum of functions, from large machines for energy production to the very small ones in medical equipment. An unforeseen and immediate stop of performing of basic function in rotating machines - the transfer rotational motion, almost always has the occurrence of a disaster accident as a consequence, followed by huge destruction of some parts or of an entire machine system. The best examples are the accident of the generator rotors presented in Fig.1 and Fig. 2. It is obvious that the facilities of these plants are no longer functional. [1, 2].

In order to avoid an accident, it is necessary to detect the changes in machinery condition in due time, in relation to the wear, deformations, unbalanced operation, or other disturbances, in order to promptly prevent excess damages and the consequences of these faults. The condition of machines, damages, and in many cases, future damages are possible to discover with the help of certain symptoms like, for example, mechanical vibrations, noise, dilatation, temperature changes, etc. From the abundance, according to the condition of relevant parameters, on the damages are best indicated by the mechanical vibrations. The mechanical vibrations stand out because they depict all the significant damages to the machine and because they are possible to be measured with simple equipment..

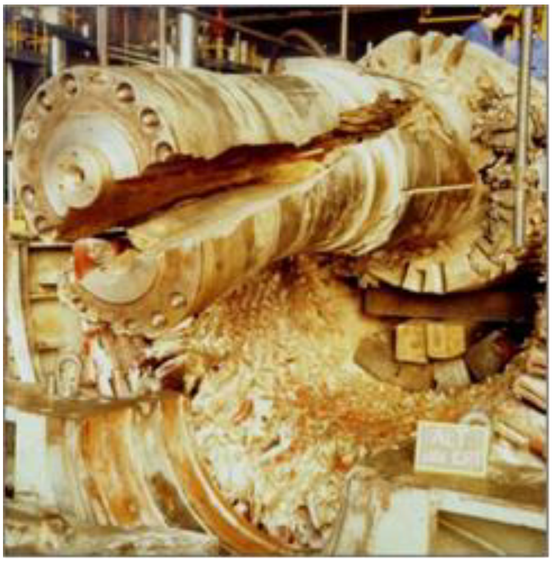

Fig. 1. The breakdown of a generator in one power plant in France [1]

Fig. 2. The breakdown of a Russian power plant [2]

The aim of this paper is to present VIBROT - a complex software for the diagnostics of rotary machines that was developed in the Laboratory for Mechanical Constructions at the Faculty of Mechanical Engineering in Podgorica

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(Figure 3.). The software was developed in the LabVIEW development environment, supported by MATLAB. These two programs are the two most important software tools for the acquisition and processing of measurement signals [3].

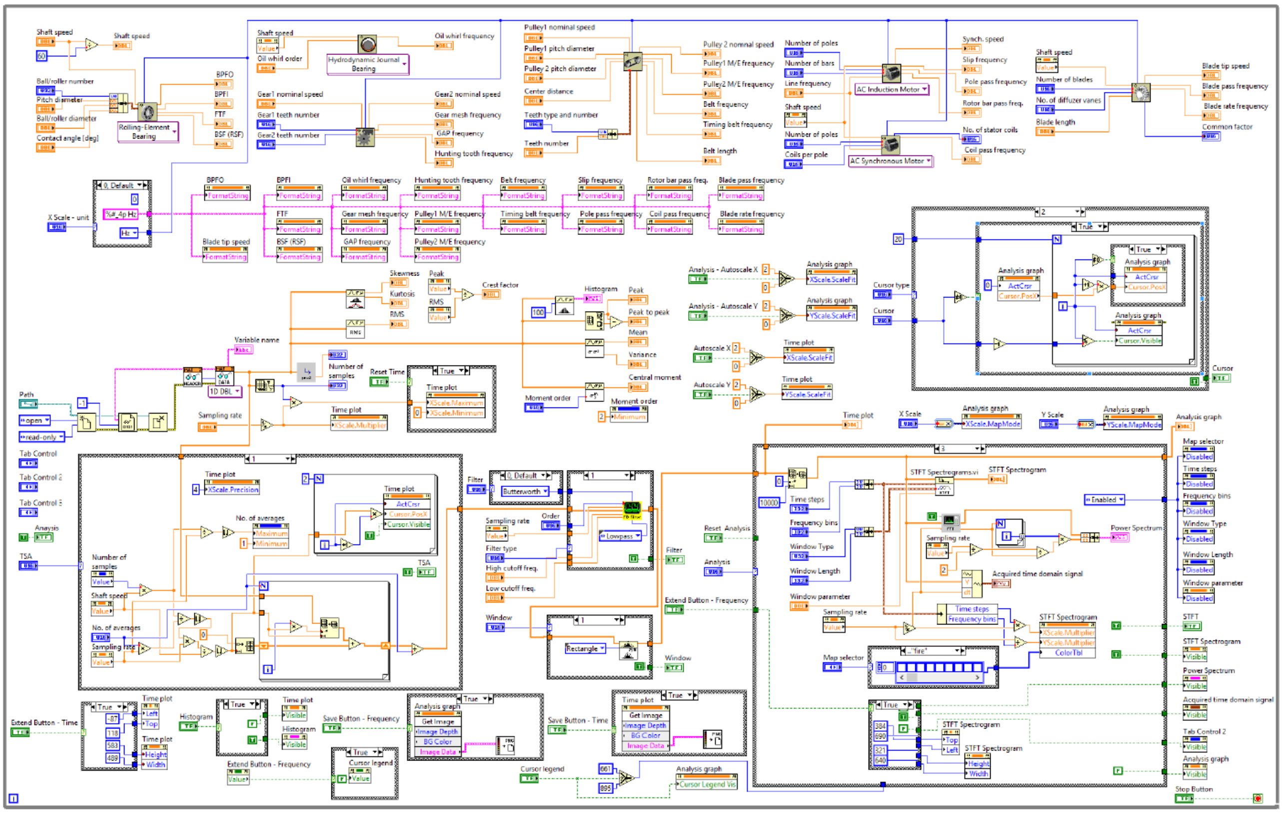

Fig. 3. Block diagram of the VIBROT

VIBROT is primarily intended for technical diagnostics and the prevention of accidents of large rotary machines. One of the most important and most frequently used elements in rotary machines are rolling bearings. They serve to support shafts and axles and have the task of ensuring the relative movement of rotating parts, transferring the load from rotating elements to the structure, and ensuring the necessary accuracy between parts in relative movement. They are primarily used to support an element with rotary motion. However, they are also used for joints with straight and helical movement, for example with guides and threaded pairs [4-6].

Rolling bearings are the most widespread machine elements. There is almost no machine, apparatus, or device that does not contain a greater or lesser number of rolling bearings in its construction. In many cases, they are considered critical elements in construction. The functionality, reliability, and exploitability of most machines largely depend on the working characteristics of the rolling bearings. Numerous studies show that over 50% of machine system failures are due to engine and bearing failures [7]. When a bearing fails, it usually results in expensive and unplanned downtime of the entire machine system, which regularly exceeds the price of the bearings themselves many times over [8].

Although bearing failures are the main cause of failures of rotary machines, most often, when a failure occurs, not enough attention is paid to its main cause - bearing failure. For example, when the wear of the bearing causes damage to the gears of the reducer, the accident of the gears is regularly commented on, and the costs and complications surrounding its repair are mentioned, while the basic cause of the breakdown, bearing failure, is ignored, and is often not given any importance and the causes of that failure are not investigated. Ignorance and failure to investigate the cause of the failure usually result in the repetition of the same or similar accidents. This significantly increases costs and reduces confidence in the value and quality of existing production equipment. This often results in replacements of existing equipment for new, often many times more expensive, which requires new unjustified costs, without reason and any real need for it [9].

Therefore, special attention must be paid to the control, analysis, and solving of problems related to bearings. By proper use and maintenance of bearings, a lot can be done to prevent the failure of machine systems and avoid breakdowns and other consequences that are detrimental to the environment and the safety of workers. Without the use of well-organized systems for maintenance, monitoring, and diagnosis of the working condition of rolling bearings, it is difficult to deal with these problems. The purpose of this work is to present the techniques and methods for diagnosing the state of the operational correctness of rolling bearings, which the VIBROT software has and which provide the possibility of early detection of failure of the bearing.

II. LabVIEW Software Development Environment

LabVIEW ™ (Laboratory Virtual Instrument Engineering Workbench) is a software development environment, based on the use of a Graphical User Interface - GUI. With this development environment, it is possible to implement a complete measurement-acquisition system, from accepting signals from hardware to analysing, displaying and archiving data. It differs from other similar development systems through its usage of graphical programming language instead of written instructions for generating program code and creates programs in the form of a block diagram (Fig. 3).

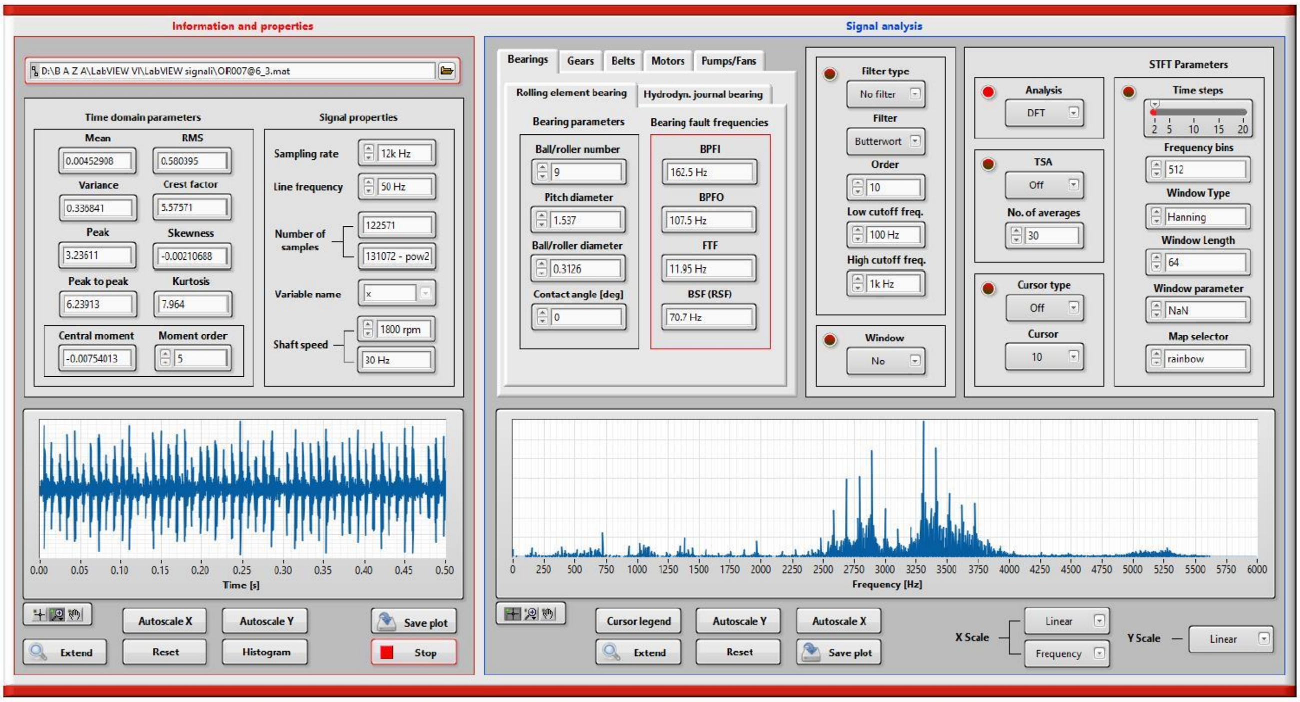

Fig. 4. VIBROT user graphical interface - GUI.

The principle governing these programs is called data flow. Unlike text-based programming languages, in which the code is executed sequentially, one by one the instruction line, execution of the program according to the principle of data flow is determined by the data itself..

LabVIEW ™ allows to program devices that perform the same role as conventional measurement and control instruments, with the complete processing and analysis of data being performed on a computer. The hardware that is then added to the computer is usually comprised of acquisition cards, which have multiple analogue and/or digital inputs and outputs, through which the acquisition of the signal to the computer is enabled, that is transmission control signals from the computer.

So, with this approach, a personal computer takes over the role of a conventional instrument, while the graphical user interface programmed into LabVIEW ™ looks like a measuring instrument itself. For this reason, the term "virtual instrumentation" was created. It was defined in the 80s of the twentieth century by the American company National Instruments - NI, the world's leading company in the field of measurement and acquisition systems based on personal computers [5].

III. DESCRIPTION OF THE VIBROT SOFTWARE

VIBROT is a complex software, which combines almost all methods for processing vibrations in the time and frequency domain. Graphical User Interface - GUI of the software are shown in Fig. 4.

GUI software consists of two main panels:

• The left panel named Informations and Properties - offers the possibility of a simple analysis of vibrations in the time domain;

• The right panel named Signal analysis - serves for more complex signal processing, using selected analytical methods.

Panel named Information and Properties, providing simple vibro diagnostics analysis in the time domain. The input data is the corresponding *.mat format file, the frequency of discretization and other input parameters. As output is obtained the graph of vibrations in the time domain and various statistical parameters such as kurtosis, crest factor etc.

The second panel marked by Signal Analysis, allows for a more complex vibro diagnostics analysis, using more sophisticated analytical methods for signal processing.

This Panel contains several cards to calculate the characteristic frequency of rolling and slide bearings, gear and belt drives, as well as motors, pumps and fans. The input parameters of this part are the values of the structural parameters of the mentioned assemblies (engine speed, number of teeth of the gear, number of balls in the rolling bearing, etc.), and consequently, the corresponding characteristic frequencies are displayed at the exit. The Panel also offers the ability to filter signals using a variety of digital filters provided by the LabVIEW development environment. For the purposes of this software, Butterworth's, Chebyshev's, Inverse Chebyshev's, Elliptical and Bessel's low-pass and high-pass filters were used, as well as the frequency transient and steady-state filters.

A window named The Analysis Type offers the ability to apply some of the following methods for signal processing:

- Discrete Fourier transform;
- Short-term Fourier transform;
- Envelope analysis;
- Cepstrum analysis;
- Spectral Kurtosis;
- Time synchronous signal averaging.

IV. VALIDATION OF THE DEVELOPED SOFTWARE

In order to test the efficiency of the developed software, the analysis of the vibrations of real systems has been done in which the presence of certain irregularities or damages has already been undeniably determined. Vibration measurement was carried out at the Dynamic Testing Device for Rolling Bearings, developed at the Faculty of Mechanical Engineering in Podgorica. The device is shown in Fig. 5. The bearings used in the test are artificially damaged and then assembled for the needs of certain experiments in progress research.

Fig. 5. Test bench.

A. Test bench

The test bench is based on a shaft that is supported in two ball bearings and powered by an electric motor of 1.5 kW (Fig. 5). On the front of the shaft, the bearings are being tested. Depending on the need, it is possible to change the shaft rotational speed. The experiment employed a rotational speed of about n = 1750 rpm, corresponding to a shaft frequency of fo = 29.17 Hz. The speed was measured by a stroboscopic lamp.

The device enables the measurement of relative vibrations (displacement) between the outer ring of the bearing and the rotor and measuring the absolute vibrations of the outer ring of the bearing. For this experiment, the measurement of absolute vibrations in the radial vertical direction was used. The sensor output after appropriate filtration to eliminate unwanted noise and static voltage is fed into a 16-bit 12-channel 200 kHz data acquisition board and shown on the monitor. The measuring system enables the measurement of vibration acceleration in the range of ± 490.5 m/s2 and the frequency range of 0.5-10000 Hz.

Data acquisition management is accomplished with the LabVIEW software package.A detailed description of the Test bench, together with a detailed description of the test procedure and the instrumentation used for the acquisition of data, can be read in the literature [11].

B. Characteristics of tested bearings

A rolling ball bearing 6205 was used for testing. Table 1. shows the values of the characteristic frequencies for the rolling bearing model used.

On one of the balls at each of the bearings artificially is made damage of the elliptical shape, dimension of about 2.5x3.5 mm by grinding, as shown in Figure 6.

Fig. 6. The appearance of the damaged ball

TABLE I
CHARACTERISTIC FREQUENCIES OF ROLLING BALL BEARING 6205

Tip Ležaja	FTF	BSF	BPFO	BPFI
SKF 6205	11,61	68,75	104,57	157,96

C. Experimental procedure

As a result of each measurement on the tested bearings, a time record of the absolute vibrations of the bearing is obtained. The display of one of the records is shown in Fig. 7.

The Nyquist sampling principle was employed to eliminate any chance of aliasing leading to the generation of false frequency contributions in the frequency spectra. Note that the sampling frequency should be at least twice that of the measured (maximum frequency of interest). However, the recommendations are that the sampling frequency is ten times greater than the maximum frequency of interest. Since the maximum calculated values of the characteristic frequencies of the tested bearings range within the limits of up to 160 Hz, the sampling frequency of 10 kHz adopted is more than enough. With each of the tested bearings, a vibration level was sampled in the time interval of 15 seconds. Thus, vibration records of 150000 data were obtained for each repeated test..

Time-varying measurement results were processed in the

VIBROT software, using the frequency analysis of envelope, which is one of the most commonly used methods for the vibro diagnostic analysis of rolling bearings. The frequency spectrum of the envelope of the vibrating signal from one of the bearings is shown in Fig. 8.

D. *Discussion of results*

In the envelope vibration spectrum, harmonics corresponding to the frequency of the damage are marked "line-point" with the red line, while the harmonics corresponding to the rotation speed of the rotor or to some other reference frequency (for example, the Frequency of damage on the cage) are marked with the same line type, orange. Sidebands around the frequency of damage and its harmonics, with the aim of better visibility of the spectrum of vibrations, are marked with a standard line, orange, and green.

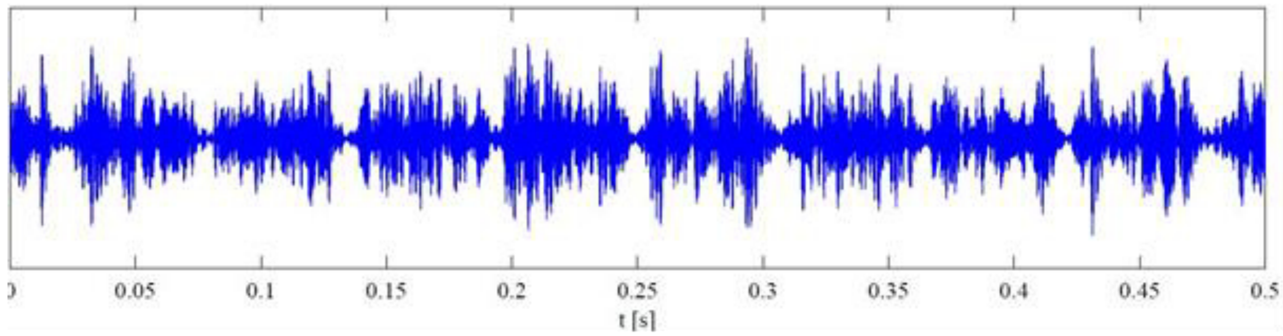

Fig. 7. A crude signal in a time domain

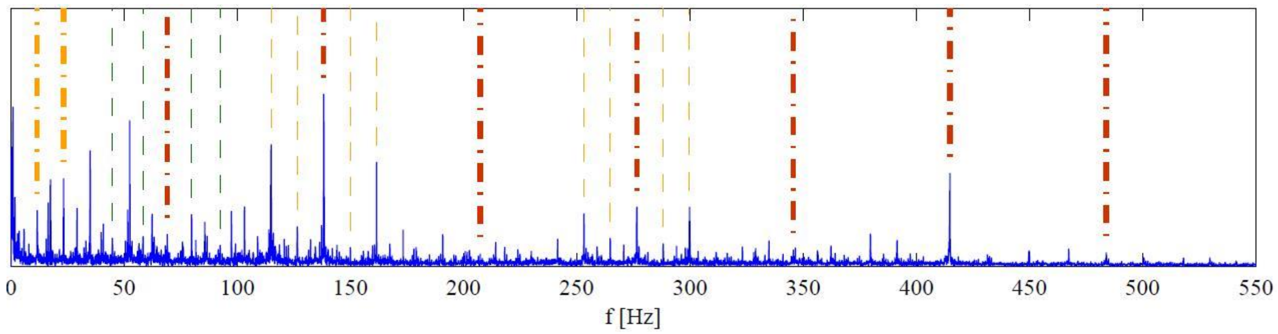

Fig. 8. Spectrum envelope signal.

V. CONCLUSION

In practice, it has been proven that vibration analysis is one of the most common methods for diagnosing the condition of machine plants, for the simple reason that it has a number of advantages compared to other methods. In this regard, the complex software for the vibration diagnostics of rotary machines, popularly called VIBROT, developed at the Faculty of Mechanical Engineering in Podgorica, can be greatly used for these purposes. The software is easy and user-friendly, it is characterized by a clear user interface and contains all the most commonly used techniques for vibration analysis of rotary machines.

In order to test the efficiency of the developed software, the analysis of real vibrations from the rolling bearings was carried out on which the presence of irregularities has already been established. The obtained results indicate that by using the developed software it is possible to perform an efficient diagnostic of the condition of the rolling bearings.

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