Understanding Stress Wave Analysis

CONDITION BASED MONITORING SOLUTIONS

INTRODUCTION

StressWave analysis is the process of examining data collected by StressWave sensory technology to identify a given piece of plant equipment's current operating condition. This data is collected by data collection units located adjacent to the plant equipment; depending on the mechanical complexity of a given machine, multiple sensors may be utilized to characterize the condition of the equipment. These data collection units are equipped with between two and eight sensors. They take periodic high-speed data samples, called "Digital Records" or DRs, from each sensor, and then reduces these records into several statistical values, including: Total StressWave Energy (SWE); StressWave Peak (Amplitude) Energy (SWPA); Delta StressWave Energy (DSWE), which is taken as the difference between 2 sensors; and Total Accumulated StressWave Energy (TWSE).

Based on these various statistical values, the units automatically store the current DR into a local buffer for retention and additional analysis by the site server. Measurements such as the SWE reading's value magnitude, in conjunction with the DSWE value (on variable load/speed machines) provide a general indication of the level of wear detected in the machine.

BASICS OF STRESSWAVE

After the initial placement and calibration of the SWE reading on a machine, the SWE level will slowly rise as the machine experiences accumulated wear over time. Rapid rises (persistent step changes not associated with normal loading variations) in SWE readings are considered abnormal and indicate an immediate change in the operational condition of the machine, which would strongly suggest the need for further analysis. Since the SWE values are directly related to the friction and stress being generated in the machine, load and speed changes will also change SWE.

With machines that have constant changes in speed and/or loading, it is recommended that a DSWE computation be used to reduce the effects of those changes on the data. When two sensors are monitoring the SWE from opposite ends of a common DSWE, computation can reduce the effects of load-induced SWE changes on the data – load changes will be detected by both sensors, and thus the difference between the two signals will be reasonably constant unless one of the sensors detects elevations in SWE that are not operationally induced by expected speed/load changes.

If the unit decides that further data analysis is necessary or desirable, the central site server will be advised of the captured DR; the central server will then upload the DR and place it into the relational database tables. The site server is a rugged, mission-critical computer module that collects the operational statistics from every unit on a constant basis, generating machine composite operating condition indications for every monitored machine.

The communications between the site server and the units can be a combination of wireless, serial cable, Ethernet, and fiber-optic connections, depending on the plant layout and conditions, making data transfer from the units quick and easy. The server has the capacity to handle enough units for even the largest facility, and will interface with existing plant automation and control systems, such as PLC, DCS, and SCADA systems, in order to record the key plant operational parameters that impact the loading on the various machines.

The site server also automatically correlates the SWE readings with machine loading in order to learn what levels of SWE are typical and normal for each machine at their various levels of loading. This allows the server to identify anomalous SWE levels that would indicate increased wear and mechanical degradation along with possible lubrication problems, even across machines of varying loading levels. The data collected by the site server (including any DRs) provides a short-term (3 to 6 months) operating history for each machine, as well as the data needed to compute the condition index values for each machine.

Although the units will automatically collect and save DRs when they determine that conditions indicate an anomalous condition, the site server also has the ability to command them to take and upload a DR. Since the site server also monitors selected process conditions (typically via a link to the plant automation system), it can be configured to force a DR whenever a pre-defined set of conditions are detected. This can be used to insure that a DR is taken whenever a machine is in a startup condition, at elevated load levels, or just to make sequential readings under identical operating conditions.

Understanding Stress Wave Analysis

It is important to understand that Curtiss-Wright's StressWave technology works on the direct measurement of friction and impact events taking place internal to the machine being monitored. Unlike other technologies, Curtiss-Wright has no need to determine the 'baseline' operational characteristics of a given machine in order to make an initial determination of machine condition. No properly manufactured and maintained machines should have high friction levels in their moving components; even an asset such as a grinding or milling machine would not be expected to have high friction levels in its drive train. Though some machines, such as reciprocating compressors, will exhibit periodic impact events as a normal occurrence, even they should not develop new ones over time. Thus, with Curtiss-Wright's StressWave technology the current condition of any machine can quickly be determined, and then have its changes can be identified and tracked.

ADVANCED DATA ANALYSIS

For any given machine there are four basic ways in which Curtiss-Wright uses the data from our sensors to determine the operational condition of any given machine: SWE trending over time, possibly in combination with a DSWE calculation; Histogram (probability density) computations performed on the collected DRs; Fournier analysis (spectral components) performed on the collected DRs; and SWE correlation with relevant operational (load-related) measurements.

The basics of SWE time trending have already been discussed above – however, if two sensors are available on a common shaft, then DSWE can also be used as a measure of machine health. Just as with SWE, the DSWE value will trend upwards and accelerate its rate of increase over time as the machine's condition deteriorates. If no other indications are present, DSWE and SWE are good general indicators of machine health. DSWE is often best used when variable speed or loading conditions exist.

The DRs collected for a given machine offer additional clues and indications about the machine's condition; integration of the stress wave energy recorded during the collection of a DR provides the basis for the SWE value. In a healthy machine, the DRs appear as a series of low and roughly constant amplitude readings; this means that as the mean/average amplitude measured by the DRs increases with wear, the corresponding SWE value will also increase. Machine loading events, such as speed increases, will cause temporary increases in SWE, so even when a stress wave reading is being taken at both ends of a common shaft, the bearings at both ends will 'feel' the effect of the load changes simultaneously and will increase or decrease correspondingly. DSWE uses the difference between SWE readings at the two ends to eliminate the effects of load changes on readings, resulting in a value that instead reacts to non-load related factors, such as machine wear and deterioration.

Plotting this stress wave data in histogram format (quantity versus amplitude in a probability density) for a machine in good condition generates a very narrow bell-shaped histogram plot, positioned at the low amplitude section in the left end of the chart. As wear increases or skidding/slipping events occur, the shape of the histogram changes – for example, spreading (also known as skewing) and shifting of the histogram's mean value provide clear indications of lubrication problems and/or wear increases. If a physical defect, such as a crack, chip, spall, or dent, develops in the machine, or if the machine develops an imbalance or an alignment problem, this will normally result in repetitive impact events that show up as repetitive spikes in the data set. The sensitivity of the sensors is such that even a very miniscule physical defect, even something like a slight surface scratch on a bearing race or subsurface micro-fracturing, will produce signals that can be detected.

In the same way that the histogram will spread out and shift to higher mean amplitude values, the base noise level of a spectrum plot will rise as the machine wear level increases. Aside from the identification of physical damage, a rise in base FFT noise levels, without specific spectral peaks being detected, provides a means for differentiating between increased wear and actual damage. In some instances, a bearing in good condition will sustain physical damage due to high momentary stresses – the FFT will identify this condition, even though the SWE and histogram values might still indicate that the bearing is exhibiting low levels of friction.

The site server computes and stores a set of value-distribution statistics for each DR collected (such as skew, mean, kurtosis, etc.) and uses them to monitor the changes in machine condition over time. It then performs a spectral component analysis on each DR collected and stores relevant component's detected frequency information, such as their amplitudes and if they are a primary or harmonic component. If RPM data is available from the machine, then spectral components can often be related to known machine defect frequencies for possible identification of the damaged area. The server also tracks the development of damage over time and provide a damage index factor based on the changes of spectral composition.

Since the SWE levels of a given machine will vary as the machine's loading changes, it is possible to monitor the SWE and the associated operating parameter(s) that denotes loading, then correlate these values for the operating range of the machine. The associated operating parameter(s) might be RPM, or might be a head pressure, a weight, a valve position, or other such process measurements. The site server interrogates the plant control system to collect these measurements and store them with their concurrent SWE readings. After monitoring the machine for a reasonable operating interval, the site server will have sufficient data to determine what the 'expected' SWE reading should be at any particular load level of the machine. This information allows the site server to identify abnormalities as well as to gauge the relative deterioration of the machine.

By storing this data and later recomputing the same SWE-versus-load values after additional elapsed operational run time, it is possible to obtain a relative comparison of the machine's current operational condition versus its starting condition – this same type of computation can also be used to compare the performance of equivalent machines with similar run time accumulations to identify which has the most physical deterioration. By combining the information generated by these four different analytical approaches with the data from all of the sensors attached to a given machine, the site server will generate a composite 'machine condition' rating value that can be used to trigger alarms, e-mail notifications, and initiate work orders on asset and maintenance management systems, as shown in the section below on data exchanges with external systems.

OPERATIONAL DISPLAYS

The site server is not just a powerful data collection and analysis system – it also provides a wide range of information display and analytical tools. It is normally placed on the facility LAN so that authorized plant personnel can access its generated web displays. Any plant personnel with a password and ID can log onto the site server using their desktop PC and a web browser – no special client-side software is needed in order to access the site server, and for added security digital certificate validated web browsing access (http/s) is supported. Upon login, users will be taken to a plant overview summary page that gives a composite machine condition indication for each machine being monitored. Any machine can be specifically selected, displaying a more detailed diagnostic and trend-history display set for review. When conditions dictate, the site server can even let users dispatch e-mail notifications to designated plant personnel. Additional system configuration pages, such as for adding additional sensor units or defining the data exchanges with other systems, can be used to customize and parameterize the system. Navigation among and between displays is simple and mouse-based.

The data, such as the SWE, DSWE, SWPA, and TSWE values for each machine, that is collected and stored in the site server is designed and displayed to provide a short to moderate term view (3 to 6 months) of the machine's health status. If desired, Curtiss-Wright can set up a corporate server at a designated central site for any customer, and can set up the various site servers to send their data to this central server. Alternatively, if the site server is provided with Internet access through the facility firewall, then its data can also be sent via the Internet to a secure server maintained by Curtiss-Wright; here the data is archived over a much longer time span (years) and routinely backed up for security purposes.

INTER-SYSTEM DATA EXCHANGES

One of the most powerful capabilities of the StressWave technology is its ability to provide a direct relationship between operating conditions and asset wear. This can provide operational knowledge that can lead to best practices for extending asset operational life. For any given asset the site server is configured to collect the process measurements that relate to the operational load placed on that item. This could be a measurement of speed/RPM, a measurement of head pressure, or even, in the case of a conveyor system, a weight. The load-related, real-time operational data collected by the site server and used for the correlation of SWE readings is typically obtained by making a communications connection to the plant/facility automation systems – this may be a DCS, a PLC-based system, or even a SCADA system. The site server can interface with these systems through several different connectivity options; serial or Ethernet interfaces can be used for the direct connection, and the site server can utilize one of several data exchange protocols, including: Serial MODBUS protocol, IP (Ethernet) MODBUS, OPC (OLE for process control), ftp file transfers, SQL, ODBC, and XML (including MIMOSA).

If the necessary measurements are not available through a plant's automation system, the site server can be equipped with physical I/O hardware that can read the measurements directly. Several commercial I/O hardware families and most PLC models are supported for this purpose.

In addition to the data that the site server collects, it also has the ability to provide machine-specific condition index values that indicate the relative operational condition of each machine, which can be used to initiate work orders for maintenance and repair activities such as inspections, lubrication, alignment, and repair. The communication mechanisms defined above for real-time data collection can also be used for the delivery of data to other systems, such as maintenance and asset management systems.

If the site server is placed onto a plant LAN or corporate WAN, then it can also be configured to send e-mail messages to designated recipients through the existing e-mail SMTP server. Based on the type of notification and the level of seriousness, the site server will create and dispatch e-mail notifications to user-defined lists of personnel. The site server will need to be assigned an account on the e-mail server and includes an SMTP client for sending messages to that server, similar to a desktop PC.

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CURTISS-WRIGHT CENTRAL MONITORING

Although the site server has a moderate data storage capacity, it is not normally equipped to retain data beyond a six month period. In addition, a site server is only equipped to collect and correlate data within the site/plant/facility where it is installed. For clients who have multiple facilities and who would like to make corporate-wide comparisons of assets, or who want to have data retained for longer time intervals, Curtiss-Wright offers a centralized StressWave monitoring and analysis center. The server at each plant site can be configured to send secure, VPN-protected copies of its data over the Internet to the Curtiss-Wright centralized monitoring facility, where this data will be retained for many years and can be used to perform more advanced analysis, including corporate-wide analysis. With corporate level data it is possible to compare asset performance across a broader base of equivalent assets, as well as to compare asset performance by facility, which can lead to the identification of 'best-in-class' operational and maintenance procedures.

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