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Stress Wave Analysis for Critical Asset Monitoring

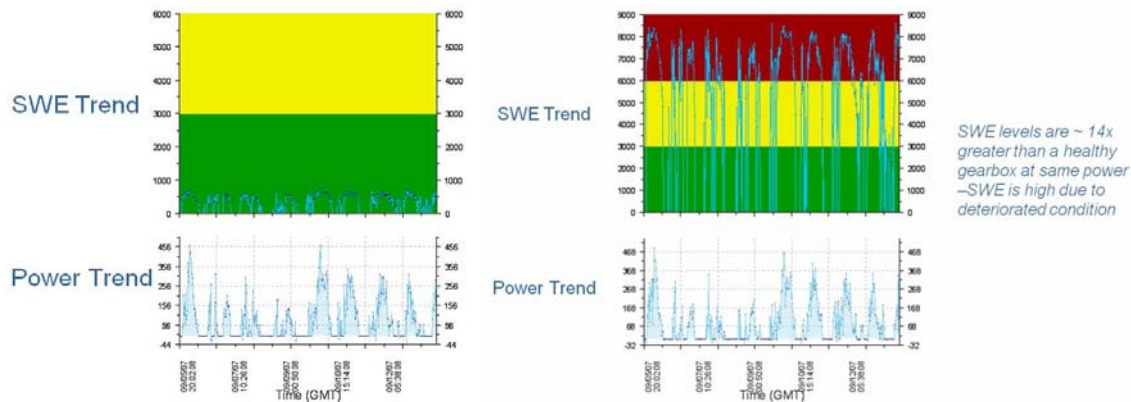
By Tony Amato

Stress Wave Analysis (SWAN) is an ultrasonic instrumentation and analysis technique for the quantitative measurement of dynamic contact stresses between moving parts in operating machinery. It was originally developed to identify abnormal sources and causes of friction and shock (such as damaged gears and bearings) in kinematically complex gearboxes, where vibration analysis proved to be impractical. SWAN systems employ a unique sensor that utilizes the sensor's resonant frequency to selectively amplify low amplitude stress waves, and specialized signal conditioning to filter out structural vibration. This provides the ability to quantitatively measure, and trend, low energy sources of friction and shock, in the presence of high background levels of vibration and audible noise repeatedly and reliably. SWAN systems are currently deployed across a broad array of industries and applications, ranging from cruise ships to process industry, from high speed gas turbines to low speed wind turbines; and most recently in gas storage, detecting internal leakage in valves.

One of the features computed in SWAN, is Stress Wave Energy (SWE). SWE is directly proportional to the friction between moving parts that are separated by a lubricant boundary layer. Since friction is a function of both speed and load, SWAN is an excellent method for understanding dynamic loading in operating machinery, as well as detecting classic rolling element defects, imbalance, et al. In this respect, friction is said to be a first order response to changes in load, speed and component health, whereas temperature and vibration tend to be second order responses. Friction is an immediate response, and will change by orders of magnitude in proportion to input forces and component health. This makes SWAN an effective early warning system, because it can distinguish between mechanical component health and operating condition.

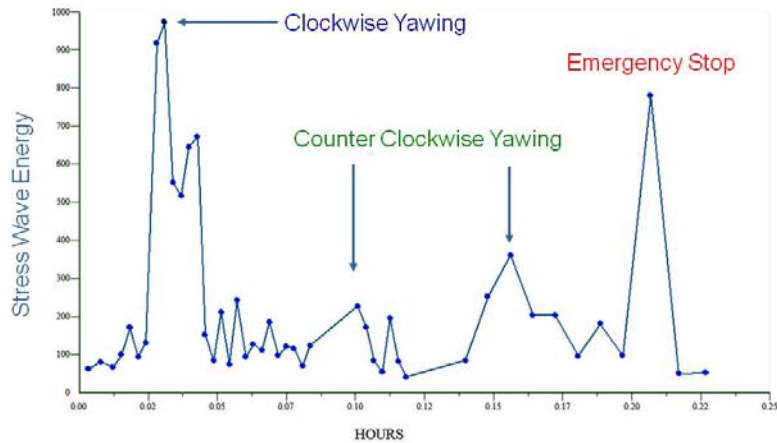
To use a health care analogy, an EKG is used to understand how the human body responds to changes in the external environment. Under load there is an expectation that stress levels will rise. An EKG reveals if the increase in stress is appropriate for the conditions; if so then the patient is healthy, if not then the abnormal stress is caused by a condition and the earlier the detection, the greater the probability of successfully managing that condition. This is analogous to machinery and it is the fundamental to understanding the methodology of SWAN.

The Stress Wave Energy trends shown below are from two wind turbine generators (WTG's) of the same make and model, operating at the same wind facility. Power output (or production in kW) is trended below the SWE. The WTG on the left is stable and correlates nicely with power output (note the production levels vary with changing wind speeds). The level of stress is appropriate for the operating regime (as indicated by the green zone) and so this is a healthy gearbox. The WTG on the right clearly has an unhealthy gearbox. Again SWE moves with power output, but the SWE levels for the same power output levels are ~ 14 times greater than a healthy gearbox. The stress levels are not appropriate for this operating regime because there is an unhealthy mechanical component, causing the increase friction.



It's important to emphasize that SWE levels are orders of magnitude greater than those of a healthy gearbox. This means that failure progression started long ago, progressing to its current. A SWE trend of this gearbox from the time when it was healthy, until now, would reveal the failure process by showing the SWE trending upwards out of the green zone, into the yellow, then red zone. There would be ample time to take corrective or mitigating action, and plan corrective maintenance. Until corrective maintenance can be performed, constant monitoring of the SWE trend reduces risk associated with continued operation and avoidance of possible secondary damage under controlled conditions. In this case the automated analysis determined the failure was due to high speed intermediate shaft bearing.

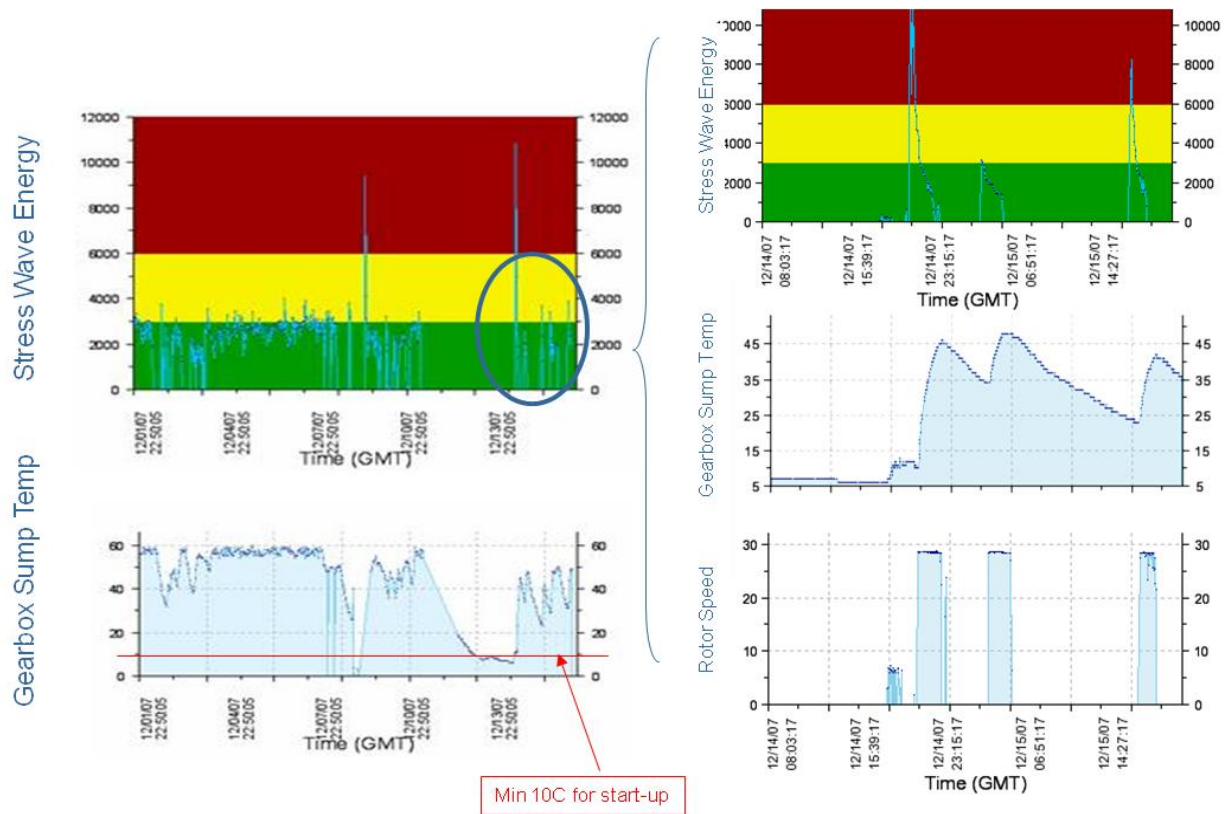
Stress Wave Energy captures the dynamic loading of a component. In the figure below, the Stress Wave Energy trend is from a main bearing of a wind turbine. This bearing is a slow rotating, grease fitted radial bearing. WTGs are constantly correcting for wind direction (yawing) to extract the maximum energy. The loading on this bearing is dynamic. The clockwise yaw produced the highest transient loads, possibly due to the gyroscopic forces of the rotor, while counter-clockwise yaw produces far less loading. The operator can now contemplate changes to the control logic to perhaps slow down the rate of yaw when turning clockwise in an effort to reduce these transient loads.



Stress Loads on Healthy Main Bearing of Wind Turbine while in Production

As an interesting aside, an emergency stop occurred while this WTG was in full production. Conventional wisdom holds that emergency stops produce rather violent loads on the drive train and should be avoided. Of course this is true; however, Stress Wave Energy shows that normal operations can produce loads on the main bearing that are larger than an e-stop. Some operators are using “easy-stops” in the control logic instead of “hard-stops” under certain operating conditions. You can see why actions like this, that recognize and eliminate unnecessary loading makes perfect sense to preserve remaining useful life.

SWAN is also an effective method to detect lubricant condition, typically the leading edge of the failure process. As lubricant begins to lose its ability to maintain boundary layer separation due to temperature, chemical breakdown, additive package failure or contamination, the friction increases as does the SWE levels.



The data in the figure above was taken on a wind turbine generator (WTG) gearbox under normal operations in cold weather conditions with variable wind speeds. The SWE trend indicates a mechanically healthy, although somewhat worn gearbox. The SWE trend moves in response to the dynamic loading on the gearbox which is directly proportionate to rotor speeds. The gearbox sump temperature, shown directly below the SWE trend, shows the thermal cycling that occurs as the rotor speeds respond to changing wind speeds. Note that the rotor is capable of reaching full production (~30 RPM's) from dead standstill in less than 30 seconds. As one would imagine, the lubricant effectiveness is a function of oil temperature. The minimum recommended oil temperature for rotor start-up is marked by the red line. The resultant high stress loading due to the lack of lubrication as the rotor speed increases is captured by changes in SWE. These SWE transients are operationally induced periods of high contact stress and should be avoided when possible, because it's consuming component life. An investment in a cold weather start package might be a worthwhile investment for this operator. However a closer look provides more insight.

Figure 2 shows the SWE trend, oil temperature and rotor RPMs during several rotor start/stop cycles. A closer look on the last area of activity is revealing. You can plainly see the effect on friction when the oil is below minimum; however you can also see the difference in the stress energy levels when the rotor

spools up when the oil is at 35C and 25C. The 10 degree difference in temperature causes nearly a threefold increase in SWE. With this knowledge the operator can consider other options to mitigate frictional energy therefore extend part lives. Stress Wave Analysis captures the complex nature of mechanical system dynamics. It has proven itself as a useful, actionable tool for the operator, the maintenance provider and the reliability engineer.

About the author

Tony Amato is an Executive Vice President, Swantech responsible for Operations and Finance. He has been with Swantech since 2005. Mr. Amato has over 15 years of experience in aviation gas turbine maintenance, serving as General Manager of Pratt and Whitney's Aircraft Engine Overhaul and Maintenance Service Center. Mr. Amato served in the U.S. Air Force as Program Manager of the B-1B Defensive Avionics platform, achieving the rank of Captain. He holds an MBA from Columbia University and a BS in Aerospace/Mechanical Engineering from New York Institute of Technology. You can contact him at tamato@swantech.com or more information on Swantech can be found at www.swantech.com. Swantech is a business unit of Curtiss-Wright Flow Control Corporation.

About Curtiss-Wright Flow Control

Curtiss-Wright Flow Control specializes in the design and manufacture of highly engineered valves, pumps, motors, generators, electronics and related products for the commercial nuclear power industry, oil and gas processing facilities, and a range of critical military programs. CWFC's innovative, high-performance products play an integral role in our nation's defense, and in the safe, efficient operation of power plants and other industrial sites worldwide. Based in Falls Church, VA, the company has 3,000 employees worldwide and is the Flow Control operating segment of Curtiss-Wright Corp. For more information, visit www.cwfc.com.

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Curtiss-Wright Corporation is a diversified company headquartered in Roseland, N.J. The company designs, manufactures and overhauls products for motion control and flow control applications, and provides a variety of metal treatment services. The firm employs approximately 6,800 people worldwide. More information on Curtiss-Wright can be found at www.curtisswright.com.