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University POLITEHNICA of Bucharest, Machine and Manufacturing Systems Department
Bucharest, Romania

CONSIDERATIONS REGARDING THE MONITORING AND DIAGNOSTIC OF MANUFACTURING SYSTEMS FOR PREVENTIVE MAINTENANCE

Ilie Octavian POPP, Ioan BÂRSAN

Abstract: *Continuous monitoring of the processes in the operating machinery has always been considered as one of the most efficient methods for machine condition assessment. Recently, a major step forward in the development of microprocessor and signal analysis technology has occurred that allows the development of powerful, efficient, and, at the same time relatively in-expensive systems for continuous condition monitoring of different machine parameters. These systems have become widely used in many enterprises and now, the market-place shows continuously growing demand for such systems.*

Key words: *vibration monitoring system, diagnostic, equipments, maintenance.*

1. INTRODUCTION

Continuous monitoring of the processes in the operating machinery has always been considered as one of the most efficient methods for machine condition assessment. Recently, a major step forward in the development of microprocessor and signal analysis technology has occurred that allows the development of powerful, efficient, and, at the same time relatively in-expensive systems for continuous condition monitoring of different machine parameters. These systems have become widely used in many enterprises and now, the market-place shows continuously growing demand for such systems. Older systems have only been able to detect changes in vibration levels and patterns but not the reasons for the changes. Until now, this problem has been solved by the efforts of a limited number of very qualified experts in condition diagnostics and this fact has resulted in limited distribution of the technology in the industry. This situation has begun changing recently as a result of major steps forward in the development of condition diagnostics methods for machinery which include significant increases in the ability to define defects that can be detected in the incipient stage of their development as well as automation of the condition diagnostics process. As a result, the experts' productivity has been significantly increased and, in many standard situations, the experts have been replaced by specialized diagnostics software programs.

A new generation of such systems is described below. Such a system for rotating machinery condition monitoring and diagnostics using vibration analysis combines all the modern condition monitoring and diagnostic methods and the latest developments of microprocessor and computer techniques. This generation of the systems may be recognized by the automatic condition diagnostics of particular machine units allowing reliable operation of the machine, not by continuous condition monitoring, but by intermittent monitoring with intervals between measurements up to weeks or even months. The main emphasis is applied to portable, off-line systems that allow condition monitoring of hundreds of machines, thus decreasing the expense on condition monitoring and diagnostics by orders of magnitude [3].

2. MONITORING AND DIAGNOSTICS TASKS

The main task of the machine vibration monitoring system was previously the monitoring of the vibration parameters chosen either by the machinery designers or users with the purpose of detecting changes in machine operating conditions. The new systems, despite that they are usually referred to as condition monitoring systems, can have new tasks including machine vibration monitoring and intervention in the operation of the machinery. Vibration monitoring, in turn, may include the comparison of the machine vibration parameters with the parameters of a group of other identical machines, i.e. monitoring by a set.

The tasks that had been stated for the new generation of condition monitoring and diagnostics systems can be divided into three main groups [2]:

- The first group includes the traditional tasks for vibration state development monitoring and prediction for machines or their units operating in standard conditions. This is usually done using permanent measurement systems installed in the most important machines and equipment. The standard modes not necessarily are limited to stable conditions, but may include startup and transition modes as well.
- The second group is the tasks connected with the comparison analysis for a group of identical objects. These can be not only the machines, but also their units as well as the equipment that is not a source of relevant vibration. In the latter case, the vibration can be excited by external sources of vibration including, for example, shocks. Typically, these are the tasks of final tests of manufactured or repaired products and

are usually done by condition monitoring systems installed in the test stands. This is why they are referred as test stand condition monitoring systems.

- The third group of tasks is defined by the abilities of condition diagnostics. This is the monitoring of detected defects development starting from their incipient stage when the traditional condition monitoring systems do not identify the vibration changes as a machine defect. Typically, these defects occur either immediately after machine manufacturing (installation) or during the first half of service life during the initial stage of particular machine unit wear. This type of machine condition monitoring provides long term condition prediction for the non-failure machine operation period and residual service life after development of severe defects.

For several years, vibroacoustical machine condition diagnostics developed in two directions as a part of condition monitoring and as a standalone direction aimed at the detection and identification of defects.

Today, the detailed condition diagnostics methods allow detection of most incipient defects before the vibration state of machine changes. This fact inspired the development of a new generation of condition monitoring and diagnostics systems. As a result, the tasks of such systems undertook considerable changes. In particular, primary attention was focused on the each machine unit condition assessment and the integral estimation of the condition of the machine as a whole was based on the conditions of all the machine units. More attention was paid to the high frequency vibration component measurements and, consequently, the acceleration signals rather than velocity or displacement.

The main tasks for condition diagnostics, both functionally without any changes in machine operation mode and in testing under the influence of external controlled vibration exciters, also can be divided into three main groups. This division is based on the method used for determining diagnostics standards. These standards are used for defect detection, identification, and development prediction [6].

The first group uses standards based on a group of consecutive measurements of diagnostic signals for each machine (history based standard). These methods were traditionally used in condition monitoring systems and the main type of vibration signal analysis was narrow band spectrum analysis.

The second group of tasks used the standards formed by single vibration measurements conducted on a group of identical machines' units (set based standard). These tasks are typical for the final output control at repair or production shops. A number of signal analysis techniques can be applied in this connection, but the most powerful method is similar to the previous case using spectrum analysis of the vibration signal.

The third group contains the tasks with the most complex solutions for development, but they are most efficient in practical diagnostics with prior known standards. Thus condition diagnostics can be done using a single vibration measurement. Typically, the solution of most complicated problems is based on the analysis of signal modulation processes, for example, using the spectrum analysis of low frequency oscillations of high frequency signal power, including vibration excited by periodic shock pulses. In this case the standard of the defect free state is most typically considered the absence of certain features in the analyzed signal.

The new generation of condition monitoring and diagnostics systems reliably detect, not only potentially dangerous defects of any of above groups at the initial stage of their development, but also identify the exact defect type and its severity. Only in this case and, taking into account prior known development rates for each of defect types, is it possible to provide long term condition prediction and residual service life of the machine or its unit. This task is considered to be the main one for the new generation of the condition monitoring and diagnostics systems.

3. METHODS OF DIAGNOSTICS

The increased number of tasks available in the new generation of condition monitoring and diagnostics systems has resulted in advances in both existing diagnostic technology and the development of new diagnostic and condition monitoring methods.

The main signal analysis method for rotating machinery condition monitoring is still narrow band spectrum analysis of vibration and noise signals. Among the new technical solutions are automatic spectra processing with the extraction of harmonic components and detection of their amplitudes and frequencies as well as their possible origin. Such automation allows much more reliable trending of the signal component development and predicts their changes, especially in cases of fluctuations of the rotation speed from measurement to measurement.

When the spectrum exceeds the alarm level condition monitoring system issues an alarm signal. Usually the alarm levels are entered by the operator according to his experience and machinery design specifications (Fig. 1).

Another important point is separation of condition monitoring of a machine as a whole versus its particular units. In the first case, the measurement points are distant from the primary vibrating units and close to the less noisy ones and condition monitoring is done mainly by the analysis of low and medium frequency vibration. In the other case, the measurement points are chosen directly on the monitored unit case and condition monitoring is combined with diagnostics. Here, most attention is paid to the high frequency vibration [4].

New methods of comparative vibration signal parameters analysis are developed for the final test control after machine assembly or repair, i.e. for condition monitoring by a set. The best way to form and adapt a vibration state standard for new generation condition monitoring and diagnostics systems is to do it jointly with condition diagnostics when only the machines with no severe defects detected by diagnostic routines are used to form vibration state standards.

Condition monitoring by a set has one more peculiarity. It is possible use of external vibration exciters or shakers, especially in cases when the unit under control does not generate vibration while the test measurements are being performed.

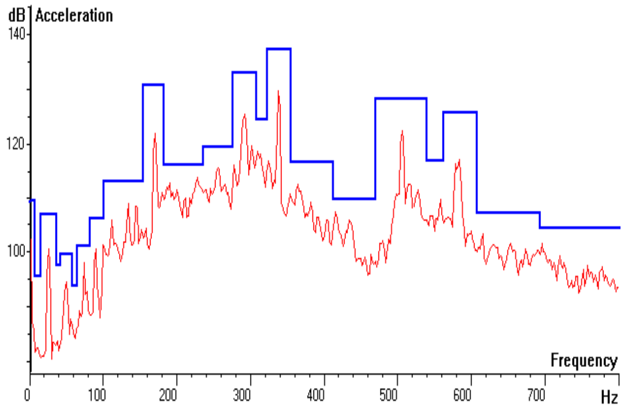

Fig. 1. Autospectrum with the alarm level.

Principally, a new technical solution in the new generation condition monitoring and diagnostics systems is the monitoring of machine or machine unit technical condition. To do so using each of vibration measurement, the automatic diagnostic system makes a condition diagnosis with identification of all possible defects, even in their incipient stage. Next each defect is monitored during its development. This approach allows the prediction of defect development and the accurate prediction of residual service life for the machine or its unit.

The existing first generation systems are completely open ones, and the customer can enter any parameters and symptoms he would like to use in diagnostics to detect and identify defects. Typically, the designers limit the customers only in the changes of the software routines for state recognition, but the knowledge bases can be edited by the customers by entering defect symptoms and rules for their recognition. Of course, the established standard rules are preloaded in these databases and the customer initially has to select the ones to be applied for his problems.

This type of systems has its own advantages and disadvantages. Its main advantage is the ability to be adapted to both diagnostic objects and measurement instrumentation available for the customer. The adaptation can only be done by a highly qualified expert so that contradictory rules or very high weight coefficients for the rules that give rather high errors are not entered. The volume of such work is very high and practical use of this system for condition diagnostics may only begin after several months of system adaptation.

The previous statement reveals the main disadvantages of open systems. Besides the huge amount of work required for the system adaptation, such a system requires a lot of work to make additional diagnostic measurements not used in condition monitoring, and then entering them into the main expert database. Such measurements are typically needed to increase the diagnostics reliability.

The second approach to the condition monitoring and diagnostics systems development is the closed type of diagnostic structure. In this case, all diagnostic rules are chosen and tested by the developers of the system and the system itself is optimized for the selected types of measurements. These systems are oriented to the condition diagnostics of standard machines or their units, e.g. bearings, gears, impellers, etc. Operating such a system does not require any user training in vibration analysis or condition diagnostics as all the measurements, data transfer and condition diagnostics are automated. The fact that these systems are specialized for certain diagnostic measurements results in minimum prices and maximum possible productivity and efficiency of the system.

A short description of physical processes behind the most efficient diagnostic methods for rotating machines is presented below [3].

The condition diagnostics of bearings is done by the analysis of low frequency fluctuations of friction forces and the power of the high frequency vibration excited by them. To do so, the spectrum of high frequency vibration power oscillations is measured, i.e. spectrum of high frequency vibration envelope.

Condition diagnosis of geared, chain, worm, and other types of mechanical transmissions is done using the analysis of shock loads occurring in the gear interaction which are transferred to the bearings of the transmission. The shock loads in the transmission can be both positive loads that increase the load on the bearings and negative loads that decrease the bearing load. The changes in loads are also detected by the analysis of vibration envelope spectra measured on the bearings housing.

Condition diagnostics of working wheels rotating in the gas or fluid flow is done by the appearance of an increased turbulence "cloud" in the flow which can either rotate together with the defective blade or appear periodically in the defect zone on the stationary inner surface of the machine body. The properties of this turbulence "cloud" can be analyzed by the envelope spectra of the high frequency noise of the flow or vibration of the machine (pipeline) body excited by the flow.

Defects of electric machines (electromagnetic system of the machine) are found from the appearance of pulsating torque in the machine. This torque may pulsate at different frequencies and may result in changes of machine vibration patterns at a number of machine points and directions. For the identification of these torque symptoms, we use autospectra of the machine body vibration.

4. SYSTEM CONFIGURATION

The configuration of condition monitoring and diagnostics systems is defined by the choices of means for measurements and physical process analysis and by the configuration of the software package. Thus, from the measurement instrumentation the systems can be divided into three main types – portable, stand and stationary.

The first type uses portable measurement instrumentation for the measurements and analysis of vibration, noise, temperature, current, etc. The systems of the second type are usually a part of different temporary test stands. As usual, transducers are temporarily mounted at the measurement points for the time required for measurements and diagnostics. The third type is stationary condition monitoring and diagnostic systems that operate together with the diagnosed object and continuously monitor its condition. Transducers are permanently installed in the diagnosed object together with the signal and communication -lines that are connected to the meas-

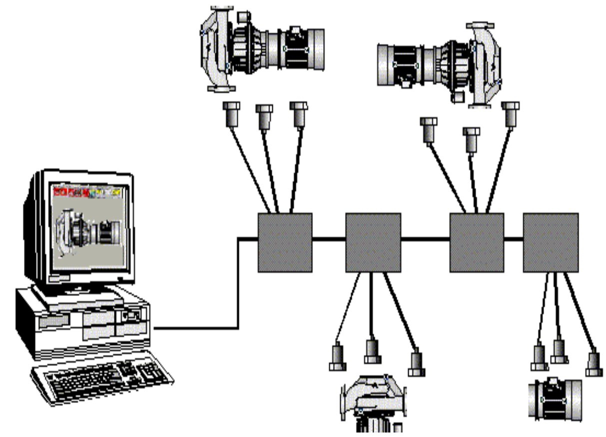

Fig. 2. Stationary condition diagnostics and monitoring system.

urement instrumentation, monitoring and diagnostics system.

Some of the systems used for practical diagnostics can have extended capabilities combined from different types of systems. Thus, it is very often that portable condition monitoring and diagnostics systems are used together with transducers permanently mounted in inaccessible points with signal lines brought to accessible places. Some times, stationary systems are equipped with portable measurement instruments to obtain measurements in additional measurement points.

Figure 2 presents a typical configuration of a stationary system that differs from the first stand by the presence of additional commutation and preliminary signal conditioning blocks [1].

The software for condition monitoring and diagnostics systems consists of three main modules. The first one is the signal analysis, the second one is condition monitoring and the third module makes condition diagnostics and prediction. Each of software modules may have several ranges of complexity that is defined by the tasks of the system [5].

The lowest level of software complexity is found in systems used for alarm condition monitoring. Their main task is to shut down the machine (equipment) when the vibration level (power) or the level of some vibration components exceeds the specified allowed levels. The most difficult part of such a system is the choice of measurement system, taking into account reasonable pricing and the ability to do continuous vibration monitoring.

Often the condition monitoring systems having vibration state prediction capability possess one of the most complex software systems for signal analysis and condition monitoring. At the same time, the condition diagnostics modules are at rather low level in this type of system; typically this is an expert system that helps in the interpretation of monitoring measurement results.

The highest level of condition diagnostics software posses the detailed diagnostics systems that are aimed on the incipient defect detection and defect development monitoring with machine (machine unit) condition and residual service life prediction.

But most of these systems do not have the most advanced signal analysis and condition monitoring modules as the tasks for the vibration monitoring are not so complex in these systems and all types of vibration analysis are standard.

5. CONCLUSIONS

The new generation of condition monitoring and diagnostics systems differs by the detailed solution of diagnostic problems that allows making a step from machine vibration state monitoring to the monitoring of the machine technical condition.

Most rotating machine defects can detected by such a system much before dangerous situations occur. It allows the efficient use of, not only stationary on-line continuous monitoring systems, but also portable, off-line systems for condition monitoring and diagnostics as well.

The tendency toward a rapid decrease in the expenses of the condition diagnostics is evident. This allows the introduction of condition diagnostics, not only for the primary, most important equipment, but also for supplementary machinery as well and, thus, more wide introduction of preventive condition based maintenance.

One more result of customer’s experience in work with portable systems in transportation, was the development of test stand systems for condition monitoring and diagnostics for a set of identical objects. Experience showed that such a condition diagnostics system used for the wheel cartridges using a single vibration measurement on box bearings, for example, decreases the number of bearings failures by many times.

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Authors:

PhD, Eng, Ilie Octavian POPP, Assoc. Professor, "Lucian Blaga" University of Sibiu, Faculty of Engineering "Hermann Oberth", Department of Machines and Machinery,

E-mail: ilie.popp@ulbsibiu.ro

PhD, Eng, Ioan BĂRSAN, Professor, "Lucian Blaga" University of Sibiu, Faculty of Engineering "Hermann Oberth", Department of Machines and Machinery,

E-mail: ioan.barsan@ulbsibiu.ro