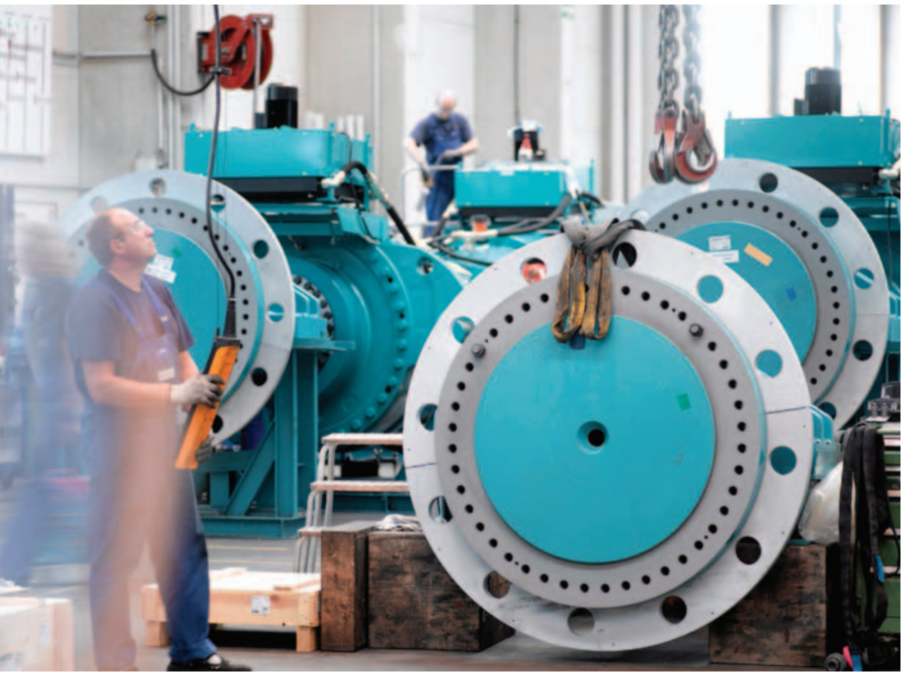
Looking for trouble

Diagnosing problems in rotating machinery before anything has a chance to break makes a whole lot of sense. Dr Tom Shelley reports on the technologies making a difference

Faults developing in rotating plant of all sorts generally need to be discovered and diagnosed well before they reach the point of causing a very expensive failure. But although there are several technologies available – for example, vibration sensing, laser alignment, heat measurement, oil analysis and electrical performance – a difficulty for plant engineers is knowing which to use on their particular application.

The truth is some techniques compete, while others should be used in combination. It's also the case that many have now reached very high levels of sophistication and most can now also put information online for remote access. However, few are cheap and, inevitably, there is the cost versus benefits issue – although, where rotating machinery is concerned, almost any cost that leads to diagnosis and remedial action in time to avoid breakdown is usually small.

Consider wind turbines: with generators built high up on towers, many at sea, we're not just talking about the costs of straightforward repair, but also those incurred by difficult access and risky working environments. Yet careful observation of almost any large group of such machines usually reveals one or more not working. Complete failures are rare, but gearbox and bearing failures are not uncommon. Indeed, all 30 of the Danish Vestas-made 2MW wind turbines, erected at Scroby Sands off the coast of Norfolk, broke down within one year of installation. Failures here included 27 generator side intermediate speed shaft bearings, 12 high speed shaft bearings and four generators.



Geoff Walker, a director of electric motor diagnostic systems developer Artesis, believes that wind turbines suffer from two sets of fundamental design problems. One set arises from their variable speeds and loads, while the other stems from scaling up designs at a rapid rate. Looking at the former, he explains that, whereas power station generating sets spin up to speed in anything from 30 minutes to several hours, but then maintain an exact rpm, the natural variation in wind speed means that a wind turbine generator undergoes constant speed and load changes. As for design change, he points to the fact that wind turbines are growing larger quite rapidly, so there is little time to learn from experience.

Artesis uses NASA-developed technology to deduce the health or otherwise of electrical machines and the equipment connected to them, using instantaneous measurements of voltage and current. Developed primarily for electric motors, it can equally be applied to generators, which, as Walker observes, "are merely motors run in reverse".

As well as revealing electrical machine problems, such as insulation breakdown and changes in air gaps, the monitored signals also depend on torque and radial loads acting on the rotating shaft. Walker explains that this is because radial loads induce "some displacement, which results in a change in the air gap". Inductance between rotor and stator is extremely sensitive to changes in the air gap, and so this is reflected in changes in the phase angle between voltage and current, and voltage and current frequency components. Additionally,

changes in torque cause changes in phase angle, which Walker likens to compressing a spring.

Artesis is a young company, but increasingly established in the white goods and water and wastewater treatment industries, where its systems have been used on, for example, inaccessible borehole pumps. Says Walker: “We also have good experience with diesel generators up to 70MW.”

The most common method of condition monitoring for rotating machinery, however, is sensing vibration, either with permanently installed instrumentation or a touch probe. But, if the machinery is rotating slowly, as in wind turbine rotors, it is difficult to obtain reliable information from the volume of acceleration signals produced and so false alarms are likely to occur.

Shocking information

So what’s the answer? One comes from SPM Instrument UK, which markets a technique based on detecting shock pulses, as opposed to RMS vibration. The method, which relies on detecting voltage spikes from piezoelectric transducers, has been around for decades. But, at the recent Drives and Controls exhibition, the company launched a patent pending version ‘SPM HD’, which is particularly effective at ignoring spurious signals, while highlighting significant ones.

On a wind turbine, this might mean measuring rotation speed, gearbox load, gearbox temperature and wind speed, in addition to detecting outputs from the 35kHz shock front transducers. With that additional information, the firm says it is possible to detect signals that correlate with shaft rotation speeds and thus indicate bearing or gear tooth damage, while ignoring signals likely to have arisen from, for example, tower vibration in high wind.

Its system has been field tested on four twin-wire presses in the Hallsta paper mill in Sweden. These run at 10 to 15rpm in an environment where bearings and machine parts are exposed to moisture and running water. Hallsta preventive maintenance engineer Per Ljungström explains: “Among all the measuring techniques we have tested, SPM HD is the first that’s able to indicate developing bearing damage. Thanks to the readings, we have been able to see months ahead that the lifetime of a particular bearing is nearing its end.”

To date, Hallsta has detected six bearing damage problems. “In rough numbers, we have saved about €7,000 worth of bearing replacement on working hours alone, because we were able to do the replacement work during planned shutdowns, rather than running the machine to breakdown,” says Ljungström.

But these costs pale into insignificance beside those associated with wind turbine faults, where a gearbox can cost €220,000 to replace onshore, or around €1 million offshore, as against just €17,000 for an overhaul – making the SPM HD system even more attractive. Incidentally, it’s also in use on container cranes in Antwerp, where the signal processing takes wind speed, torque and load into account when deciding which information is significant and which is not.

Another way of separating out useful information from vibration transducers is acceleration enveloping. This depends on picking up natural frequencies of vibration in structures that are excited by repeated impacts caused by a developing fault. Typical transducers are accelerometers capable of producing waveforms that can then be high-pass filtered, rectified, enveloped and processed, using Fast Fourier Transform electronics. The resulting envelope spectrum then reveals defect repetition frequencies.

Pushing the envelope

The technique has been applied successfully by Bentley Nevada to wind turbines developed by GE Energy. And, talking of energy, it is possible to have vibration transducers powered by the very vibrations they are measuring – mounted directly on rotating equipment, from which they can transmit data by low power radio. Perpetuum in Southampton has developed a free-standing harvester (FSH) that, in the words of company president Roy Freeland, “contains circuitry to condition power, so you get dc that is usable by wireless sensors designed to be powered by batteries”.

Output is up to 4mA at 5V, which, Freeland says, can be used to charge a supercapacitor, from which current can be drawn, as needed. Perpetuum’s devices are hermetically sealed and are being used as optional components of GE Bentley Nevada’s ‘Essential Insight Mesh’ wireless monitoring system.

Meanwhile, excessive heat generation is also a good indication of misaligned shafts, excessive preload on bearings and similar mechanical problems. In the old days of steam locomotives, capsules of aniseed were incorporated into white metal plain bearings, so that the rising smell would

Top: the cost of undetected failure
Above: predictive maintenance in action

Pointers

- Wind turbines suffer from the issues of variable speeds and design change
- Motor monitoring electronics can be turned to generators and turbines
- Shaft torque, radial loads and bearing issues submit to this condition monitoring technology
- Vibration sensors have limited value on slowly rotating machinery
- However, a derivation that analyses shock pulses is showing promise
- ‘Acceleration enveloping’ offers a similar technique
- Heat generation also provides useful clues

warn of overheating. Thermocouples can nowadays be used for online condition monitoring, but the task can sometimes better be undertaken from a distance, using thermal imaging cameras.

At Clarks' warehouse in Street, Somerset, for example, thermal imaging was used to detect a damaged motor and gearbox, a phase imbalance on shrink wrapping machines and damage to the X-axis on a stacker crane.

Kevin Ashman, site manager for Knapp UK at Clarks, says: "We would never have found these risky problems at that early stage without the thermal imaging equipment. Correcting these faults in a controlled way avoided breakdowns that would have been extremely costly for Clarks."

While far from cheap, thermal imaging cameras are no longer excessively expensive either. The Fluke Ti32 and TiR32 imagers, for instance, use 320 x 240 pixel chips and cost less than £7,200. Users can marry thermal and visual light images, and record voice comments of up to 60 sec duration with each image.

This company's cameras are tested to withstand a drop of 2m, and are IP54 protected to withstand water and dust. Thermal sensitivity is better than 0.05°C at 30°C target temperature. Temperature measurement range is -20°C to +600°C for the Ti32 and -20°C to +150°C for the TiR32.

However, having identified the source of overheating, the next stage is always to discover the cause. If bearings or gears are not running rough and there is nothing wrong with lubrication, the next point (and sometimes the first) to look for is misalignment of shafts. Small amounts of misalignment, which are hard to measure using conventional instruments, will cause problems that can be rectified using laser alignment equipment.

C-Cubed sells equipment made by Hamar Laser in Danbury, Connecticut, USA, for aligning shafts that need to be in line or parallel. In each case, they simply clamp on to shafts and produce orthogonal laser scan lines that are reflected back. Alternatively, SPM Instrument UK sells a competing system, 'Easy-Laser', developed by Damalini in Gothenburg, Sweden. And there are other similar systems from which to choose.

But another important tool for fault diagnostics is lubricant analysis – looking especially (but not only) for metal particles in oils and greases. There are two distinct approaches – remote, online analysis using sensors (as is widely used in Formula 1 cars and aircraft engines) and offline measurement, either on-site using maintenance engineers' kits or simply sending oil samples off to a laboratory.

Martin Lucas, managing director of Kittiwake Developments, observes: "On-board test kits and wear debris monitors can provide accurate information in minutes, but the real value comes from continuous monitoring of these critical systems. On-line sensors for monitoring the health of equipment, such as vibration sensors, have been in use for many years and are well trusted."

Oily observations

However, only in the past few years have lubricant condition sensors become widely accepted. "Now, the condition of the lubricant, the presence of contaminants [including water leaks from seal failures] and even the amount of wear debris and the wear mechanism occurring can be monitored on-line," continues Lucas.

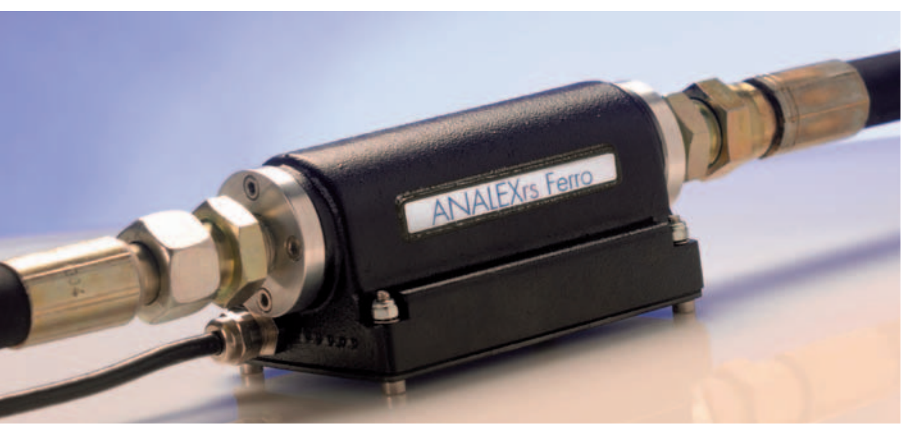
Indeed, oil sensor technology is advancing apace, with sensors mounted in oil circuits able to provide an early warning for bearing and gear wear debris, lubricant health and remaining life, as well as lubricant moisture content – monitored remotely and in real time. What's more, systems are increasingly providing easy-to-understand results through a multitude of communication channels. "These are undoubtedly the future of lubricant condition monitoring," insists Lucas.

By way of example, Kittiwake has a metallic particle sensor that provides a debris tally of both ferrous and non ferrous metal particles. It does this using inductive coil technology and software to deduce a particle size and distribution count. The more severe the wear problem, the more a rotating machine produces large debris particles.

The company also now offers other sensors, such as total ferrous debris devices that use magnetometry to yield information about particles in the range 0 to 2,000 parts per million with automatic air blast zeroing, as well as oil condition and moisture sensors.

Offline, the company offers laboratory testing equipment, sampling equipment and test kits. These are still no replacement for microscopic examination of oil debris, however, which can reveal precisely where particles are coming from and thus which piece of the rotating plant is wearing and liable to break.

Research into even better equipment and methods continues apace. PE



Kittiwake's metallic particle sensor that provides a debris tally of both ferrous and non ferrous particles, using inductive coil technology