A Novel Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor (OFFSHORE WIND TURBINE APPLICATIONS)

A Novel Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor
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Fatigue damage assessment with conventional strain gage method:

- **The most common method to determine fatigue assessment on existing structure before cracking propagation relies on strain gage monitoring .**
- **This strategy consists in recording the local strain variations and post-analyzing them in order to identify the stress ranges, the mean stress values, and the number of cycles for each.**
- **To this aim, the most widely used method is the Rainflow method .**
- **Miner's Rule can then be used to assess the final damage based on existing fatigue assessment on similar details .**
- **Such method therefore requires a rather high amount of recorded data and of electric supply as rather high frequencies of sampling are used.**

Figure 1. Typical Monopile Wind Turbine (left) and Mini Jacket type Wind Turbine (right).

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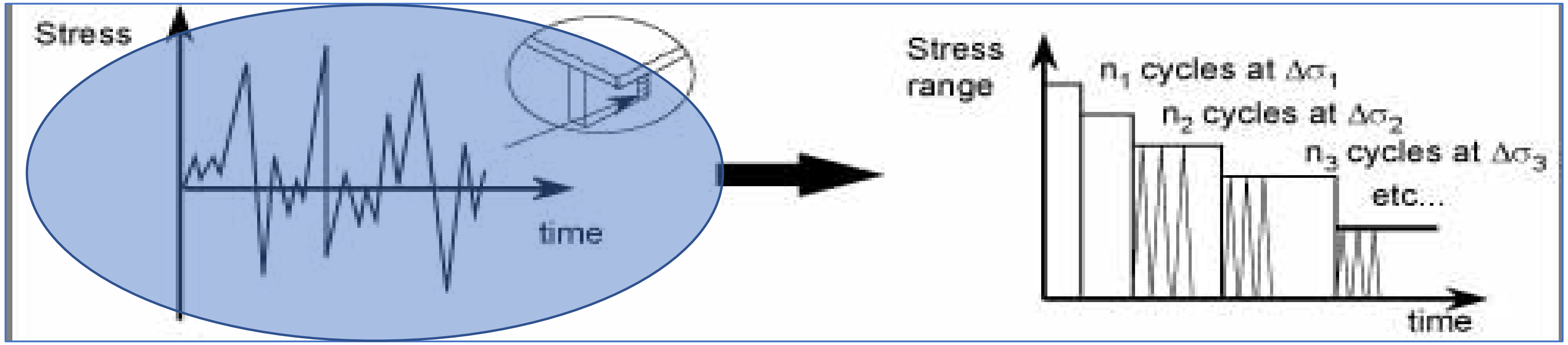

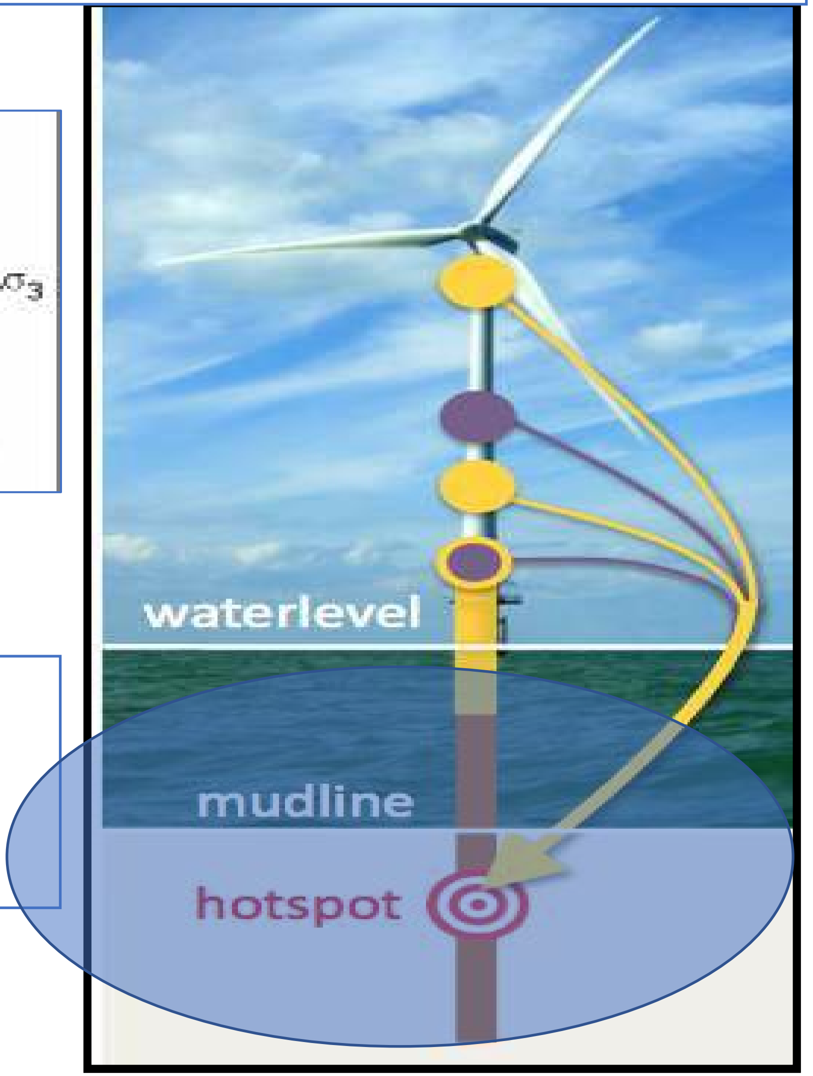

- **Elements and Factors of Fatigue Design for WIND TRUBINES**
- **Identify all the Fatigue Critical HOT SPOTS in STRUCTURES**
- **Install Fatigue Damage Sensors in order to monitor the RESIDUAL FATIGUE STRENGTH**

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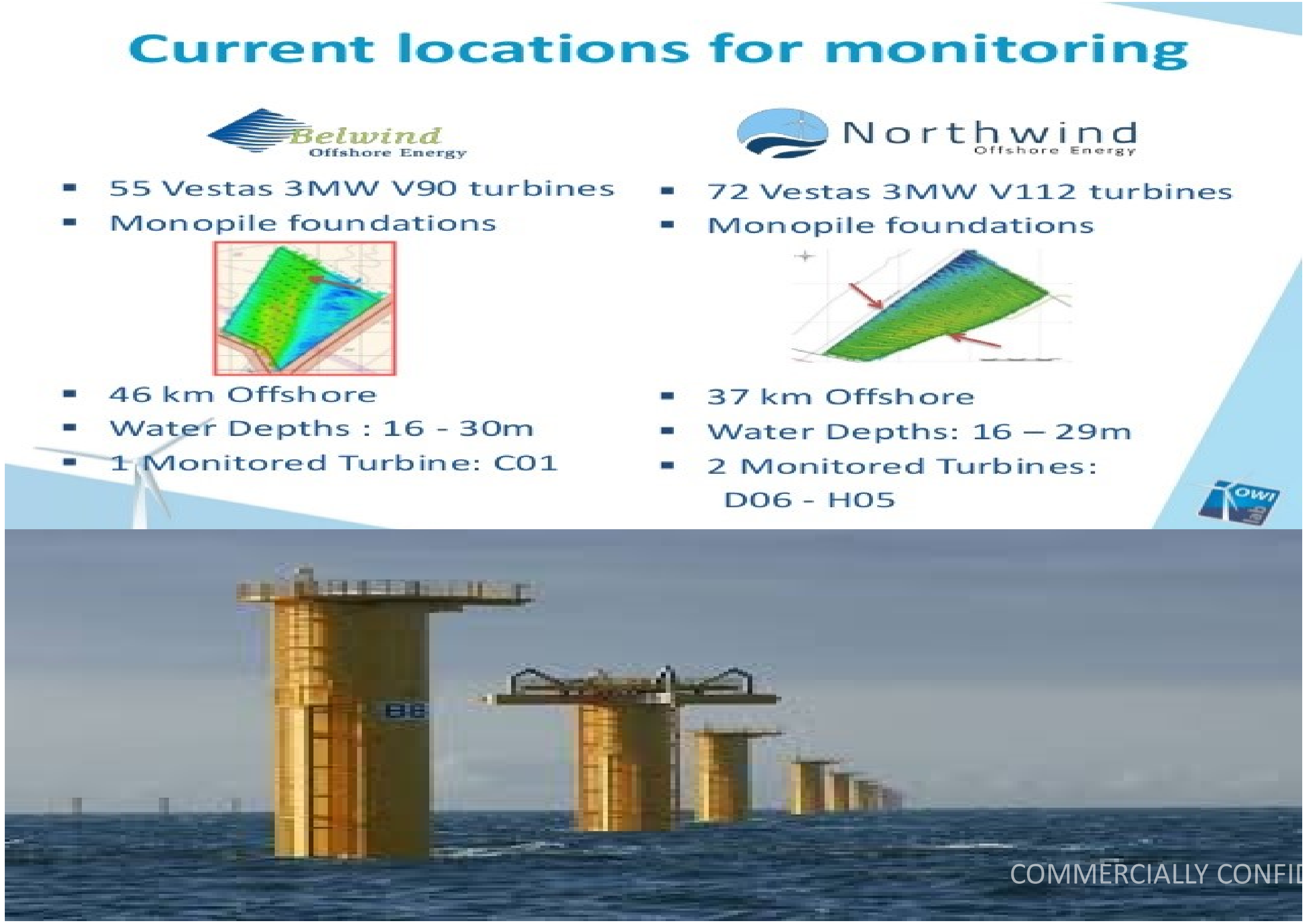
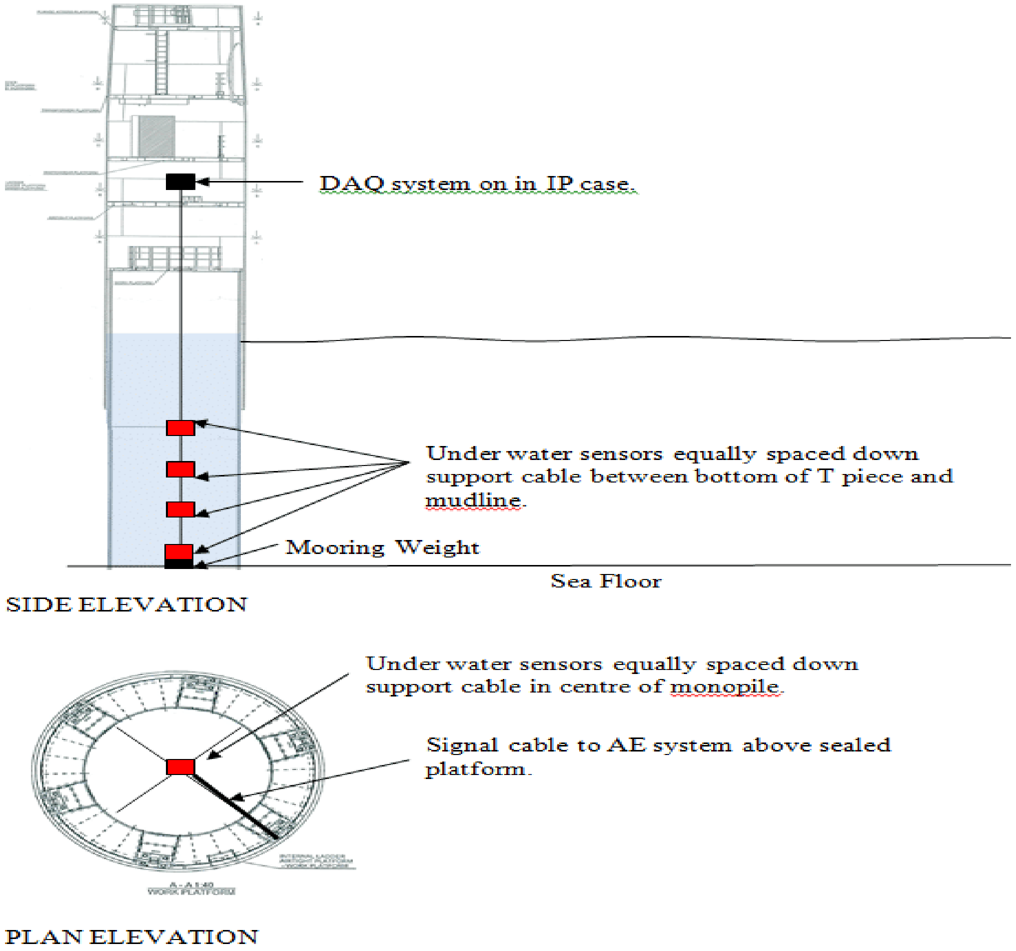
Fatigue Critical HOT SPOTS in OFFSHORE WIND STRUCTURES for the applications of fatigue sensors in order to monitor the RESIDUAL FATIGUE STRENGTH or CUMULATIVE FATIGUE DAMAGE INDEX





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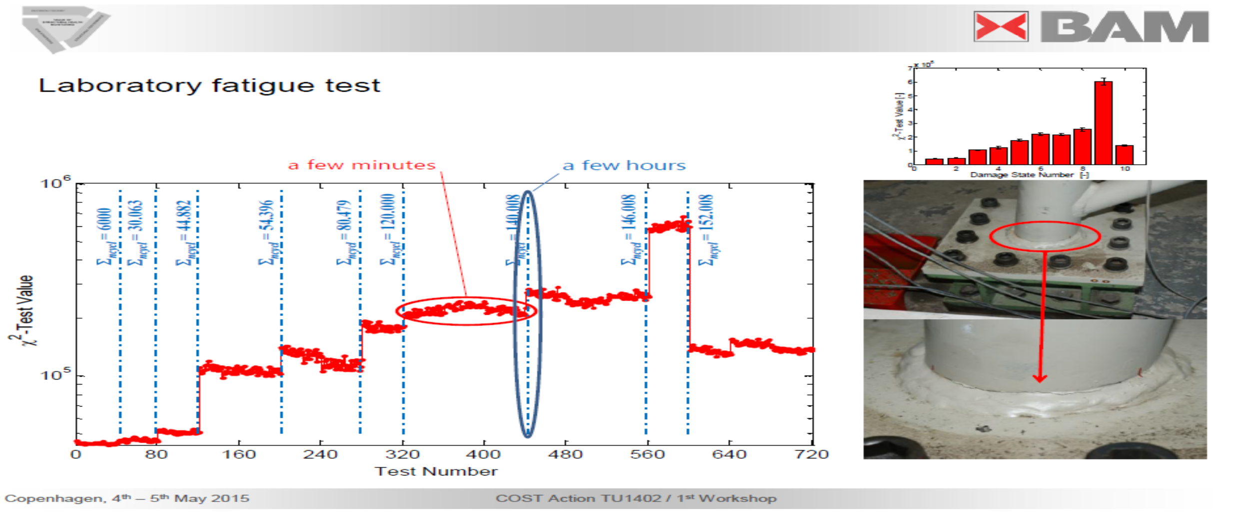

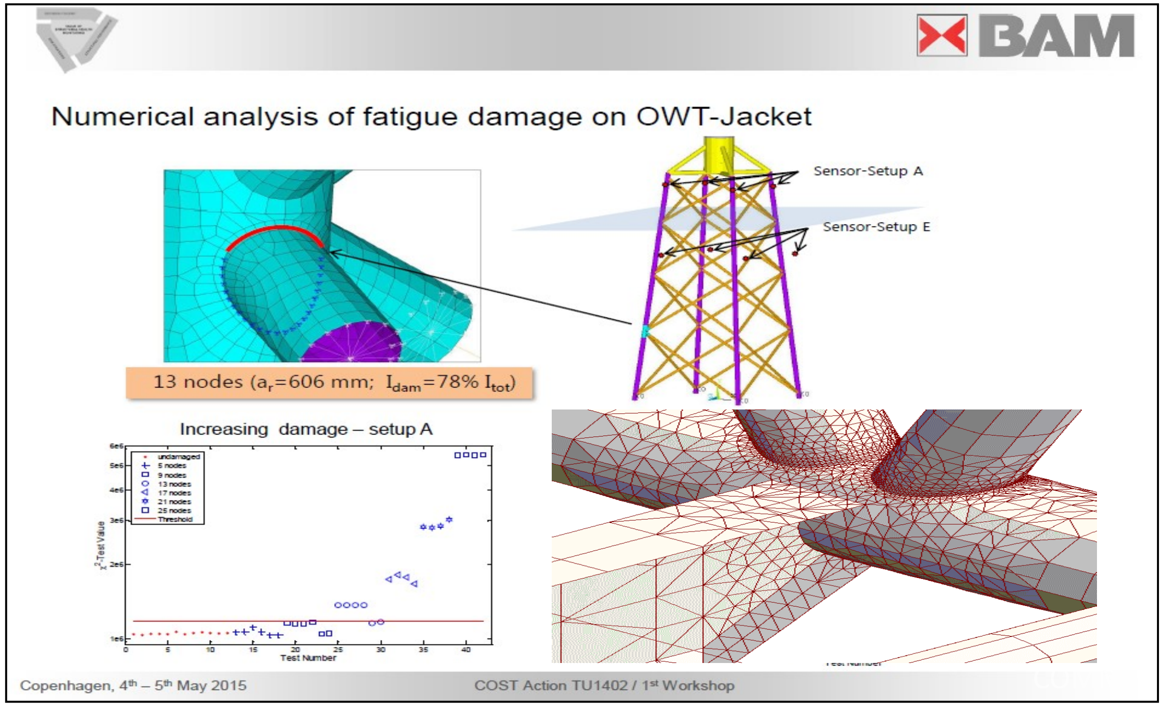

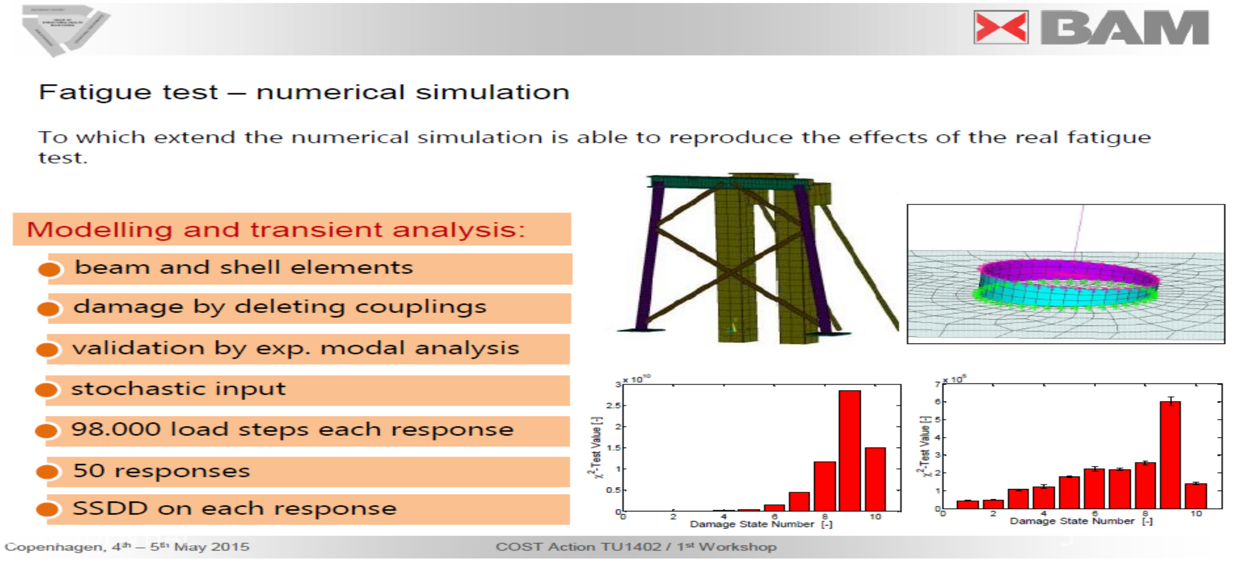

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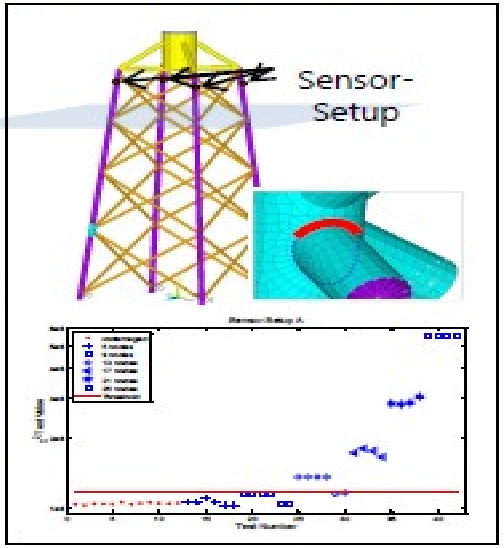
(WIND TURBINE APPLICATIONS)

Fatigue Critical HOT SPOTS in OFFSHORE WIND STRUCTURES for the applications of fatigue sensors in order to monitor the RESIDUAL FATIGUE STRENGTH or CUMULATIVE FATIGUE DAMAGE INDEX

Numerical simulation OWT:



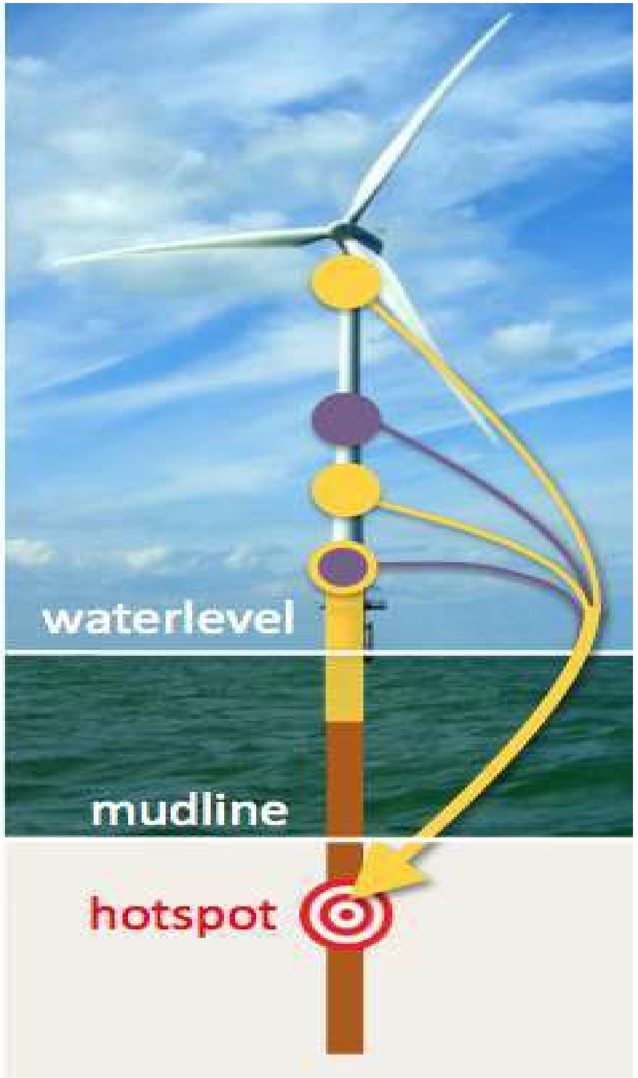
To consider beside others:

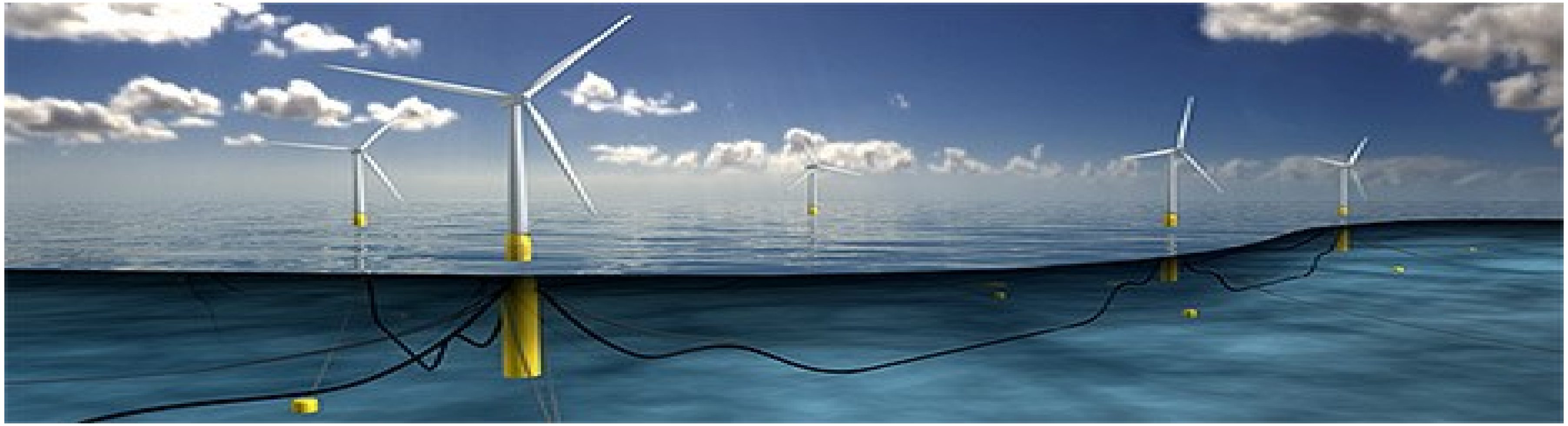
- Dynamic properties
- Realistic Loading
- Environmental nuisance
- Operational influences

A Novel Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor
(OFFSHORE WIND TURBINE APPLICATIONS)

- The typical mechanisms of failures as suffered by wind turbine components, along with the consequences thereof.
- These depend on the reliability and the degradation of turbine components, such as gearboxes, blades, bolts, and welded details, e.g. in the tower.
- Continued operation of a turbine is limited by safety requirements, but it also depends on a cost–benefit calculation for the expected remaining lifetime.
- Information from inspections, condition monitoring (CM), and structural-health monitoring (SHM) is useful to update the estimate of the turbine's reliability in its remaining lifetime, if the information can be coupled with appropriate deterioration models.

A Novel Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor
(OFFSHORE WIND TURBINE APPLICATIONS)

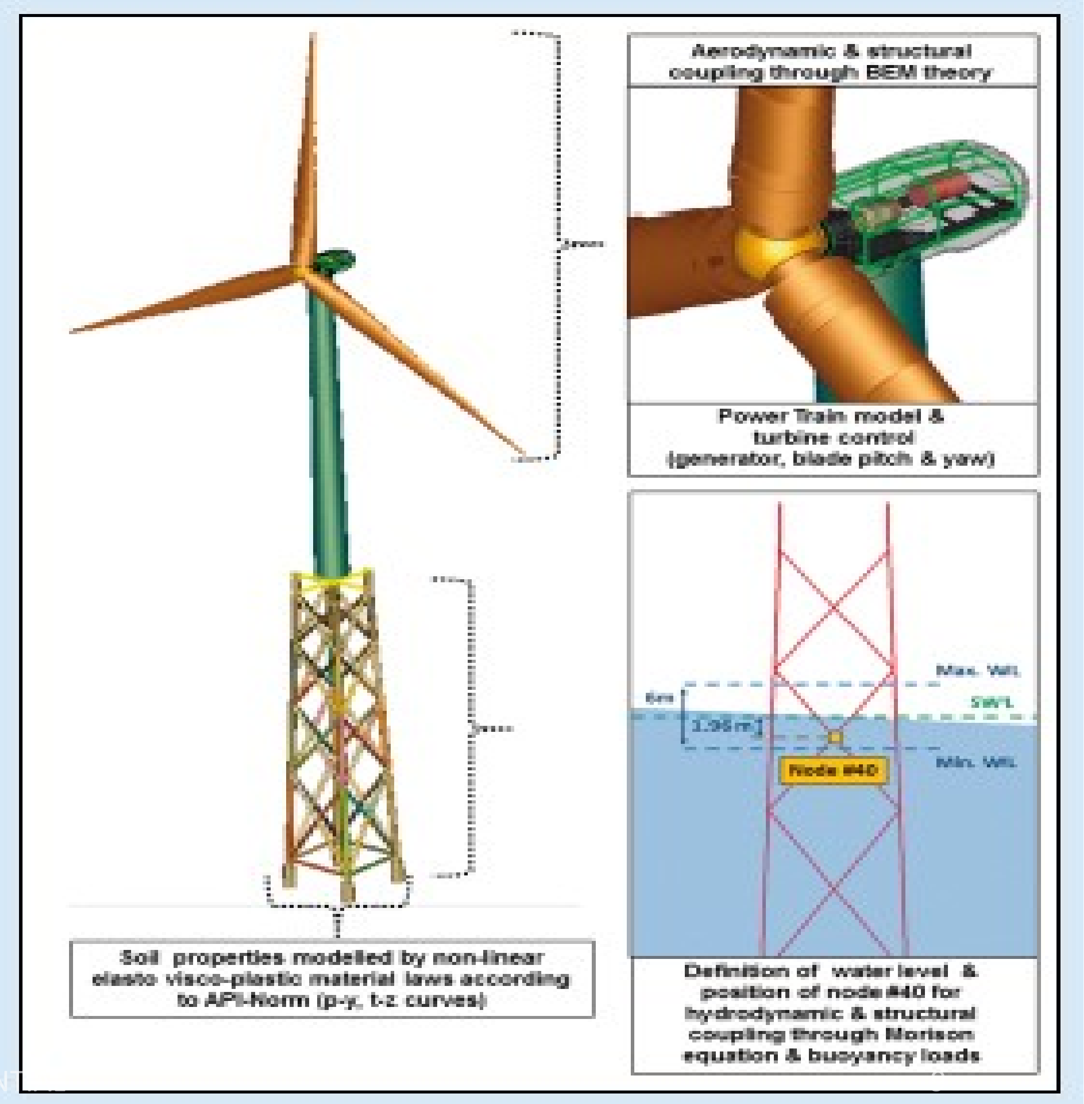




- **All prior analysis assumes that the installed strain gauges are attached to the fatigue hotspots, which is not always feasible. For monopile-type foundations the fatigue hotspot is often situated below the sea-level at the mudline of the Time, Strain and Wave impacts.**
- **In the Figure, Strains measured during two confirmed wave impacts. A reliable remaining lifetime assessment will need to take into account the occurrence of these environmental events in foundation.**

A Novel Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor
(OFFSHORE WIND TURBINE APPLICATIONS)

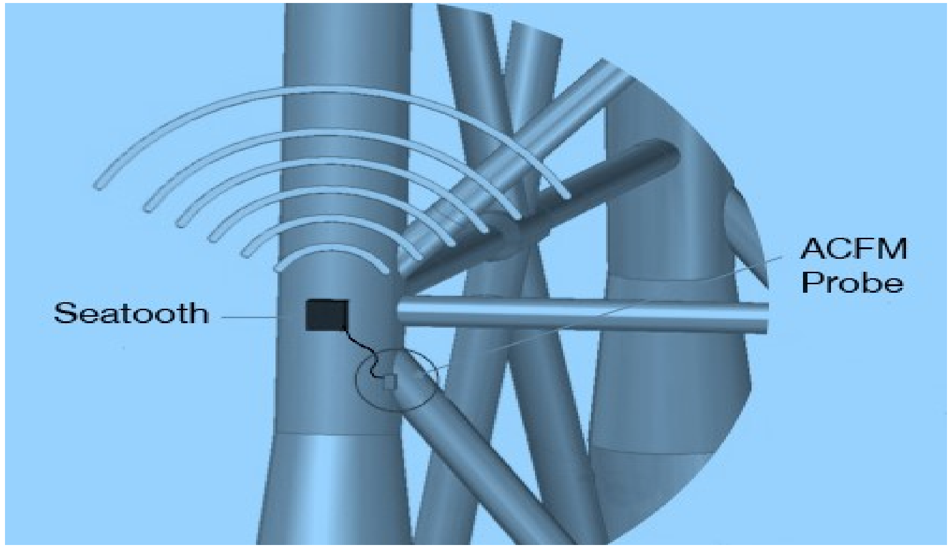
Fatigue Critical HOT SPOTS in OFFSHORE WIND STRUCTURES for the applications of fatigue sensors in order to monitor the RESIDUAL FATIGUE STRENGTH or CUMULATIVE FATIGUE DAMAGE INDEX



A Novel Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor
(OFFSHORE STRUCTURES APPLICATIONS)

The idea of monitoring a situation before it becomes critical is well-known in many fields of engineering involving machinery. Wind farm operators also choose to have condition monitoring performed on their entire wind farms, because:

- **The structures have few and well-defined weak points**
- **There are a large number of similar structures**
- **Maintenance is expensive and complicated**
- **Proactive measures will limit expensive production stops**



A Novel Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor

(OFFSHORE WIND TURBINE APPLICATIONS)

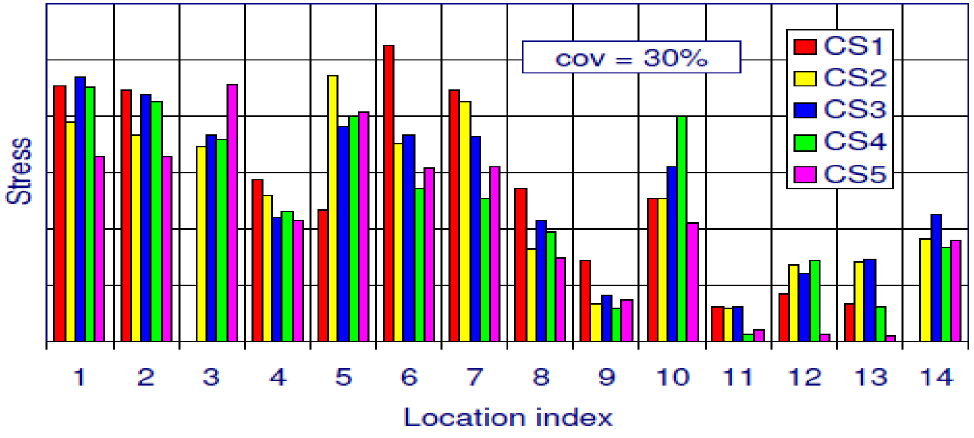


Figure 6. Stress prediction benchmark – stress results

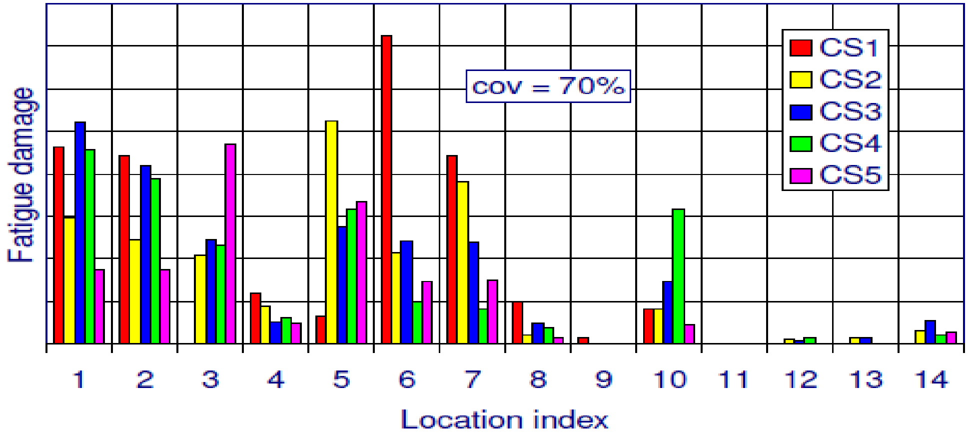
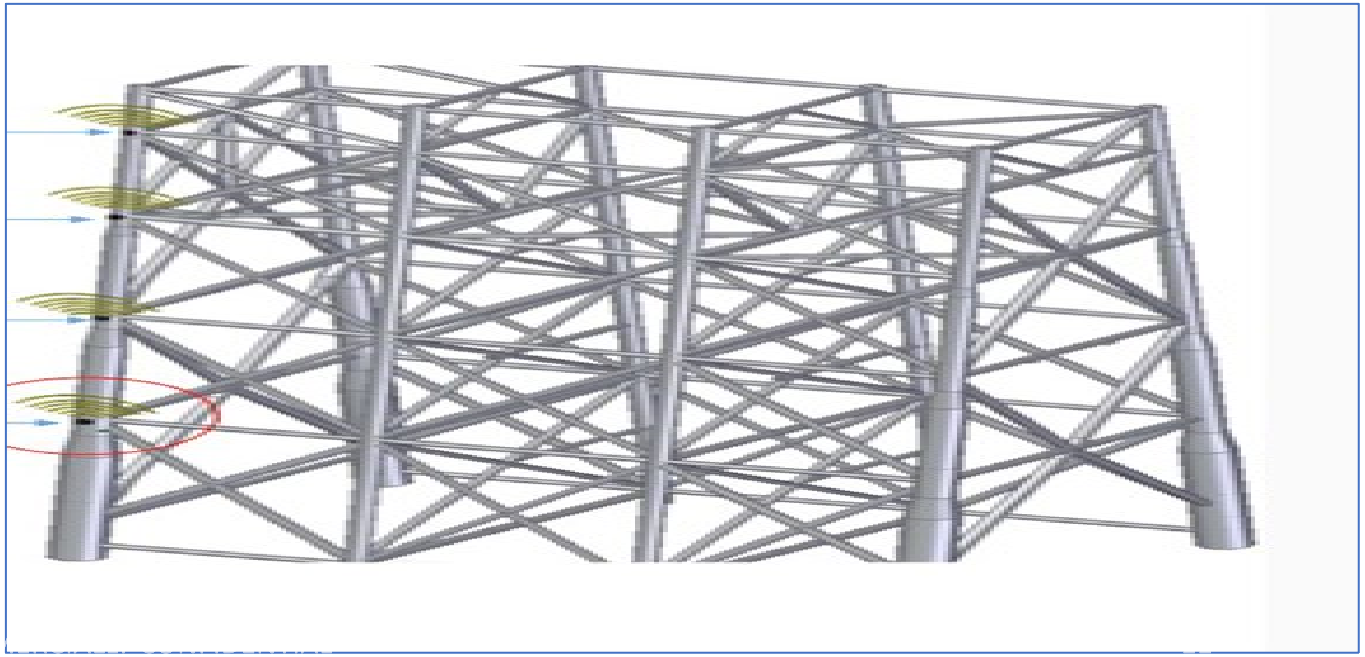


Figure 7. Stress prediction benchmark – lifetime results

Fatigue Critical HOT SPOTS in SHIP STRUCTURES for the applications of fatigue damage sensors FDS in order to monitor the RESIDUAL FATIGUE STRENGTH or CUMULATIVE FATIGUE DAMAGE INDEX

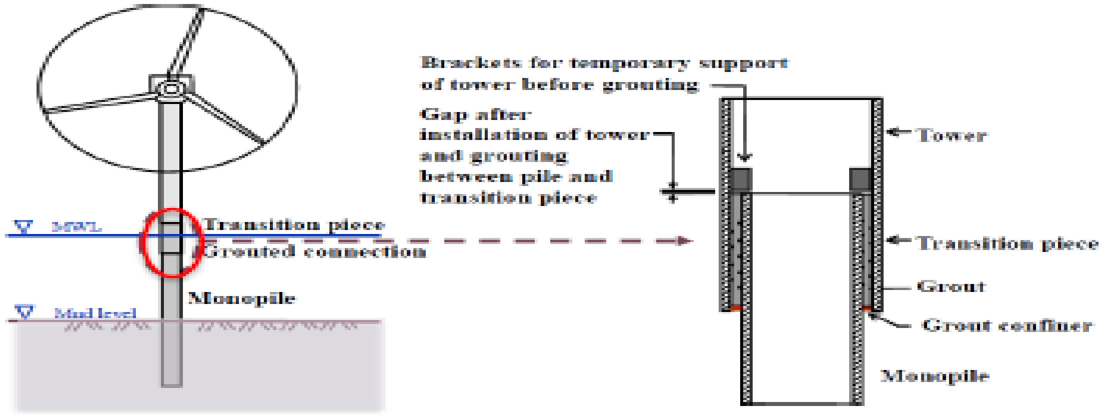


A Novel Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor
(OFFSHORE WIND TURBINE APPLICATIONS)

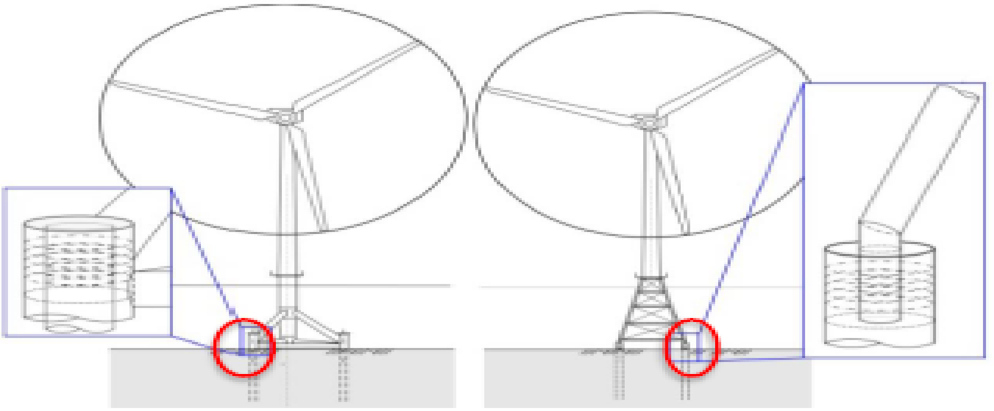
The grouted connection

Issues and need for Structural Health Monitoring System

- Grout-filled space between the two steel components of the pile and sleeve of Offshore Wind Turbines (OWTs)
- Between the tower and the substructure in the case of a monopile OWTs, or between substructure and foundation pile in the case of jacket and tripod OWTs
- Due to high dynamic loadings, significant sliding damages of grouted connections have been reported in 2009-2010 → The problem affected 600 of the 988 monopile OWTs in the North Sea
- Repair cost:120,000 euro per turbine (IHS Emerging Energy Research)



OWT with a monopile substructure and detail of a grouted joint (DNV,2014)



OWT with a tripod / jacket substructure and detail of a grouted joint (Schaumann et al., 2013)

A Novel Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor
(OFFSHORE WIND TURBINE APPLICATIONS)

Fraunhofer IWES

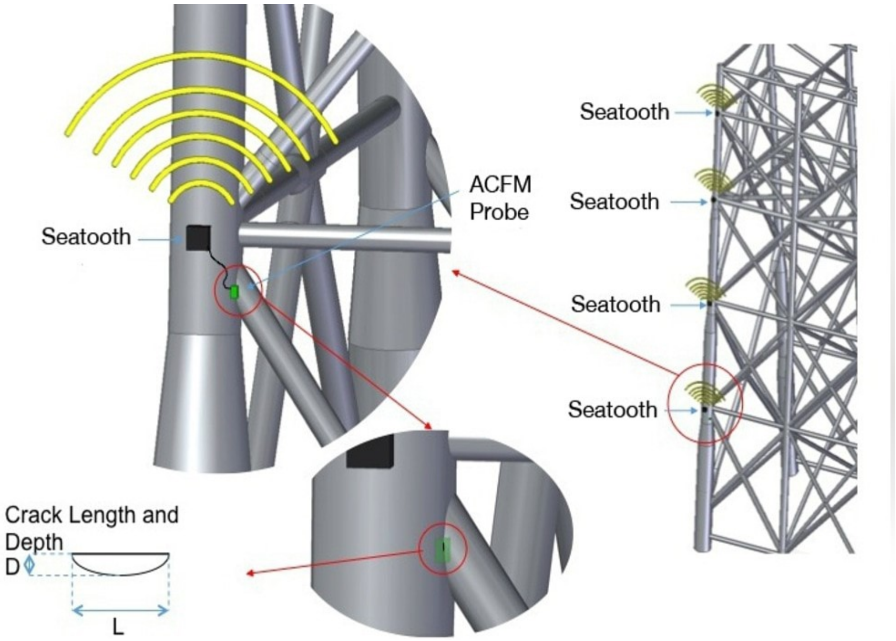
CM & SHM for offshore wind turbines

Issues and perspectives

- Real-time information from permanently fixed sensing or actuation devices
  - Condition Monitoring (CM) for electrical and rotating components in the nacelle
  - Structural Health Monitoring (SHM) for the structural components (blades, tower, foundations ...)
- Optimising the maintenance & inspections (Condition-based maintenance) and reducing the O&M costs
- By predicting early faults, avoiding critical repairs, optimising scheduled maintenance activities
- More and more interest in the last decade → overall for Condition Monitoring (CM) systems
- **OWT owners are more and more interested in the development of SHM systems**

A Novel Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor
(OFFSHORE WIND TURBINE APPLICATIONS)

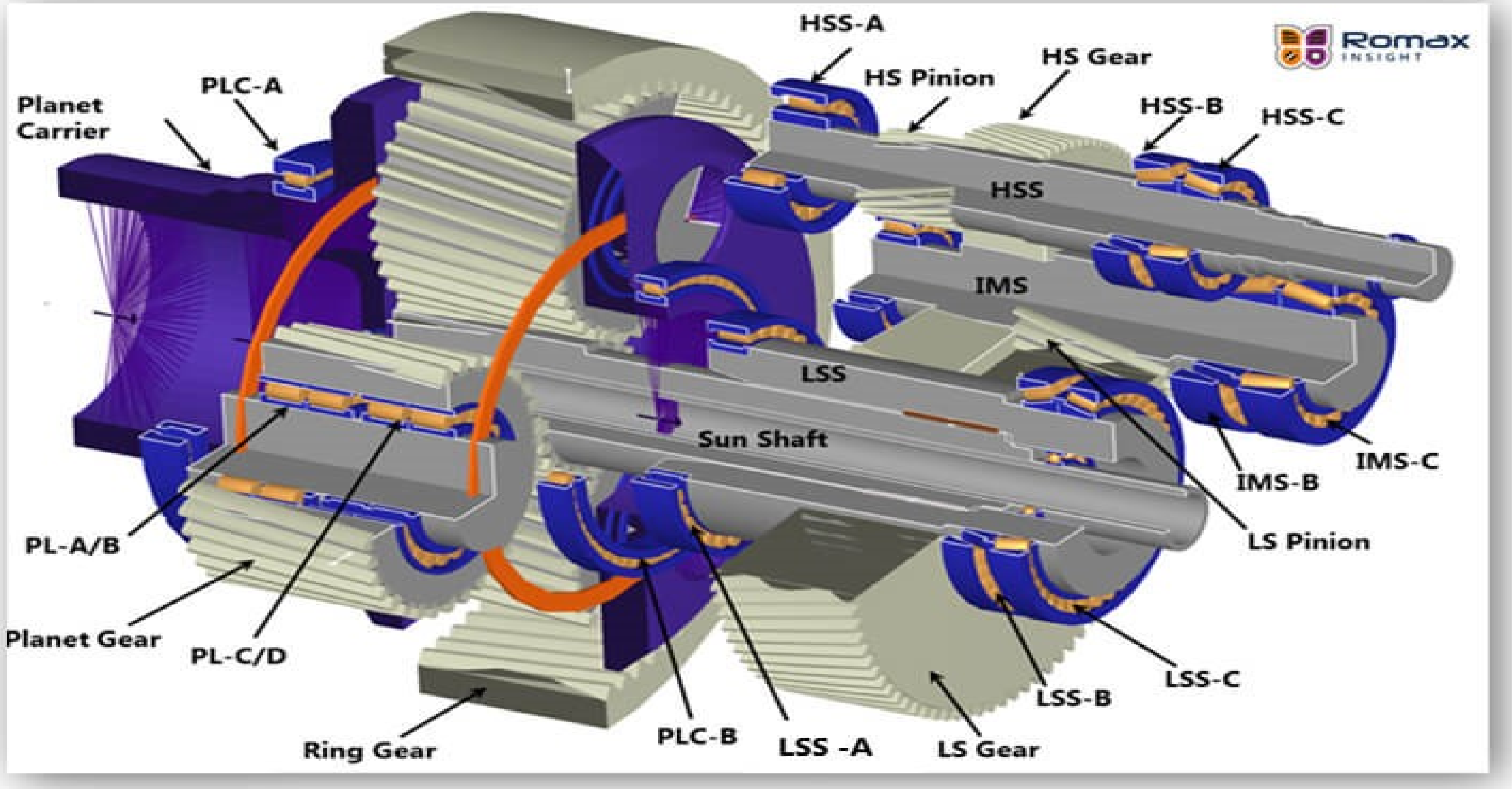
- **Fatigue cracks may occur with low probability when the turbine reaches its design lifetime.**
- **Generally, the consequences of a large fatigue crack in the circumferential weldings will be catastrophic, resulting in the tower's total failure. Criticality will be increased if the welding is exposed to corrosion.**



Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor Network

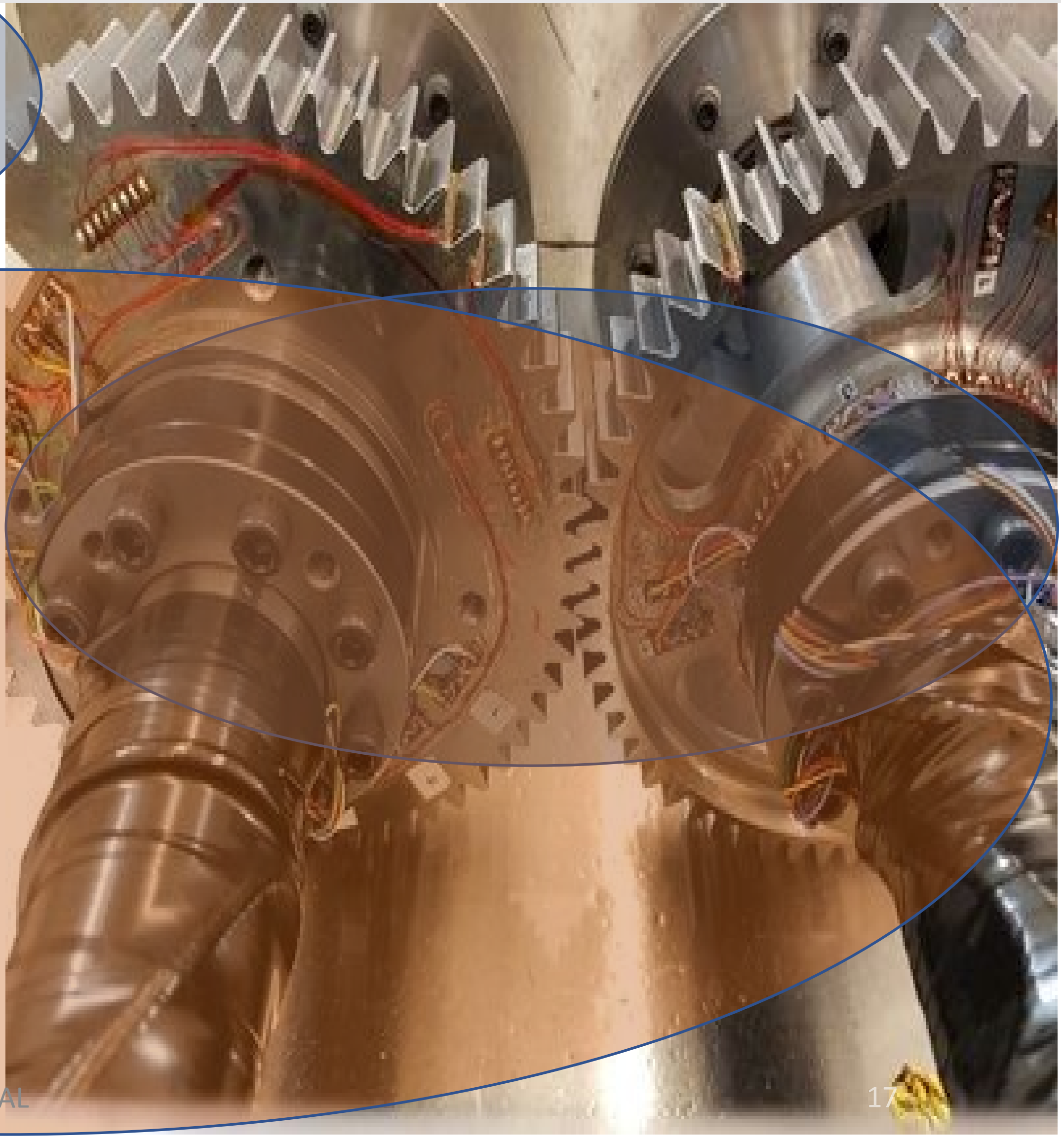
(WIRELESS FATIGUE DAMAGE SENSOR NETWORK FOR INTELLIGENT STRUCTURAL HEALTH MONITORING, MAINTENANCE AND DESIGN)

(IoT INTELLIGENT FATIGUE DAMAGE SENSOR FOR WIND TURBINES GEARBOX APPLICATIONS)



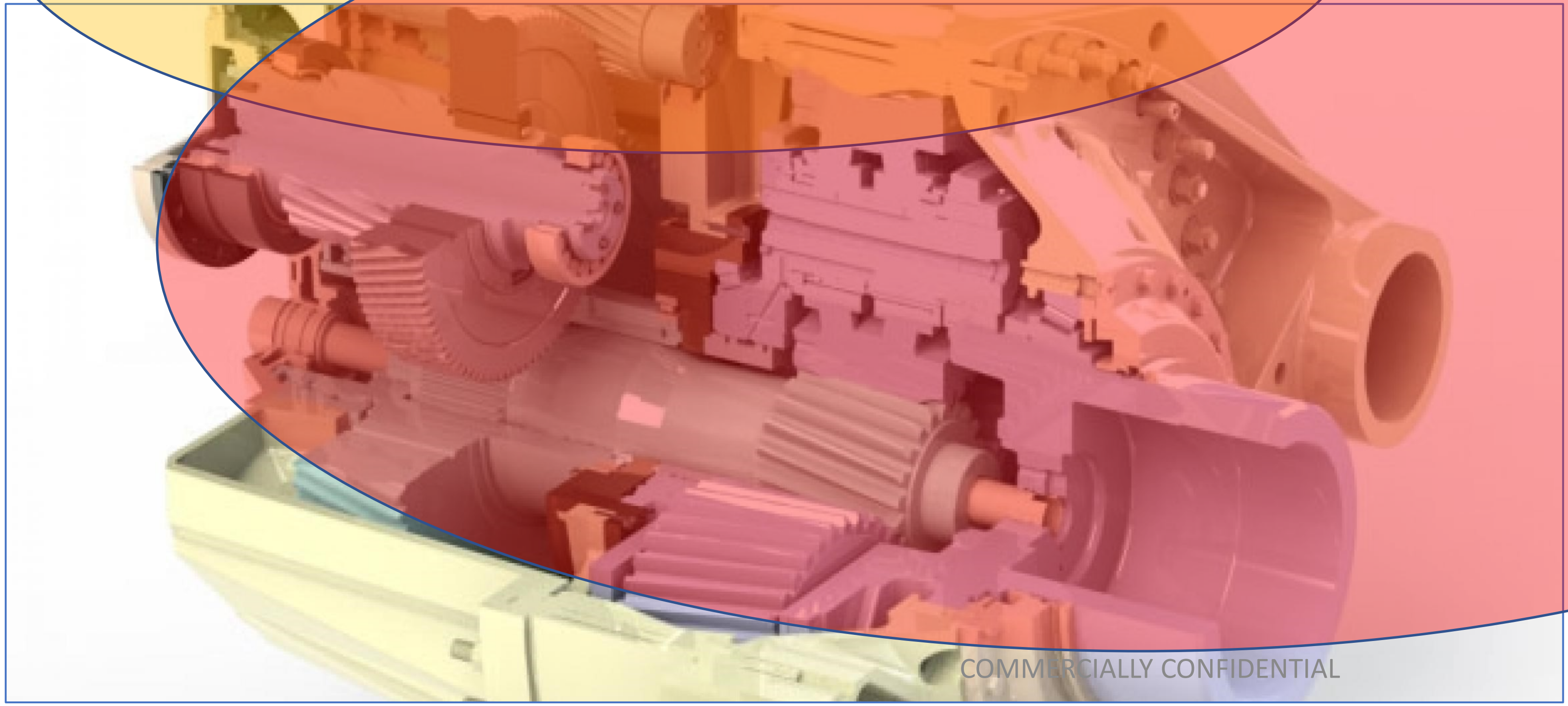
Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor and Sensor Network for GEAR and GEARBOX PREDICTIVE MAINTENANCE APPLICATION

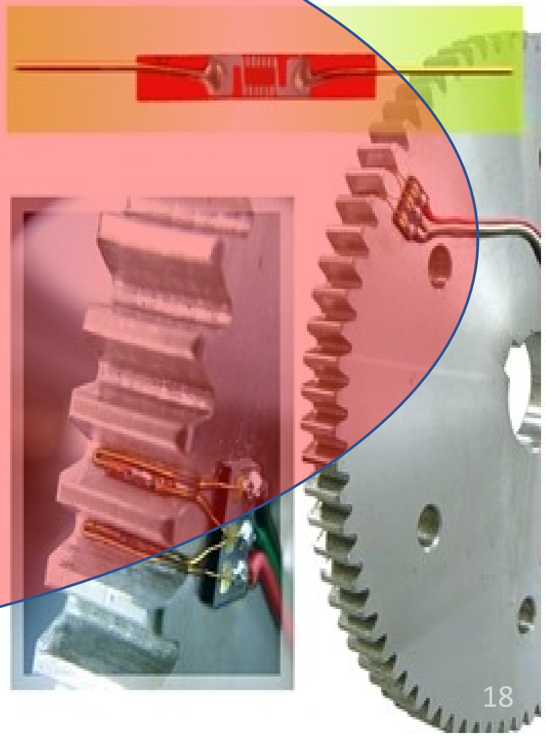
- **Gears are one of the most important machine elements in the industry. They are using many areas such as; automotive, energy, aviation, etc.**
- **Gears are exposed to higher loads day by day due to the increase in power and speed on the machines. Therefore, the stress values which are occur on the gear root is also increase. These stresses cause to damage on the teeth root.**
- **Thus the stress values have to be decrease to design optimum gear body. In this study, the effects of root radius on the gear bending stress are evaluated by using finite element method. At first, gears with standard root radius is investigated both DIN 3990 and finite element method. After the validation of finite element model, the root radius of the gear is taken as parameter.**



Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor and Sensor Network for GEAR and GEARBOX PREDICTIVE MAINTENANCE APPLICATION

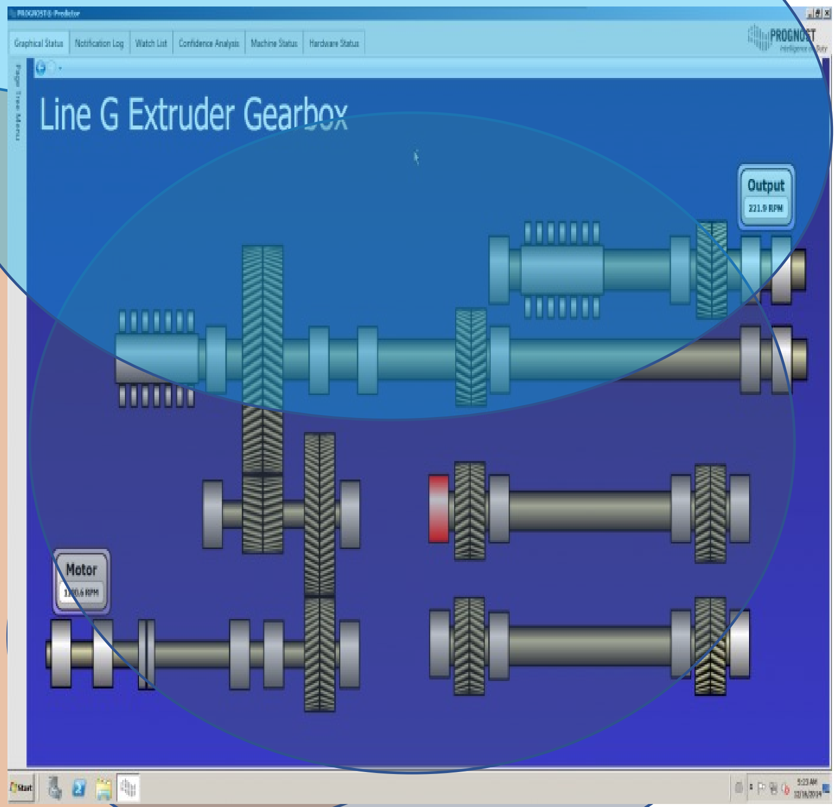
- **Gear is widely used in rotating machinery and transmission devices, and it is one of the most important parts in mechanical equipment.**
- **The research done by gear scientists have shown that gearbox's failure 60% source from gear.**
- **When gear failure occurs, it will lead to the suspension of work, resulting in production losses and casualties.**





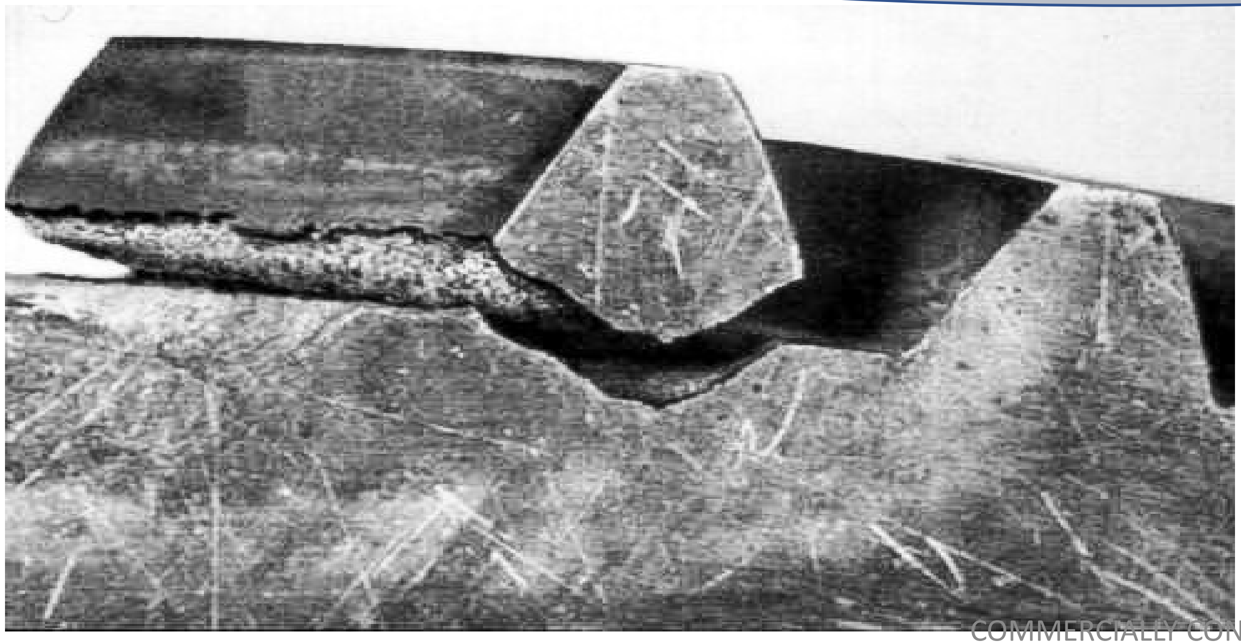
Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor and Sensor Network for GEAR and GEARBOX PREDICTIVE MAINTENANCE APPLICATION

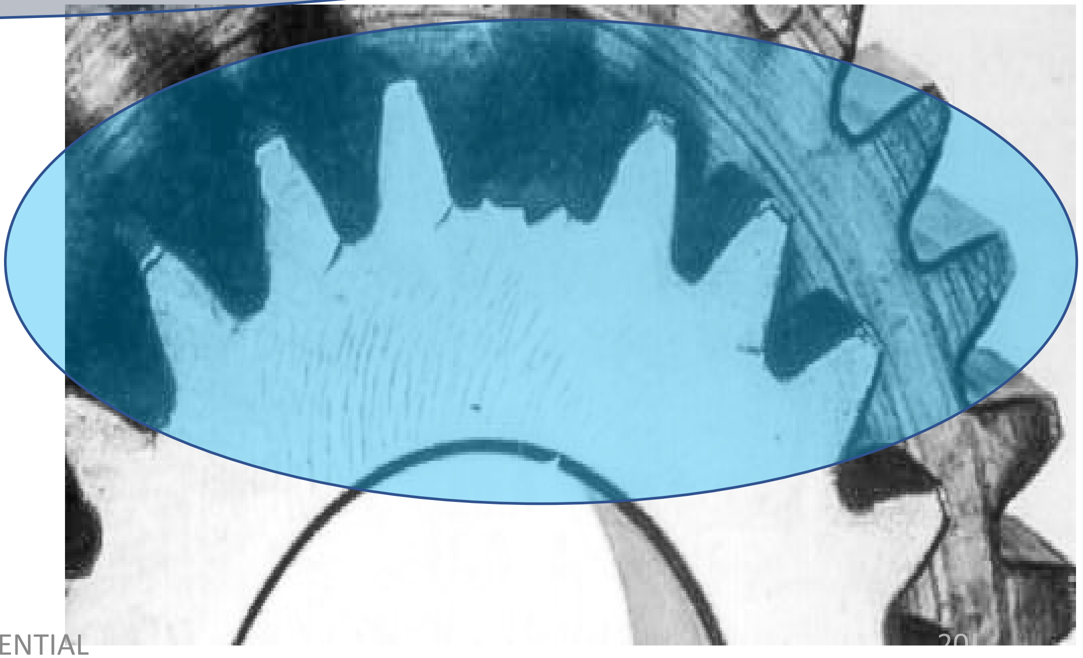
- **GEARS are widely used in ROTATING MACHINERIES and transmission devices, and it is one of the most important parts in mechanical equipment.**
- **<u>The conducted researches have shown that gearbox's failure 60% source from gears. When gear failure occurs, it will lead to the suspension of work, resulting in production losses and casualties.</u>**
- **Predicting remaining useful life of the in-service gear based on historical data has a profound significance to engineering and manufacturing, it can improve the production efficiency and reduce the accident rate.**
- **In order to predict gear's remaining useful life effectively, establish an effective life prediction models.**
- **There are two main methods to predict RUL, physical based methods and data driven methods.**



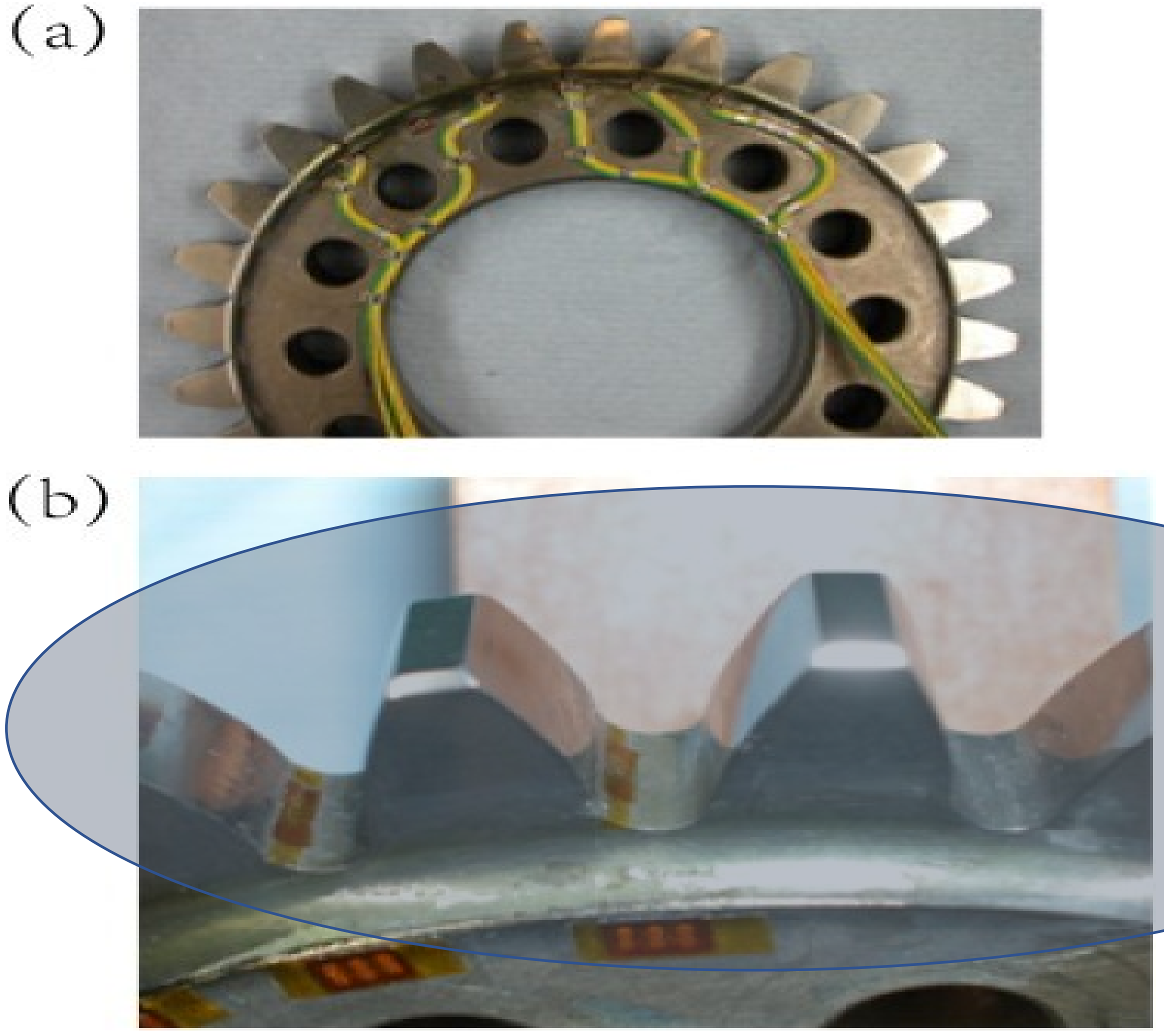
Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor and Sensor Network for GEAR and GEARBOX PREDICTIVE MAINTENANCE APPLICATION

- **The GEAR TEETH FAILURE starts as a crack which is usually at the root of the tooth and proceeds across the base of the tooth until the complete tooth breaks away from the gear.**
- **When a failure arises from this cause there are often other adjacent teeth showing cracks at an earlier stage of development.**





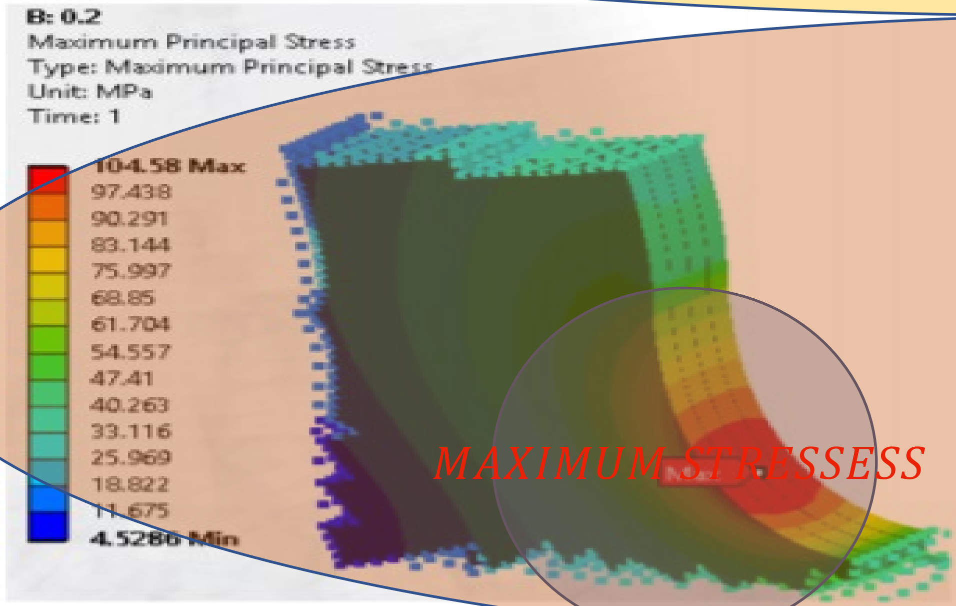
Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor and Sensor Network for GEAR and GEARBOX PREDICTIVE MAINTENANCE APPLICATION



- **For longer fatigue life, quiet and safety operation of gears, dynamic loads need to be reduced.**
- **Bending stresses that occur at tooth root are one of the preventive factor for optimum gear design. Awareness of these stresses, especially in design stage, is also important for taking precautions to gear damage and improvement load carrying capacity.**
- **Due to developments in engineering technologies gear's durability and load carrying capacity also can be modified with different ways such as change of root radius for reducing these stresses.**

Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor and Sensor Network for GEAR and GEARBOX PREDICTIVE MAINTENANCE APPLICATION

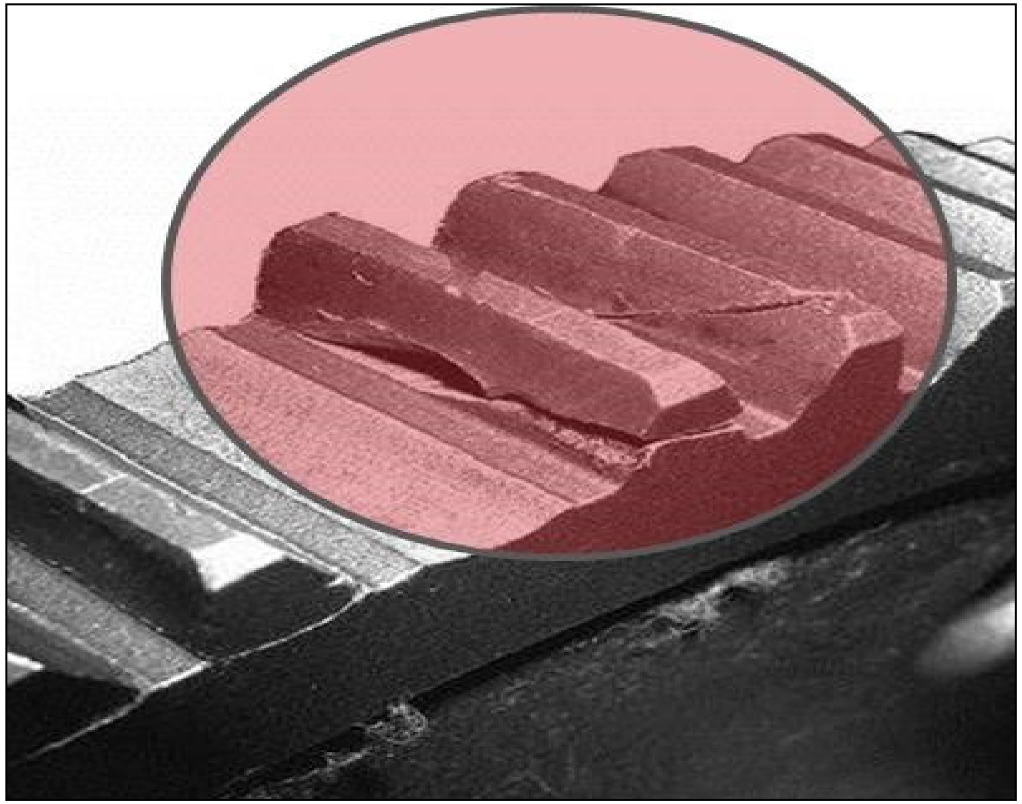
- **The gear transmission stresses cause to damage on the teeth root as shown in the figure below.**
- **The stress values have to be decrease to design optimum gear body.**
- **The effects of root radius on the gear bending stress are evaluated by using finite element method.**
- **The gears with standard root radius is investigated also by using DIN 3990**



ρ=0,2*m

Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor and Sensor Network for GEAR and GEARBOX PREDICTIVE MAINTENANCE APPLICATION

- **Bending fatigue is a failure mode that affects gear teeth. Bending fatigue failures occur when the stress at the root of the gear tooth exceeds the capability of the gear material. This can be due to excessive loads, incorrect heat treatment, inclusions in the steel or a notch in the root of the tooth.**
- **The appearance of the fracture surface will vary depending on whether the failure was high or low cycle fatigue. Features such as ratchet marks are occasionally present and indicate multiple crack origins.**
- **Bending fatigue failures can be prevented by decreasing load, increasing gear material strength or optimizing the gear root fillet geometry.**



Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor and Sensor Network for GEAR and GEARBOX PREDICTIVE MAINTENANCE APPLICATION

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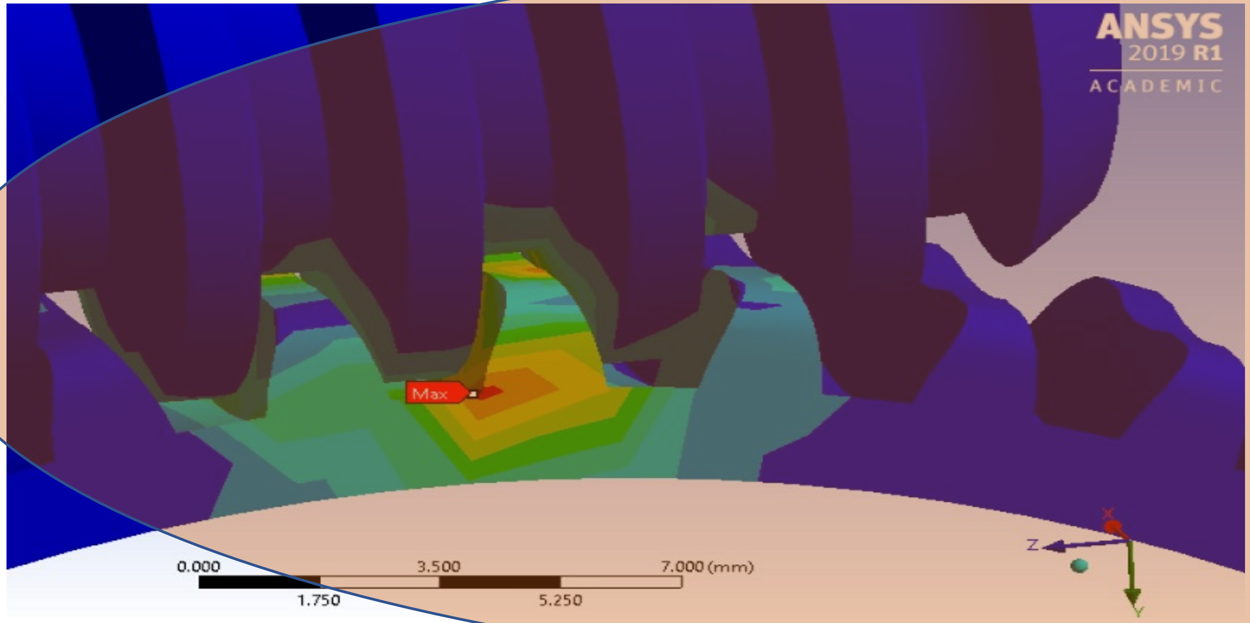
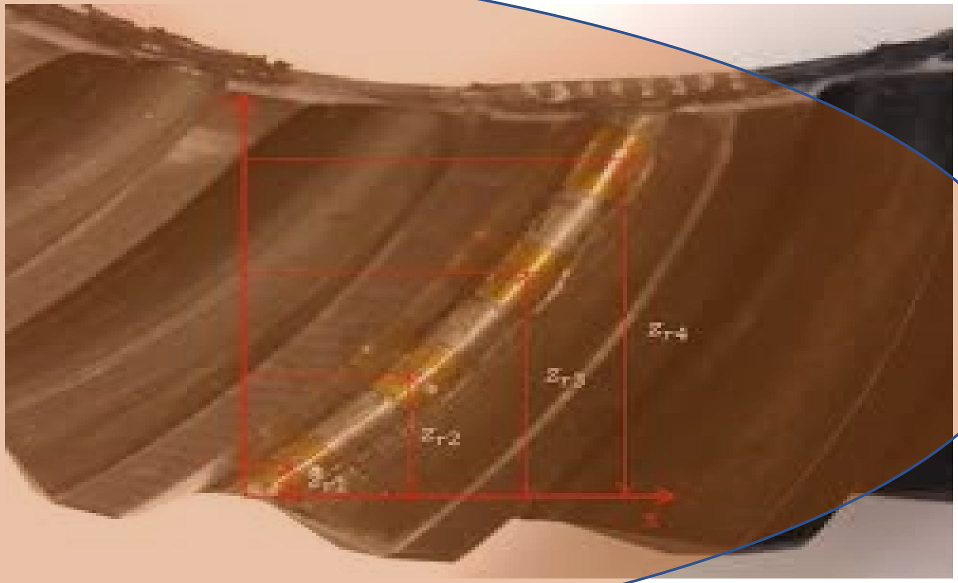
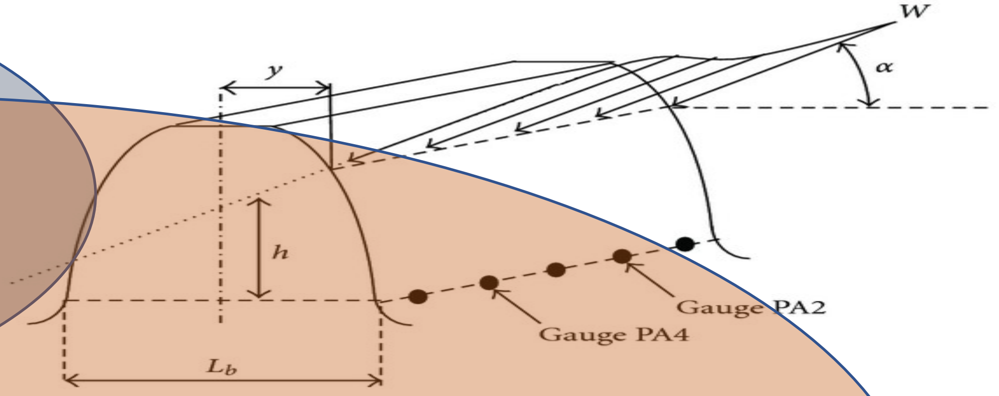
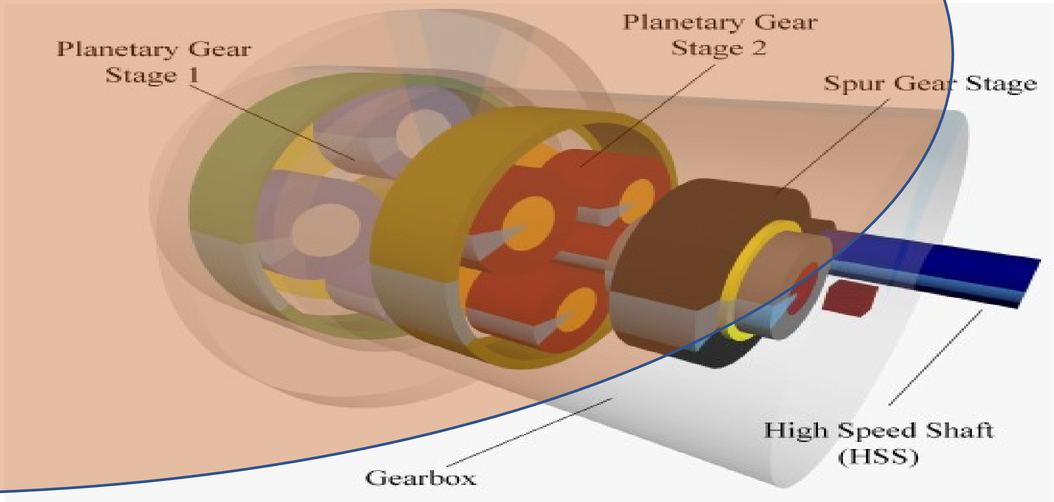




Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor and Sensor Network for GEAR and GEARBOX PREDICTIVE MAINTENANCE APPLICATION

- **Currently, many of the gear REMAINING USEFUL LIFE-(RUL) physical based method is based on the Cumulative Fatigue Damage Theory, in which the Linear Cumulative Fatigue Damage Theory (Miner rule) is to use the most widely, and the method is used to design gear transmission system and analysis gear.**
- **Considering the influence of the residual stress on the contacting fatigue limit, predicted the fatigue life of gears by combining the fatigue life prediction technique**.





Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor and Sensor Network for GEAR and GEARBOX PREDICTIVE MAINTENANCE APPLICATION

In gearbox condition monitoring, a variety of sensing techniques have been instrumented to acquire gearbox mechanical components' conditions. According to the correlation between sensing parameters and gearbox mechanical components' conditions, these sensing techniques can be categorized into direct sensing and indirect sensing methods [1]. Direct sensing techniques measure actual quantities that directly indicate gearbox mechanical components' conditions (e.g. oil debris mass). Inductance type oil debris sensors have been used to monitor the health of gearbox mechanical components [2]. Inductance type, oil debris sensors count particles and approximate debris size and mass based on disturbances of a magnetic field caused by passage of a metallic particle. However, such direct sensing techniques usually involve high cost, and present some practical limitations during gearbox normal operations. Therefore, oil debris analysis is often performed offline or in the laboratory.

Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor and Sensor Network for GEAR and GEARBOX PREDICTIVE MAINTENANCE APPLICATION

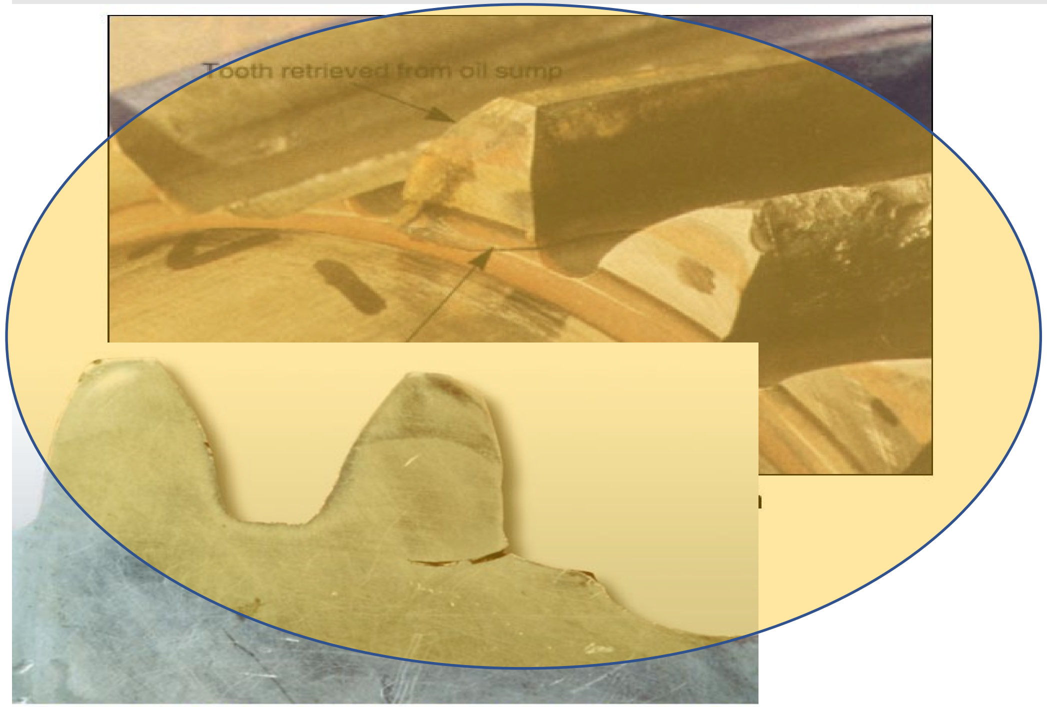


Figure 3. Fatigue Crack in Gear Tooth Root Fillet.

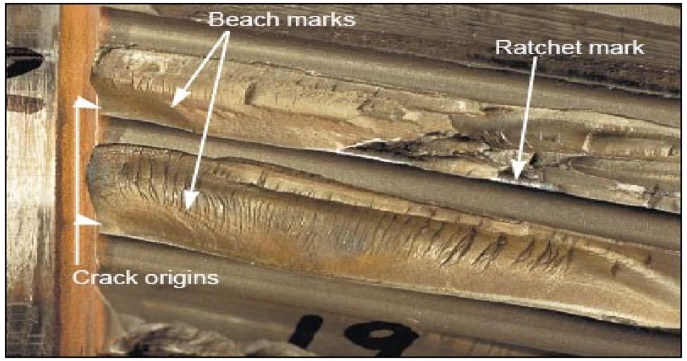
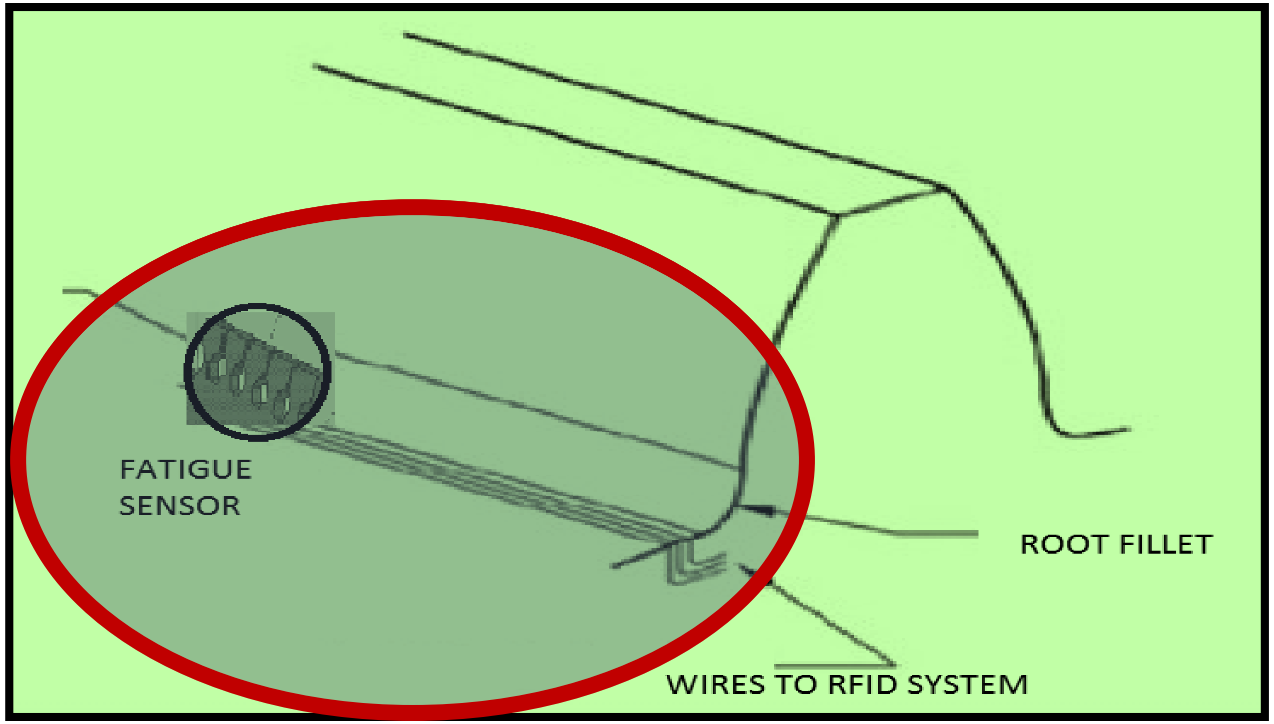


Figure 2 — Bending fatigue fracture surfaces for the wind turbine gear of Figure 1. The leading tooth (bottom) failed first, then shifted additional load to the trailing tooth (top), which also failed.

Bending fatigue is a failure mode that affects gear teeth. Bending fatigue failures occur when the stress at the root of the gear tooth exceeds the capability of the gear material. This can be due to excessive loads, incorrect heat treatment, inclusions in the steel or a notch in the root of the tooth. The appearance of the fracture surface will vary depending on whether the failure was high or low cycle fatigue. Features such as ratchet marks are occasionally present and indicate multiple crack origins. Bending fatigue failures can be prevented by decreasing load, increasing gear material strength or optimizing the gear root fillet geometry.

Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor and Sensor Network for GEAR and GEARBOX PREDICTIVE MAINTENANCE APPLICATION



- **Repairing or replacing a failed wind turbine gearbox is an extremely expensive undertaking. Gearbox failures are one of the largest sources of unplanned maintenance costs in the wind industry.**
- **When a failure occurs, it is important to correctly identify the failure mode so that the appropriate actions can be taken to reduce the likelihood of a reoccurrence of the same type of failure.**

Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor and Sensor Network for GEAR and GEARBOX PREDICTIVE MAINTENANCE APPLICATION

- **Gear is widely used in rotating machinery and transmission devices, and it is one of the most important parts in mechanical equipment.**
- **The research done by gear scientists have shown that gearbox's failure 60% source from gear.**
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