AUTOMATIC DIAGNOSIS

Guide for Maintenance Supervisors & Reliability Engineers

Optimizing the efficiency of a condition monitoring program thanks to an expert system with a confidence level indication.

TABLE OF CONTENTS

ABOUT THE AUTHORS

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Brian has been involved with reliability technologies for over 25 years. As a VibrAlign Product Manager and former Sales Manager, Brian travels the country to educate on the value of precision alignment. Brian is now in charge of the ONEPROD line of smart condition monitoring solutions for the US market, actively promoting the HAWK, FALCON, EAGLE, and MVX.

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Patrick is the director of the ONEPROD brand of condition monitoring solutions from ACOEM. At the head of the product & services department since 2012, he started his career 30 years ago as vibration engineer in the field of acoustic discretion of rotating machines for submarines. He then dedicated his work to the diagnosis and monitoring of rotating machines in a wide range of industries, through the evolution of ACOEM Company. In 2007, he was recognized as an expert of the French nuclear industry with the AREVA group in Mechanics and fluid mechanics, Dynamics, e.g: vibrations, noise, seism, impact, Plant/Equipment - Control & Management System, Monitoring Systems/Asset management Systems, Instrumentation, and plant Plant/Asset Heath monitoring instrumentation. Patrick is also the author several patents with direct application to the monitoring & diagnosis of rotating machines: US 6,705,168 B2 Process and device for processing of vibrations measurements of a rotating machine rotor; 20160041068 Wireless Collection and Analysis of Machine Data (patent pending); 20160041070 Automatic Rotating-Machine Fault Diagnosis With Confidence Level Indication (patent pending)

1. VIBRATION ANALYSIS: A Demanding Job

Any condition monitoring program starts with a machine classification to determine which of the machines in the facility will fall into the program and how they will be monitored. It will depend on several criteria, such as:

- How critical is the machine for the process (how dependent is the process on that machine)
- Which failures are we trying to prevent, can they be detected, how can we detect them, and how early can they be detected
- How much time will it take to repair the machine
- Maintenance challenges associated with the repair (spare part management, maintenance operation requiring specific resources like cranes…)

Once a machine is included in the program, it will be necessary to monitor it to prevent unexpected failures. This implies that even a healthy machine will be under close watch.

Among the many techniques of condition monitoring available today, vibration analysis is undeniably the most commonly used. Vibration analysis involves several steps, including the measurement itself and the actual analysis. A standard approach of vibration data involves the systematic review of each machine which is part of the program. Beside the fact that this is time consuming, it most often results in a non-prioritized analysis. In most of the cases about 70 to 80% of machines in a program are in a healthy status at any given time.

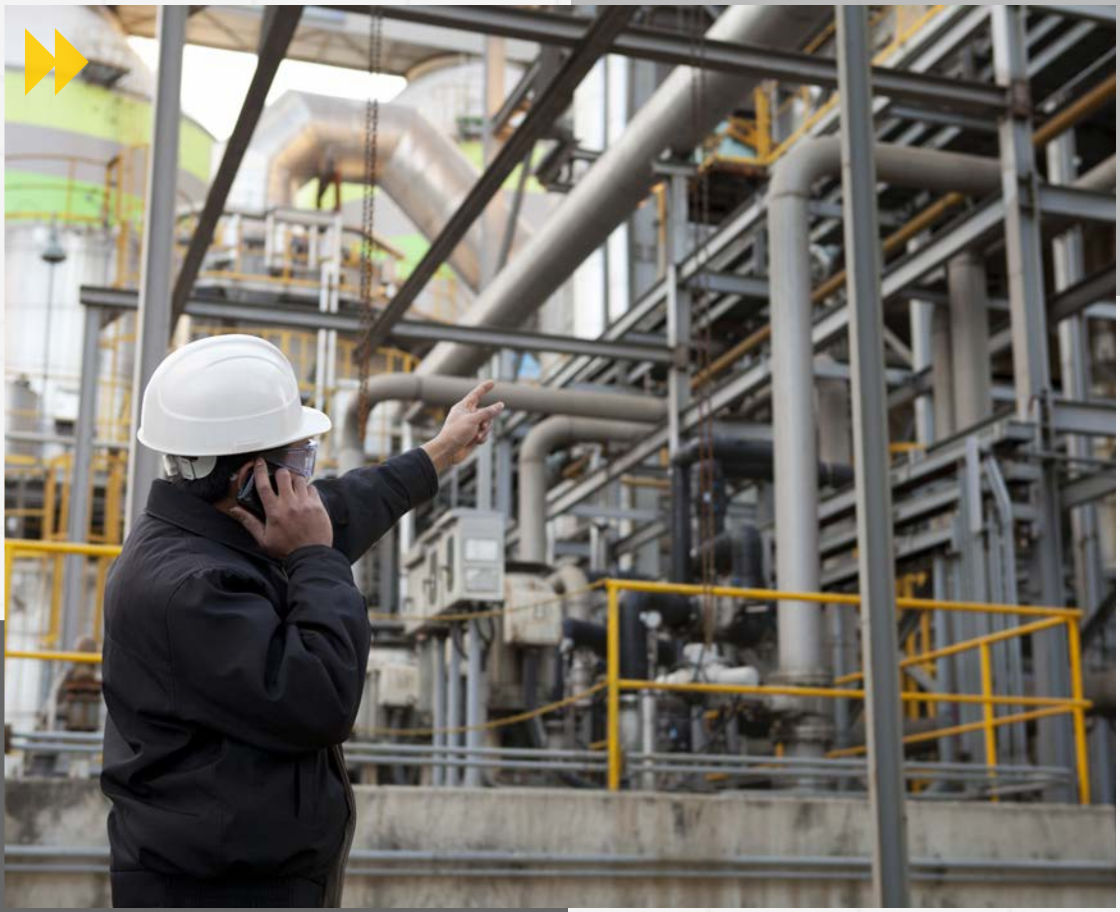
What if there was a better way that allowed the condition monitoring program to focus on the critical cases?

2. GUIDE FOR MAINTENANCE SUPERVISORS & RELIABILITY ENGINEERS

A A common objective: Improving reliability with limited resources

Once a program is established, the opportunity for improvement mostly resides in changing the measurement strategy. This can result by investing in more systems (e.g. adding online monitoring), and/or adding more people to the team to provide a closer watch on different machines (e.g. increasing the frequency of measurement and analysis).

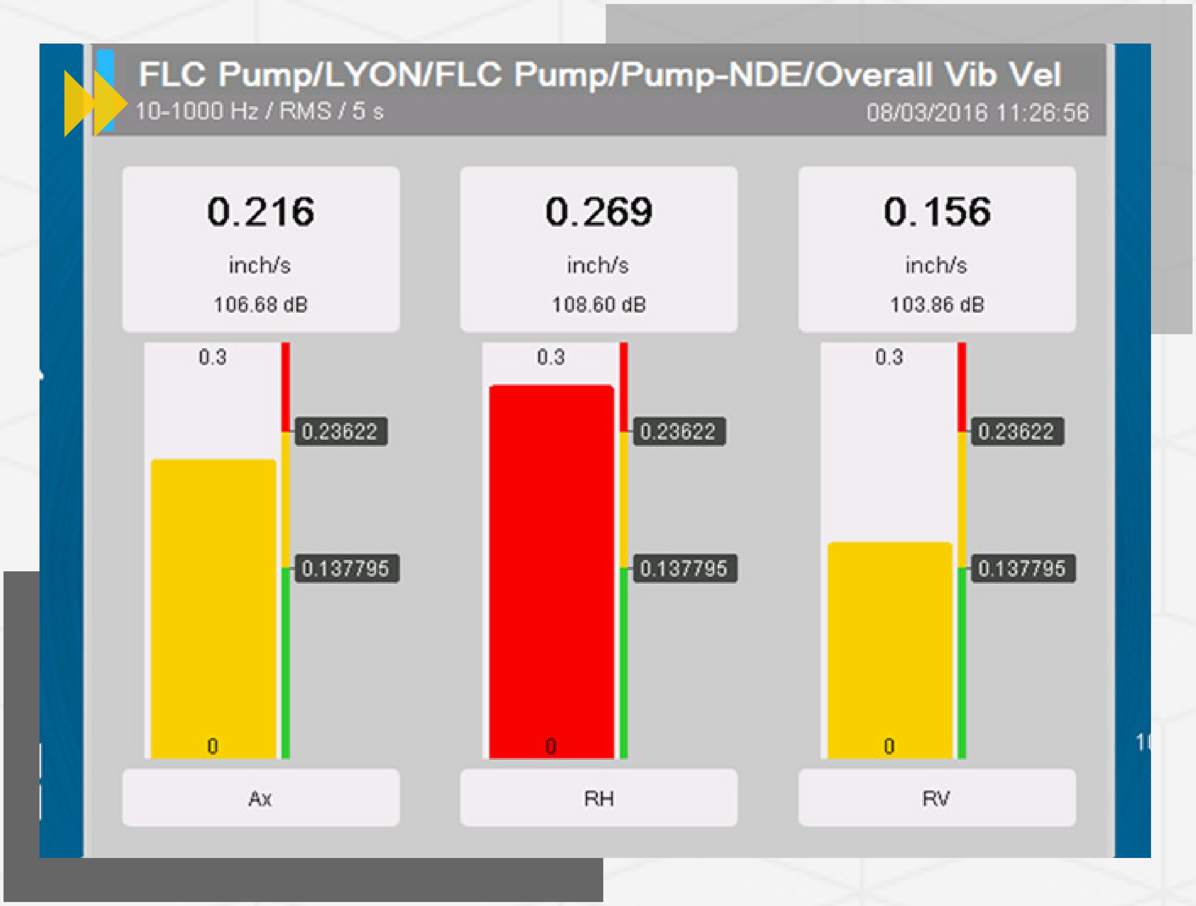
All condition monitoring programs are limited by the expandability of hardware and human resources. This paper will present solutions that allow for improving a condition monitoring program's efficiency without requiring additional resources.



B What does the ISO10816 standard say?

In the world of vibration analysis, one of the things that is hardly questionable is the ISO10816 standard on the “Evaluation of machine vibration by measurements on non-rotating parts”. It gives clear instructions on the vibration measurements to perform and the thresholds to apply, depending on the machine class (power, speed, type of mounting…). Many OEM’s of industrial machinery are using the ISO10816 standard in their maintenance procedures and recommendations.

The ISO10816 standard doesn’t provide any help in defining the diagnosis and faults present on the machine, but does give an overall recommendation on the machine global health: Based on the value of the velocity vibration measurement, it is possible to evaluate the risk of failure dependent upon the machine class.



Overall velocities at the pump Non Drive End bearing based on ISO standards for this machine type.

C What does the vibration analyst say?

A vibration analyst will have to rely on the fault identification to provide maintenance recommendations to best schedule and orient the repair actions. All vibration analysts will agree with the following statement: If the vibration level conforms to the ISO10816 and there are no shocks on the machine, then this machine is healthy.

If this condition is not valid, then he will go into a deeper analysis of the vibration data, looking for symptoms to try to identify faults on the machine and provide maintenance recommendations based on his evaluation of the risk, in the same way that a doctor would do on a patient to diagnose his sickness and give the best recommendations to cure it.

Depending on the situation, while analyzing the data, even the best expert in the world could hesitate between several possible causes explaining a given vibration behavior. Some machines can potentially present several faults, including faults that may be induced by one of the other faults. An expert will always weigh his results, showing in his report the problems that are most likely present on the machine, and guide the maintenance staff on where to start to correct these problems.

D What is an expert system?

"In artificial intelligence, an expert system is a computer system that emulates the decision-making ability of a human expert. Expert systems are designed to solve complex problems by reasoning about knowledge, represented primarily as if–then rules rather than through conventional procedural code"

Applied to our field of application, an expert system would be an AI able to establish an automatic diagnosis of rotating machines. The expert system would have to review automatically each raw spectrum and time waveform to identify and evaluate the faults severity. It would present them in a prioritized way according to the confidence given to each fault detected, so that it can orient the maintenance actions to be carried out. On the top of that, just like the expert, it should be able not only to point to faults detected but also to give an overall assessment of the risk evaluation and tell the user if immediate action needs to be carried out.

E Solutions for improving a condition monitoring program's efficiency with existing resources

It is possible to help expert users today to focus on critical machines thanks to the use of an adequate expert system. To achieve this goal, this system should provide the following information:

[1] Risk assessment indicator: Focus on critical machines

By assessing the machine overall health and presenting it in a simple form, such as a GREEN, YELLOW or RED flag, the expert could prioritize his analysis:

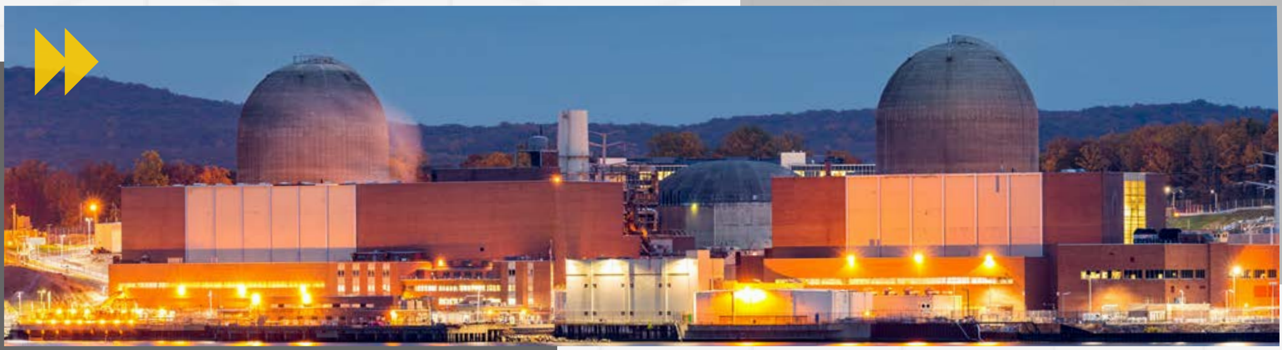
- No need to have to look at the machine in GREEN
- Start with the machines in RED
- Review the YELLOW tagged machines in a second step.

The best solution relies on systems that can take into account:

- The ISO10816 standard.
- The presence of shocks
- And just like an expert, assess the risk based on the faults and symptoms detected

As examples:

- An unbalance defect could be diagnosed with a high vibration level on a machine, but depending on the asset, it does not necessarily need to take an immediate action.
- On the other hand, the accumulation of multiple faults on a given machine, even if each single fault doesn't show the highest severity level, could represent an important risk for a given machine, and requires immediate attention.



[2] Confidence level indicator: call to action or guidance for the diagnostic?

Giving an automatic diagnosis result is a good thing, but if a defect detected with high confidence level is represented in exactly the same way as a defect detected with a low confidence level, it may lose the trust of the user and force him to check every single result given by the automatic system. This does not help at all to improving the efficiency of the program.

To do so, the best solution is to use a system having a symptom based approach (as the expert would) and is able to characterize the fault presence probability based on the symptoms detected. The best AI solution identified today is the Bayesian network, fully taking into account that weighting process and best using the experience acquired in a given field of application.

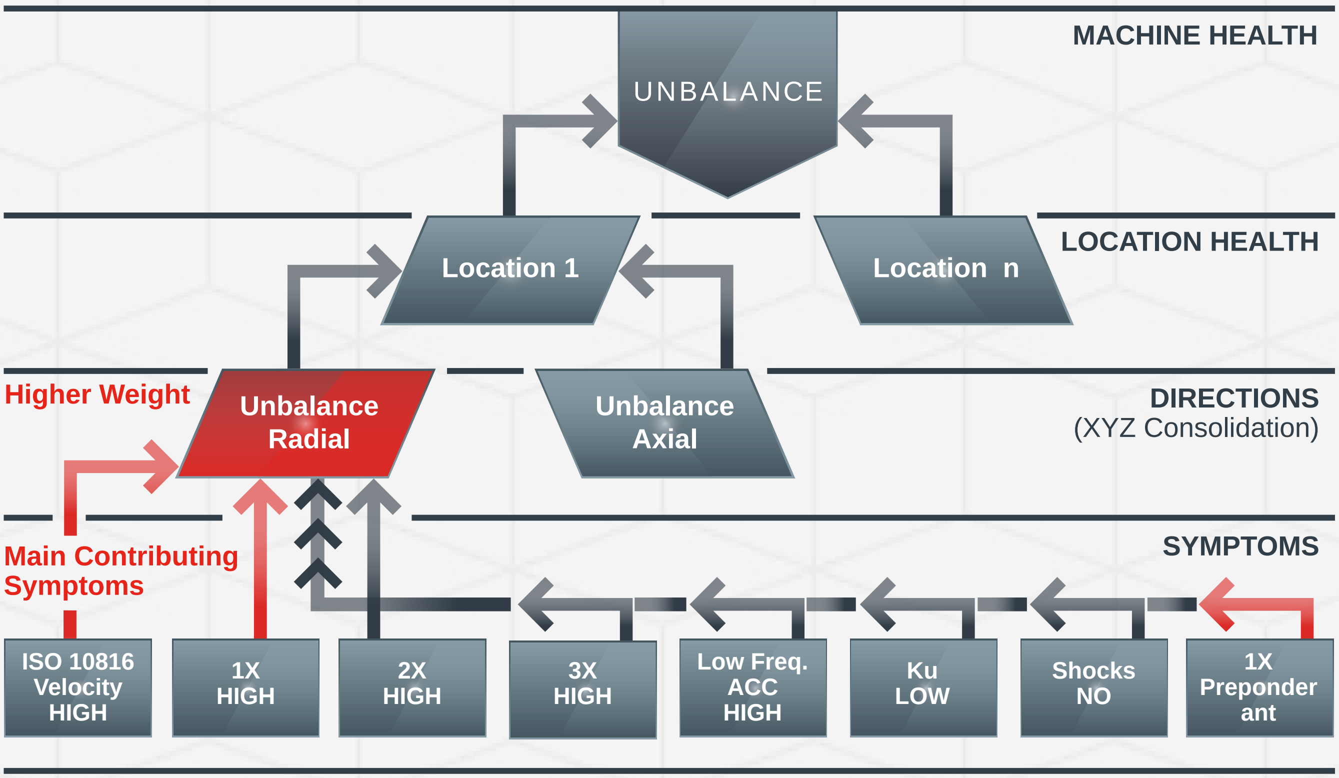
“Bayesian” as defined by the Merriam-webster dictionary: “being, relating to, or involving statistical methods that assign probabilities or distributions to events (as rain tomorrow) or parameters (as a population mean) based on experience or best guesses before experimentation and data collection and that apply Bayes’ theorem to revise the probabilities and distributions after obtaining experimental data”

Each fault can characterized by symptoms. Examples of symptoms could be:

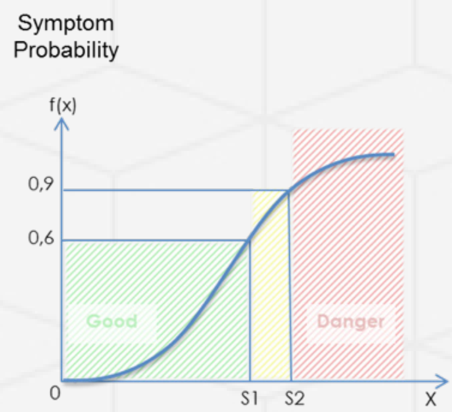
- A value of overall velocity vibration considered to be high
- The presence of shocks
- the bearing temperature considered to be high
- the evolution compared to the previous measurement considered to be high

Just like a vibration analyst, the expert system will look for these symptoms, and compute the probability of presence of the defect, based on the probability of presence of each of the symptoms characterizing the defect.

Here is an example below to illustrate an unbalance defect. The unbalance is for instance characterized by several symptoms that can be found in the vibration data, some being more important than others. The direction of measurement, in which the symptoms are found, could also impact the fault presence probability.



In addition to that, the probability of presence of each single symptom can be run through an algorithm that will weigh the result, such as a sigmoid presented below.



When a value of an indicator X < "S1" it is projected through the sigmoid, the resulting symptom probability (value between 0 and 1) will be way below 0.60. On the other hand, a value of X > S2 projected on the sigmoid will remain close to 0.90. This approach avoids the basic limitations of a simple thresholds violation. In other words, is 1.01 really a dangerous value for a given indicator when 0.99 is OK?

With such an approach, the confidence level associated with each fault can be displayed with great accuracy. The user can then determine very easily if the automatic result should be converted immediately into action, or if it should just be taken as guidance in identifying the best diagnostic?

[3] Empower the maintenance staff with automatic & instantaneous result

Another way to improve the efficiency of a condition monitoring program resides in the following solution. With an easy to use expert system able to give instantaneous results in front of the machine:

- Time can be saved as the results can be interactive, and avoid multiple trips and bureaucratic procedures to take actions. For example, if a bearing or lubrication defect is detected, the automatic recommendation could be “first grease the machine, if it doesn’t change the behavior, schedule the bearing replacement”.

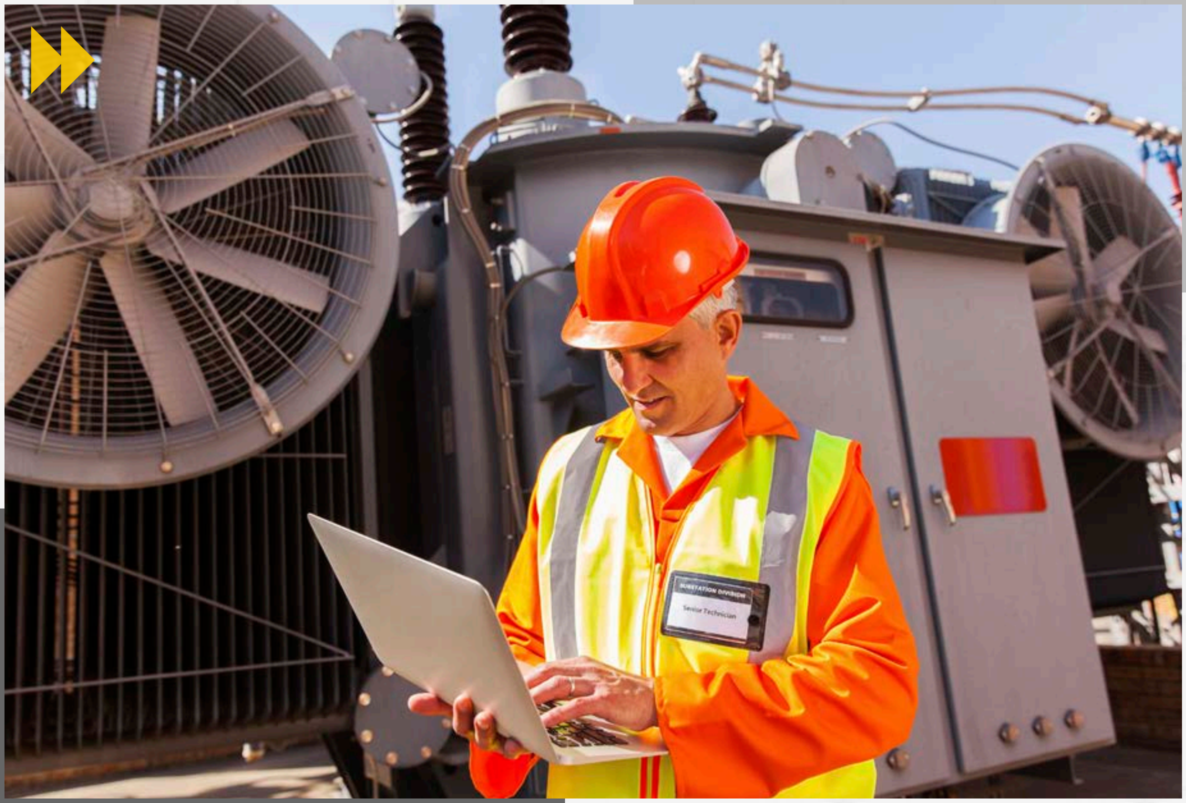
- More checks could be performed by other maintenance staff, not necessarily part of the reliability department. If a machine presents suspicious behavior (noise, temperature), one can easily check the machine and call the expert accordingly.

- Additional checks can be performed by other maintenance staff on machines out of the program: with an automatic result with a good confidence level, people would be able to make a decision without help of the expert who is only focused on the machines that are part of the condition monitoring program.

[4] Easy & reliable set up of the system

Last but not least, a prerequisite for such a solution to really be helpful resides in its ease of set-up. Numbers of expert systems have failed in the past, not because of their accuracy but because of the complexity of set up. What's the point in having an a so called expert system if only an expert of the expert system itself is able to set it up correctly and adjust it according to the type of machine?

The expert system should be able to determine by itself what should be measured according to the type of machines (type of components, speed, power, type of mounting, etc.), in order to always give the most accurate automatic result, and this, in a matter of minutes. You can't afford to spend more time than that if you need all your maintenance staff empowered to make easy health-checks of suspicious assets, not necessarily part of the condition monitoring program.



F Summary

Expert systems providing automatic diagnosis of rotating machinery are a simple and effective solution to improve a condition monitoring program's efficiency, without additional resources. The requirements of the system to provide such performance are:

- To provide an easy and reliable way to set up the expert system, that can be achieved in a matter of minutes by any skill level personnel.
- To provide a first level of risk assessment, so that the expert can prioritize his analysis and focus on critical machines.
- To provide a confidence level associated with the fault detection, so that it can immediately be converted to an action, or used as guidance to further analysis.
- To provide instantaneous results so that direct actions can be taken on the machine without help of an expert, on machines that are part of the condition monitoring program.
- To provide instantaneous results so that other maintenance staff can carry out checks easily and autonomously, on machines not part of the condition monitoring program.

By improving the efficiency of your condition monitoring program, additional production uptime can be realized, and maintenance costs continuously optimized.

SOURCES

- ISO 10816-3:2009 Mechanical vibration - Evaluation of machine vibration by measurements on non-rotating parts -- Part 3: Industrial machines with nominal power above 15 kW and nominal speeds between 120 r/min and 15 000 r/min when measured in situ
- US Patent Trade Office: Patent publication n° 20160041070
- Wikipedia
- Merriam Webster dictionary