TECHNICAL ARTICLE

EMBEDDED INTELLIGENCE AND COMMUNICATION ENABLING RELIABLE AND CONTINUOUS VIBRATION MONITORING

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Sensor-based process monitoring and predictive maintenance offer the promise of zero downtime, reduced maintenance costs, and improved worker safety. These long sought benefits have been elusive, as previous technology offerings have had limitations, or have had their own overhead costs or risks, that outweighed the advantages.

Rather than attempting to leverage individual technologies to solve a complex problem, a more deliberate and strategic full systems view of vibration monitoring can yield the long sought value of the technology.

Advances in sensors and sensor processing now allow deployment of fully embedded and autonomous sensing systems, capable of reliable detection and analysis of equipment defects, imbalances, performance shifts, and other anomalies, as shown in Figure 1.

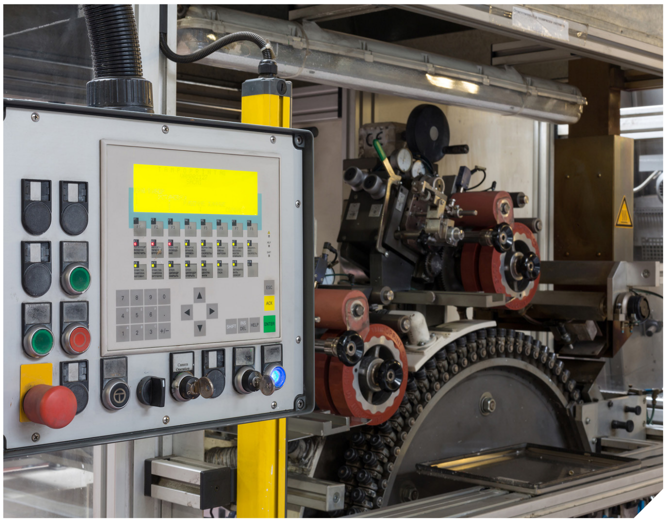

Figure 1. Automation of condition monitoring and maintenance represents a high value target for wireless sensing networks.

Before implementing a fully embedded and autonomous sensing system, it is important to analyze and consider four primary system design aspects, as follows:

1. Accessing high confidence process data
2. Interpreting and distributing the data
3. Accounting for process variations
4. Understanding recent technology advances

Accessing High Confidence Process Data

Process monitoring can be particularly valuable in a production facility for high value equipment, as in the manufacture of sensitive electronic components. In this instance, subtle shifts in the assembly line may lead to reductions in factory output, as well as critical end equipment specification shifts. Past approaches leveraged handheld vibration probes such as those depicted in Figure 2. One major drawback of this approach is the lack of repeatable measurements. Slight differences in the probe location or angle will produce inconsistent vibration profiles, making time comparisons inaccurate. Another limitation is the lack of real-time notification of vibration shifts.

Figure 2. Current approaches to equipment vibration monitoring lack repeatability and reliability.

A more ideal sensor would be both compact and integrated sufficiently to allow direct and permanent embedding within the equipment, eliminating any concerns of measurement location shift and allowing complete flexibility in the scheduling of measurements. Such a sensor would be a fully autonomous sensor processing system, including sensor, analysis, storage, and alarm capability all in a small form factor delivering the fastest notification of vibration shifts and the ability to provide time-based trends. Thus, a fundamental shift in approach is necessary. The enabling technology exists today, but the problem does not end there.

Interpreting and Distributing the Data

Factory equipment typically have multiple sources of vibration (bearing defects, imbalance, gear mesh), including those sources that are by design, such as a drill or machine press that produces vibration during standard operation. A time-based analysis of the equipment produces a complex waveform, combining these multiple sources and providing little discernible information without subsequent fast Fourier transform (FFT) analysis. With embedded FFT capability, an autonomous sensor can enable real-time notifications.

Many existing solutions are based on piezo sensors that, at their typically low level of integration, rely on external computation and analysis of the FFT. This not only eliminates the possibility of real-time notification, it also places a substantial additional design burden on the equipment developer. With embedded FFT analysis on the sensor, vibration shifts can be isolated to specific sources immediately (Figure 3). Beginning with a fully integrated sensor can also reduce development time for equipment designers by 6 to 12 months.

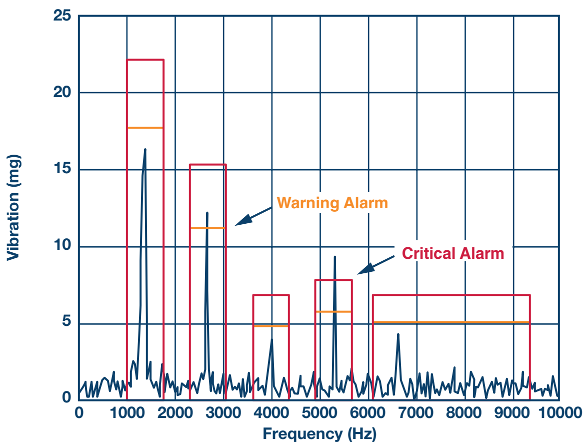

Figure 3. Embedded FFT analysis with programmable filtering and tuning control.

Another complication of existing solutions is that most are analog output only, leading to signal degradation during transmission and complex offline data analysis. Most examples of industrial equipment, which can benefit from vibration monitoring, tend to exist in noisy, moving, inaccessible, and even dangerous environments. In these cases, there is a strong desire to reduce the complexity of interface cabling and to perform as much of the data analysis at the source as possible to capture the most accurate representation of the equipment vibration.

An integrated, preferably wireless, smart vibration sensor facilitates immediate access and greatly simplifies the deployment of the sensor network at a significantly reduced cost. Once deployed, however, there are still complications, which if not addressed up front, can diminish the integrity of the system.

Accounting for Process Variations

Within a factory setting, vibration profiles are complex, time shifting, and susceptible to variances based on equipment, materials, and location. The question of where to place sensors is critical, but also highly dependent on the type of equipment, the environment, and even the life cycle of the equipment. With the high cost of sensor elements limiting the number of probe points to one or a few, this question is more critical. An even more serious consideration is the integrity of the sensor data itself. Without a reliable sensor, identified performance shifts could be attributed to either the equipment or the sensor.

A baseline equipment response is a useful tool in adapting a sensor analysis program to changes in equipment life cycle. Even simple analog sensors can allow this, assuming the operator takes measurements, performs the offline analysis, stores this data offline, and somehow properly tags to the specific equipment and probe location. A preferred and less error-prone approach would allow baseline FFT storage at the sensor head, eliminating any potential for misplaced data. The baseline data also helps with establishing alarm levels, which again would ideally be programmed directly at the sensor. Therefore, in any subsequent data analysis and capture where warning or fault conditions are detected, a real-time interrupt can be generated.

Regardless of the technical approach, a proper vibration analysis program may be monitoring tens or even hundreds of locations. Over the course of a given piece of equipment's lifetime, this may produce the need to capture thousands of records. The integrity of the predictive maintenance program depends on the proper mapping to location and time of the sensor collection point. For the lowest risk and the most valuable data, the sensor should have a unique serial number and the ability to time stamp the data, in addition to embedded storage.

Even with good traceability as previously described, the more challenging question is how to best capture slight variances in equipment performance as well as adapting sensors to various equipment. Since the signal and sensor conditioning and processing is specific to unique equipment and its life cycle, there are several important considerations in sensor design.

For instance, designers need to determine if the sensor should be configured for early life, when equipment faults are less likely, or end-of-life, when faults are not only likely but potentially more detrimental. The preferred approach is an in-system programmable sensor that configures to changes during the life cycle. For example, relatively infrequent monitoring (for lowest power consumption) should be used during the early life cycle, followed by reconfiguration to frequent (user-programmed period) monitoring once a shift (warning threshold) has been observed.

Embedded analog-to-digital conversion and processing (for example, at the sensor head vs. off equipment) allow for configuration and tuning in-system, as shown in Figure 4. The ideal sensor would provide a simple programmable interface that would streamline equipment setup through quick baseline data captures manipulation of filtering, programming of alarms, and experimentation with different sensor locations. This same

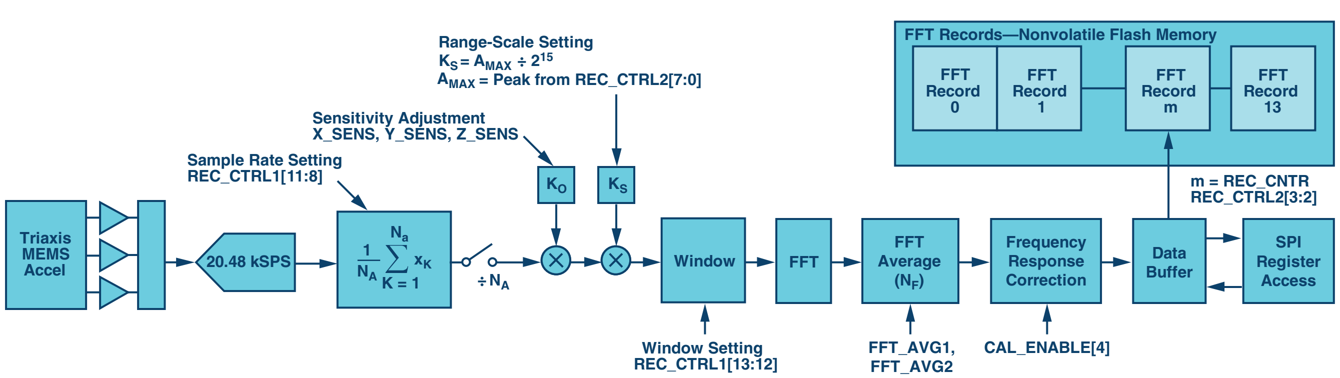

Figure 4. Representative integration of a fully embedded and intelligent vibration monitoring system.

tunability, in conjunction with the embedded baseline performance data, can allow for in-system adaption of the embedded sensors characteristics to the life cycle of the equipment.

Understanding Recent Technology Advances

The previous discussion highlighted methods to improve existing sensor-based approaches for vibration monitoring related to process control and predictive maintenance. As fault tolerance and monitoring is at the heart of the problem, the sensor itself should be scrutinized for reliability. What if the sensor becomes faulty (performance shift) rather than the equipment? Also, when operating with a fully autonomous sensor, how confident can we be that the sensor continues to work at all? With many transducers, such as piezo-based, this presents a serious limitation, as they have no means of providing any sort of in-system self-test. An essential requirement of a high confidence process control program must be the ability to remotely self-test the transducer. This is now possible with some MEMS-based sensors (Figure 5), where an embedded digital self-test closes the final gap on a reliable vibration monitoring system.

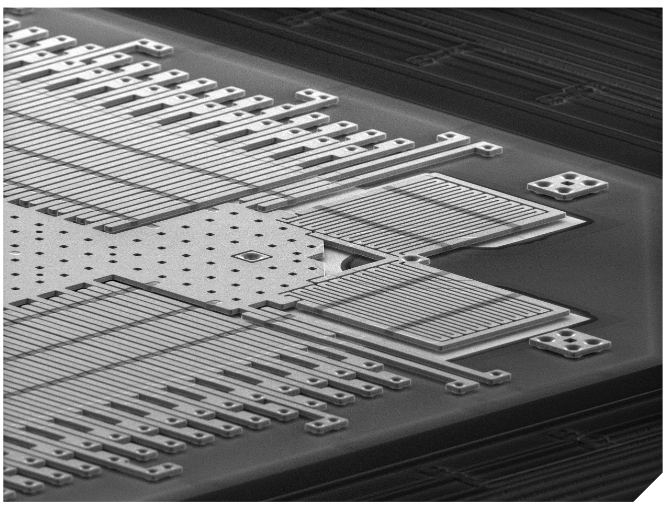

Figure 5. MEMs-based vibration sensors offer the added advantage of sensor self-test.

Combining the advantages of MEMS-based vibration sensing with wireless connectivity, solutions today can allow multiple remote sensing nodes to communicate through various wireless standard interfaces to gateway nodes, which provide data aggregation and further offline trend analysis and learning (Figure 6).

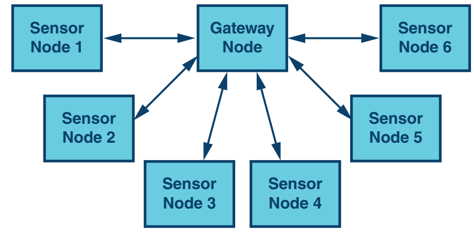

Figure 6. Six remote sensor nodes autonomously detect, collect, and process data and wirelessly transmit it to a central controller node.

Wireless connectivity also promises a more pervasive deployment of vibration sensing. Such fully integrated sensors, which do not depend on retrofitted wiring/infrastructure and more precisely and reliably detect performance shifts, offer the opportunity to drastically reduce upfront and recurring maintenance costs.

Finally, coupling the transition to embedded and continuous monitoring, with cloud-based analytics, provides a multiplying effect on the intelligence and expertise in the equipment monitoring field as it exists today. With more reliable and capable sensor nodes, enabled by MEMS approach, this sensor-to-cloud model will help realize the long awaited full potential of real-time, condition-based predictive maintenance.

For more information on Analog Devices' approaches to vibration monitoring, please click here.

About The Author

Bob Scannell is a business development manager for Analog Devices inertial MEMS products. He has been with ADI for 20 years in various technical marketing and business development functions ranging from sensors to DSP to wireless. Previously, he worked at Rockwell International in both design and marketing. He holds a bachelor's degree in electrical engineering from the University of California, Los Angeles, and a master's in computer engineering from the University of Southern California.

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