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ICE LOAD MONITORING SYSTEMS, *SHIPRIGHT* SEA EVENT ANALYSIS PROCEDURE FOR ICE

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ABSTRACT

Full scale data provides a valuable source of information to researchers, designers, operators and the wider marine industry, in providing knowledge, understanding and design verification. Monitoring systems have evolved over the years and now employ the latest technological measurement equipment, whilst shipping activities in cold climates has increased significantly in recent years, and been coupled with new operational performance of ships in ice. The ship-ice interaction for these vessels is consequently a significant component of performance and capability in ice, in which full scale data can play a vital component. In recognising these aspects and changes, Lloyd's Register has developed a *ShipRight* Sea Event Analysis procedure for ice, SEA(ICE). This paper provides a summary of key elements of the procedure and measurement systems, including those for hull structures, engineering systems and underwater observations, as well as discussing the attributes of ice trials and noting some of the calculations that can be performed from the data obtained.

1. INTRODUCTION

Full scale data provides a key element in understanding and managing the risks for ships when navigating in ice. These risks include hull and propeller damage due to ice collisions and impacts, which may consequently harm the crew and environment. Ship monitoring systems mitigate these risks by providing a mechanism to warn crew when approaching hazardous situations, whilst also providing researchers a further insight into the ice interaction mechanisms and loads when navigating in ice. Measurement systems also permit designers to compare the ship's ice performance against the specification, thus allowing future ship designs to be improved and reduce the risks when navigating in ice.

Lloyd's Register Ship Event Analysis (SEA) procedure was introduced in January 1997[1], and has had a steady stream of applications to vessels with monitoring systems installed in compliance with the procedure, see Figure 1. Noticeably, there has been a significant number of current applications to LNG carriers.

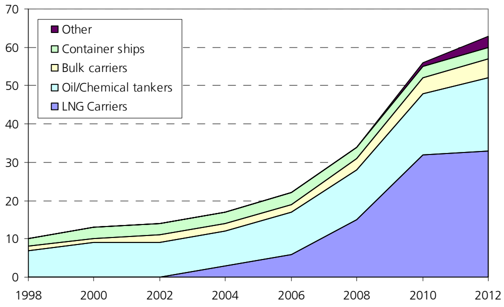

Figure 1. Number of ship types with *ShipRight* SEA notation

The concept is based on providing real-time hull stress, motion and pressure information to the ship's officers in order to assist them in making decisions that will enable them to work within design or operational limits and reduce structural and, in some cases, cargo damage in heavy weather or sea ice. It is recognised that having a hull surveillance system on board is not a total solution to prevent hull structural and cargo damage but, if used properly, it will allow the ship's officers to monitor how the ship is responding against its design limits and allow rapid verification of the effect of any change in speed and/or heading.

Full scale measurements have been undertaken on ships navigating in ice for a number of years. Both Hänninen[2] and Slaughter et al[3] provide useful sources, with inventories of ship ice load measurements. Most systems have been applied to icebreakers rather than commercial ice class ships, however ship designs for navigation in ice are becoming more complex, with advanced icebreaking hull forms and improved propulsion systems, as well as advanced ice detection and navigation equipment, and it is therefore important the crew of these specialised vessels have an understanding of the characteristics and performance in ice. Likewise, as design methods also become more sophisticated there is a clear need for validation with full scale data to verify them. In response to these developments Lloyd's Register has developed the *ShipRight* procedure SEA(ICE). The procedure outlines the systems that can be employed to monitor the ship's hull girder stresses and local ice loads for ships navigating in ice, and warn the ship's personnel that the load levels or the frequency and magnitude of ice impacts are approaching a level where corrective action is advisable. This paper discusses some of the measurement systems for ice and explores some of the facets involved and incorporated in the *ShipRight* SEA(ICE) procedure and monitoring systems.

2. MEASUREMENT SYSTEMS OVERVIEW

Measurement systems will vary depending on the ship type, structural arrangement and machinery configuration. Measurement equipment typically include strain gauges, accelerometer(s) and pressure transducer(s). For each, the installation, set-up, calibration and operational verification varies. In particular, it may be noted that the accuracy, range and frequency response, method of counting, and recording data, may be different for each system. Typically, block diagrams illustrating the operation of the system, description of the method and capability of the data recording system, and description of the output display method, as well as facilities for examination of the recorded data, are required to realise all the aspects of the system.

3. ENVIRONMENTAL AND OPERATIONAL PARAMETERS

As a basic prerequisite, a general measurement system should be provided to monitor the following environmental and operational parameters:

- wind, air temperature and weather conditions;
- sea temperature and ice conditions (the latter measurements may be undertaken by through approximation of ice conditions in way of observations and ice charts, or through specialist equipment, discussed in detail later in this paper);
- vessel speed, position and heading.

Such a system may be naturally included as part of the conventional ship design, and if so would not need to be supplied by specialists with the acquisition of data obtained through equipment normally installed and displayed on the bridge. However, links into these systems, and the drawing out of a subset of data, might need to be arranged. Typically the ship speed, position and wind speed are obtained from the ships Global Positioning System (GPS) and the

National Marine Electronics Association (NMEA) protocol data is filtered and recorded on the main Data Acquisition PC.

4. HULL STRESS MONITORING SYSTEM

Hull monitoring systems may be divided into two aspects, global load and local ice pressure systems. The following discusses the differences in these systems.

4.1 Global ice load monitoring system

These systems are usually applied for icebreakers and icebreaking ships, where aggressive ice navigation is required, such as ramming ice ridges. Typically, the global load systems for ice are a replication of those used in open water. The intention of these systems is to provide a hull surveillance system that monitors the vessel hull girder stresses and motions.

In these applications, the hull stress monitoring system is configured to display in real time and record the hull stress and motion information from at least two strain gauges and accelerometer. The system should measure the hull girder longitudinal stress as close as practicable to the position(s) where it is expected to be most significant. If such stress cannot be measured at the appropriate location then they may be adjusted by a method to represent the stresses in that location. The position of the strain gauges should take account of the structural configuration of the ship and its mode of operation. In general, strain gauges are to be positioned on the upper deck and the vertical acceleration at the bow measured on the centreline, see Figure 2 below.

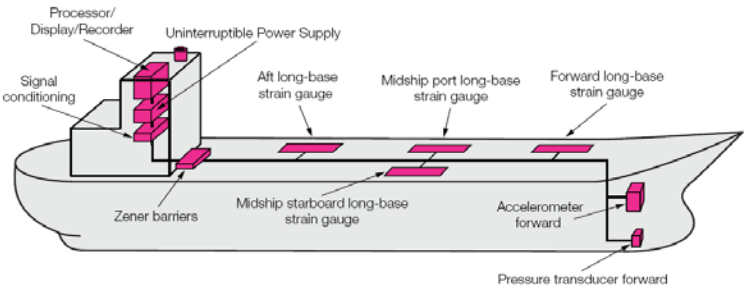

Figure 2. Typical hull measurement system

4.2 Local ice pressure monitoring system (at critical locations)

These are the most common arrangements installed for ships navigating in ice, where the systems are configured to display in real time and record the hull stress from a series of strain gauges along the operating waterline. The systems measure the hull structural member stresses as close as practicable to the position(s) where the ice loads are expected to be most significant. In general, the position of the strain gauges should be near the bow or bow shoulder regions, with the strain gauges arranged along a number of secondary member frames.

A minimum set of strain gauges may be applied in the most significant regions of the ship as an aid to the crew, but the system may also be used for research as a tool to further the knowledge about ice loads acting during the different operations in ice. In this respect, additional tri-axial and uni-axial strain gauges can be placed at other important locations on the hull structure, i.e. at midships, aft shoulder and stern, as well as the bow and forward shoulder. There is obviously an associated increase in installation cost for additional gauges, although this may be considered as a comparatively small cost with regards to the total cost, as any measurement system will require cables, storage system, etc., and thus the installation of gauges only forms one element. In order to position the strain gauges, the results of a finite element computation of the relevant parts of the hull structure may be examined and the results of the measurement programme may also subsequently be compared with these numerical predictions.

4.2.1 Strain gauge configurations

The strain gauges are usually configured to measure the strain through a shear arrangement (uni-axial gauge at 45degs) at either end of the secondary frame or a series of uni-axial strain gauges along the length of the secondary frame, see Figure 3, although other local panel systems do exist. Shear gauge arrangements have the benefit of providing a direct ice load over the length of the frame, whilst uni-axial strain gauges require conversion from the stress on the stiffener. This is however offset by the ease of installation, with the shear gauges being more intricate to install, and the uni-axial gauges also providing a better indication of the location of the ice load acting on the frame, rather than a total force.

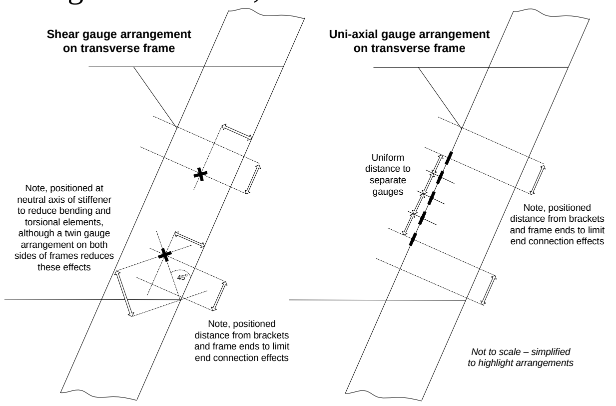

Figure 3. Strain gauge locations and arrangements for transverse frame

Where it is proposed to measure the structural response due to ice loads through the stress in the hull plating, rosette gauges may be used, although it should be noted that determining the ice load from plate structure is a complicated issue. Where these are in addition to the strain gauges provided to stiffeners, as detailed above, they can be fitted to the plating adjacent to the strain gauged stiffener to provide correlating data. Measurements to primary members are specially considered, but in general are provided with uni-axial strain gauges or rosette gauges.

The linear range of each strain gauge should be in excess of the expected ice loads specified in Part 8 of the Rules for Ships[2]. The strain gauges should be configured for temperature compensation and have an operation temperature range suitable for intended environmental conditions which may include low temperatures. The hull strain gauges lead wires are connected directly to a local data acquisition chassis. At this point a USB to Fibre Optic converter is used to transmit the digital data to the ships bridge location.

4.2.2 Strain gauge calibration test

To ensure the working order of the gauges fitted to the hull structure they should be calibrated using a precision shunt resistor and thus simulating a known electrical response from the gauge, which is subsequently recorded on the data acquisition PC, as illustrated below in Figure 4. The pressure measured by the strain gauges at each location should initially be set to the static pressure value due to the ship's draught at an agreed loading condition. The pressure measured by the strain gauges at each location may then checked against a different loading condition. In addition, to calibrate the sensitivity of the gauges, a frame or region may be subjected to a known force using a load cell and pulley system, or similar.

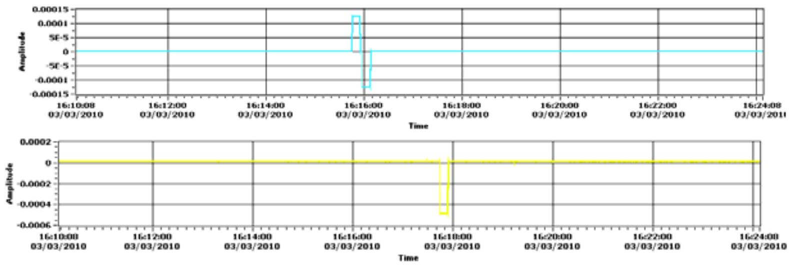

Figure 4. Calibrations for shear gauge (upper graph) and rosette gauge (lower graph). Note the positive/negative calibration result from the full bridge arrangement for the shear gauges and half bridge on the rosette gauge.

5. DATA RECORDING, STORAGE AND DISPLAY

The data recording system using a removable permanent data storage medium, typically through hard drives, should have the capability of storing the required data for a continuous period of at least one month, with facilities to enable the recorded data to be examined. The system should have the capability for continuous recording of the following information:

- maximum, minimum and mean values of stress, acceleration and pressure
- maximum peak to trough values of stress, acceleration and pressure
- number of ice impacts
- time and date referenced to the Universal Time Constant (UTC)
- environmental and operational parameters

It may be noted that previous systems often only recorded and displayed significant ice impacts. However, this often only gives a limited picture of the loads, where knowing when low loads are experienced is just as significant as knowing when high loads are experienced, and technology is now available to continuously record this data.

The displayed information on the bridge varies, depending on the company supplying the equipment. A minimum capability to display maximum, minimum and mean levels of stress, acceleration and pressure, and response trends against permissible limits is generally considered the minimum information to be displayed. The system should also allow the classification criteria for each strain gauge and load calculation from the strain gauge at each measurement location to be viewed.

Whilst a display of real time values are useful, the number of occurrences of significant ice impact events within a (one hour) period (and updated at least every five minutes), should also to displayed. A visual alarm may then be provided to indicate when the measured stress/ice load exceeds the classification criteria or a user selectable criteria. The data should also be displayed in a manner which enables the trends in the data to be seen over (at least) the previous four hours.

When the information provided by the hull surveillance system is displayed in more than one location, the remote display should be identical to those displayed on the visual display unit positioned on the bridge. It may also be preferable to have two (or three) specific monitors thus allowing the crew to simultaneously observe each performance characteristic.

6. INSTALLATION

Early engagement during the design or construction has obvious benefits as there may be a quantity of equipment which may need to be custom made for the vessel, although, clearly this equipment can only be designed once ship parameters and physical properties are fully resolved.

All electrical equipment associated with the hull surveillance system located in hazardous areas should be intrinsically safe and of a type permitted by Pt 6, Ch 2,13 of the Rules for Ships. Likewise strain gauges should be protected from mechanical damage from operations within the space as far as practicable. Strain gauges should be protected against power surges and made watertight, where the latter is particularly important to consider for gauges in ballast tanks and can be achieved using epoxy and mastic coatings as well as water protected cables.

Each data acquisition chassis is normally powered through the ships power and provided with a connection to a USB digital data to fibre optic converter unit. The fibre optic cable is then feed to a reverse converter located on the bridge. It should be noted however, that care is needed during the installation of fibre optics cables due to their fragile state and they should be run in protected and unobtrusive positions.

Cabling will require a combination of dedicated fixed cables for signals and mains voltage supply to the conditioning equipment. Cable runs of monitoring systems are an intricate part of the system and require significant consideration to ensure optimal routing. During installation, routing of cables through piping and manholes may be necessary, and additional gaskets provided to allow the cables to be feed out. Likewise, penetrations through bulkheads need to be considered and meet the requirements for full watertight integrity where cables pass through bulkheads and decks.

The main computer and systems for the centralised control station on the bridge may be located below the floor, with a penetration to the workstation desk to run the power, keyboard, mouse and internet cable connections. The system below the floor can then consist of the associated power sources, USB connectors, and series of external hard drives to record the data. A portable CD drive is also useful so it can be connected for periods to back up data. An internet connection can also be installed to provide the system status and any data acquired.

Generally the systems require minimum maintenance, however any dynamic components may require periodic inspection coupled with calibration measurements. Such work would normally be undertaken on an annual basis and to suit the vessel’s other routine maintenance or lay-over periods.

7. ICE TRIALS AND IN-SERVICE DATA ACQUISTION

During the process of fitting an ice monitoring system, the following phases are typically planned for the project:

Phase 1 Initial discussions, system(s) design and definition of the sensor locations
Phase 2 Installation of system(s), including all necessary sensors
Phase 3 Ice trials and voyages
Phase 4 Continuous monitoring and analysis of the data

All four phases will need timescales and deliverables associated with them. In particular, the length of Phase 4 will need careful consideration, and the amount of crew involvement, as this is an area where most long-term monitoring systems are at risk. As such, prior to the ship entering service, and also during the first voyages, measurements should be recorded to ensure the system is operating correctly and any final adjustments can be made.

7.1 Ice measurements

A fundamental aspect of ice monitoring systems is the measurement of ice conditions. Currently there are very few accurate measurement systems available that can be fitted to ships, so ice measurements are usually confined to dedicated ice trails, rather than whilst in service. During the ice trials, measurements to the ice thickness, ice type, strength, and salinity of the ice and associated periodic sea temperatures is made, by periodically stopping the ship and members undertaking these measurements, see Figure 5.

Figure 5. Ice field measurements

Visual data forms another valuable source of information, and may also be coupled with edge detection software to calculate ice thicknesses. Video images can be made from a number of locations on the ship, although typically form two elements; one of the surrounding ice field usually from external bridge wing cameras, and one for ice interaction observations from cameras arranged to monitor close to the waterline. It should however be noted that these generally capture the ice conditions above the water, whilst most of the physical ice features are below.

A range of ice conditions exist that the measurements can be undertaken in and so should be categorised, including open water, level ice, mid channel, channel edge, ridges, and ice floes. It may be noted that ice channels vary greatly, depending on the width and thickness, for example typical old brash ice channels have 100% ice coverage made up of small floes, whilst new channels may be 80% with larger floes. Measurements of channels thus should include the channel ice thickness and floe size, although noting that measurements in the centre of the channel can only made using a boat. Likewise, floes size vary in concentrations, thickness and diameter.

Ice measurements during trials are also dependent on the actual ice conditions, thus when using these for verification of performance, data interpolation is often required. Equally, with some aspects these are difficult to measure and quantify, such as ice drift, so regions known with ice movement in localised areas should be avoided. Several runs and measurements (minimum of three sets) in similar conditions may also be required to provide sufficient confidence in the data. Measurement of the ice bending strength is typically through a flexural failure test of an ice sample.

The snow thickness data for each day may also be recorded, although it should be noted that the snow may be considered in the resistance (performance) calculations, but for the purpose of investigating the ice loads to the hull structure they may be assumed to be negligible.

Other means of ice measurements include electromagnetic or radar, although often correlation with ice charts and satellite information is a less costly solution. Details of ice thickness detection and measurement systems that are fitted in conjunction with the monitoring systems should include the method of detection, measurement, storage of data and integration with the monitoring system.

7.2 Sequence of trials

In addition to undertaking trials in different ice conditions, the ship conditions may also be varied during trials. A summary of the some of the trial tests is as follows:

- Straight line with varying propulsion settings (e.g. full, ¾ and half power, and combinator settings for controllable pitch arrangements)
- Turning various angles (e.g. 25, 15 and 5 deg), and with varying propulsion settings
- Zigzag manoeuvres various angles (e.g. 15, 10 and 5 deg), and with varying propulsion settings

It is also worth mentioning that during turns, the ships speed should be established and then the turn made (rather than from stationary) to represent typical navigation scenarios. Equally, a zigzag manoeuvre is carried out, principally for the brash ice tests due to the confined width of the channels whilst turning, but also bearing in mind to take into account the potential increase in loads due to the change in heading rotation. The runs may also be varied to include the vessel draught and heel/trim, where the former may be to investigate the propeller performance (i.e. changes in hullform and propeller immersion), and the latter may be to investigate the manoeuvrability in ice (where the change in hull angles may assist in breaking ice). In addition, a number of general manoeuvring measurements may be recorded whilst the ship is navigating between trial runs. It may be noted that the sequence and combination of trial runs will be determined on the basis of ice conditions, the available navigation conditions and time.

8. DATA ANALYSIS

It is anticipated that the data collected will be analysed in accordance with current best practice analysis and data procedures, and compared with the appropriate Rules and Regulations, such as the Polar Ice Class Rules, and *ShipRight* procedures. Additional calculations may include hull local pressures and global loads for specific ice conditions and predefined operating scenarios. The data may also be compared and analysed with respect to previous trials on various ships during ice voyages, in order to determine any underlying trends. The following discusses some of the aspects involved in converting the data and subsequently reviewing this.

8.1 Conversion of strain gauge values

The configuration of the gauges measure the elongation of the material when subject to a change by the resistance change, which is then converted to a voltage change using the wheatstone bridge. So for the conversion of frame shear gauges, the shear strain is calculated through measuring the tensile and compressive strain acting at 45 degs. The vertical force may thus be assumed to be the ice force acting on the frame and calculated from, $Fv = y\ G\ A$. Where, A is the cross sectional area of the structural member and associated plating, y is the shear strain, and G is the Shear modulus (79 GPa for steel).

The first phase of conversion of plate rosette gauges analysis typically includes the strain conversion to stress to give an indicative load acting on the structure. The strain gauge measures strain by the ration of the elongation to the original length and the conversion to stress may be through the relationship between stress and strain in a homogenous material, which may be expressed using Hooke's law. For the rosette gauges, the strain is measured in three directions at 45 degrees, and using Mohr's circle, the stress state on any other plane may thus be calculated including the relationship for the primary stress direction and stress value. The conversion of the stress from the plate field into the subsequent ice loads becomes more complex and requires detailed investigation considering the structural response and ice conditions.

The conversion of the primary members follows the same approach as the plate rosette gauges and, equally in a similar manner, is a complex task.

8.2 Visual observations

Observations form a key element in the analysis to help identify the ice interaction scenarios with the ship during the different ice conditions based on observations using photographs or videos to illustrate particular incidents or aspects. From the observations of ice breaking formations some general correlation between the ice loads in different ice thickness and manoeuvres can be made.

Visualisation of data is also useful, both of the time histories of gauges, so particular features and trends may be observed and in relationship to activity on other gauges or runs, as well as in displaying the data in relation to the ship parameters (such as speed and heading), as shown in Figure 6 below. In the latter it may be noted that in instances with large amounts of data channels pictorial representation of the ship with the measurements overlaid provide a useful means of illustrating the various loads and stresses acting.

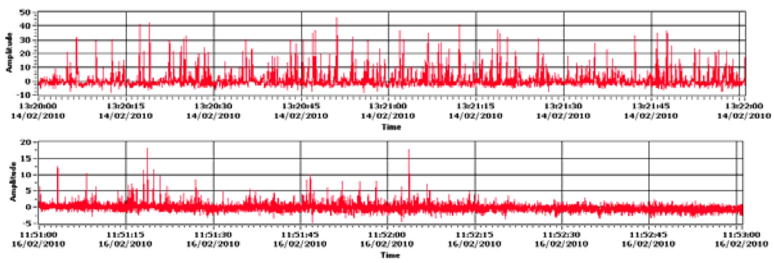

Figure 6. Example of time histories, in 32cm level ice (upper graph) and 21cm level ice (lower graph)

8.4 Statistical analysis

An initial overview of the data includes the maximum, mean measurements, and number of ice impact events. Further detailed analysis includes the rate of loading, relationship between the ship speed, power settings and ice conditions, as well as histograms and probabilities.

9 ADDITIONAL MEASUREMENT SYSTEMS

The following discusses measurement systems that can be installed in addition, and complimentary to, the hull monitoring systems.

9.1 Machinery performance monitoring system

Machinery performance monitoring systems are typically installed on the each of the propulsion units and comprise the following measurements:

- engine rotational speeds
- shaft torques
- shaft thrust
- shaft dynamic bending
- tri-axial vibration measurements vicinity of the shaft bearings
- stern tube bearing temperatures
- control pressures (controllable pitch propellers and steering mechanisms)

The shaft rpm and torque measurement systems are often fitted to the shaft in a position with ease of access. The rpm recording systems typically use an infrared pickup fixed to the ship structure adjacent to the shaft and with reflective tape placed onto the shaft. Cables then run through to a counter timer card in the data acquisition chassis using a once per revolution trigger. Torque may be recorded using a twin chevron torque strain gauge arrangement via telemetry transmitter on the shaft, and a pickup and demodulator by the side of the shaft. It may be noted that dedicated thrust and torque measurement devices may also be installed, which improve longevity, as the units are constructed under more controlled production conditions, although this often is a more costly investment.

The thruster angles and propeller pitch angles can be independently verified using measurement systems or obtained through the manufacturers system through connection to the central processing unit. The propeller control pitch pressures and steering gear pressures are often connected through a series of pressure transmitters along with the hydraulic connections to connector points on the propulsion unit terminal blocks. The cables from the pressure gauges then feed to a voltage input card on the data acquisition chassis.

It is worth noting that due to the variety of system measurements, the signal processing will be a combination of multi and single channel devices, particularly if measuring points will be in disparate compartments. Equally, the cable runs for machinery should be sited out of the way as far as practicable, e.g. behind machinery and along piping etc. (Fibre optic) cables from the machinery chassis to the bridge can lead through the same route as any other (fibre optic) cables used for hull structure systems.

9.2 Propeller-ice-flow observation system

As noted previously, still images and video can provide a unique insight into the performance of the ship and permit understanding of interaction events such as ice impacts, propeller interactions and hydrodynamic effects. Observations of the propeller action can be made during normal open water and ice operation. This has previously be achieved through reinforced glass panels sited in the hull, but also be achieved through the use of Lloyd's Register’s boroscope observation capability. A small number of M20 tapped holes can be inserted in the hull at predetermined locations to enable observations of the propeller action during normal open water and ice operation. Furthermore, these tapped holes, which are fitted with sea cocks, will have the double function of accommodating the boroscope tube and also pressure transducers should these be required. These observations can be made in a number of locations for different views and also synchronised with the other measurements described.

9.3 Ship Motions

Accelerometers can be installed to measure movement and displacements of the ship. The accelerometers may be located in critical positions and are typically set to record in three directions, x - longitudinal, y - transverse, and z - vertical. These can also be combined with rotational rate sensors to measure the total ship accelerations and the three-dimensional angular rotational rates of the ship. Multiple sensors can be arranged on the ship to compare ship motions at different locations to determine the flexibility or rigidity of the ship, and global ice impact forces can be calculated by reverse engineering the force that would have been required to produce the measured ship's response under certain ice load scenarios. These systems can also be combined to compliment with the hull stress monitoring systems, and thus provide greater accuracy of ice loads and ship response.

9.4 Noise and vibration monitoring

Icebreaking requires increased engine power and significant energy, part of which is released through noise and vibration. The continuous monitoring of noise and vibration can be carried out compartments, such as machinery room(s) living quarters, and specialised equipment and laboratory rooms. The noise and vibration measurements can be synchronised with other measurements described in this paper and the results displayed on the bridge in the similar manner. It is likely that a commercial-off-the-shelf system, suitably customised, can be suitable for this purpose.

9.5 Monitoring of thermal response of hull and deck materials

Suitable steel grades are used to protect against brittle failure, which may lead to the potential loss of the ship due to structural failure, crew injury due to deck equipment material failure, or environmental damage due loss of vessel hull integrity or cargo deck equipment operability. Temperature measurements can be made on a variety of key structural primary members and critical locations around the vessel, such as external shell plating, deck strakes, stern plating, internal stiffeners, etc. In addition, a number of deck equipment and systems can be measured, such as bollards, winches, cranes, piping systems and valves. The measurements can be made using a number of thermocouples and thermometers equipped with recording devices, as well as a hand held infrared thermometer. The combination of devices would record the steel temperatures and would register and record the space and external air temperatures in the various locations.

9.6 Ice accretion and winterisation

Icing onboard a ship is caused by freezing spray and atmospheric icing from rain, fog, snow etc., and presents a major obstacle for ships. The principal danger is of the additional weight above the centre of gravity and consequently the loss in stability. However, ice accretion will cover exposed equipment and needs to be removed to allow access. Ice may be removed with mallets and spades, assisted by pressurised hot water and steam jets. However, sensitive equipment, such as electrical actuators, should be protected from these operations and mediums. Systems to measure the ice build up permit an early warning system to crew such that corrective action may be taken, or so that trace heating systems can be activated. Likewise monitoring systems can be applied that control the heating of the winterised items and provide efficient use of the electric or steam capacity.

10. CONCLUSIONS

Lloyd's Register *Ship Event Analysis* procedure was first published in 1997 and has since been implemented on an increasing number of ships. The procedure provides an industry standard for ship monitoring systems and the latest update to include SEA(ICE), for ice load monitoring systems, provides a further enhancement for ships operating in low temperature environments.

The development of the procedure has included a number of notable aspects, including the global and local ice load measurement systems, along with the associated measurement equipment, storage and display requirements. As a result, ice monitoring systems assist the ship’s officers in making decisions that will reduce the risk and protect the ship, and give greater confidence in operations in the ice conditions.

It is however acknowledged that further research is needed in this field and that monitoring systems provide a valuable mechanism in the development and enhancement of ship designs and operations. It is hoped that more systems will be employed in the future towards this end, and with open forums to exchange data. The aim of developing our knowledge in this subject will improve the safety in cold climates for the ship, crew and environment. The *ShipRight* procedure provides a significant step towards this goal.

11. ACKNOWLEDGEMENTS

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