Enabling an Intelligent Planet

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Machine Condition Monitoring = Improved Manufacturing

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Traditional manufacturing done with saws, lathes, CNC systems and other rotary machines suffers unexpected downtime due to equipment failure. What can be minor or catastrophic component breakdowns are the result of thousands of cutting, milling, drilling and other operations. However, with new machine condition monitoring technology the onset of such failures can be caught before they destroy machine parts or production, thereby avoiding unplanned for downtime and lost production. What's more, machine condition monitoring can ensure that equipment is used as efficiently as possible, leading to greater manufacturing throughput as well as higher quality product. This white paper examines the challenge of machine condition monitoring, outlines a predictive maintenance solution, and provides some examples of implementation.

The drawbacks of traditional manufacturing

Rotary machines form the backbone of traditional manufacturing. CNC, or computer numerical control, machines employ rotary cutters during the milling process, which removes material from a workpiece by spinning the material being milled or the tooling. This is done under the control of a computer, resulting in a level of precision and automation not possible with manual units. The same sort of computer control is often exercised with industrial sawing, drilling and other material processing.

Such rotary machines are widely used and their use is growing. For instance, analysts at Transparency Market Research predict the worldwide market for CNC machines will expand at a compound annual growth rate of 6.3 percent from 2015 to 2024, with the value of this machinery increasing from US$ 52.6 billion in 2015 to US$ 93.4 billion in 2024 while the Asia Pacific region will see a 19.04 percent CAGR.

Trend-lines such as these that point to an increasing utilization of rotary machines are a consequence of expanding manufacturing. For example, a composite index of manufacturing, the J.P. Morgan Global Manufacturing PMI, stood 52.9, a 69-month high, in February 2017. Anything above 50 indicates growth and analysts characterized the PMI as rising due to improved rates of manufacturing worldwide.

However, there are challenges hidden within this picture. One is that the global manufacturing index shows that output prices are rising at a slower rate than output itself, a sign that manufacturers face price pressures and so must find ways to do more with less.

Another challenge is that repeated sawing, milling, drilling and other operations wear out tooling and machine components. Manufacturers, then, are faced with a choice. They must replace tooling and components because failure to do so can lead to one, or both, of two bad outcomes: out-of-spec production or machine failure. Either can happen due to wear out of machine components or tooling.

Traditionally, the solution to this problem has been component replacement and tooling changes on a schedule, supplemented with periodic inspections. From data collected through machine use, manufacturers know that a bushing may last so many hours of operation or so many units of production. Similar data often is generated for all other machine components and for the process tooling itself. From this, manufacturers will determine a schedule that, in theory, avoids both subpar product and machine shutdown.

That solution, unfortunately, is not perfect. One issue is that scheduled replacement tends to be set too frequently, often to minimize the possibility of complete component failure or lost production. This results in less production due to lower machine utilization and higher cost because of increased consumption of parts and tooling. A second issue that even when carefully drawn up, replacement schedules cannot entirely minimize unexpected downtime or out-of-spec manufacturing.

The cost of downtime varies by industry and includes lost capacity, lost production and the expenditure of direct labor and inventory, as well as intangible expenses related to responsiveness, innovation and more. When tallied up, downtime expenses can be quite high. A survey of more than 100 automotive parts manufacturers put the total cost of downtime at $22,000 a minute. Other studies have shown the amount of production capacity lost to downtime can run anywhere from five to 20 percent.

Traditionally, this is simply a cost of manufacturing. However, price pressure and tightening delivery schedules mean that every aspect of manufacturing must be investigated and improved upon, if possible. Given that, can something be done to further decrease downtime and lost production?

Detect change and prevent problems
A solution lies in the first C of CNC: computer. Computers enable automation and that, in turn, gives rise to rotary manufacturing machines that are more capable and offer greater throughput than is possible with manually-controlled machines. Putting the same technology to work can lead to the detection of small problems before they become big, thereby enabling preventative maintenance.

How can that be done and what should a solution look like?
A characteristic of rotary machinery is rotation. Spindles turn, often at thousands of revolutions per minute. That movement may be used as is in a milling or drilling operation. In other instances, spinning may be converted into a linear motion, as is done with saws.

That basic movement gives rise to vibration and noise, with both set by the machine and what it is doing. Think of a car, which when moving produces sounds that the driver finds typical. A change in the level or type of noise indicates a problem. The same is true of vibration, with this again being of a given frequency during normal operation and a different value when something is wrong. There are also other indicators of unusual operation. One is heat, with the temperature often climbing rapidly when there are issues. Another is smoke.

Anyone who's been in a car with a problem knows that smoke and its immediate precursor, heat, are often the last signs of trouble. Vibration and noise, in contrast, often show up much earlier, possibly at a time when fixing the issue would have been considerably less expensive and troublesome.

The same is true for rotary machines. As conditions change within the machine, vibrations will evolve, moving from a normal steady state to some new pattern. That will be followed by changes in noise, with this detectable after the vibration changes begin. Eventually the machine temperature will begin to rise, followed by the appearance of smoke, and then an emergency stop.

The time scale for this sequence is roughly as follows. Vibration changes typically appear months before any of the other indicators. A bearing, for example, with a worn spot that puts it slightly out of round will begin to impact the vibration pattern of a machine as many as three or more months prior to any change in noise level or other characteristics. In turn, such noise changes will appear weeks before an emergency stop of a machine. Detectable temperature variations will show up days and smoke minutes before such a stop.

As can be seen, a machine condition monitoring solution should work by detecting and analyzing vibration and noise. Those leading indicators both appear far enough ahead of any machine shutdown to make maintenance easier to schedule. Additionally, detecting problems as early as possible also makes any upkeep easier and less costly to perform.

Thanks to the miniaturization of key components and other technology advances, accelerometers, which detect vibration, and microphones, which detect noise, are smaller, less expensive and more capable now than they were in the past. Thus, capturing vibration and noise changes are easier to do today than was the case years ago.

There is another important development that makes monitoring easier. The advent of inexpensive computers and sophisticated software makes it possible to more readily analyze and spot subtle vibration and noise differences. A rotatory machine, after all, will always be vibrating and producing noise. That will change with the load. Thus, the noise and vibration when material is being milled will differ from those times when nothing is being machined. When milling is taking place, machine conditions at the beginning of the operation will differ from those at the end. Thus, detecting important yet slight variations in vibration and noise demands sensitive detectors, sufficient computing power and sophisticated software.

To complete this picture of a solution, other elements must be added. For one thing, data acquisition capabilities should be linked to the Internet so that analysis can be done remotely. This would be convenient and could improve analysis performance.

Being able to use a web services-based system, for instance, for pattern recognition would allow scalable analytics, potentially enabling more minute condition changes to be spotted. Also, any machine condition monitoring solution should also not require new manufacturing machinery, a benefit to the large installed industrial base. Finally, a solution should be easy to install. After all, the idea is to solve problems, not create new ones arising from a cumbersome installation process of a monitoring system.

The result of such machine monitoring will be greater insight into conditions. Such information can be used to schedule preventive and predictive maintenance. The outcome can be less unplanned downtime and less downtime overall, thereby increasing machine throughput. There also can be an improvement to product quality, as more consistent machine conditions can lead to more consistent product.

Machine condition monitoring examples
Now that an ideal solution has been outlined, we will look at implementations and results.

For the implementation, we start with an IEPE, or integrated electronics piezoelectric, accelerometer, microphone, speed and/or impact sensor. As the name implies, these contain a sensing element made of a piezoelectric material, which converts mechanical strain into an electrical signal, and an electronic circuit to amplify this signal and transmit it to an external device. Such a sensor produces a low-impedance signal that can travel through long cables in a factory environment with little degradation, an important plus given the typical situation in most industrial facilities. These sensors are mounted on or near the rotary machine being monitored.

The signals from the sensors must be converted from an analog to a digital format. The speed and resolution with which this can be done is critical. These parameters, along with sensor performance, determine the quality of the information feeding into the data analysis. Thus, these need to be high performing.

For instance, the Advantech PCIE-1802 card does this data acquisition for eight channels at sampling rates of up to 216 kilo samples per second (KS/s) with 24-bit resolution delta-sigma analog to digital converters. The sampling rate means more data points, making for better pattern extraction and matching. The resolution bit-depth means that weak signals and fine changes can be detected in vibration, noise or other parameters.

The card offers 115 dB dynamic range, with input voltages being anywhere from +/- 0.2 to 10 V. It also has full auto-calibration and a built-in anti-aliasing filter, ensuring that the conversion of incoming signals is as free of artifacts and errors as possible.

Another example of this part of the solution is the Advantech MIC-1810 DAQ embedded platform. It features a 12-bit, 500 KS/s 16-channel analog input in a fanless embedded platform. It is compact, measuring 165x130x59 millimeters. It also includes an i3 Celeron Intel processor, thereby providing processing capabilities suitable for different applications.

With the sensor data captured and converted, it then is necessary to analyze it to look for changes in machine conditions. This should include time- and frequency-domain analysis, as well as calculations of physical values for vibration, noise and other characteristics. Examining the data in different ways and for different time or frequency scales will help ensure that patterns are detected and problems spotted as soon as possible.

One example of implementation can be found at a highly-rated industrial band saw manufacturer that wanted to implement machine monitoring and predictive maintenance. Industrial metal band saws are typically used in harsh environments where abrasive dust, vibration and knocks and electrical noise when drive motor kicks on and off are common. The solution that was implemented involved current sensing and a resistance temperature detector (RTD). By using an Advantech MIC-1810, the manufacturer met monitoring and cost goals.

A similar solution was implemented by a manufacturer using a cold-forming screw and bolt process. Previously, this process was a black box, with no real data about current internal conditions with the mold. Using a piezoelectric sensor attached to the cold-forming mold, the manufacturer improved the process, making it more consistent and thereby reducing the number of defective parts produced.

The concepts behind these examples can be extended. For instance, rotating machine analysis is typically done with Fourier-based algorithms, which work well when rotational speeds are constant or nearly so. However, in situations where this is not the case, then more sophisticated analysis is needed. Uploading data to the web makes this easier to do because it allows more processing power to be brought to bear on the problem. Since vibration changes may occur months before a problem appears, real-time analysis of signal data need not be a requirement.

As the examples above show, machine condition monitoring can be applied to many situations, preventing downtime and improving product quality. The payoff will vary by industry and circumstances. However, the figures from automotive parts manufacturers reveal that reductions in downtime can be worth tens of thousands of dollars a minute.

Conclusion

With machine condition monitoring, manufacturers can improve the performance of rotary machines in two ways. First, they can carry out predictive maintenance programs. These can substantially cut the operational downtime of such machines from the current five to 20 percent to something much less. Based on surveys of manufacturers, that could reduce expenses significantly. Secondly, monitoring can improve product quality by ensuring more consistent manufacturing.

However, success in machine condition monitoring depends on selecting the right solution and partner. The solution should enable a high sample rate of conditions because that will make monitoring more effective. The partner should have expertise in industrial operation and automation. Factory floors and other areas where machine conditions are monitored tend to be dirty in a physical and electrical sense. A partner with expertise in the demands of such locations will help ensure a machine condition monitoring project is successful.