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Online Gearbox-Load-Monitoring to Increase Gearbox Reliability

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1. Introduction

Failures of Gearboxes within Offshore-Windpark-Applications lead to long downtimes and high repair/replacement costs. The strategic goal for Offshore-Windturbines is to avoid gearbox failures at all. This goal is only then realistic if the real loads and forces are measured in real time at high frequencies by the gearbox. The paper will report about a Mechatronic gearbox-prototype of the 1,5 MW-class with integrated contactless load-sensors, analytic electronics/software and a highspeed fieldbus-interface for communication with the turbine controller. The full integration of mechanics, electronics, software and communication.

2. Motivation/Objectives

Up to now, there are no measurement methods in place allowing accurate, high frequent sample rated, reliable and durable Detection of operating loads of the gearbox in wind turbines.
Based on challenging environment condition in wind turbines (wide temperature ranges/ EMV/ Humidity/ high dynamic Wind speed changes/complex vibration characteristics/ salts/gear lubricants/etc.) the installation of load monitoring sensors does currently not allow promising results.

Due to the experiences in the field of unexpected overload situation there is still an urgent need for turbine owner as well as turbine manufacturer of getting an accurate load detection system implemented which must be able to cover all these critical parameters so that finally following targets can be reached:

1. *Defensive self protection system of gear units*
2. *Pro-active performance control of turbines*
3. *Drive train adjustment as well as optimization*

3. State of the Art of Load sensing

The load detection gets currently calculated based on the rotational gearshaft speed as well as Power/ Efficiency parameters by the turbine controller.
High dynamic load peaks or vibrations aren't getting detected with that method.
For getting some torque data short/mid-term (for several days/weeks) there are possibilities to apply strain gauges (DMS) or a torque gauge bar (see also Fig. 3.1) on the drive shaft.
The implementation/procedures of these "wired solutions" plus the required torque calibration is very complex and are not reaching the required accuracy for allowing reaching the three targets mentioned above.
These methods are very sensitive and unreliable based on the critical environment at the gear shaft!
>> None of these are capable for wind turbines as long term solution especially for a gear life operation cycle!

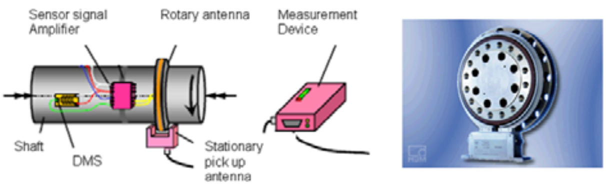


Fig 3.1: State of the Art of possible Load Sensing at gear shaft DMS Application + Torque Gauge bar

Picture (Fig. 3.1) does show alternate methods of detecting torque values on the gear shaft.
Wiring/ Implementation efforts are strong linked with high technical risks as well as short term accuracy, only.

There is just one method available for reaching the gearbox load measurement requirements (long term):

>>> ***Non Contact Torque Measurement Technology!***

4. Magnetostriction

There exists one technology which is able to cover these non contact torque measurements under these intensive wind turbine requirements.
The technology is part of the physical phenomena "Magnetostriction".
Magnetostriction is the relationship between the volume of a Ferro magnetic body and the presence of magnetic field. The effect was first identified in 1842 by James Joule known as the "Joule effect".

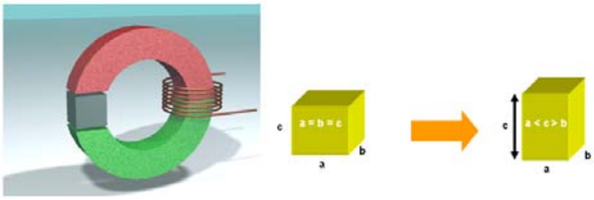


Fig. 4.1: „Magnetostriction"

When applying mechanical forces (stresses) to a magnetised Ferro Magnetic body, the "Magnetic Main Axes" will react in proportion to the applied mechanical forces.
Restrictions apply when entering the state of "Plastic Deformation".

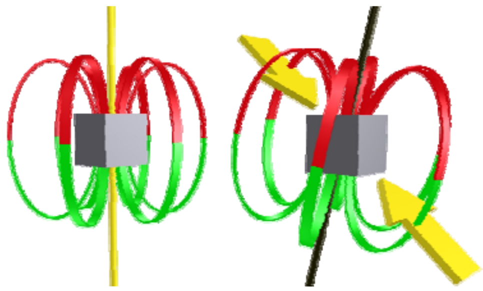


Fig 4.2: Magnetostriction characteristic "mechanical forces on Ferro Magnetic body"

A Puls Current Modulated Encoding technology (called "PCME"), will apply to an already existing shaft, to measure absolute torque (and other physical parameters) with a signal bandwidth of 30 kHz and a repeatability of 0.01%. The systems total electrical current consumption is below 10 mA.
To achieve the best possible PCME sensor system performance it is important that each sensor module has been optimized in physical dimension, location and orientation. In the following each sensor element is explained in detail and the available design options are listed and described.

The key features of the Torque Sensor Technology:

- True Non-Contact sensing technology
- Measurement repeatability of 0.01%
- High signal bandwidth of up to 30 kHz
- Designed for harsh environment
- Low system complexity
- Low current consumption <10mA
- Suitable for high volume applications

>> No mechanical changes are necessary on the existing shaft, nor will anything be attached or glued on the shaft in any way.
The shaft keeps all of its mechanical properties when the technology is applied.

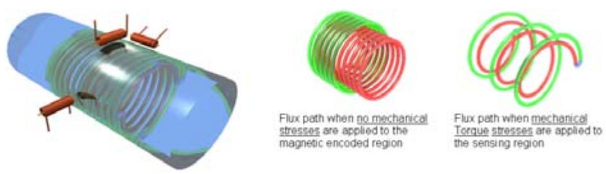
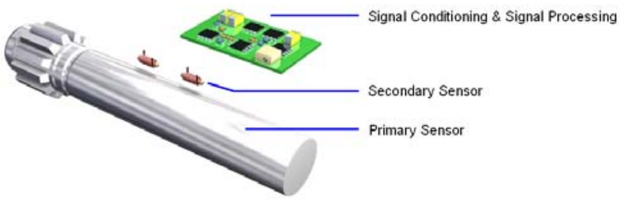


Fig. 4.3: Gear Shaft with PCME encoding area + Properties of magnetic encoded region

A typical sensor system, based on the PCME encoding, does consider three main building blocks (or modules):

- Primary Sensor
- Secondary Sensor
- SCSP (Signal Conditioning & Signal Processing Electronics)



The **Primary Sensor** is a magnetically encoded region on the shaft. The encoding process is performed "once" time only (before the final assembly of the power transmitting shaft) and is permanent. The power transmitting shaft is also called Sensor Host (or SH) and has to be manufactured from ferromagnetic material. In general, industrial steels that include around >1.5% to <8% Ni are a good basis for the sensor system. The Primary Sensor converts the changes of the physical stresses applied to the SH into changes of the magnetic signature that can be detected on the surface of the magnetically encoded region. The SH can be solid or hollow.

The **Secondary Sensor** is a certain number of Magnetic Field Sensor (MFS) devices which are placed close to the magnetically encoded region of the SH.
However, the MFS devices do not need to touch the SH so that the SH can rotate freely in any direction. The Secondary Sensor converts changes of the magnetic field due to the changing of torque (caused by the Primary Sensor) into electrical information. Passive MFS devices (coils) will be used as they can be potted and used in harsh environments (for example in oil) and operate in a very wide temperature range. Only the potting material determines the resistance against the environment conditions.

The **SCSP (Signal Conditioning & Signal Processing)** electronics drive the MFS coils and provide the user with a standard format signal output. The SCSP electronics are connected through a twisted pair cable (2 wires only) to the MFS coils and can be placed up to 2 meters away from the MFS coils. The SCSP electronics can get developed custom designed and has a typical current consumption of 6 mA.

Attached Pictures (See Fig. 4.4) does show the characteristic of the magnetic field/ PCME area on the shaft referring to load changes, the usage of the technology on a Winergy 1,5MW Gearbox as well as a measurement protocol real time with the load sensing technology.

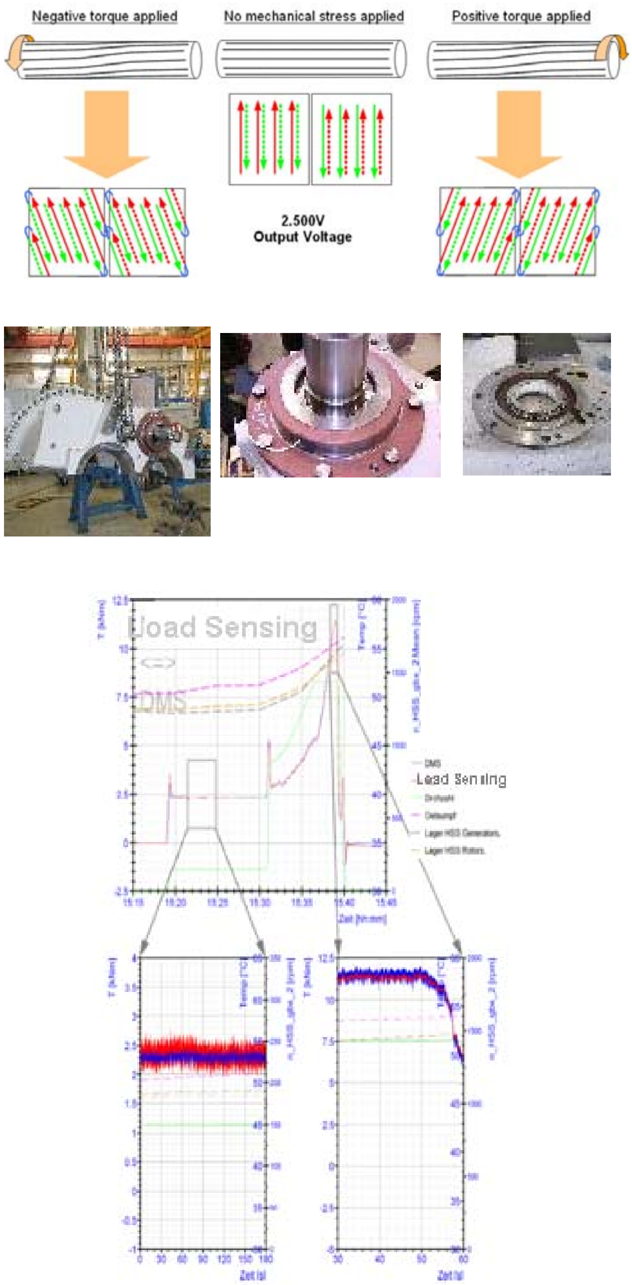


Fig. 4.4: Non contact torque sensing + Signal Conditioning & Signal Processing

Summarizing the Advantages of that non contact load sensing technology:

>> Measuring absolute mechanical forces in turbine applications Non-Contact, Reliably, at Lowest Cost!

- No mechanical changes required on the Sensor Host
- Nothing will be attached to the Sensor Host
- SH can rotate at any desired speed
- High measurement repeatability
- Very high signal resolution (>14 bit)
- Low current consumption (typ. 5 mA)
- Very high signal bandwidth (up to 30 kHz)
- Excellent measurement linearity
- Wide operating temperature range(-40°C to +250°C)
- No changes need to be made to the power transmitting shaft
- Can be applied to already existing applications
- Very small dimensions: Fits in even very tight spaces
- Works in water and in oil
- Can not be destroyed through abrasive materials
- User Friendly Sensor Signal: 5 Volt analog or digital encoded
- Real-Time measurement: No phase delay, No signal creeping
- No signal creeping or other unwanted short / long term effects
- No re-calibration or other regular sensor maintenance required
- Is the absolute lowest cost sensing solution on the market

5. Integration into Wind Gearbox

To implement that sensor technology into Winergy gearboxes an intensive test&validation program is currently in process. Several tests on gearboxes/gear shaft are currently testing these system requirements under “real life” operation at German Ruhr-University test benches in Bochum as well as integration into a series gearbox and test at Winergy test bench at Winergy Research & Development Center in Voerde/Germany.
Test Routines will be 100% the same in comparison to other Winergy production gearboxes!

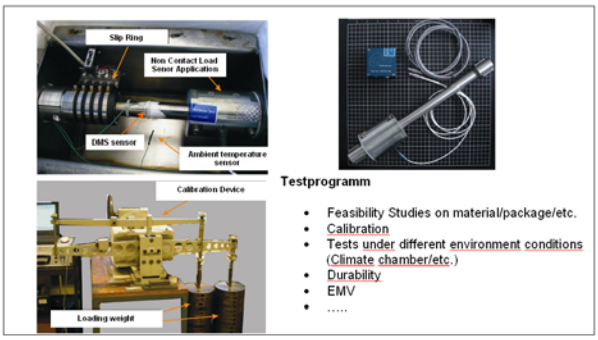


Fig. 5.1: Winergy R&D tests at Ruhr-University in Bochum, Projects Wireless Torque Sensor

For doing calibration and accuracy tests of the new non contact load sensor a small shaft with same material specification as an original gearbox shaft of a wind turbine got magnetic encoded as well as equipped with a DMS for allowing comparison of the data. The test application was also specified for doing climate tests in a climate chamber testing temperatures of -40°C up to 100°C. Loading weights were used at the test bench for defining the exact load for doing the Load Calibration tests (See Fig. 5.1)

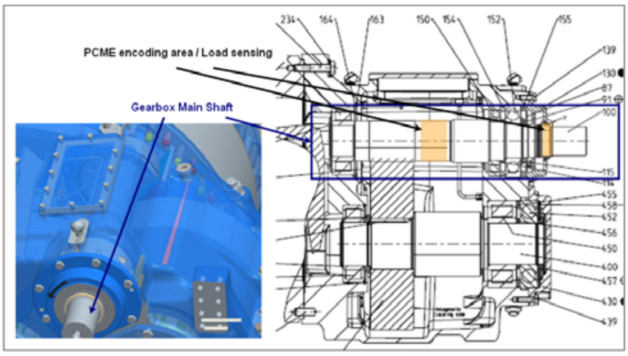


Fig. 5.2: Winergy R&D tests on gearbox at R&D Center in Voerde/Germany

On a 1,5MW Gearbox the original shaft got magnetic encoded in 2 defined areas (see Fig. 5.2; orange coloured boxes) and the Application of the secondary sensor is positioned very close to the shaft within the gearbox.

6. Condition Diagnostics System (Implementation of Load Sensor)

Besides the productivity of a wind turbine, wind park operators are more and more interested in reducing their life-cycle costs. Condition-based maintenance means increased availability and reduced life-cycle costs at the same time.
Due to this it is necessary to monitor the conditions of wind turbines and their components in an overall approach based on CM-relevant real-time data on the wind turbine, providing information and automatic diagnosis in advance in cases of potential failure.
The new Winergy Condition Diagnostics System supports wind park operators and wind turbine manufacturers.

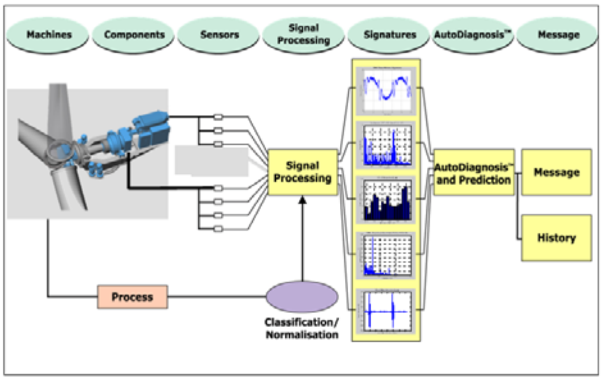


Fig. 6.1: Condition Diagnostic System; System Function Overview

Reliable, efficient, flexible
The system is based on standard products, which are proving themselves in daily operation worldwide. The Analysis and Diagnostics System records, processes, visualises and stores signals (analog and binary) and numerical data.
Based on the latest industrial PC technology (Microbox PC) and hardware I/O nodes, the modular structure is flexible and grows with the requirements of the customer.
Standardised interfaces ensure reliable, simple connection of the most varied signal sources.
High scanning rates, synchronised data recording and intelligent software algorithms guarantee detailed analysis and diagnosis of the signals.
The system can be integrated into existing and new wind turbine systems interference-free and for use with multiple devices.

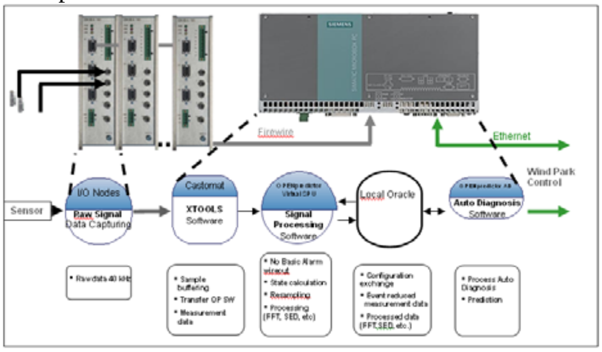


Fig. 6.2: Condition Diagnostic System; System Architecture

The Load Sensor values will get added into the Winergy Condition Diagnostic System allowing most professional data diagnosis as well as prediction of the turbines.

Due to the very high flexibility on interfaces the Load Monitoring/Condition Diagnostic System does also allow using the Torque sensor signal for getting connected to the turbine controller (See also Architecture of Turbine Controller/Condition Diagnostic System).

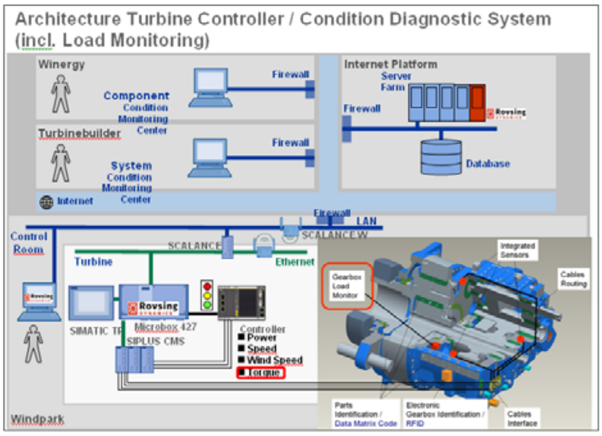


Fig. 6.3: Winergy Turbine Architecture Condition Diagnostic System/Controller (incl. Load Monitoring)

The diagram shown above (Fig. 6.3) does represent Winergy Architecture of the gearbox high speed data interface allowing new load sensor implementation for Condition prediction as well as for Controller purposes.

Getting that Load sensor technology and the overall prediction/control system in place, Winergy AG will become first manufacture worldwide getting real torque value out of the gearboxes so that the customer will have huge potential on improving their turbine operation for the benefits of

a) *Defensive self-protection system of gear unit*
b) *Pro-active performance control of turbine*
c) *Drivetrain adjustment as well as optimization*
d) *Professional prediction of turbine via Winergy Condition Diagnostics System*

7. Conclusion/Perspective

The integration of online Load-Monitoring into Winergy´s gearboxes for wind turbines went through serious research efforts which proved that the technology of Magnetostriction can be applied into series wind turbine gearboxes. This will be a breakthrough in gearbox reliability and optimizing the overall performance of the entire drive train by smart new regulation algorithms. Winergy will deliver towards beginning of this year the first series gearbox to the customer and will introduce this new technology into all future gearboxes.

References

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