CONDITION MONITORING BASED ON FMECA: A CASE STUDY OF SENSORS SPECIFICATIONS FOR MARITIME

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Abstract:

For Maritime, one technical challenge associated with ship machinery condition monitoring is to select the best suitable sensors technology as ship owners always desires an economically viable, maintenance-free while technically reliable monitoring system. In this case study, condition monitoring of a tunnel thruster based on Failure Mode, Effects and Criticality Analysis (FMECA) was chosen to demonstrate the basic approach to overcome this challenge. Based on potential failure modes, four types of condition monitoring technologies including Vibration Monitoring, Acoustic Emission Monitoring, Wear Debris and Water in Oil Monitoring, and Thermal Monitoring are recommended. Out of these technologies, the sensor specification for a reliable vibration monitoring is discussed in detail as an example.

Key words: Condition Monitoring, Sensor, Vibration, Failure Modes.

Introduction:

In Maritime, the motivation for introducing condition monitoring (CM) is to increase the overall safety level in order to reduce the risk of loss of life and property, also minimizing the costs associated with maintenance. This can be achieved through increased reliability of the component or system being monitored and reduced consequences of failures. All these goals require a deeper understanding of condition monitoring technologies including the immediate needs to define data flow, sharing and hardware specifications of sensors. The technology for condition monitoring is directly related to failure modes, which can be varied greatly for different industries. Technical challenges associated with ship machinery condition monitoring include selecting the suitable technology for sensor data flow, sharing and hardware of monitoring systems.

The process and data flow in a ship machinery condition monitoring system is sketched in Figure 1, where in this paper sensor specifications was rendered through a case study carried out between DNV GL and Rolls-Royce Marine (RRM) involving condition monitoring of tunnel thrusters. [1]

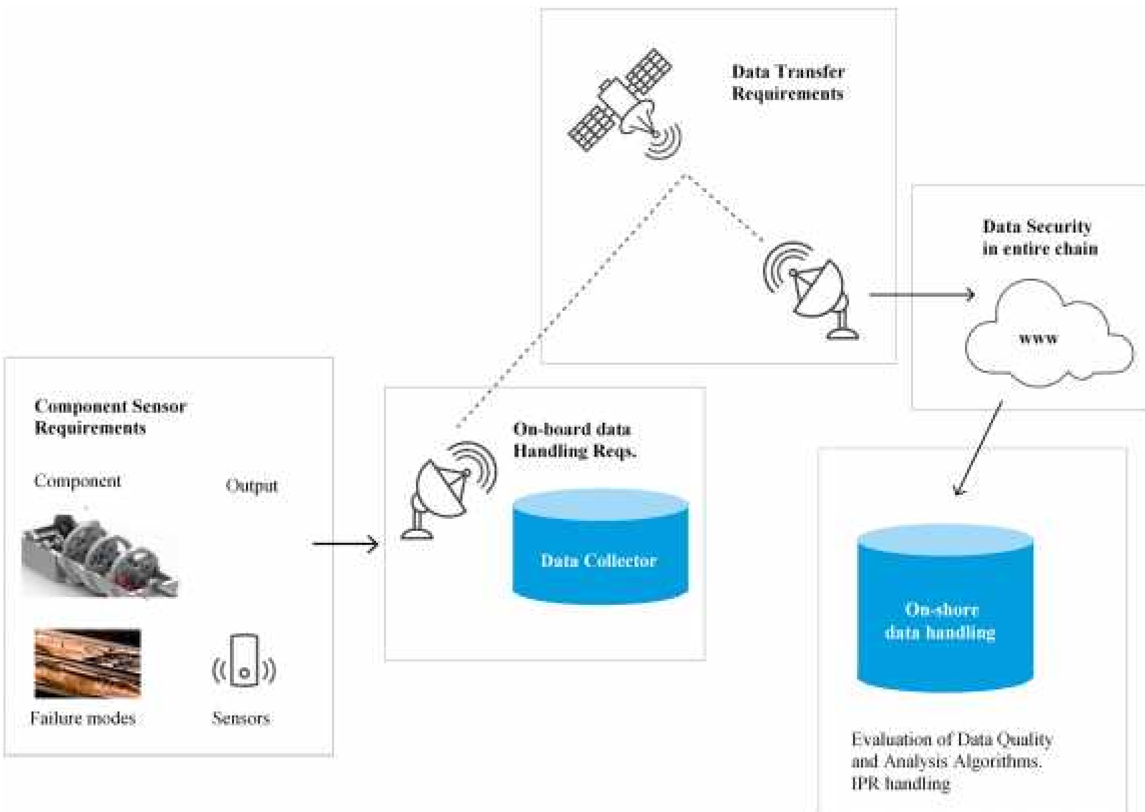

Figure 1: An overview of data flow of ship machinery condition monitoring

Case Study and Failure Modes

A case study involving condition monitoring of tunnel thrusters was performed to demonstrate the basic sensors specifications of CM system based on FMECA concept. Rolls-Royce TT2200 DPN FP thrusters are used as the system for condition monitoring. To carry out an FMECA of tunnel thrusters, many considerations must be given beyond the components themselves, i.e. a systematically analysis need to be performed based on different types (class) of vessels they were installed on and their functionalities. For example, if in a vessel, two identical bow thrusters were installed, then loss of one thruster is acceptable for a short period of operation. In this case, failure of a single component resulting in a system failure can be identified as Medium to High. However, if there is only one bow thruster installed on a vessel, then any failure of a single components resulting in the loss of thruster (the system) is unacceptable and must be prevented from happening in the maintenance plan. In addition, an immediate reaction plan to these incidents must be in place in the condition monitoring plan (maintenance plan). In this situation, any failure mode resulting in the system failure will be identified with a criticality of Very High. Figure 2 illustrated the definition of criticality of this case study and the recommended actions. It should be understood that during this case study, the criticality of each component/subsystem in the tunnel thruster determined was approximately, but conservatively, and only one thruster was considered (for example, loss of this thruster will affect the dynamic position of the vessel). The criticalities as graded in Table 1 were in five categories of Very Low, Low, Medium, High, and Very High. Equipment with Very Low or Low criticality can be subject to corrective maintenance. Equipment with Very High criticality must be considered for re-design/redundancy to decrease criticality. The remaining equipment of Medium to High criticality is to be evaluated further. [2]

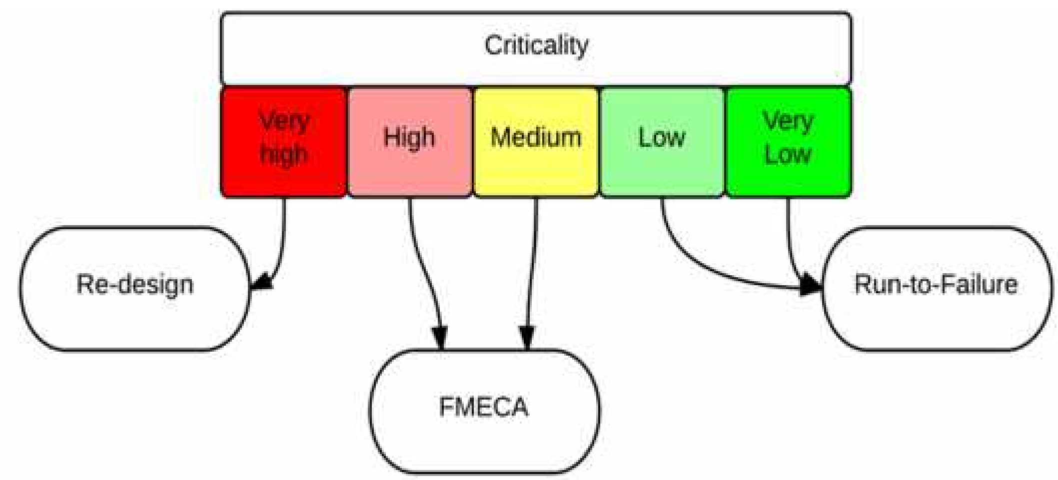

Figure 2: The Criticality definition and the associated actions of the case study

Table 1: Important Failure Modes, Failure Criticality and Monitoring Technology of Tunnel Thruster Case Study.

Component	**Failure Modes**	**Failure Effects**	**Failure Criticality**	**Sensors**
Electric Motor	Overheating	Short motor life to motor failure	High to Very High	Temperature
Frequency Converter	Temperature induced	Components/ system failure, Won't start	High to Very High	Thermography

Shaft	Shaft failure	Components/ System failure	High to Very High	Vibration, Acoustic Emission, UT
	Sheared Shaft, Shaft failure	Seized	High to Very High	Vibration, Acoustic Emission, UT
Tooth Coupling	Teeth wear away	High vibration to system failure	Medium to Very High	Vibration, Torque, Particule analysais/ Wear Debris
	Tooth fatigue failure	High vibration to system failure	High	Vibration, Torque
Rolling Bearing	Rolling contact fatigue	Seized to system failure	High to Very High	Vibration, Temperature, Oil analysis (off site)/ Wear Debris
	Plastic deformation	Noisy/Excessive vibration, Seized Motor, Loss of torque	Medium to Very High	Vibration
Bevel Gear	Plastic deformation	Noisy, Vibration, System Failure	Medium to Very High	Oil analysis (off site)/ Wear Debris, Vibration
	Tooth flank contact fatigue	Vibration, System Failure	Medium to Very High	Oil analysis (off site)/ Wear Debris, Vibration
Propeller Blade	Fatigue failure	Loss of Torque, Vibration, System Failure	Medium to Very High	Torque, Vibration, Ultrasonic
Lubrication System	Pressure drop	Components/System failure in long term	Medium to Very High	Oil Pressure
	Overheating	Components/System failure in long term	Medium to Very High	Temperature

SENSOR SPECIFICATIONS

It is essential to select suitable sensors for ship machinery condition monitoring, not only need to consider the physical elements they measure, but also need to evaluate the installation, cost, maintenance and calibration. Although sensors differ greatly in their physical principles, their selection can be guided by the following procedures:

1. Determine the variables to be measured,
2. Determine the technical specification of sensors for each measurement,
3. Determine the availability and affordability of sensors,
4. Determine the installation, maintenance plan and calibration procedure of sensors.

Based on FMECA and testing results, four types of monitoring technologies are identified as Vibration Monitoring, Acoustic Emission Monitoring, Wear Debris and Water in Oil Monitoring, and Thermal Monitoring. In this paper, the sensor specification of vibration monitoring will be given as an example.

Machine vibration can be measured by three representing motion parameters: acceleration, velocity and displacement. The corresponding vibration sensors are accelerometers, velocity vibration sensors, and proximity vibration sensors, respectively. Selection of a suitable vibration sensor depends on the frequencies of interest and signal levels that are involved. For example, DNV GL Guidance for Condition Monitoring, Classification Note 10-2, summarized the relationships between sources of vibration under fault condition and the corresponding frequencies that significant vibration velocity peaked. These types of table are the basics for determining the technology specification of vibration sensor, and should be prepared in the CM planning phase such as through an FMECA process. Each type of these sensors is mature and can be easily customized to meet ship owner's requirement for condition monitoring. Table 2 is a brief comparison of vibration sensors for the measuring parameters, sensing mechanism, advantages/disadvantages etc. To select the correct types of vibration sensors for condition monitoring, the following criteria can be considered:

1. The source of vibration,
2. The vibration level and frequency range,
3. The temperature range,
4. The environment factors (e.g. corrosive condition or combustible atmosphere),
5. The interference with electromagnetic fields (electromagnetic compatibility) or acoustic fields,
6. Electrostatic discharge (ESD) conditions,
7. Sensor size, cost, packaging and weight considerations.

Accelerometer type of vibration sensors measures the degree of vibration through measuring acceleration. It can measure mechanical vibration levels through a single axis, or determine the type of vibration or the direction of acceleration through tri-axial. Accelerometers designed for measuring vibration are based on the piezoelectric effect. Piezoelectric accelerometer is the mostly used vibration sensors that rely on piezoelectric effect by capturing acceleration data at a faster rate. In a piezoelectric accelerometer, a force applied to a crystal will create a high-impedance charge resulting in a voltage across the crystal. These sensors require an external amplifier (note that most of the modern sensors are designed with integrated amplifier) to amplify the piezoelectric charge and to provide an impedance buffer. They can respond to vibrations with frequencies down to 4 Hz. However, due to the temperature reaction of the material, these devices can lead to thermal noise. Nowadays, many types of commercially available MEMS accelerometers are the better choices for vibration monitoring, because the integrated (built-in) digital signal processor (DSP) and band-pass filter can reduce or even eliminate the noise. [3, 4] Velocity sensors are used for low to medium frequency measurements (0.5 to 1000 Hz) which are useful for vibration monitoring of rotating machinery. Traditional velocity sensors use an electromagnetic coil and magnet system to generate a velocity signal. Today, piezoelectric velocity sensors are becoming popular due to improved capabilities and their rugged nature. However, most of these sensors are bulky and heavy making them unsuitable for vibration measurement of delicate parts. [5] A commonly used displacement vibration sensor is the proximity vibration sensors such as an Eddy-Current probe, which determines the vibration through measuring the change of eddy currents. An Eddy-Current sensor is a noncontact vibration measurement tool with high frequency response (up to 80 kHz) to accommodate high-speed motion. In addition, the ability to determine relatively small motions (i.e. very weak vibration) and non-contact motion make it a suitable tool for engine rolling bearing vibration, shaft motion and internal clearances monitoring. The major drawback of Eddy-Current probe is that they are sensitive to electrical and mechanical noise. In addition, the installation and maintenance of this type of sensors is complex. [6]

Table 2. A Comparison of Three Types of Sensors for Vibration Monitoring.

	Accelerometers	**Velocity Vibration Sensors**	**Displacement Vibration Sensors**
Measuring Parameters	Acceleration	Velocity	Displacement
Sensing Mechanism	Piezoelectric Sensors	Electromagnetic transducer	Capacitance sensors or Eddy-current probe
Major Advantages	Good response at high frequencies; Able to stand high Temperature; Small size	Good response in middle range frequencies; Able to stand high temperature; Low Cost; No external power needed.	Non-contact, No wear; Able to measure both static and dynamic displacements; Good response at low frequencies

Major Disadvantages	Sensitive to high frequency noise; Higher cost	Low resonant frequency and phase shift; Large footprint; Cross noise	Bounded by high frequencies; Sensitive to Electrical and mechanical noise
Wireless Capability	Commercially available	Not available	Possible, not yet commercially available.
MEMS-based devices available	Commercially available	Not available	Commercially available

In the tunnel thruster CM case study, accelerometer type vibration sensors, SPM SLD144S were applied for vibration monitoring of “stern tunnel thruster TT2200 DPN CP” electric motor housing (Non-drive end horizontal direction, and top of horizontal direction, as well as “stern tunnel thruster TT2200 DPN FP” electric motor housing (Non-drive end horizontal direction, and top horizontal direction). The installation locations of these sensors are illustrated in Figure 3. The same type of sensors was also applied for vibration monitoring of starboard propulsion line PTI (power take-in) motor housing and reduction gear housing, and port propulsion line reduction gear housing. The SLD144S sensor is a piezoelectric accelerometer of compression type with built-in preamplifier, designed for vibration monitoring of industrial machinery. It was designed with side entry which is especially suitable for use where installation space is limited, and can be used in harsh industrial environments where moisture/water poses constant challenge, for example, the marine environment where tunnel thrusters were in. The electrical signal is isolated from the transducer housing. The transducer is mounted against a smooth, flat surface on the machine. In the following table, major technical specifications of this sensor are listed. The SLD144S was a type of vibration sensor based on the patented shock pulse method (SPM), which was applied to detect the short duration shock waves caused by rolling element bearing defects. The major difference between conventional accelerometers and SPM sensors compared is that SPM sensors are operated at 32 kHz (resonant frequency). In this way, even weak shock pulses can generate large output signals are generated from. The signals of SPM sensors include both the magnitude of the shock peaks (dBm) and of signal level between the peaks (dBc). In addition, by performing FFT (fast Fourier transform) analysis on the signals. Some degree of the causes of fault can be revealed. [7] The major limitation is that by using SPM sensors, the user needs to use SPM’s data analysis protocol. Based on the manufacturer technical data sheet, a list of general requirement of vibration sensors used for the ship machinery condition monitoring is rendered. However, it is worth to point out that the parameters specified in Table 3 have not been verified and can only be used as general reference based on references. [8-14]

Table 3. Technical Specification for Accelerometers Type Vibration Sensors for Tunnel Thruster CM

Tech Specification	SLD144S Vibration Sensor	General Vibration Sensors for Ship Machinery CM
Nominal sensitivity, main axis	100 mV/g	10-500 mV/g
Transverse sensitivity	Max. 10%	Max. 10%
Typical base strain sensitivity	0.01 m/s2/µ strain	0.01-0.05 m/s2/µ strain
Linear frequency range	2 Hz - 10 kHz (±1dB) (–3 dB at 0.7 Hz)	2 Hz - 10 kHz (±1dB) (–3 dB at 0.7 Hz)
Max. peak acceleration	600 m/s2 = 60 g	100 g
Settling time	3 sec	1-5 sec
Bias point	11 to 13 V (typical 12 V)	11 to 13 V (typical 12 V)
Temperature range	40° C to +125° C (–40° F to 260° F)	0° C to +175° C
Power requirements	24 V /2 - 5 mA	5-24 V (1-10 mA)
Casing	Stainless acid proof steel	Anti-Corrosion/Marine Environment Resist materials preferred
Isolation	Case isolated, > 1 Mohm	Case isolated, > 1 Mohm

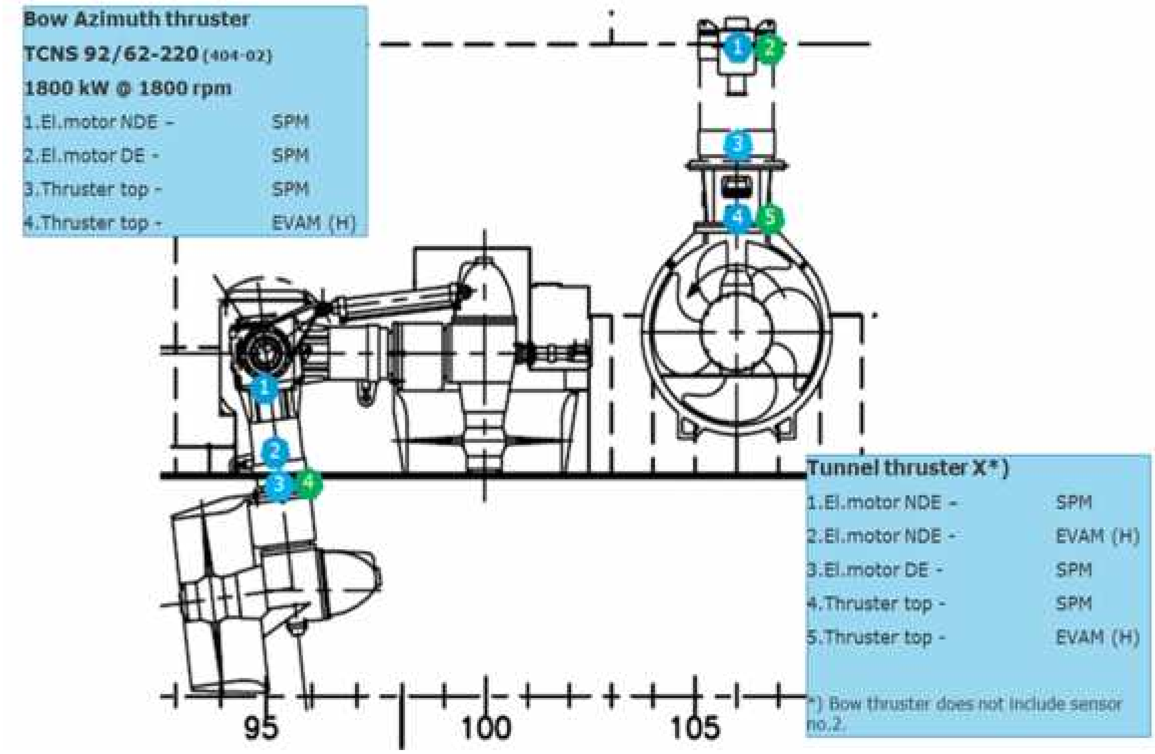

Figure 3. The Sensors Installation Locations for the Tunnel Thruster CM Case Study.

CONCLUSIONS

A case study on CM of tunnel thrusters was carried out as the effects to define the general sensor specification in CM for Maritime applications. Based on the testing results, four types of CM technologies are identified as Vibration Monitoring, Acoustic Emission Monitoring, Wear Debris and Water in Oil Monitoring, and Thermal Monitoring. The sensor specifications of vibration monitoring were given as an example.

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Bibliography:

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