Managing Gearbox Failure

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INTRODUCTION

The wind industry has had a chronic problem with the reliability of its gearboxes [1], [2]. Experience has shown that premature gearbox failure is a leading maintenance cost driver that can easily consume the profit margin from a wind turbine operation. Condition monitoring is already understood to have potential to mitigate this risk by managing gearbox maintenance through the promises of reliable early detection. Early detection enables the operator to minimize gearbox damage, avoid full failure and plan the repair, thus, simultaneously reducing the repair cost and business interruption costs. Oil debris monitoring for the wind turbine industry is now a proven, effective condition monitoring technique that does provide reliable early detection and quantification of internal damage to gears and bearings of the wind turbine gearbox without the need for expensive hardware or expert data interpretation. GasTOPS has successfully transitioned its MetalSCAN technology from aircraft, marine and power generation gas turbine engine applications to the wind turbine gearbox, and, with hundreds of fielded applications, MetalSCAN is becoming the standard for gearbox condition monitoring.

This paper provides a technical description of the technology, how it is applied to the wind turbine gearbox, the basis behind the development of simple condition indicators permitting easy and reliable determination of gearbox condition, and actual data from fielded wind turbine units.

MANAGING THE RISK

For years the wind industry has been evaluating condition assessment technologies that are capable of detecting bearing and gear damage at an early stage, while providing insight into the extent of the damage and its impact on the remaining useful life of the gearbox. It is understood that condition monitoring cannot be used to avoid damage occurring to the equipment, however, the right technique can be used to effectively limit the damage and avoid failure of the equipment, where failure is defined as damage sufficient so that the equipment can no longer function. Managing the risk in the context of the wind turbine gearbox through the use of an effective condition monitoring technique is based upon planning the maintenance actions, thus achieving:

1) Reduction of lost revenue – the wind turbine can be scheduled to be out of service for only one day, possibly a calm wind day, where the crane, spare gearbox and maintenance crew are on site before the shutdown.

2) Reduction of repair costs - reduced damage within the gearbox means that the extent of the repair of the gearbox is much less than when there is extensive damage.

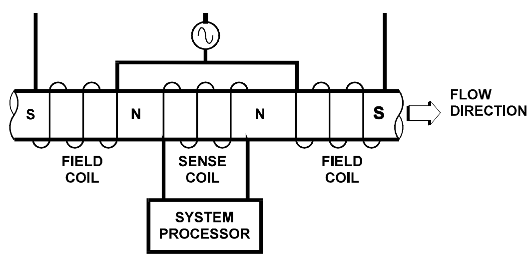
3) Reduction of removal costs – The crane can be scheduled well in advance, thus allowing for reduced crane transport times.

An additional benefit of effective risk management is the potential for improved coverage from the insurers, which is delivered in terms of reduced premiums, reduced deductibles and/or reduced depreciation.

OIL DEBRIS MONITORING

It is now recognized that in-line oil debris monitoring can provide the wind industry with condition assessment information necessary for the industry to effectively manage the risk associated with premature gear and bearing failures.

The MetalSCAN sensor is a flow-through device which installs in-line with the oil system and allows the entire oil flow to pass without restriction. The sensor functions by monitoring the disturbance to a balanced alternating magnetic field caused by the passage of a metallic particle past the sense coil assembly.



Sense Coil Assembly

The particle couples with the magnetic field as it traverses the sensing region, resulting in a characteristic output as shown.

Sensor Output Signal

Each time a particle passes through the sensor, an electrical pulse is generated which is counted by either a stand-alone alarm module or directly by the wind turbine's monitoring system.

MetalSCAN Alarm Module

Confusion With “Particle Counters”

MetalSCAN Sensor

It is noted that MetalSCAN is not measuring the condition or cleanliness of the oil. This function is the perview of a class of products commonly referred to as “particle counters” which indicate the cleanliness of the oil by measuring the transmissibility of light through the oil. Monitoring the condition of the oil using this class of “particle counters” can be valuable for triggering oil changes, however cleanliness has not been known to correlate to component damage in the wind turbine gearbox, particularly in the early stages of damage. Conversely, oil debris monitors such as MetalSCAN do effectively monitor component damage by detecting the individual metallic particles produced from surface fatigue damage on bearings and gears.

MetalSCAN Pedigree

Over the past fifteen years MetalSCAN has been developed and successfully applied to critical rotating machines in the aviation, marine and energy markets. Its first application was on the F119 engines of the USAF F22 Raptor advanced tactical fighter, from which the MetalSCAN has been tailored for use on other applications and platforms.

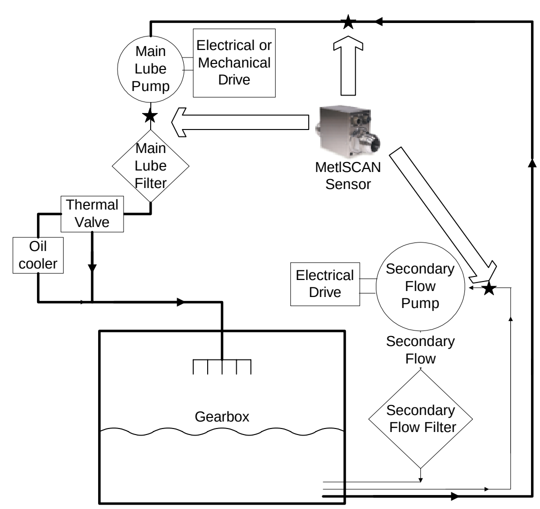
The MetalSCAN Industrial product line has been available in the Energy market for aero-derivative engines used in the production of electricity in power plants and compression of gas in pipelines for over 10 years. With over 300 aero-derivative engines now fitted worldwide and having accumulated well over 12 million hours of operation for the fleet, MetalSCAN has become the industry standard for oil debris monitoring for high value rotating equipment. Today GE Energy offers MetalSCAN for fitment to their LM6000, LM2500 and LM1600 engines, and Pratt & Whitney to their FT4 and FT8 engines, both new from the factory and in the aftermarket.

MetalSCAN is also used in marine propulsion applications. Today the leading cruise lines have MetalSCAN fitted to their vessels which use propulsion pods. Installed on over 25 of these large cruise ships to date, MetalSCAN monitors over 1,200 MW of installed propulsion power delivered through the ABB and Rolls Royce pod units.

Application of MetalSCAN to Wind Turbine Gearboxes

Application of MetalSCAN to the gearboxes of wind turbine power generation units were initially trialled in Northern Europe. Over a hundred wind turbines had been fitted with MetalSCAN in support of initial technology introduction and condition indicator development. Evaluation programs were conducted by wind energy stakeholders, including wind energy research institutions, major manufacturers of turbines, gearboxes and industry leading operators. MetalSCAN has also gained approval from a number of insurance companies who recognize its risk reduction value which results in an offering of improved insurance coverage for less premiums if MetalSCAN is fitted.

MetalSCAN is designed to be easily installed in the full flow of the lubrication system before the oil filter to detect the presence of metal particles. The MetalSCAN sensor is commonly installed before the lube pump inlet or after the lube pump discharge depending upon system configuration. This full flow approach is recommended as it provides the most direct means of early detection and damage quantification. An alternate installation method is to install the sensor in the low flow secondary or “kidney loop” oil filtration circuit. The flow rate of this circuit is typically only a few percent of the main lubrication flow.



Typical MetalSCAN Installation

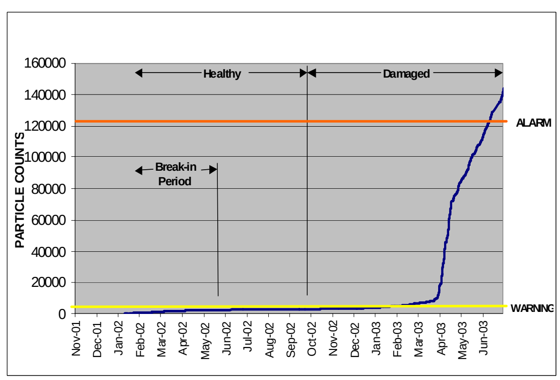
In either case the sensor generates an electrical pulse for each metal particle above the minimum size threshold (260µm Fe for full flow 120µm Fe for secondary flow installations). The signal is interfaced to a host, either a stand-alone alarm module or directly to the wind turbine's monitoring or control system. The host recognizes the passage of the particle, and increments a counter, which is then compared to the condition indicator tailored for the specific gearbox model. The condition indicators are based upon simple criteria which establish whether the gearbox is healthy or not, and if not how much damage exists, and how much longer the gearbox can be operated. All this is performed local to the host with no need for expensive expert based analysis and consultations.

Condition Indicators for the Wind Turbine Gearbox

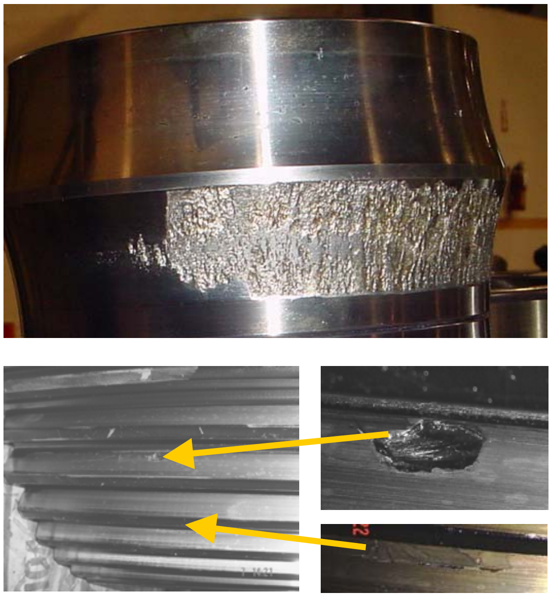
MetalSCAN's condition indicator, is developed to define reliably whether the gearbox is healthy or not, and if not, how much damage exists in relation to a damage limit. "Reliably" is defined simply as " without missed indications and without false indications".
The MetalSCAN damage limit for the wind turbine gearbox is based upon limiting the internal damage to a level where the cost of repair is low (requires repair to only a few components – one or two bearings, instead of a complete overhaul of the gearbox). This condition indicator is simple, based upon a correlation which relates the cumulative MetalSCAN particle counts to the extent of physical damage to the damaged bearing or gear component. This condition indicator can easily be applied to any gearbox type and model, a principal that is difficult to achieve for other monitoring technologies. Several independent research organizations have confirmed the effectiveness and reliability of the MetalSCAN damage indications. NASA conducted a study detailing the effectiveness of oil debris monitoring in detecting the early onset of gear failure [3]. The findings were as follows: "The first being, oil debris analysis is more reliable than vibration analysis for detecting pitting fatigue failure of spur gears. The second finding is that some vibration algorithms are as sensitive to operational effects as they are to damage. The third finding is that vibration algorithms FM4 and NA4 Reset do not indicate damage progression, but the increase in oil debris mass is related to damage progression"

A CASE STUDY

In late 2001, a wind turbine installed in the United States was fitted with MetalSCAN as part of a technology evaluation. The sensor was fitted to the wind turbine gearbox main lube system. Data was collected remotely and the readings were analyzed on line. The trend showed three distinct phases associated with the health of the gearbox, the break-in phase, the healthy phase, and the damaged phase. The gearbox was new when the MetalSCAN was installed and monitoring started with commissioning of the gearbox. Nine months after installation, a minor step change in particle counts occurred. As operations continued it was observed the rate of particles began to rise slowly, indicating the early stages of damage within the gearbox. At four months after the first indication, the particle counts crossed the warning threshold. The warning threshold provides a "wake up" indication of damage, but does not indicate that failure is imminent. Three months after this warning level was crossed, off-line vibration equipment was installed, which failed to confirm conclusively that damage was occurring within. Five months after the initial indication the rate of particles increased steeply with the rate of about 1500 particles per day. Eight months after the initial indication and four months after crossing the warning limit the particle counts crossed the alarm limit, indicating that damage would become severe if repairs are not made.
One month later the gearbox was removed and stripped down, revealing damage limited to one planetary stage bearing and one planetary stage gear. MetalSCAN had detected the initial bearing damage nine months prior to removal and had given five months of reliable warning that the gearbox was damaged. MetalSCAN provided ample lead-time to the operator to proactively deal with the gearbox repair, thus minimizing down time and avoiding secondary damage to the system.



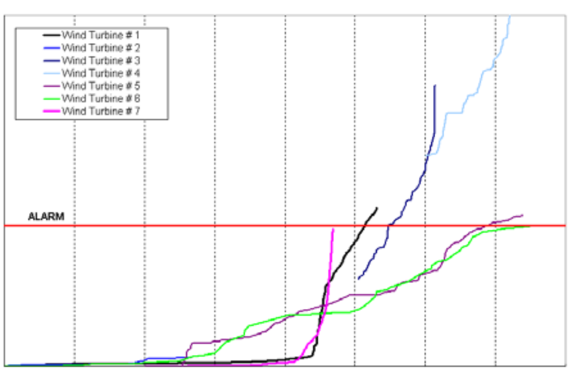
Case Study Damage Progression



Case Study Bearing and Gear Damage

Other Field Examples

The damage progression displayed in the case history is representative of gearbox damage events that have occurred on other wind turbines. MetalSCAN already has numerous wind turbine gearbox damage events recorded as shown below. The plot shows data for six different events where the data is normalized to the alarm limit to factor out the particle counts variation due to different gearbox models. MetalSCAN consistently provides 3 to 5 months reliable warning of progressing gearbox damage prior to risk of severe damage to the gearbox. Similar results have been achieved by GE Wind as presented at the EWEA conference in 2004 [4] and 2006 [5].



Wind Turbine Gearbox
Damage Progression Field Results

CONCLUSIONS

Condition monitoring is now recognized in the wind turbine industry as a necessary element for managing gearbox failures. Industry effort to identify technologies that provide reliable condition indication have shown that reliability of indication is the significant challenge to the traditional condition monitoring methods when applied high up in the wind turbine nacelle.

A significant population of fielded examples on actual wind turbines as well as independent research results has demonstrated that MetalSCAN can be used to effectively manage the gearbox risk and lower operating costs for the wind turbine operator. MetalSCAN makes it possible for operators to reliably identify the onset of damage and to monitor the damage progression over time, thereby eliminating expensive gearbox failures for the future. Unscheduled repairs to gearboxes and their associated high costs can be avoided.

REFERENCES

[1] Elize de Vries **"Gearbox failures and design Solutions"** 02/03/06 as retrieved on www.earthscan.co.uk/news/article/mps/UAN/639/v/1/sp/332948698814330909590

[2] **"The gearbox: windpower's Achilles' heel"** Nov 2005 issue of Windpower monthly as retrieved on http://windpower-monthly.com/nov05/cont.htm

[3] Paula J.Dempsey and Abdollah A. Afjeh **"Integrating Oil Debris and Vibration Gear Damage Detection Technologies Using Fuzzy Logic"** July 2002 NASA / TM – 2002-211126 <http://gltrs.grc.nasa.gov/reports/2002/TM-2002-211126.pdf>

[4] James R. Rasmussen, Richard F. Bauer, David Lemieux GE Energy, Issaquah, USA
Christian Schram, Udo Ahmann GE Energy, Germany
"Wind Turbine/Generator Divetrain Condition based Monitoring"
As Presented at 2004 EWEA conference

[5] Mahesh Morjaria, Vinay Jammu and Jan Hemmelmann / GE Energy
"Effective Operations and Maintenance of Wind Turbines Through Use of Advance Services Technologies"
As Presented at 2006 EWEA conference
Athens Greece