Collection & Analysis of Data for Ship Condition Monitoring aiming at Enhanced Reliability & Safety

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ABSTRACT

This paper presents the onboard measurement campaign for the case study of a container ship and provides a customary methodology for monitoring important machinery systems. The main principle aim of this paper is to collect important machinery data and parameters from critical systems, located in the engine room of the ship, by determining systems to be monitored, scenarios for monitoring, sensors and suitable portable equipment and physical parameters to be inspected.

KEY WORDS: Maintenance; reliability; ship performance; condition monitoring; measurements

NOMENCLATURE

BBN	Bayesian Belief Network
BS	British Standards
C.W	Cooling Water
CBM	Condition Based Maintenance
CM	Condition Monitoring
DSS	Decision Support System
F.O	Fuel Oil
IMO	International Maritime Organisation
INCASS	Inspection Capabilities for Enhanced Ship Safety
L.O	Lube Oil
MRA	Machinery Reliability Assessment
O&M	Operation and Maintenance
P-F	Potential-to-Functional failure
RBI	Risk Based Inspection
RCM	Reliability Centred Maintenance
T/C	Turbocharger
Temp	Temperature

INTRODUCTION

Maintenance is an important contributor to reach the intended life-time of technical capital assets and is defined as a combination of all the technical and associated administrative activities required to keep equipment, installations and other physical assets in the desired operating condition or to restore them to this condition (BS, 1993). Maintenance also includes the engineering decisions and associated actions that are required for the optimisation of specified equipment capability, meaning the ability to perform a specified function within a range of performance levels that may relate to capacity, rate, quality, safety and responsiveness. Furthermore, maintenance costs are a significant portion of the operational cost and breakdowns and downtime have an impact on plant capacity, product quality and cost of production as well as on health, safety and the environment. Thus, nowadays, the shift of maintenance as a strategic perspective within a company organization can be attributed to the utilisation of more advanced technologies, increased emphasis on safety, new environmental legislations, optimised operations with increased fuel efficiency and reduction of emissions (Parida et al., 2015) .

Maintenance was initially treated as a course of action that could be accomplished in a random day by day operation. The main aim was not to lose operational time and to minimise unexpected failures. At first maintenance was nothing more than an inevitable part of production, thus it was considered as a necessary evil. Repairs and replacement were tackled only when necessary with no optimisation taking place. However in the last years this attitude has changed (Pintelon and Parodi-Herz, 2008) and is considered a strategic activity that ensures operation reliability systems and their associated components.

Maintenance tasks affect the reliability and availability standards of the shipping industry and are an important factor in the lifecycle of a ship that can minimize down-time and reduce operating costs (Lazakis and Olcer, 2015). The importance of maintenance is demonstrated by the fact that it is the only shipboard activity to have one whole element assigned to it (IMO, 1993). Also, due to the impact of shipping on the environment and the importance of the safe operation of ships; ship owners and operators pursue to adopt a maintenance plan and procedures that will reduce costs, promote the lifecycle integrity and enhance the energy efficiency of the ship.

Amongst the various forms of maintenance, three types can be distinguished. These are namely corrective, preventive and predictive maintenance. Corrective maintenance was initially applied to ships, while preventive maintenance started being applied to ships successfully due to ISM code and regulations and was then followed by predictive maintenance advances (Lazakis et al., 2010). Predictive maintenance did not emerge as a replacement for corrective and preventive maintenance, but as an additional tool, which seeks to minimize, through the monitoring of specific parameters, maintenance costs and losses in equipment (de Faria Jr et al., 2015). Predictive maintenance can be categorized into three categories of maintenance methods. These are Condition Monitoring (CM), Reliability-Centred Maintenance (RCM) and Risk-Based Inspection (RBI). Nowadays, maintenance is encountered as an operational method, which is employed as a profit generating process and a cost reduction budget centre through an enhanced Operation and Maintenance (O&M) strategy. Therefore, maintenance should seek the intervention in equipment through a strategy of reducing the intervention time, leaving the system unavailable for the shortest time possible (de Faria Jr et al., 2015).

In this respect, this paper presents the onboard measurement methodology as suggested by the INCASS (Inspection Capabilities for Enhanced Ship Safety) FP7 EU funded project. INCASS tackles the issue of inspection and maintenance for ship structures and machinery by integrating robotic-automated platforms for on-line or on-demand ship inspection activities with real time structural and machinery information using sensors. These data will be incorporated with structural and machinery risk analysis, reliability and criticality based maintenance for implementing specific inspection tasks and for providing input to a decision support system for continuous monitoring, risk analysis and management of ship operations. The deployment of the overall developed onboard INCASS system will be based on three case studies (tanker, bulk carrier, container ship) for testing and validating the INCASS framework under realistic operational conditions.

Existing literature related to this study and the INCASS Machinery Reliability Assessment (MRA) tool are briefly summarised in the following section. The data collection sources are then presented followed by the machinery onboard measurement methodology undertaken for the case study of the container ship. Finally, a brief summary of this research outcomes and directions for future research actions are discussed in the conclusion section.

BACKGROUND

Condition Based Maintenance (CBM)

The concept of Condition Based Maintenance (CBM) was first introduced by the Rio Grande Railway Company in late 1940s and was initially called predictive maintenance (Prajapati et al., 2012). There are various definitions on the concept of CBM. Bengtsson (2004) shortly described it as preventive maintenance based on performance and/or parameter monitoring and the subsequent actions. According to British Standard (2012), CBM is defined as the maintenance policy carried out in response to a significant deterioration in a machine as indicated by a change in a monitored parameter of the machine condition. Butcher (2000) defined CBM as a set of maintenance actions based on real time or near real-time assessment of equipment condition, which is obtained from embedded sensors and/or external tests & measurements taken by portable equipment. Hence, unlike breakdown maintenance and preventive maintenance, CBM focuses on not only fault detection and diagnostics of components but also degradation monitoring and failure prediction. Generally, CBM can be treated as a method used to reduce the uncertainty of maintenance activities and is carried out according to the requirements indicated by the equipment condition. Until now it has been difficult to achieve effectiveness of maintenance operations because there is no information visibility during product usage period. However, recently, with emerging technologies such as Radio Frequency IDentification (RFID), various sensors, Micro-Electro-Mechanical System (MEMS), wireless tele-communication, Supervisory Control and Data Acquisition (SCADA) and Product Embedded Information Devices (PEID) are expected to be rapidly used for gathering and monitoring the status of components, sub-systems and systems during their usage period (Shin and Jun, 2015).

In order to develop a CBM strategy, it is essential to understand equipment failure behaviour (Prajapati et al., 2012). Condition monitoring technologies are applied through various tools by recording and evaluating different measureable parameters. These technologies include vibration monitoring, noise monitoring, thermography, oil analysis and tribology, combustion performance monitoring and electrical signature analysis (INCASS, 2014a). Sullivan et al. (2010) also discuss various condition monitoring technologies and techniques such as lubricant/fuel, wear particle, bearing temperature, infrared thermography and motor current signature analysis.

Online & Offline Monitoring Methods

Related to the particular instrumentation used for CBM applications, two methods may be employed: the off-line and on-line methods. The off-line method consists of periodic measurements (e.g. daily, weekly, monthly) and allows trend analysis to be performed for the sampled parameters, after a period of data collection activity. This data will assist in measuring the rate of degradation of certain equipment and machinery systems. The equipment needed to acquire this data consists of analysers or data collectors (permanent or portable equipment), used together with the necessary sensors, a computer and specific software employed. The on-line method is used for continuous monitoring, by installing permanent sensors and wiring to a data acquisition and processing system. This maintenance measure is aimed at critical equipment in the production and operation of the installation of machinery systems and can also be applied to systems where access is difficult or severe ambient conditions may affect the personnel operations (INCASS, 2014a). Therefore by taking into account the above remarks, the appropriate methods for the onboard measurement campaign can be selected.

Vibration Monitoring

Vibration monitoring applications provide an indication of rotational machinery, dealing with environmental conditions, material state and current operational status. It is mostly applicable onboard ships for main engine, diesel generators and pumps rotating components, bearings, gears and shafting systems (INCASS, 2014a). Thus, vibration monitoring techniques can be used to detect fatigue, wear, imbalance, misalignment, turbulence in such systems. Vibration monitoring measures the frequency and amplitude of vibrations. Readings change as machinery wears and these readings can be interpreted as indicators of the machinery condition and maintenance actions can be scheduled accordingly. Vibration readings are taken by first eliminating the background noise associated with an equipment operation. Usually bearings are the best places for measuring machine vibration as these locations are where the dynamic loads and forces are applied. To obtain a complete vibration signature of components, tri-axial measurements should be made at each location with rotating components. Each one of these locations vibrates at one or more distinctive frequencies and different faults cause vibrations at different distinctive frequencies. The mix of these distinctive frequencies results in the complex vibration waveform at the measurement point. The purpose of vibration analysis is to identify those frequencies that can be associated with a source and to detect changes in the overall signature with time in order to execute the appropriate maintenance actions (Tsang et al., 2006)

INCASS Machinery Reliability Assessment

The INCASS MRA tool consists of three stages, the data acquisition and processing, the reliability model and the Decision Support System (DSS). The MRA methodology includes the gathering of data in order to process them. Data is categorized amongst historical, expert and real time monitoring. Raw data (unprocessed information collected from experts and onboard sensors), is transformed to data input for the MRA tool (Figure 1). The collected data is classified by component, sub-system and main system levels. The following phase involves the real monitoring signal processing. At this phase, signals are filtered and unnecessary information gathered from the environment of operation is removed, followed by the transformation of physical sensorial measurements to reliability inputs. The MRA model employs a network arrangement similar to Bayesian Belief Networks (BBNs) (Dikis et al., 2015). This allows for probabilistic and mathematical modelling by considering actual functional relations and subsystem/component interdependencies. Finally, the DSS is utilized for local (onboard) and short term decision making, but also for onshore (global) for longer term predictions and decision features.

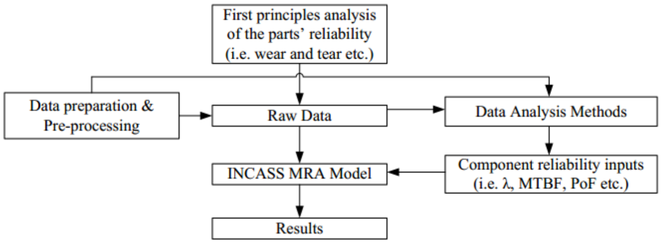

Figure 1. Machinery Reliability Assessment (MRA) process diagram (Dikis et al., 2015)

MRA involves the machinery risk and reliability analysis and processes. At the process level, various methods are employed for the condition and failure diagnostics as well as signal pattern recognition of the received and pre-processed data input. The filtered/processed data is transformed into component reliability inputs such as failure rates (λ), Mean Time Between Failures (MTBF) and Probability of Failure (PoF). Lastly, the INCASS MRA model aims to predict the future condition of the under investigation ship machinery and equipment. This prognostic feature tends to forecast the failure occurrence (failure modes and events), the time that this failure will take place as well as the components, sub-systems and systems that will be affected.

DATA COLLECTION SOURCES FOR MACHINERY SYSTEMS

Data sources for ship machinery systems were extensively examined in order to obtain adequate and useful information for the three case studies (tanker, bulk carrier, container ship) which assists in identifying the most important and critical parameters and systems to be monitored. The identified parameters and systems (INCASS, 2014b), are also critical in analysing and determining ship reliability and performance, compared to gathering a vast amount of data which may or may not be useful for such kind of analysis. More than sixty different documents (reports, drawings) were collected and examined in order to visualize all data and information available. The ship machinery data/information collected is divided into four major subsections. These include Classification Society machinery information, machinery drawings, PMS and real time monitoring data. These sources are used for selecting ship machinery systems and equipment to be monitored and evaluated for the three case studies. However, all three ship types have similar information categories. In the case of the tanker vessel some machinery parameters (e.g. cargo pumps) differ from those of the other ships due to the characteristics of its operational profile. Figure 2, shows the data sources used for the machinery part of the ship.

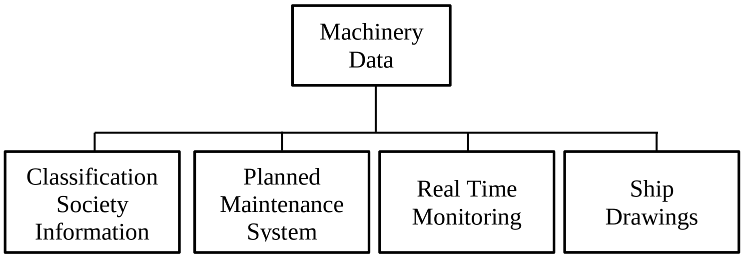

Figure 2. Machinery data sources

Additionally, machinery information contains reliability data, critical jobs list and maintenance information from operators, and real time monitoring data which displays the machinery components and parameter types analysed for condition monitoring. The machinery statutory survey report is one of the most common Classification survey reports that states the condition of the major machinery systems. This report contains the faults identified, actions taken and recommendations for future action and work. This can be helpful on creating historical information on ship machinery and it can be used to determine the reliability of various systems and components. Classification Societies also provide expert incident data for different machinery components. This also helps in determining the reliability of different components. This reliability information in turn, can be combined with conditions of the component failing in order to investigate the risk and criticality values for each component.

Another major drawing is the GA plan which includes different sectional views of the ship that describe the position of ship machinery, such as the engine room and the steering room. Tank top plan view can be also useful as it can give a more detailed map location of the machinery onboard the ship. Within the engine room space, second and third deck plans also describe the particular system components and their interactions with each other more clearly.

Furthermore, one of the major types of operators' report is the voyage noon report, which demonstrates the operational conditions of the vessel at the time of data recording and voyage. A typical voyage report contains information on date, sailing time, location, barometer reading, wind force & direction, speed, voyage distance, wave height, revolutions per minute, fuel consumption and additional remarks. There are various other internal reports generated by ship operators for their own use. One of them is the components jobs report. This report contains the list of all available ship machinery components. This type of report can help to have an idea of the available components on the ship and the typical frequency of maintenance for each of them. This typical frequency can be used as the basis for improving reliability of the components. One other beneficial report generated by ship operators, is the critical jobs report which includes all previous inspection, maintenance and repair jobs performed on ship machinery systems. Finally, it can also provide extra information on running hours of components, which would be vital on determining their associated reliability values. Real time monitoring data is carried out using PMSs and different types of sensors. The machinery systems and parameters selected for the onboard measurement campaign are described in the following section.

ONBOARD MEASUREMENTS METHODOLOGY

The onboard measurement campaign aims at collecting real time monitoring information, raw data, for machinery reliability analysis and assessment. The DSS provides onboard decision support taking into consideration the risk and criticality assessment and the information gathered from the MRA tool, as demonstrated in Figure 3.

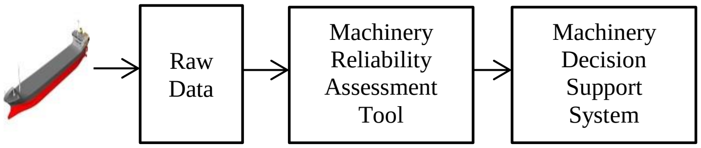

Figure 3. Raw data to DSS framework

The onboard measurement methodology can be seen clearly in Figure 4 which aims in answering which systems/parameters will be monitored (what), when will the selected systems/parameters be scheduled to be monitored (when) from the crew or technicians (who) and if permanent sensors or portable equipment will be used (how). Finally, the cost of implementing different monitoring scenarios, sensors or portable equipment is also taken into account (how much).

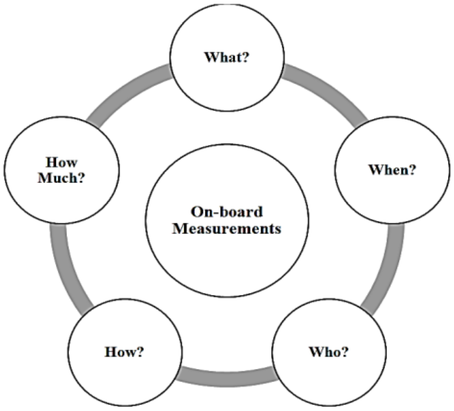

Figure 4. Onboard measurement methodology

Selected Machinery Systems

The major machinery systems selection is based on the data/information gathered as part of this onboard measurement campaign and expert knowledge and experience. Four systems are selected and their corresponding subsystems and components have been examined in order to identify and select which specific equipment and parameters will be monitored. The identification of main systems, sub-systems and components, also reflects the criticality of onboard machinery based on their consequences and impact on ship safety, unavailability and equipment cost. At this point it is important to mention that the initial classification of the criticality level of the machinery systems and equipment was based on industry best practices and standards, as well as on the operating/running hours of such systems onboard ships. Thus, based on the systems selected and the parameters to be monitored, the number of sensors for each system can be designated. The four main systems selected, are namely the ship main engine, turbocharger, steering gear and pumps. These systems are extremely vital regarding ship operation, safety and energy efficiency.

The main engine comprises of systems such as the main shaft, lube oil and fuel oil systems, cylinders, pistons, scavenging air receivers and air coolers, all important both if examined as an individual system but also as an interconnectivity of systems with interdependencies that when operated correctly and maintained efficiently contribute to the safe and efficient operation of the main engine as a whole (INCASS, 2014b). The turbocharger may vary in numbers depending on the engine type. Turbine and compressor blades and inlet piping are monitored. Moreover, the steering gear system includes components such as rams, hydraulic valves, hydraulic pumps, actuators and bearings. Finally, there is a vast number of pumps used onboard a ship for purposes such as heating, cooling, lubricating and transferring fuel to the main engine amongst others. Pumps selected for the onboard measurement campaign include pumps such as fuel, lube, ballast, cooling and fire pumps. Additionally, for the case of the tanker ship, cargo pumps are also monitored.

Monitoring Scenarios & Sensors

Three main scenarios are considered as displayed in Figure 5 for monitoring the condition and performance of the machinery subsystems/components onboard. The first scenario considers the use of only sensors (e.g. thermal, vibration) for the level of monitoring. The data from the sensors will be collected at regular intervals. These intervals can range per hour, per 4 hours, per 12 hours or per day, depending on the requirements and level of analysis to be conducted. The second scenario, considers the combination of attached sensors plus periodic measurements by inspection companies or technicians at various intervals (every 2-4 months). Periodic measurements can be obtained using handheld/portable equipment. Finally, the third scenario considers using only periodic measurements by inspection companies or technicians every 2-4 months intervals.

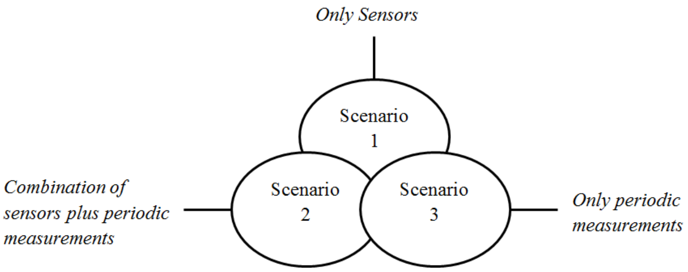

Figure 5. Scenarios for machinery monitoring

These proposed monitored scenarios provide an indication of the various strategies that can be followed in order to measure parameters for machinery equipment based on the requirements and demands of a ship operator or shipping company. The three scenarios provide different configurations for obtaining measurements and time intervals. Moreover, the scenarios will be selected based on further discussions and agreement with ship owners and operators. Thus, is can be seen that the modelling and strategy behind these different scenarios can provide a flexible condition monitoring scheme for ship operators/owners.

Moreover, the type of sensors selected will depend among a number of factors such as the type of machinery, which parameter detects best a specific fault or failure and the frequency range of interest. Additionally the factors were further scrutinised in order to assist with the data collection activity, introducing the variables to be controlled such as temperature, pressure, vibration, deflections and clearances as explained and demonstrated in the following section.

Case Study

Each machinery system consists of several components and these components themselves require various types of parameters to be monitored or calculated. Using the data collected for the selected machinery systems, a list of parameters is generated in order to gather real time data that will be utilised in the MRA tool (Dikis et al., 2015) and decision making.

An onboard measurement campaign was conducted on a Panamax class container ship operated from one of the project partners of the INCASS project. The measurements were collected during the journey of the container ship through the Mediterranean Sea. The main aim of this campaign was to collect data from the identified systems and parameters, in order to utilise this data gathered for purposes of testing and validated the developed INCASS MRA tool (INCASS, 2015d).

During this campaign, the onboard measurement activities regarding machinery systems, were separated into two parts. The first part is related to data collected from sensors and data that already exists onboard the vessel itself. All related measurements referring to this part, were collected from the monitors in the engine room control room, temperature sensors located on the shaft bearings and also from pressure gauges (suction and discharge) installed and located on various pumps located in the engine room. Measurements were collected per hour interval.

Table 1 and Table 2 present a sample of the list of parameters monitored for the turbocharger and main engine, alongside the units used for monitoring these parameters for four hourly intervals (1-4). Tables 1~2 provide information for four continuous hourly intervals Excel spreadsheets have been constructed that contain all data recorded during this onboard measurement campaign for all mentioned systems. Through the data collected and research, it is highlighted that parameters such as temperature and pressure are critical records of ship performance. Furthermore, the engine parameters are the best source for finding out any faults or variations regarding the performance of the engine. For example, variations in temperature, pressure and power produced by each cylinder can be frequently monitored and adjustments can be done accordingly in order to achieve enhanced and efficient engine combustion.

Table 1. Turbocharger parameters measurements

Parameters	Units	1	2	3	4
No.1 T/C L.O Inlet Pressure	kg/cm2	2.7	2.7	2.7	2.6
No.2 T/C L.O Inlet Pressure	kg/cm2	2.7	2.7	2.7	2.7
No1 T/C Rpm	RPM	6040	4380	4447	4385
T/C No.1 Exhaust Gas Out Temp	Deg.C	214	211	218	217
T/C No.2 Exhaust Gas Out Temp	Deg.C	117	116	154	158
L.O T/C Inlet Temp No.1	Deg.C	53	53	55	55
L.O T/C Inlet Temp No.2	Deg.C	53	53	55	55
L.O T/C Outlet Temp No.1	Deg.C	58	57	60	60
L.O T/C Outlet Temp No.2	Deg.C	51	52	54	54

Table 2. Main engine parameters measurements

Parameters	Units	1	2	3	4
Main L.O Inlet Pressure	kg/cm2	2.8	2.8	2.8	2.8
Main L.O Inlet Temp	Deg.C	4.5	44	44	44
Piston Cooling Oil Inlet Pressure	kg/cm2	2.7	2.7	2.7	2.7
F.O Inlet Pressure	kg/cm2	8.2	8.2	8.2	8.1
F.O Inlet Temp	Deg.C	131	137	136	138
Air Cooler C.W Inlet Pressure	kg/cm2	3	3.1	3.1	3.1
Scavenging Air Manifold Pressure	kg/cm2	0.5	0.3	0.3	0.3
Exhaust Valve Spring Air Pressure	kg/cm2	6.5	6.6	6.5	6.6
Camshaft Bearing Temp (Aft)	Deg.C	43.3	44	44.1	44.1
Camshaft Bearing Temp (Fore)	Deg.C	44.5	45.2	45.5	45.7
Thrust Bearing L.O Outlet Temp	Deg.C	47.8	46.3	46.5	46.5
Cyl 1 Exhaust Gas Outlet Temp	Deg.C	283	257	259	258
Cyl 2 Exhaust Gas Outlet Temp	Deg.C	259	229	229	227
Cyl 3 Exhaust Gas Outlet Temp	Deg.C	286	258	260	258
Cyl 4 Exhaust Gas Outlet Temp	Deg.C	274	244	244	243
Cyl 5 Exhaust Gas Outlet Temp	Deg.C	277	233	233	232
Cyl 6 Exhaust Gas Outlet Temp	Deg.C	280	243	242	242
Cyl 7 Exhaust Gas Outlet Temp	Deg.C	296	256	256	255
Cyl 8 Exhaust Gas Outlet Temp	Deg.C	292	249	250	250

For the main engine, most parameters include temperature and pressure readings for fuel oil, lube oil and also temperatures related to cylinders and bearings. The same types of parameters are measured for all other systems. For pumps, suction and discharge pressure are monitored and flow rates. Additionally, parameters such as engine rpm, fuel load indicator and vessel speed were also recorded.

The second part of the container ship onboard measurement campaign is related to data collected and analysed using portable handheld equipment. The different techniques applied for monitoring data on the selected machinery systems (main engine, turbocharger and pumps) include vibration monitoring, ultrasound, current analysis and thermography. In the case of pumps, vibration monitoring was conducted in different Measurement Points (MPs), such as the free end of the electric engine, coupled end of electric engine and the coupled end of the pump. For the case of the main engine, the points as illustrated in Figure 6 were measured.

Data collected on a regular basis is used to monitor trends of certain parameters that represent acknowledged faults. Indeed, the faults that can be detected with this practice need to have a “representative and mostly unique” signature that are monitored along time to detect abnormal variations that may mean a signal for degradation. According to this, these data can only be used in comparison with a baseline taken in the same piece of machinery or similar, when it is known that the machinery is in good condition. Finally, the initial definition for the periodicity of this type of measurements is defined according to its criticality and the expected P-F interval of the different faults. This is then modified according to variations observed in these parameters so it can be then inspected more closely and according to experiences and practices gathered during operation.

Measurement points in the different pieces of machinery are selected according to standardised practices and experience. Finally, acquisition parameters were defined according to the operational condition of the machinery and the fault detection to be captured.

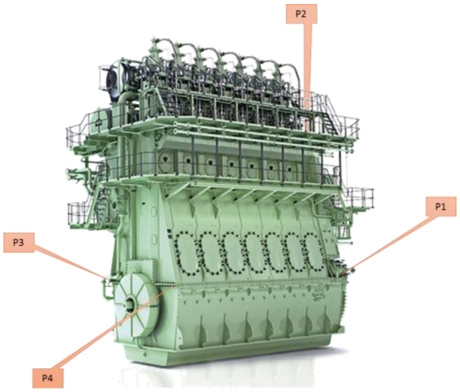

Figure 6. Main engine vibration monitoring Measurement Points (MPs)

During this onboard measurement campaign, several pieces of machinery equipment were measured (Table 3) using commercial equipment (CSI 2130) and a new measurement recording system, developed within the INCASS project, aims to provide and implement an easier and cost-effective predictive maintenance programme, which can be used from crew members onboard the ship. Table 3 demonstrates the equipment measured with the relative technologies and the Measuring Points (MPs).

Table 3. Summary of the measurements performed

Equipment	Technologies	MPs
4 Air compressors	Vibration, Ultrasounds, Current Analysis	4
2 Sea Water Pumps	Vibration, Ultrasounds, Thermography	3
1 Fresh Water Pump	Vibration, Ultrasounds, Thermography	3
1 Fresh Water Ejector Pump	Vibration, Ultrasounds, Thermography	3
Oil-Water Separator	Vibration, Ultrasounds, Thermography	3
Stern-Tube Lube Oil Pump	Vibration, Ultrasounds, Thermography	3
Bilge Pump	Vibration, Ultrasounds, Thermography	3
Feed Water Oil Purifier Pump	Vibration, Ultrasounds, Thermography	3
2 Blowers	Vibration, Ultrasounds, Thermography	2
2 Diesel Engine Generator	Vibration , Ultrasounds	10
Main Engine	Vibration	4
Main Trafo	Current Analysis	1

As previously described, vibration measurements are used to monitor the mechanical condition of pumps, the fouling of the blades as well as their hydrodynamic characteristics. Ultrasounds are a very good technique to detect incipient failures in bearings. Finally current analysis is mainly used to monitor the condition of the electric engines of each piece of machinery. Figure 7 illustrates an image taken during the measurement campaign for the case of an air compressor.

Figure 7. Image taken during the measurement campaign

MRA Validation

The data collected from the onboard measurement campaign will convert the defined parameters that are normally monitored in a regular predictive maintenance programme, into inputs for the probabilistic assessments carried out by the INCASS MRA tool.

The objective of collecting this data is to provide a first initial step in utilising these parameter data for validating and testing the MRA tool in the near future, once sufficient data has been collected from other planned onboard measurement campaigns on the three case studies of the INCASS project.

The validation will be performed in a simplified system (Central Cooling System), as seen in Figure 8, in which different measurements along time will be taken. These data are used in a first stage to define baselines for any of the faults considered in the probabilistic analysis and then the data will be post-processed (comparing them with the baselines defined) to convert them, into input data of a fault tree, which is a widely used tool in various industrial sectors, for reliability and safety analysis of systems. It is likely that during the period of the measurements no actual faults will take place. Thus, some simulated faults will have to be included in the raw signals recorded. These simulated faults will be created according to past experiences in similar pieces of equipment.

The results of this analysis will be then compared with the results obtained from the MRA tool in order to validate the methodology developed within INCASS.

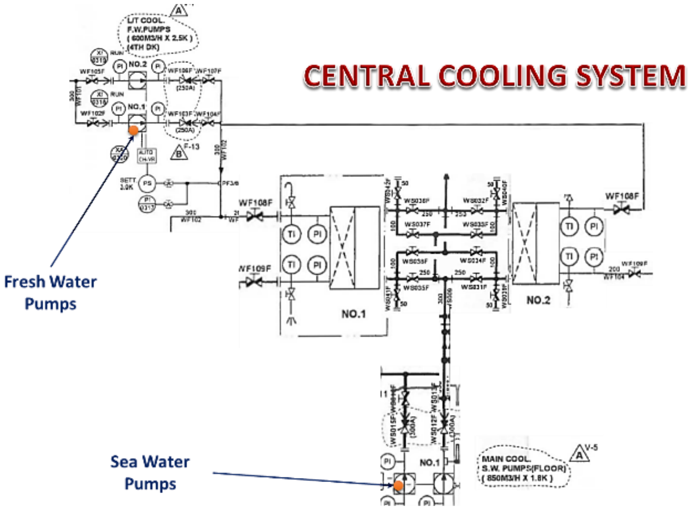

Figure 8. System to be used for the MRA Validation

CONCLUSIONS

This paper presented the onboard measurement campaign for the case of a container ship. The data collection sources required for defining a ship onboard measurement campaign for machinery data was presented and identified. Furthermore, the process for the machinery measurements onboard the ships was demonstrated. Machinery measurements present the definition of the selected machinery systems under examination, the different possible scenarios available for monitoring these systems and the selected monitored parameters. Additionally, the parameters were further scrutinised in order to assist with the data collection activity, introducing the variables to be recorded, such as temperature, pressure, vibration, deflections and clearances. Moreover for each mentioned sub-system, the specific components and the level of survey involving off-line, on-line, periodic monitoring is also identified. The onboard measurement outcome will be further utilised for input in the INCASS MRA tool, capable of calculating and assessing the performance and reliability of ship machinery systems, aiming at optimised operations by applying smarter decisions and maintenance action strategies.

Measurement campaigns have to take place on regular basis in order to monitor the machinery condition analysing trends and changes of system/component behavior. A number of onboard measurements have been scheduled for the container, tanker and bulk carrier until June 2016. These future measurements will provide the means for testing and validating the MRA tool, but also, the INCASS platform as a whole, including the structural reliability tools and the robotic applications. Future research steps include the possibility of also providing the crew of a vessel with handheld equipment in order to send periodic measurements to the shore-based office. A future possibility is also an onboard real time data report and analysis, which for example, could be applied to examine the energy (fuel) utilisation onboard. Additionally, more systems can be monitored such as boilers, generators depending on the level of investment. Monitoring of additional systems under real operational conditions, would ensure safer, increased operational efficiency of the ship with optimised operations such as increased fuel efficiency and emissions reductions. Finally, based on the implementation costs, more sensors can be installed on a specific system of interest or periodic measurements can be conducted, to allow for improved measurements and data collection for analysis and assessment in order to enhance safety, maintenance, efficiency and ship performance.

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