Intelligent Sensors in Vibration Monitoring

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Abstract

Plant Asset Management (PAM) seeks to improve competitiveness by minimising the plant’s operating expenses and modifying operating models. The possibilities offered by technical facilities, increase in knowledge and acceptance of condition monitoring (CM) to support management strategies have increased the urgency of change in traditional CM. In plant productivity strategies condition monitoring is therefore increasingly moving towards proactiveness. Intelligent condition monitoring sensors will play a significant role in proactive CM.

Keywords: Condition monitoring sensor, remote monitoring, acceleration measurement, vibration analysis, intelligent sensor, 4th derivative

1. Introduction

The key competition factors in industry are the high reliability of production, quick and prompt delivery of goods, high quality of products as well as environmental protection and ensuring safety at work. Meeting these requirements requires in particular profound knowledge of machine diagnostics, i.e. the skills needed to secure the “health” of machines. Persons or professional entities carrying out diagnostics are expected to address the following questions:

- Is the object being inspected in good condition or not?
- If it is not in good condition, then what is the fault?
- How long will the machine continue to operate?
In the case of manual CM, the measurer makes regular inspections on the machines and analyses their condition on the basis of data obtained by means of data collectors. The need and time for maintenance actions is estimated based on the analysis. Furthermore, the measurer also inspects the machines using the senses and applies the results in the analysis [1].

Vibration measuring is based on the following simple facts [2]:

- All machines vibrate as a result of both large and small defects.
- Excessive vibration means that defects have become mechanical problems.
- Different problems cause vibration in different ways.

The simplest way to monitor a machine is to look for trends in vibration levels. Experience has shown that the root mean square and peak values of a signal are good indicators of vibration severity.

For economic reasons the aim has been to ensure that the downtime required for maintenance occurs less frequently than today. It is therefore essential that potential failures are discovered at an even earlier stage than before. In bearing fault detection more sensitive methods, such as time derivatives higher than acceleration, are applied. On the other hand, high quality requirements have led to a situation where certain machine components have to be replaced much earlier than necessary in view of their mechanical condition. A good example of this are soft calendar rolls, in which even relatively small vibration can cause unevenness on the paper, considerably impairing its quality.

Furthermore, it should be noted that measurements should provide a possibility to recognize wrong machine operating practices. The resonance condition represents a classic example of this. Another example is a water turbine that operates in a power range where strong cavitation can occur [3]. This can lead to premature damage and expensive maintenance work of runners and flow channels. The use of advanced signal processing methods can reduce the risk of operating the machine in the cavitation area.

There is a clear need in industry to move from manual condition measurements towards permanent intelligent measuring solutions. Along with the retirement of ageing condition monitoring personnel, a great deal of traditional know-how is lost and the pressure to apply
automated condition monitoring is growing. Moreover, large manufactures have experienced a growing need to integrate permanent sensors in their products in order to monitor the operation and condition of these products. This also requires efficient use of the existing data communication networks and their compatibility with the monitoring equipment [4].

Permanent condition monitoring systems are generally massive in size and are used to monitor critical parts of the process. The information provided by them can be analysed either automatically or manually, depending on the intelligence of the system. They have alarm limits, the exceeding of which activates an alarm. More intelligent CM systems can provide automatic analyses and can also include properties that enable them to directly adjust the functions of a process. Small permanent systems can be used to protect certain parts of a process. They do not necessarily need to be connected with more extensive systems, but instead can operate as individual monitoring elements [4].

2. On Vibration Monitoring Equipment

In condition monitoring, vibration is normally measured by means of:
- simple handheld vibration meters
- data collectors
- permanent condition monitoring systems

Measurements are usually performed by means of a handheld vibration meter, which measures the root square mean value of vibration velocity, i.e. the vrms value in the frequency range 10 to 1000 Hz. They allow monitoring the development of unbalance, misalignment and bent shaft, for instance. The drawback is that the meters do not permit a more detailed analysis of the cause of failure. Furthermore, sometimes data need to be stored manually.

A data collector makes it possible to collect peak values, rms values, time domain signals and various spectra, for example. The results are downloaded on a PC for analysis and for monitoring trends. This measuring practice has the following drawbacks:
- the person conducting the measurement has to go to the machine
- the measurement can involve safety risks, and working conditions can be poor
• measurements are carried out relatively infrequently and not always at the same point
• when probes or magnets are used the linear range of the measurements does not necessarily cover very high frequencies
• it is more difficult to make a reliable prognosis if measurement data are available rather infrequently
• the measurement itself is labour-intensive.

One of the benefits is that during the measurement process it is also possible obtain information using the senses, which facilitates the analysis.

A very large permanent condition monitoring system can include from 100 to 1000 sensors. Such systems can be found in paper machines, for instance. Typically they have a powerful mainframe computer, which collects acceleration or displacement signals in a digital form and processes the signals. The drawback of such solutions is that they are impractical to use if only a small number of sensors is needed.

Service providers have understood the significance of proactive condition monitoring as a factor for increasing production and improving utilisation rate [5]. Along with the service business the industry can benefit from the savings derived from centralised condition monitoring and optimising the number of personnel. Professionals use a lot of time in moving from one monitoring object to another. The industry has begun to understand the remote monitoring possibilities offered by modern technology, and many plants are moving towards centralised monitoring.

Along with the development of technology, the measuring resolution of sensors increases, and more measurement data are generated and stored. Therefore, it is essential to ensure that the data received can be processed as close to the measurement object as possible. In such a case the methods that are found necessary in the CM process can be integrated into sensors and analyses can be automated.
3. Intelligent Sensors

Intelligent condition monitoring sensors can perform calculations inside the sensor. They have distinct advantages compared with old measuring solutions. Their use enables one to eliminate the drawbacks connected with data collectors that were discussed before. On the other hand, if the object of comparison includes medium-size systems, for example, the initial investment required to implement intelligent sensors is much smaller than in the case of solutions involving a mainframe computer. However, nothing prevents the use of intelligent sensors for building – either step by step or as a single project – a large measuring system.

An intelligent sensor should be capable of processing measurement data and responding to service requests made over a data communication network. The ‘intelligence’ of a sensor means that the sensor processes, analyses and post-processes the results using its integrated software and circuits. Sensors need to be easily connectable using the existing data communication networks.

The functions of an intelligent sensor must comply with the requirements of the market both from the point of view of applicability as well as functionality. On the other hand, an intelligent sensor provides results with at least an equal degree of reliability as traditional methods. Furthermore, obtaining information corresponding to sense-based observations is important as well. For instance, listening to the measurement data helps separate different failures types. Moreover, a sensor should be capable of operating independently and has to be particularly fault tolerant and maintenance free.

4. Ethernet as a Data Transmission Channel

The connectivity of a sensor with the Ethernet network facilitates real-time remote monitoring. The power supply possibility complying with the Ethernet standards ensures that no separate power supply is needed; instead the sensor is ready for use with one Ethernet cable connection. Connecting a sensor to the Ethernet network also allows updating the sensor software over the network as well as taking advantage of the ample supply of network equipment. With the Ethernet network there is no need to use expensive fieldbus solutions.
The Ethernet also offers a large number of alternatives for utilising the Internet in respect of remote condition monitoring, as the Ethernet TCP/IP and UDP protocols are a global standard. However, challenges can hardly be avoided. These are caused mostly by including new equipment in the network environment, as the reliability and safety of the data network is critical to any company. Furthermore, the most common and reliable connections do not always reach the monitoring object.

5. Some Solutions for Sensor Power Need

Running machines generate lot of different types of energy, such as thermal, mechanical vibration and radiation energy, which in future can be utilised in sensors. This energy can be harvested from the object being monitored and used as a power source for sensors. There are different methods of harvesting energy from machines, such as piezoelectric materials [6].

However, the amount of energy supplied in this way is rather small and is sufficient for rather simple sensors only. Harvested energy is generally under mW. In future, it would be possible to manufacture sensors that consume little energy. Then the energy harvested from the vibrating machine can provide sufficient power to the sensor, and for a short reach wireless data transmission [6]. Another way of harvesting energy from a machine is to take energy by means of a current transformer (CT) from the magnetic field around the power-line of the machine. A CT can be used in inverter-fed electric motors [7].

6. Data Processing with Intelligent Sensors

Developing technology makes it possible to increase sampling frequencies, in which case the quantity of measurement data increases in a time unit. There is no need to store or transfer all this data mass in such a form, but instead it can already be processed in the sensor. An intelligent sensor comprises an integrated processor, which can process measurement data mathematically. In addition, the sensor can have a memory, which is used as a program memory and for buffering data in the network traffic. The process controls the functioning of the sensor, processes measurement data and organises network traffic and communication.
With an intelligent sensor data can be collected either locally or in a centralised manner. In the case of local data collection, a sensor operates independently, collecting and processing data and transferring the required information forward. A sensor can also be connected to a local server, which collects data from the sensor and stores it (Fig. 1). In a centralised model, data are collected to a specific certain server, which is located in the Ethernet network (Fig. 2). The data can include measured raw data, results of analyses or both of them. The server can be located physically anywhere in the world.

Figure 1. Local data collection model

Figure 2. Centralised data collection, where data from the sensors are stored in a server connected to the Internet network.
7. New Service Possibilities Offered by Intelligent Sensors

The use of sensors via the Ethernet makes it possible to offer versatile services to customers, such as data collection, entry, analysis and reporting. In addition, it is possible to offer specialist services (Fig. 3), in which case a network of specialists can analyse the object via the Ethernet and render an opinion about the results. Where required, customers may purchase intelligent sensors and carry out the monitoring themselves. They may also purchase the condition monitoring service for a certain object without having to invest anything in sensors and other equipment.

8. Remote Monitoring

Remote monitoring (RM) often places various requirements to sensors, the most important one being the ability to perform measurements in a reliable manner and to transfer data and processed information over the network in real time. For RM, it is necessary to ensure among other things that sensors can be connected to the Ethernet network and that it is permitted to establish connections outside the plant if monitoring takes place there. In addition, the data transmission speed must be sufficient for the transferable data volume. In many industrial environments the use of a wireless network is fairly challenging, due to disturbing factors in the operating environment.
Owing to package delays in the Ethernet network, a sensor should be capable of buffering the data in the memory. Once the memory capacity is reached, the transmission is interrupted. Data can be transferred locally within the plant via a WLAN connection [8]. If necessary, it is also possible to use a wireless network for outbound traffic, such as a 3G or @450 connection.

9. Trend Monitoring

Machines seldom break down suddenly without any warning. From the point of view of CM, it is crucial that we can monitor the development of vibration levels as a function of time, i.e. trend of vibration levels (Fig. 4). Vibration levels are slightly higher in a new machine, due to the fact that the surfaces of machine elements have not become smooth through wear. Excessive forces caused by a fault cause vibration levels to grow, and the vibration trend becomes more prominent. The closer we are to a breakdown point, the higher the slope is. In other words, the vibration level grows considerably when the breakdown point is being approached.

![Figure 4. Typical trend of vibration levels [9].](image)

If CM is carried out using a data collector, the measurement interval can be from 3 to 6 months, for example. If the object is a critical one, the period is shorter. With an intelligent sensor measurements can be carried out automatically, in which case trends can be monitored more accurately. Automatic measurement makes it possible to carry out
measurements at short intervals, which allows eliminating the influence of random process conditions. As a result, different condition indices become even more reliable.

Selected vibration indices are used to perform a trend analysis and along with trends it is possible to assess the condition of the machine and the appropriate time for repair work. We can set various alarm limits for a trend analysis. Furthermore, by monitoring changes in the slope of the trend, additional information on the degree of the fault can be obtained.

10. Automatic Measuring of Multistage Gear

In order to make automatic measurement possible, it is necessary to be familiar with the operation principle of the object. In this case it is possible to ensure that the measurement result is comparable with any previous measurement. Often the machine is running periodically, in which case the point in time when a reliable analysis can be carried out can be determined mathematically.

A multistage gearbox was analysed in a test using automatic measurement techniques. For the purpose of the test a minor mechanical defect was made on the gearbox. In this case none of the analyses was performed using an intelligent sensor, but locally using the arrangement illustrated in Fig. 1. The measurement was carried out using the CM301 sensor of Webrosensor Oy. In the course of the measurement a lot of data were collected for later analysis and therefore the sensors were connected to a local computer. The computer was linked to the Ethernet network via a wireless 3G connection for remote monitoring.

The measurement signal from the gearbox (Fig. 5) indicates that vibration occurs periodically. The computer automatically delivered daily reports about the measurements by e-mail and processed the collected data. The system recognised automatically the operating state of the gearbox when each analysis was carried out at the same operating point.
The results were used to calculate the normalised dimensionless peak values of acceleration, the trends in which are shown in Fig. 6. This clearly demonstrates the development of the fault in the gearbox. At the end of test the gearbox was already running over its calculated lifetime.

11. Summary

The industry is at a turning point, which also concerns condition monitoring. CM is becoming a highly important part of production management. New technologies and intelligent sensors are used to detect the failures of machines as early as possible. This information is crucial when the goal is to ensure long service life.

Along with the development of new sensor technologies and electronics, the volume of data generated by sensors is growing at a huge rate. Therefore, data transmission, in
particular the intelligent processing of data, is becoming an important part of the measuring chain. Analysis is shifting closer to the machine and even to inside sensors. Sensors transmit intelligent indices so the volume of data being transmitted is significantly reduced, and therefore information describing the condition of a machine can also be sent to a mobile telephone.

Intelligent sensors are capable of processing the data they obtain, detecting an abnormal situation and forwarding information about the health of a machine. In future, these sensors will play a key role in improving overall equipment efficiency in companies, i.e. their OEE value.

References