

VIBRATION AND CONDICION MONITORING OF THE ROTATING MACHINES

Ranko Antunović[1], Branko Savić[2], Nenad Janjić [3]and Ninoslava Tihi[4]
[1]The Higher Education Technical School of Professional Studies in Novi Sad, Školska 1, Serbia, *Corresponding author*, ORCID No. 0000-0001-9915-4832, antunovic@vtsns.edu.rs
[2]The Higher Education Technical School of Professional Studies in Novi Sad, Školska 1, Serbia, 1, ORCID No. 0000-0003-3573-586X, savic@vtsns.edu.rs
[3]The Higher Education Technical School of Professional Studies in Novi Sad, Školska 1, Serbia, 1, ORCID No. 0000-0003-1795-8453, janjic@vtsns.edu.rs
[4]The Higher Education Technical School of Professional Studies in Novi Sad, Školska 1, Serbia, 1, ORCID No. 0009-0004-8009-8120, tihi@vtsns.edu.rs

ABSTRACT: With the advent of increasingly complex and demanding technical systems is becoming crucial need for the development and application of appropriate diagnostic system to provide high availability and reliability of these systems. Direct supervision and diagnostic analysis of the situation, with the specified diagnostic methods, we get good insight on the current state of technical systems and the maintenance actions carried out when needed. The paper considered importance of data selection and implementation of appropriate diagnostic techniques with particular emphasis on the analysis of the dynamic behavior of rotating machinery. Shown are some of the results of diagnostic analysis that have been conducted on the machines in a real operation, applying advanced methods of technical diagnostics.

KEYWORDS: rotating machines, monitoring, diagnostics

1. INTRODUCTION

The progress of computer and measurement techniques and the appearance of powerful software associated with the constant price reduction, provided a significant step forward in monitoring and protection of rotating machines. Regularly, such configurations became very affordable and available. Achieving the goal of inexpensive and efficient device for monitoring, all the rotating systems of major importance will be equipped with it, in less than 40 years. Thus, there would be age of error free operation in the long term. Machinery setting up would be automatically conducted for different operating modes, aimed at identifying the causes of malfunction and archiving the specific events, important for machine recording. Such devices are already deployed to monitor large number of industrial plants around the world and will remain indispensable equipment for both new and rebuilt plants [1].

The most common deficiencies of rotating machines that can be promptly identified by the use of control-diagnostic system are: unbalance (asymmetry of rotor mass and inertia), misalignment, damaged roll/sleeve bearing, faulty inclination, resonant behavior, disturbances of electrical and magnetic origin, aerodynamic and hydrodynamic influences, malfunction in gearing/belt drive, loose parts, mechanical impacts, rotor to stator scrub, mechanical rotor anisotropy.

2. PARAMETERS AND METHODS OF ROTATING MACHINES SURVEY

Monitoring parameters of the rotating machines are usually related to the structural parameters (frame and machine vibration, process and casing temperature, clearance in the bearing, oil pressure, etc..). All the parameters can be divided into several groups:

- The parameters of dynamic machine motion: absolute and relative vibration.
- The parameters of the position: the position of the rotor in the bearing sleeve, the relative motion of the shaft (axial displacement), relative elongation of the shaft, absolute elongation of the housing.
- Other diagnostic parameters: rotational speed, temperature, shaft eccentricity, electrical parameters, the acoustic parameters and the technological parameters.

In general, approximately 90% of all deficiencies that appeared at the rotating machines, affected the vibration response.

Occurrence of certain faults on the machine produces a stable excitation which generates a specific oscillatory motion. The outcome of the vibration response analysis reveals the character of the excitation force and determines the cause of machine malfunction Fig. 1. [2]

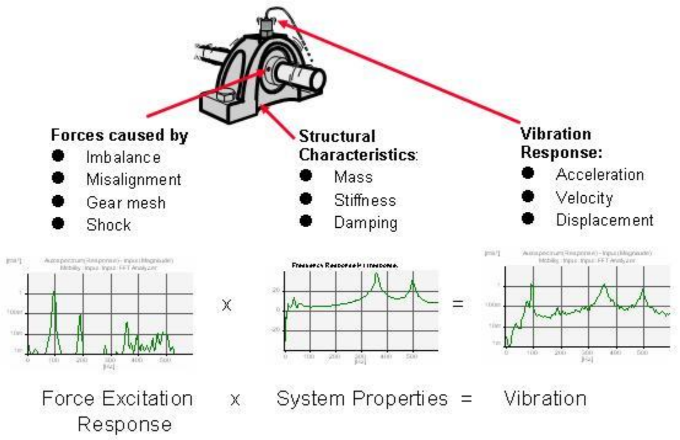

Figure 1. Dependence of system response to the excitation force

Commonly used Vibrodiagnostic methods are simple vibration severity detection, spectral analysis, phase analysis, real-time vector analysis, orbits, DC analysis, record trends, SPM analysis, energy analysis, Zoom FFT analysis, CPB analysis, cepstral analysis, SED detection, HFD, LFD, SEE technology, modal analysis. It is possible to extract major causes of dynamical disorder by early detection. [5]

There are some other methods which contribute to a proper identifying of real causes of malfunction. They are Monitoring and analysis of air gap, analysis of the magnetic flux, analysis of partial discharge, monitoring of parts wear, detection of combustion products, monitoring of system fluids (oil and lubricants, gases, coolants...), corrosion monitoring (visual methods, gravimetric and electrochemical methods)

3. DYNAMIC PROBLEMS CLASSIFICATION AND OPTIMAL DIAGNOSTIC MODEL

Dynamic problems are usually typical for certain group of machines, depending on their power, speed, size, foundation, etc. Standard ISO 10816 classifies all the machines into 4 categories. Each category is determined by the permitted level of vibration severity, disposition of measuring points, measuring axis and the recommended measuring parameters (Fig. 2).

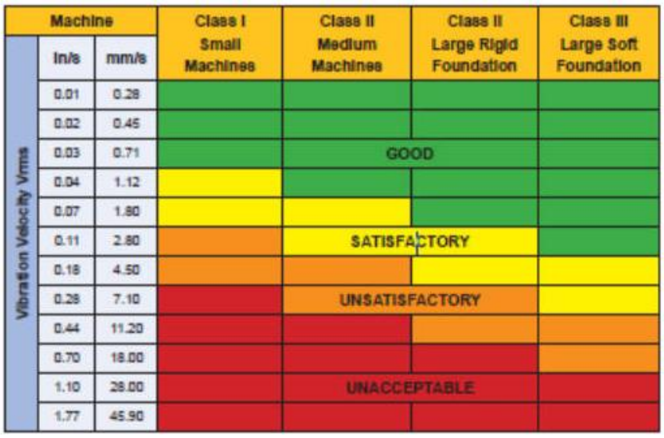

Figure 2. Vibration Severity Per ISO 10816-1

Some causes are typical for some machines. Therefore, the two families of machines are recognized:

- GROUP 1, running with rolling-element bearings

Machines classes I – in accordance with ISO 10816

Machines classes II - in accordance with ISO 10816

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- GROUP 2, running with journal bearings

Machines classes III - in according to ISO 10816

Machines classes IV - in according to ISO 10816

A true study of possible causes of disturbed machine operation, brought us to conclusion that the optimal model of fault detection must be based on [7]:

1. Identifying the cause of dynamic problem
2. Simplicity for use and performance
3. Early detection
4. Economy aspect

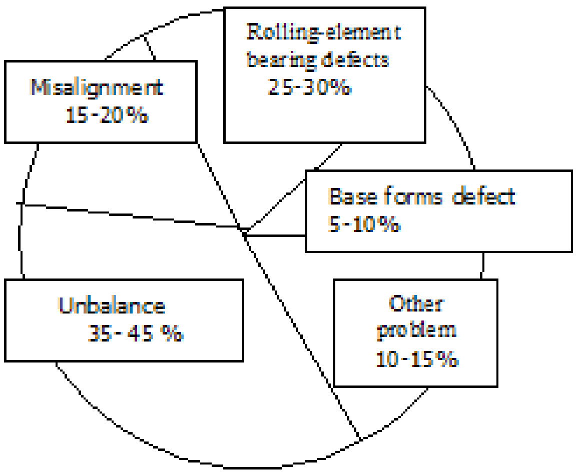

Figure 3. Probability of certain defect appearance in machines Group 1

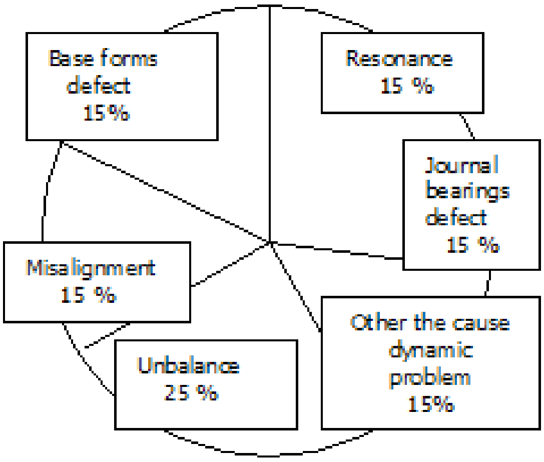

Figure 4. Probability of certain defective appearances in machines Group 2

The optimal set of methods, which satisfy the criteria, involves vibration severity detection, spectrum analysis, polar trend of the signal. Additionally, the machines belonging to GROUP 1 should be observed by HFD method, while the machines from GROUP 2 need Bode chart and orbit analysis.

4. CONFIGURATION OF THE MONITORING-DIAGNOSTIC SYSTEM

To have available the necessary information for diagnostic assessment and analysis of technical systems there must be systems for the collection of all relevant data. With the existence of a system for collecting and analyzing relevant data, there must be an organizational management system that clearly defines who gets to see what information and who comes to the appropriate decision.

To provide the appropriate data record, necessary for the evaluation and analysis, the monitoring system must be configured to collect all the relevant data. As well the device should arrange the data in a relevant form (format), appropriate for instant decisions of possible machine trip, and maintain recommendations. Systems must be restrictively conceived, allowing only authorized people to access data records, and alarm settings.

Regularly, monitoring system consists of 1) Transducers (sensors), 2) Data collect unit and 3) Diagnostic system for data recording, analysis, alarm raise and data transfer.

Signals from the sensor undergoes amplification and raw filtering too present properly vibration level, all spectral components, phase lag, etc.

Some modern instruments use a computer facility for data recording, data presentation and data transfer. Moreover, the computer is capable of detailed spectral analysis and data archiving in different forms, Fig.5.

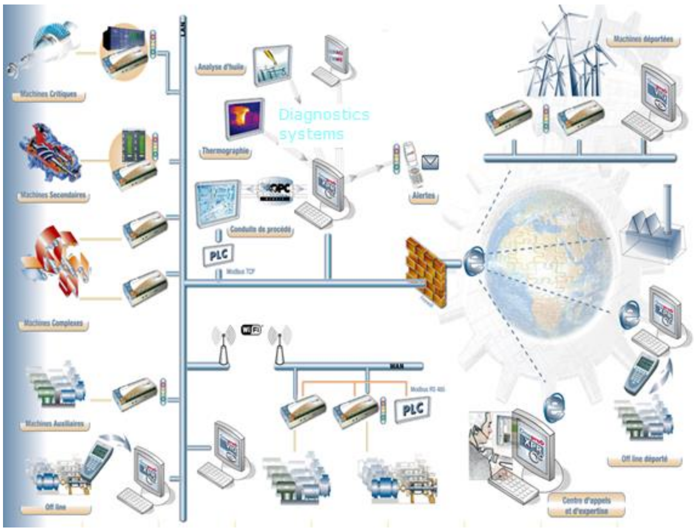

Figure. 5 Data collect, data transfer and archiving with modern diagnostic systems

Besides the ability of signal conditioning and analysis, PC can communicate with expert systems, transferring them to both data and responsibility for the proper decision. This is applicable either in the long-term operation or in transition stages like start up and machine coast down.

Most of the built-in diagnostic systems are equipped with an adaptable knowledge base. That is the memory space where the user knowledge is stored, to expand system expertise. When set, the whole diagnostic process develops automatically, securing an optimal diagnosis always at hand [8].

The development of communication allows remote monitoring of the machines regardless of their location against the location of control staff. Also, the machine producer can be involved in the monitoring process, contributing by its expertise to the competent reaction on any alert/alarm event. As well as such producer-oriented monitoring the database of systematic equipment faults is promptly updated.

5. DIAGNOSTICS ON SITE

Here follows some examples of site diagnostics, conducted at the Thermal Power Plant Gacko

5.1. Electric feed pump (machinery GROUP 1)

Location: Thermal Power Plant Gacko, Plant: Feed Pump

Technical data: electric three-phase AC motor, rated power P = 630 kW, 750 RPM.

Multistage pump, 6 impellers. Rolling bearing types: L1-6326, N326-L2, L3 and L4-6318

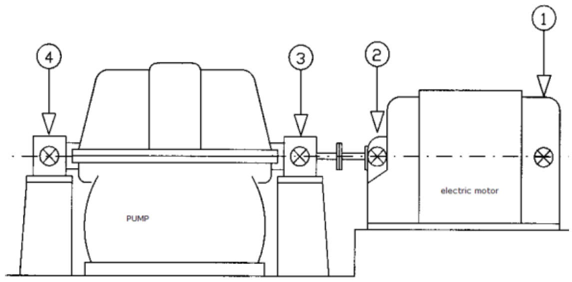

Figure 6. Feed Pump

Inspection Methodology:

1) measurement of vibration severity of all bearings in either of three main axes

2) spectral analysis at each point

3) HFD detection.

The results

- vibration severity

Table 1. *Overall vibration levels*

Bearings	Horizontal $\sum v_{RMS}$ [mm/s]	Vertical $\sum v_{RMS}$ [mm/s]	Axial $\sum v_{RMS}$ [mm/s]
1	1,6	1,2	1,8
2	1,2	1,1	1,3
3	1,9	2,1	1,5
4	3,2	3,1	1,2

MACHINE assessment

In accordance with ISO 10816 standard: *permissible.*

- Spectral analysis

Beneath is the spectral plot of the horizontal vibration at the outer, 4-th bearing. To identify the main causes of faulty behavior, characteristic frequencies are needed.

Fundamental tone of rotation is 1X = 12.5 Hz.

Frequency signature for SKF6318 is: BPFO= 38,6 Hz, BPFI=61,2 Hz; BSF=26,1 Hz; FTF=4,75 Hz,

Vane pass frequency of impeller is 12.5 x 6 = 75 Hz (BPF)

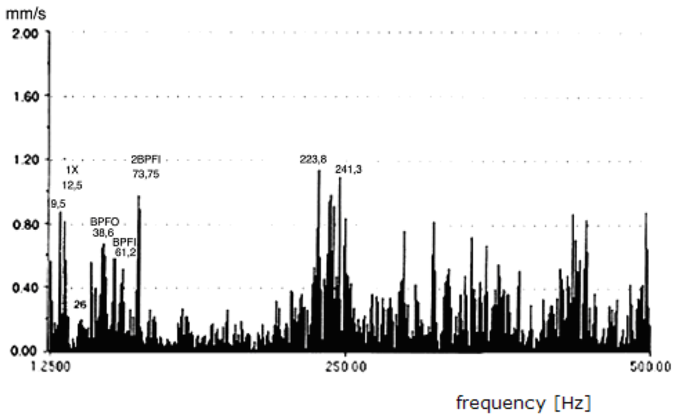

Figure 7. Spectrum plot horizontal vibration at outer 4th bearing

Spectrum plot indicates damaged rolling-element in outer 4-th bearing, Fig. 7.

- HFD overall value

HFD equals 9,2 g. This is a high value.

5.2. Turbine (machinery GROUP 2)

Location: Thermal Power Plant Gacko,
Plant: Steam Turbine

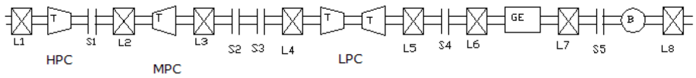

Figure. 7 Steam turbine Power train

- vibration severity

Table 2. *Overall vibration levels*

Bearings	HOR $\sum v_{RMS}$ [mm/s]	VER $\sum v_{RMS}$ [mm/s]	AX $\sum v_{RMS}$ [mm/s]
1	3,4	1,8	1,8
2	2,1	1,8	2,1
3	1,4	3,6	2,2
4	2,0	1,9	2,3
5	3,2	2,7	2,1
6	3,3	4,6	6,5
7	3,8	5,8	9,3
8	6,4	5,2	4,1

Assessment in accordance with ISO 10816 standard: permissible.

- Spectral analysis

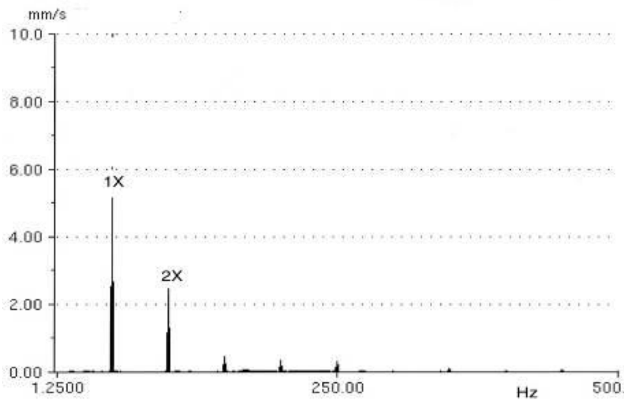

Figure. 8 Spectral plot at 6th bearing (V)

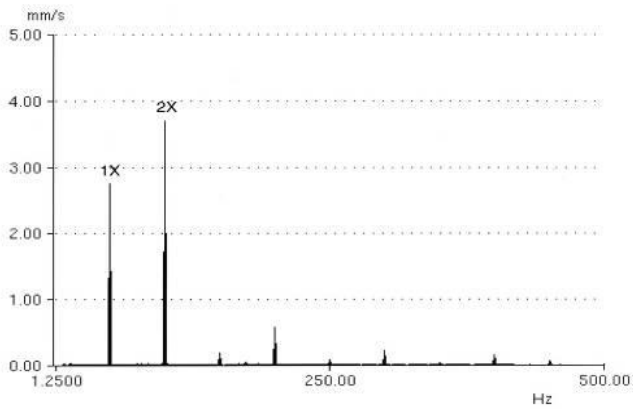

Figure. 9 Spectral plot at 7th bearing (V)

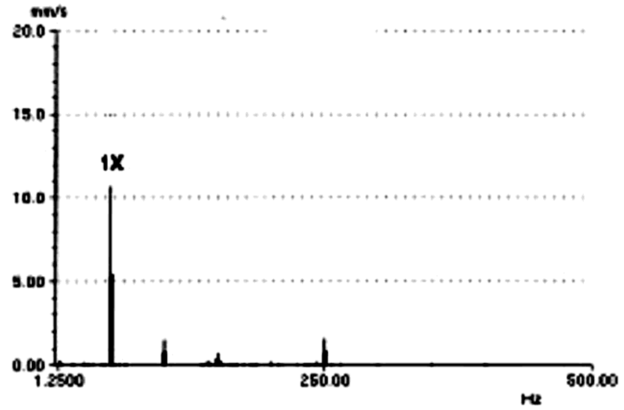

Figure 10. Spectral plot at 7th bearing (A)

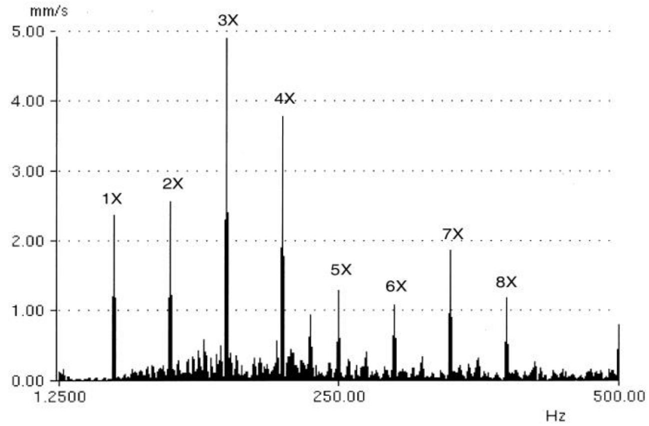

Figure 11. Spectral plot at 8th bearing (V)

Spectral plot clearly verifies that the imbalance and misalignment of the generator are the main causes of increased vibrations. Additionally, spectral plot at the 8th bearing indicates slack, while the 7th bearing suffers of reduced stiffness in the axial direction.

Note: More illustrative picture of deficiency origin is delivered with polar trend plot of 1X and 2X fundamental in radial and axial bearing of the generator, Fig. 8,9,10,11.

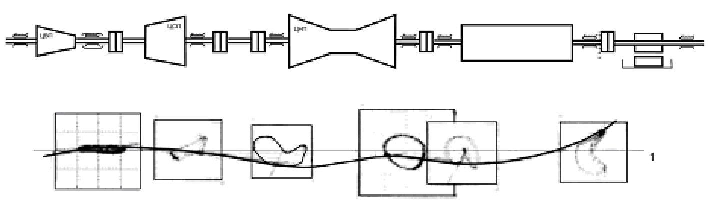

Figure 12. Orbit analysis for the turbine bearings

To identify the real cause of the problem it is necessary to correlate the diagnostic parameters with the parameters of the process.

- **Polar trend plot:** Polar trend plot 1X and 2X fundamental is made for bearings 6 and 7.
- Polar trend 1X fundamental (V) at the 6th and 7th bearing is collected while:
- Operating at rated speed (3000 RPM), without excitation on generator
- Machine at rated power
- Machine coasts down after power cut of the generator excitation.

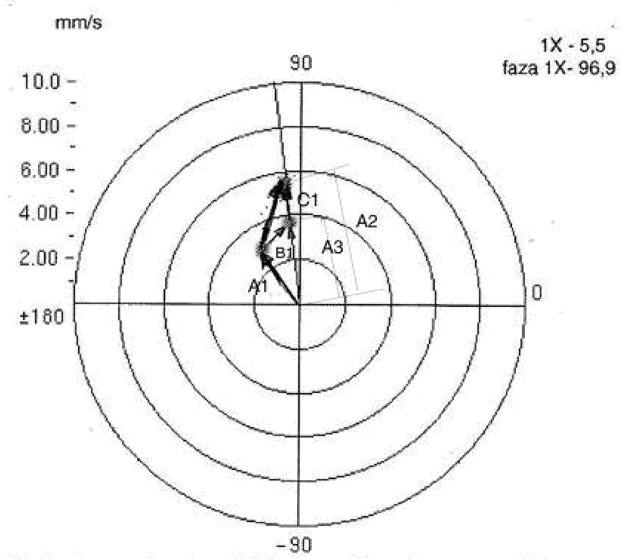

Figure 13. Polar trend plot at 6th

Polar trend plot clearly shows that there is a change in amplitude and phase of 1X Fundamental with power increase. This fact indicates the mass asymmetry of the rotor mass, possibly change in rotor geometry, which may be due to thermal distortion or impact of asymmetric magnetic field. Further analysis of the polar trend 1X Fundamental indicate also some other effects, such as:

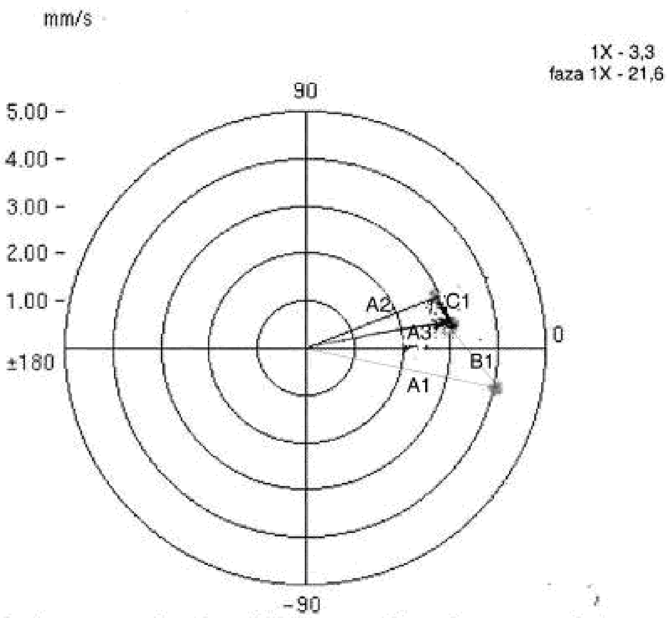

Figure 14. Polar trend plot at 7th bearing

- Vector at cold	A1- 1X intensive component, while
- Vector at a full power	A2- 1X intensive component, on full
- Vector at power cut.	A3 - 1X intensive component after

It is obvious that vector B1 (Fig. 13 and 14) indicates thermal unamiableness has a minor influence on the overall dynamic state (vibration severity slightly changes). On the other hand, vector C1 indicates asymmetric magnetic field vector, which significantly affects the dynamic state of the machine, because its phase coincides with the residual unbalance at the seventh bearing.

6. CONCLUSION

Recent development of microprocessor technology and digital signal processing allows outstanding progress in conceiving on-line monitoring systems. Nowadays bundles of signals are processed practically in real time. Therefore, modern methods in technical diagnostics provide a deep insight into the following issues:

- When and where the damage occurred (technical diagnostics)
- How the damage progresses over time,
- How soon comes the final failure (technical prognostics)
- What is the cause of failure (technical genetics)

Substantial goal of condition-based maintenance is to recognize timely the possible threats for smooth and restless operation. The set of properly configured measurements, composed with the monitoring concept and signal analysis lead to a reliable technique of early fault detection. Dynamic behavior of the machine is thus constantly observed with a high degree of proactive protection and deep understanding what occurs under the machine cover. In this way, machines are managed properly, resulting in increased.

7. REFERENCES

[1] Bently Nevada, *Predictive maintenance: How the pieces fit together*, Orbit, Vol.7, No.2, June 1986

[2] Multi-channel & multi-task Analyzer-PULSE, Bruel & Kjaer advanced training course, held in Budapest, Hungary, on 14-16 June 2005

[3] Vibracion Diagnostic Guide, SKF Reliability System, Application Note CM5003

[4] A. Muszynska, Vibrational Diagnostics of Rotatinf Machinery Malfunctions, International Jurnal of Rotating Machinery, 1995, Vol. 1, No. 3-4, pp. 237-266

[5] R. Antunović, “Advanced methods vibrodiagnostic”, Konferencija održavanja KOD-2009, Tivat, Jun 2009. god.

[6] Ward Heylen, Stefan Lammens, Paul Sas, Modal Analysis Theory and Testing, Kathoolieke Universiteit Leuven, 1997

[7] M. Sarenac, R. Antunovic, “Optimal Model for Vibrodiagnostics of Rotating Machinery”, TEHNIKA, br.5,2011, ISSN 0040-2176, pp.759-769,

[8] L. Boullart, Rijksuniversiteit Gent, INTRODUCTION TO ARTIFICIAL INTELLIGENCE AND EXPERT SYSTEMS, Belgian Institute for Automatic Control, Antwerp, Belgium

[9] Michael Flanagan, Expert System Data Acquisition, PROFILE Newsletter, Vol.4, No.2, Bruel & Kjear CMS A/S, 1996.

[10] Paul Goldman, Alex Petchenev, Agnes Muszynska, DYNAMICS OF ROTOR/BEARING SYSTEM WITH FLEXIBLE ROTOR AND FLEXIBLE BEARING SUPPORT, Design Engineering Technical Conference, septembar 14-17, 1997- Secramento, California