ShipRight

Linked Supporting Services

Annexes to Machinery Planned Maintenance and Condition Monitoring

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Lloyd's Register

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Document History	
Date:	Notes:
May 2004	Separate document created containing Annexes A to C. Annexes removed from ShipRight Procedure 'Machinery Planned Maintenance and Condition Monitoring'.
November 2004	Revisions as identified in 'Annexes to Machinery Planned Maintenance and Condition Monitoring – Changes incorporated in November 2004 version'.
March 2013	Revisions identified for introduction of ShipRight MCBM. Revisions to section B4.5 and Table B3 Analytical tests and alert levels for sterntube lubricating oil in accordance with IACS Recommendation No.36 Rev2
May 2017	Consolidated version. Includes the requirements of IACS Rec 143 'Recommended procedure for the determination of contents of metals and other contaminants in a closed fresh water system lubricated stern tube'. By adding a new section in Chapter 2 entitled 'Lubricating Water Monitoring (Closed Fresh Water System Lubricated Stern Tube)'.

Guidance on Planned Maintenance

■ *Section 1*
The Planned Maintenance Approach

Maintenance may be described as the activity of keeping structures, systems and components in good operating condition. It is an organised activity that involves both administrative and technical functions. Some common approaches to maintenance may be defined as follows:

- **Preventive maintenance**. This calls for structures, systems and components to be opened out for inspection and overhaul at specified time periods, or after a specified number of running hours, in order to ensure that the structure/system/component is in a satisfactory condition for continued operation.
- **Condition Based Maintenance**. In this case the need for maintenance is based on the performance or physical state of the structure/system/component, as determined by regular or continuous checks of applicable parameters. Maintenance is only undertaken when conditions have approached or reached the lowest acceptable standard and before serious deterioration, breakdown or failure occurs.
- **Corrective maintenance**. This is sometimes referred to as unscheduled or breakdown maintenance. It is only carried out to restore a structure/system/component back to operational condition after a failure or malfunction.

The relationship between these maintenance concepts is illustrated in *Figure 1.1.1 Relationship between maintenance concepts*. The foundations of a planned preventive maintenance scheme acceptable to Lloyd's Register are in practice made up of a combination of time and condition based maintenance methods. In addition, to deal with unforeseen circumstances, any planned maintenance scheme must also be able to deal with corrective maintenance.

It is recognised that alternative approaches to the management of maintenance may provide an equivalent level of safety and reliability. For example, Reliability Centred Maintenance (RCM) offers a structured method for analysing a system's capability to perform its functions from design through operation to decommissioning. The primary objective is to ensure the ongoing functionality of a system and this is achieved through a maintenance strategy determined from the detailed analysis. The strategy may include the use of preventive, condition-based and corrective maintenance.

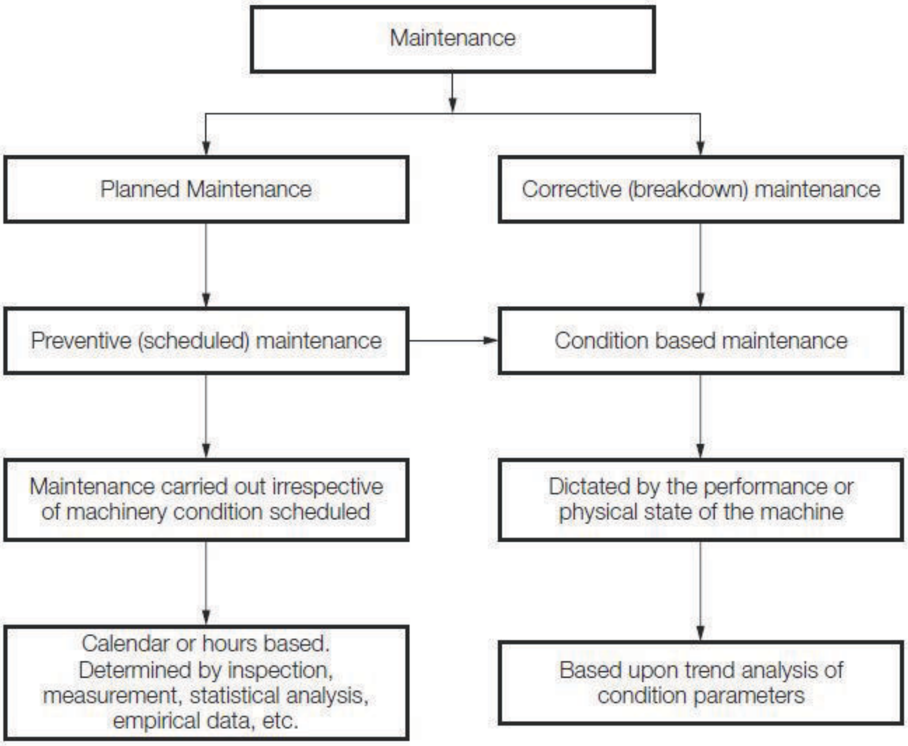

Figure 1.1.1 Relationship between maintenance concepts

■ *Section 2*
Software Based Planned Maintenance Systems

A Planned Maintenance System (PMS) is the device which facilitates the process of planning, directing, and controlling all aspects of maintenance for all systems, subsystems, and components within a defined facility. This can be on a ship by ship basis, or across a fleet. In the majority of cases these systems will be software based as the functionality and degree of integration with other parts of the business in the modern shipping context can be complex and requiring many repetitive tasks to be performed simultaneously.

The administrative functions of a software based planned maintenance system are essentially no different from older card index systems, although there are considerable advantages to be gained. In the speed of updating and retrieving information, simplified spares and stock control and the ease of trending and performing diagnostics using condition monitoring data. Interactive systems can be arranged according to the needs of the ship so that various functions can communicate, recalculate and adjust recommendations accordingly.

Some of the functions that may be found in a software based PMS are:

- Component listing to include Lloyd's Register master list numbers and identify where condition monitoring is applied.
- Maintenance schedule or planning chart, including the identification of class surveys and items dealt with.
- Job listings with dates and references.
- Details of overdue items.
- Maintenance history for each component including breakdown and defect details.
- Standard job descriptions and manufacturers service instructions.
- Condition monitoring procedures.
- Surveyor Report function.
- Exception reporting for unplanned maintenance.
- Technical data for machinery items, including references to manufacturer's service letters.

- Running time and loading data for specified machinery items.
- Spare parts information including identification, location, vendor listing and details of parts used.
- Spare parts requisitions.
- Arrangements for detailing with unscheduled maintenance.
- Security features allowing access only to authorised signatories.

■ *Section 3* **Overdue items**

No matter which type of scheme is devised it should have flexibility. Projected dates for the work to be carried out in a given period may not always be achievable, either through lack of opportunity or because the necessary spares are not available. The scheme must cater for outstanding maintenance and clearly indicate those items that are overdue and the proposed new schedule, noting that jobs may be ‘data collecting’ jobs as well as proactive physical maintenance.

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Guidance on the Interpretation of Condition Monitoring Records

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■ *Section 1*
Introduction

1.1 Purpose of document

The purpose of this document is to provide simple and practical guidelines on some of the most useful condition monitoring techniques. It gives guidance to ship Owners/ship managers who wish to establish a condition monitoring system on their ships. It is also a guide to Lloyd’s Register Surveyors who are presented with condition monitoring data as part of the survey of marine machinery. Please also refer to the Lloyd’s Register booklet; *A Guide to Condition Monitoring of Marine Machinery*, (ISBN 1-900839-27-X) which is available through the Lloyd’s Register Web Store.

■ *Section 2*
The Condition Monitoring Approach

2.1 Introduction

Condition monitoring may be described as the use of instrumentation to make regular or continuous measurements of certain parameters, in order to indicate the physical state of the machine, without disturbing its normal operation.

ISO 13372 – *Condition monitoring and diagnostics of machines* – Vocabulary states that – condition monitoring is the detection and collection of information and data that indicate the state of a machine over time.

Note

The machine state deteriorates if faults or failures occur. This information may be used to assess the condition of a machine at any given time. The trend characteristics of the monitored parameters may be used for predicting the remaining useful life before component deterioration or loss of performance reduces its ability to carry out its required function adequately.

The extent to which the planned maintenance scheme incorporates maintenance based on condition monitoring is at the Operator's discretion. It will normally be determined by the criticality of the machine concerned, the cost effectiveness of using condition monitoring as opposed to preventive maintenance and the ease with which the operating engineers can interpret the results. No matter which monitoring techniques have been incorporated in the scheme, it is important to appreciate that the rate of change of condition is just as important as the actual levels, so the value of trending the readings cannot be over emphasised.

2.2 Monitoring techniques

One of the most common techniques for determining the condition of rotating machinery is Vibration Analysis. All machines vibrate and in many cases a machine’s condition can be judged by comparing the measured broadband or ‘overall’ vibration with its normal and limiting values. In addition, a frequency analysis of the vibration signal enables the diagnosis of machinery problems. Guidance on the interpretation of condition monitoring records is given below.

A complementary approach for determining the condition of a machine is to use Performance Monitoring. For simple items such as pumps it would be normal to record suction and discharge pressure and motor current at the same time as the vibration readings are taken.

More sophisticated monitoring is necessary for reciprocating machinery. For example, diesel engine combustion pressure-time curves give information regarding the overall sealing between liner and piston rings, the balance of the engine and the condition of the fuel injection system and the general effectiveness of combustion.

Monitoring machinery condition by Lubricant Analysis allows the engineer to identify the presence of metallic wear particles carried within the oil stream. These metallic particles are analysed by type to determine which part of the machine is wearing and, by using trending, how fast. Often a secondary Wear Debris Analysis is invoked to assess in greater detail the significance of unusual wear metal results. A secondary function of Lubricant Analysis is to detect changes in the oil condition that will, if left unchecked, lead to an increased risk of failure. The type of issue that would be highlighted here would relate to increases in foreign substances such as water, dirt, soot, fuel etc, which can degrade the functional properties of the lubricant. Guidance on the typical analytical tests performed by most analysis services, examples of abnormal results and recommended actions to be taken are given below.

Thermographic imaging cameras can be used to scan the infrared emissions from any surface and produce thermal maps of the scanned area. The complete thermal image is particularly useful in detecting local overheating in electrical equipment caused by dirt, loose connections, short circuiting or unbalance in 3-phase power supplies. Thermal imaging can be used to monitor mechanical machinery for detecting uneven heat distribution caused by faulty bearings. It is also a useful aid in monitoring leakage from exhaust and steam systems as well as in ensuring insulation integrity of refrigerated spaces and furnaces. Guidance on the interpretation of results and standards applicable to thermography is given below.

Viewing different aspects of condition monitoring data simultaneously can assist correct interpretation of the results. For example an historical plot of vibration of a diesel engine turbocharger, viewed at the same time as the record of its bearing temperatures and the results of bearing lubricant analysis can provide the perspective needed to reinforce an opinion about the course of an abnormality. This may be further assisted by viewing the behaviour of other parameters in conjunction with those that show the abnormality or by analysing the performance of similar machinery on other ships in the fleet.

■ *Section 3* Vibration Monitoring

3.1 Introduction

Vibration monitoring involves the acquisition of vibration data which can then be compared over a period of time. The emphasis is on any changes in vibration behaviour rather than any particular behaviour by itself. Changes in vibration behaviour may occur for a variety of reasons, for example changes in balance, changes in alignment and worn/damaged bearings. Vibration measurements for condition monitoring may vary from simple to complex and can include continuous or periodic measurements.

Vibration monitoring systems may utilise permanently installed, semi-permanent or portable measuring equipment.

Permanently installed systems. These systems have transducers, cabling and associated signal conditioning permanently installed, with data collected either continuously or periodically. Such systems are normally only installed on complex or critical machinery, main propulsion steam turbines for example.

Semi-permanent systems. In this type of system the transducers are normally permanently installed and data is collected periodically using portable instrumentation. An example would be a turbine driven feed pump where access is difficult.

Portable monitoring systems. In general, such systems are used to record data manually at pre-selected locations on a machine at periodic intervals using a portable data collector. The data is downloaded to a computer that has appropriate software for processing and analysis. Portable systems are often used for auxiliary rotating machinery.

For consistent and comparable results, measurements should always be taken under operating conditions, that are as close as possible to those that may be considered as ‘normal’ for the machine. This requirement also covers weather and environmental conditions. Condition monitoring often involves an examination of the rate at which vibration values change with operating time. It is clearly important that operating measurements during successive measurements remain unchanged, as far as practicable. Many modern portable data collectors are equipped with the facility to indicate to the technician that the collected data is sound. This is an important feature as portable data collection is prone to human error and poor data cannot be confidently assessed. It is for this reason that persons engaged in data collection are required to be competent to do so and in general should be expected to hold the relevant certification validated by a recognised third party.

3.2 Vibration parameters

Vibration may be expressed as linear/angular displacement, velocity or acceleration. In practice, there are two types of vibration measurements that are normally used for shipboard condition monitoring of rotating machinery:

(a) Vibration measurements made on the non-rotating structure of the machine, such as bearing housings and casings. The most common measurement parameter is root mean square (r.m.s.) velocity in units of millimetres per second (mm/s). For gearing and high speed machines such as steam and gas turbines, peak acceleration is also often used and expressed in units such as metres per second squared (m/s^2) or in terms of ‘g’, the acceleration due to gravity (9,81 m/s^2).

(b) Relative motion between a rotor and the stationary bearing housings. The measurement parameter is commonly peak or peak to peak displacement in units of µm.

Special techniques are often used for the detection of defects in rolling element bearings. Various parameters such as shock pulse, spike energy, Kurtosis factor and acceleration crest factor can be used to indicate health. The measured values are often dependent on the instrumentation used and there are no internationally recognised standards for acceptability. The use of 'enveloping' is another powerful technique to extract information from rolling element bearing vibration data.

3.3 Vibration measurements

Bearing housings constrain the cyclic forces causing machinery vibration and hence they are ideal locations for measuring vibration. Measurement should never be taken at freely vibrating surfaces such as couplings or fan guards. Measurements should normally be taken in axial and radial planes with reference to the shaft axis and always in the direction where the stiffness of the structure is the least. If the bearing housing is not directly accessible, measurements should be taken on the nearest part of the adjacent structure that is rigidly connected to the bearing.

To achieve repeatability it is important that the locations of measurement points for portable monitoring systems are clearly marked and identified using a consistent convention.

Two types of transducers are commonly used for vibration monitoring:

(a) Full contact permanently or magnetically mounted accelerometers, whose outputs can be processed to give any of the three vibration parameters, acceleration, velocity or displacement.
(b) Non-contacting proximity probes, whose output is directly proportional to the relative displacement between the rotating and non-rotating elements of the machine.

All devices used in explosive environments (the pump room in an oil tanker, for example) should be intrinsically safe.

Repeatable and accurate vibration measurements on stationary parts require good contact between the transducer and the vibrating surface. Fixed transducers may be attached by drilled and tapped holes in the transducer and the machine, and joining the two by a threaded stud. Mounting surfaces should be clean, smooth and flat to avoid undue strain on the transducer. Alternatively, non-flexible cements can be used to attach the transducer to the surface. Portable systems may utilise a permanent magnet attached to the base of the transducer, quick connect couplings or hand-held probes. This should ensure that the accelerometer has a sound connection to the machine and is held at a repeatable position relative to the surface. Non-magnetic hand held accelerometers should not be used as the position will vary from reading to reading with the potential to introduce false readings.

The method of attachment has an effect on transducer performance, particularly the ability to detect high frequency vibration. For example, hand-held probes are only suitable for frequency ranges up to 1000 Hz and suitable filters should be in place to prevent signals above this frequency.

3.4 Calibration

Calibration of the instrumentation used to collect condition monitoring measurements should be carried out according to the manufacturers guidelines, or annually where these are not provided. During the annual audit of the condition monitoring records, the Lloyd's Register Surveyor should verify that any calibration certificates are up to date and appropriate for the installed sensors.

3.5 Baseline measurements

Baseline vibration data is data measured when the machine is operating at its normal load in a stable and acceptable manner. All subsequent measurements will be compared to these baseline values to detect vibration changes. For new or overhauled equipment, time should be allowed for a wear-in period before baseline measurements are taken. For equipment that has been operating for a significant period, baseline data can still be acquired and used as a reference point to detect future changes.

Baseline data should consist of a comprehensive set of measurements to define the vibratory behaviour of the machine. Subsequent periodic measurements need only be sufficient to detect changes and if necessary the baseline measurement procedures may be repeated to help determine the cause of the changes. For example, baseline data for a turbo-alternator may include broadband vibration measurements at all bearing positions, together with frequency spectrum analysis for each measurement. Periodic measurements would involve broadband vibration measurements at selected locations only.

Details such as shaft speeds, bearing and gear geometry, coupling and foundation type, model, serial number, capacity, electric motor power, number of motor poles, etc. should be recorded to enable detailed analysis of the vibration data.

3.6 Vibration analysis and assessment

Different types of machinery problems cause different types of vibration. For example, an unbalanced rotor causes a machine to vibrate differently than a worn bearing. These differences are often indistinguishable to the touch or ear. However, vibration monitoring equipment converts the vibration signals into analysis formats that help the diagnosis of problems. Two frequently used analysis formats are broadband or 'overall' vibration and frequency spectrum analysis.

3.7 Broadband vibration

Broadband vibration measures the total energy associated with all vibration frequencies generated at a particular measurement point. Values of broadband vibration can be compared to baseline measurements, assessed against vibration standards or alarm set points and displayed in trend plots to graphically show changes in machine condition over time.

Various International Standards specify the acceptable broadband vibration values for different types of machines (see References). For example, *Table 2.3.1 Vibration limits for electric motor driven rotating machinery* gives the values for assessing the vibration severity of rotating machinery driven by electric motors of various sizes.

However, absolute limits set by International Standards should be treated with caution, as they take no account of a machine's operating environment. If used to determine alarm set points they should be treated as a starting point, from which in-service experience is used to raise or lower the set point as appropriate.

For condition monitoring purposes it is often more important to observe the rate of change of vibration levels than singular values and trend plots are used to present this information. *Figure 2.3.1 Typical plot of vibration readings* shows a typical trend plot for a motor driven pump.

Table 2.3.1 Vibration limits for electric motor driven rotating machinery

	Small machines < 15 kW	Medium machines 15–75 kW	Large machines > 75 kW	
	Limit (mm/sec rms)	Limit (mm/sec rms)	Rigid foundations Limit (mm/sec rms)	Flexible foundations Limit (mm/sec rms)
Good	0,7	1,1	1,8	2,8
Satisfactory	1,8	2,8	4,5	7,1
Unsatisfactory	4,5	7,1	11,2	18,0
Excessive	> 4,5	> 7,1	> 11,2	> 18,0

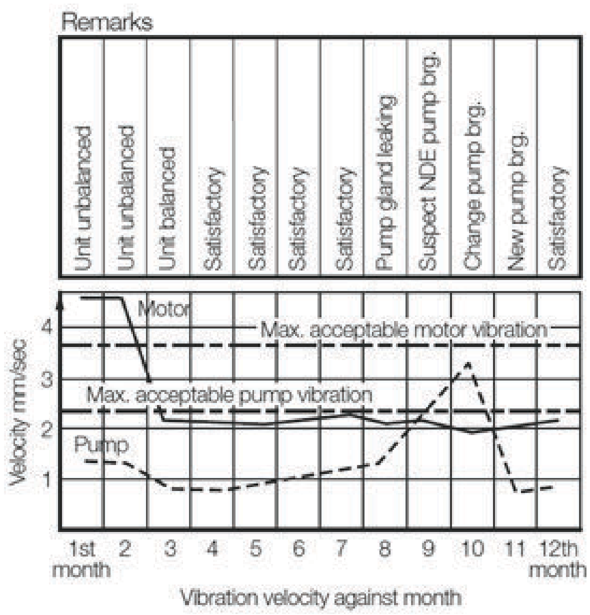

Figure 2.3.1 Typical plot of vibration readings

3.8 Frequency spectrum analysis

Because different types of machinery problems generate vibration at different frequencies, it is very useful to break down a vibration signal into individual frequency components. The amount of vibration occurring at any particular frequency is called the amplitude of vibration at that frequency. A plot of amplitude against frequency is called a frequency spectrum, sometimes known as a 'vibration signature'. Frequency is generally measured in cycles per second (Hertz, abbreviated to Hz), cycles per minute (cpm) or Orders, where:

Order = Frequency of vibration in cycles per minute/Rotor speed in revolutions per minute

Figure 2.3.2 Typical vibration signature shows a typical vibration signature.

Frequency spectrum displays are very useful in evaluating machinery condition. High vibration levels at certain orders of the rotational speed are generally indicative of faults and can be used as an aid to fault diagnosis. Some of the common faults in a rotating machine are indicated in *Table 2.3.2 Typical interpretations of the causes of vibration at specific frequencies*.

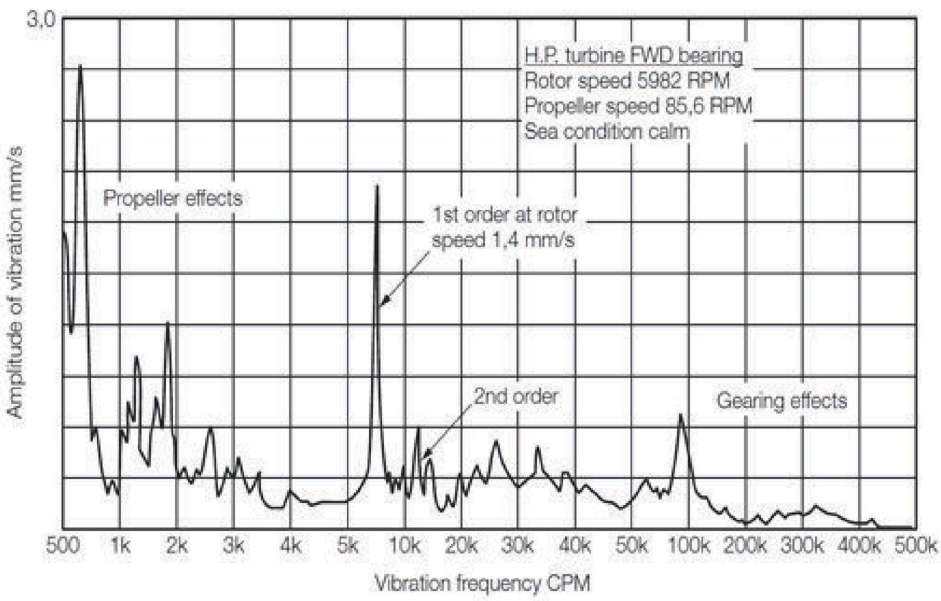

Figure 2.3.2 Typical vibration signature

Table 2.3.2 Typical interpretations of the causes of vibration at specific frequencies

Frequency of vibration	Order	Most likely cause	Amplitude	Other possible causes and remarks
1 x Rotor RPM	1st	Unbalance	Proportional to unbalance; largest in radial direction	Most common cause of vibration; Eccentric journals, bent shafts
1 x Rotor RPM (2 & 3 x RPM sometimes)	1st	Misalignment of couplings or bearings	Large in axial direction	
2 x Rotor RPM	2nd	Mechanical looseness	Radial direction	Usually accompanied by unbalance and/or misalignment Could also be rubbing effects
3 x Rotor RPM	3rd			Rare. Could be a combination of misalignment and looseness

1/2 x Rotor RPM or less	1/2	Oil whip or whirl		Occurs on high or medium speed pressure lubricated machines with plain bearings
Many times RPM	nth	Gear noise Aerodynamic forces Blade defects	Low	Gear teeth x RPM of gear wheel Blades x RPM of rotor

3.9 Specific guidance for the Turbine Condition Monitoring (TCM) descriptive note

Vibration monitoring equipment. Vibration transducers are to be of the acceleration or velocity type and are to be sufficiently direction sensitive to exclude the possibility that vibrations normal to the direction of measurement will distort the vibration readings in the direction of measurement.

Vibration measurement and interpretation. Vibration measurements should be taken on the turbine bearing housings in the horizontal direction at a height corresponding to the rotor centre line, vertically above the centre of the rotor centre line and axially parallel to the rotor axis at shaft height. Transducers are to be secured firmly to the bearing housing. Good coupling is important if errors of measurement are to be kept as small as possible. Readings of vibration amplitude should preferably be recorded in terms of root mean square velocity (mm/s RMS).

The frequency range of the vibration measurement system should cover the frequency spectrum of the turbines so that at least the 1/2, 1st, 2nd and 3rd orders of rotor vibration are determined.

Vibration measurements at periodical survey. The measurement system must be capable of recording frequency spectrum at each measurement point. It would be acceptable for the readings to be analysed subsequent to the survey but it is more desirable for a suitable analyser to be available during the survey so that vibration amplitudes over the relevant frequency spectrum can be assessed immediately. If data is analysed during the survey it would be acceptable to record the data in tabular form, but a frequency plot gives a better picture of the condition of the machine.

Recorded vibration amplitudes are to be compared with turbine manufacturers' allowed limits, National or International Standards and previous records.

3.10 References

- ISO 10816-1: *Mechanical vibration Evaluation of machine vibration by measurements on non-rotating parts – Part 1: General guidelines*.
- ISO 10816-2: *Mechanical vibration Evaluation of machine vibration by measurements on non-rotating parts – Part 2: Large land-based steam turbine generator sets in excess of 50 MW.*
- ISO 10816-3: *Mechanical vibration Evaluation of machine vibration by measurements on non-rotating parts – Part 3: Industrial machines with nominal power above 15 kW and nominal speeds between 120 r/min and 15 000 r/min when measured in situ*.
- ISO 10816-4: *Mechanical vibration Evaluation of machine vibration by measurements on non-rotating parts – Part 4: Gas turbine driven sets excluding aircraft derivatives*.
- ISO 10816-5: *Mechanical vibration Evaluation of machine vibration by measurements on non-rotating parts – Part 5: Machine sets in hydraulic power generating and pumping plants* (available in English only).
- ISO 10816-6: *Mechanical vibration: Evaluation of machine vibration by measurements on non-rotating parts – Part 6: Reciprocating machines with power ratings above 100 kW*.
- ISO/FDIS 13373-1 (Final draft): *Condition monitoring and diagnostics of machines – Vibration condition monitoring – Part 1: General procedures*.
- ISO 7919-1 *Mechanical vibration of non-reciprocating machines – Measurements on rotating shafts and evaluation criteria – Part 1: General guidelines*.
- *Ship Vibration and Noise Guidelines: Guidance notes on acceptable vibration and noise levels and their measurement*, Technical Investigation Department, Lloyd's Register.

■ *Section 4*
Lubricating Oil Monitoring

4.1 Introduction

Regular analysis of the lubricating oil of critical systems has been used for many years, with three primary objectives:

- To monitor the rate of change of lubricant condition parameters;

- to determine that the oil remains in an acceptable operating condition; and
- to detect the onset of failure mechanisms.

Many studies have shown that incorrect, dirty or degraded oil is consistently cited as the root cause of premature wear and/or failure. It is therefore useful to analyse oil on a regular basis and to take appropriate remedial action where necessary.

By extending the suite of tests and by adhering to an agreed schedule of analysis, the lubricant can yield valuable information regarding the condition of its parent machinery. By understanding and integrating the knowledge of each particular system into the engineering analysis phase of the procedure, then practical condition assessments can be made.

4.2 Practical considerations

Sample integrity. The quality of the analysis depends on the quality of the sample. Care must be taken to ensure that the sample is completely representative of the lubricant that is in intimate contact with the machinery components. In addition, the receptacle into which the sample is to be drawn must be sufficiently clean so that contaminants are not introduced.

Sample frequency. There are no absolute guidelines for the frequency of sampling of systems. However, as with all offline data acquisition, the frequency of analysis must be such that the majority of expected modes of failure can be detected prior to failure itself. The frequency of analysis will be governed by factors such as equipment criticality, usage, duty, required availability and accessibility.

Machinery details. When obtaining the representative sample, all relevant machinery details should be attached to the sample. Typical data should include, as a minimum:

- Company name.
- Ship name.
- Plant item.
- Component name.
- Sampling point.
- Date.
- Lubricant brand.
- Machinery hours.
- Oil hours.

Analysis. Certain tests can be done on board, however it is more likely that samples will be sent to a nominated service provider ashore for testing and engineering analysis. Therefore the samples will have to be sent in an acceptable manner according to the necessary regulations. The time delay between sampling and despatch may often be significant and therefore this factor should be considered when specifying the sampling frequency.

On-board actions. The Chief Engineer will review the analysis reports received on board and decide whether actions are needed. The results of these reviews should be documented.

4.3 Further analysis

Where there is evidence of a developing machinery problem, there are additional testing methods available:

Ferrography. This is a method by which the ferrous materials in a sample are subject to microscopic analysis in order to determine the type and severity of captured debris. In some operating environments ferrography is used as a primary analysis tool, however it is more generally accepted for second level analysis where concerns have already been raised.

Cleanliness or particle counting. This is an additional test which is universally recognised as a means of statistically representing the particulate size range and distribution. It is routinely conducted to monitor the effectiveness of the filtration systems on ‘clean’ oil systems such as those for hydraulic, turbine and steering gear applications. The cleanliness of the primary fluid is of particular importance in such systems as they feature components operating with small clearances and high pressures. The most commonly used standards for reporting this analysis are ISO 4406:1999, N.A.S. 1638 and AS 4059 (see References).

4.4 Condition assessment

Typical lubricating oil analytical tests and the causes of abnormal results are shown *Table 2.4.1 Typical lubricating oil analytical tests and causes of abnormal results*.

Table 2.4.1 Typical lubricating oil analytical tests and causes of abnormal results

Analysis test	Condition	Cause	Action
Viscosity	Increase	Oil oxidation Contamination by residual fuel Contamination with heavier grade oil Contamination with emulsified water	Check for blow-by, injectors, hot spots Check oil storage for contaminants Check cooling system for leaks
Viscosity	Decrease	Contamination with distillate fuel Contamination with a lighter grade of oil	Check fuel injectors Check oil storage for contaminants
Flash point	Decrease	Possible contamination with distillate fuel	Check fuel injectors
Water	Fresh	Coolant ingress Purifier faulty Rain/wash water ingress Condensation (Often in standby systems that are not fully utilised)	Check for coolant additives and seal efficiency Check purifier temperatures, flow-rate and efficiency Check tank tops and guttering. Fit guards Check grade of lubricant vs. application. Drain and refill small systems, purify others
Water	Salt	Salt water coolant ingress Deck machinery guards ineffective	Check coolant system for leaks Replace/repair or install shields to prevent water ingress
Alkalinity (Referred to as Base Number. Engine lubricants only)	Decrease	Poor combustion, cold running, exhaust valve failure, high water contamination, increase in fuel sulphur level, low oil consumption	Check and obtain correct combustion Increase lub oil temperature by reducing cooling Check exhaust valves Remove water Check fuel for sulphur content Consider higher Base Number lubricant
	Increase	Contamination with higher Base Number product. (Most common in cross-head engines where make-up includes cylinder oil drains)	Monitor Base Number and resist using High BN drains as make-up
Strong acid (SAN)	Any	Present if all alkalinity exhausted. Rarely present in non-engine oils	Change oil Select higher BN oil Check oil tank for contamination
Acidity (TAN)	Increase	The build up of weak acids in a lubricating oil can be indicative of oxidation caused by high operating temperature, hot spots, low oil level, contamination, etc.	Check temperature of bulk fluid and also local component temps Differentials of more than 10ºC could indicate component problems Check level Change oil to more thermally stable grade

Insolubles	Increase	Dirt, blow by products, wear debris, dirty fuel, lubricant degradation, poor oil/air filtration, worn seals	Check for blow-by Check wear debris Check filters Check seals
Metal elements	Increase	Metallic elements can be found in additives or from wear debris/ contaminants. By comparing known metallurgy with elemental analyses certain component wear signatures may become apparent	Check filters Review historical data trend Consider microscopic evaluation, ferrography, etc. In extreme cases inspect Check for rust
Microbial analysis (water or oil)	10^4 or higher	Modern lubricants utilise environmentally friendly additive systems that are not as tolerant to infestation by micro-organisms. These can degrade the lubricant, block filters, increase corrosive intent of the lubricant and lead to system malfunctions.	Submit sample to microbiologist Check for water/oil contamination Treat with biocides as instructed by qualified microbiologist Consider preventative actions to minimise future infestations
Particle count	Increase	Typically carried out on clean systems such as hydraulic, turbine or steering gear. Increases in this are directly associated with filtration inefficiencies	Check filter bypass system Check filter ratings Check dirt holing capacity of filter Check for sources of contamination

4.5 Screwshaft lubricating oil analysis

Lubricating oil trend analysis is one of the most important techniques for assessing the condition of screwshaft bearings. It forms part of the requirements for assignment of the Screwshaft Condition Monitoring (SCM) descriptive note, whereby withdrawal of the screwshaft from the stern bearing is not required at the normal five-yearly survey.

Lubricating oil trend analysis involves taking oil samples at regular intervals and carrying out the tests defined below. These are the minimum tests required but Lloyd's Register's own Fuel Oil Bunker Analysis and Advisory Service (FOBAS) is able to produce a more comprehensive laboratory test report.

Samples are to be taken when the oil is at its normal service temperature and the screwshaft is rotating. The sample is always to be drawn from the same position, with care being taken to ensure that the test sample is representative of the oil within the system. The test position is to be flushed through to ensure removal of any trapped oil or debris before taking the sample.

Table 2.4.2 Analytical tests and alert levels for sterntube lubricating oil can be used to assess the analysis results. The alert levels shown are for guidance only as it is more important to have a usable number of sequential results to enable any trends to be identified. When this table is used in combination with the three most recent analysis results it should assist in making a reasoned estimate of the condition of the oil and health of the machinery.

Table 2.4.2 Analytical tests and alert levels for sterntube lubricating oil

Oil test condition	Probable cause	Possible problems	Alert levels
Viscosity Increase (cSt)	Oxidation Insolubles Contamination with heavier grade	Inferior lubrication Deposits	GT 25%
Viscosity Decrease (cSt)	Contamination with lighter grade	Poor lubrication Oil leakage	LT 10%
Water Content (% vol.)	Leaking Aft seal	Emulsification Sludging	Max. 1% (*See* Note 1)

		Rust Bacteria Poor lubrication	
Acidity Increase (mgKOH/g) (*See* Note 3)	Oxidation due to: Over-heating Contamination Wear debris	Viscosity increase Poor lubrication Deposits Corrosion	GT 1,0 mgKOH/g
Insolubles Increase (%wt)	Oxidation Wear debris Dirt	Viscosity increase Abrasion	GT 1,0%
Metallic element Increase (ppm)	Contaminant and wear debris	Likely source: Bearing Shaft/rust Bearing Aft seal Sand/dirt Salt water Chloride content in water Salt water/lube additive Aft seal/bearing Shaft/brg	 Tin GT 10 Iron GT 30 Lead GT 10 Nickel GT 10 Silicon GT 40 Sodium GT 80 Chloride GT 70 Magnesium GT 30 Copper GT 50 Chromium GT 10
Microscopic analysis	Non metallic bearing wear	Bearing wear and over heating	(*See* Note 2)

NOTES

GT = greater than

LT = less than

1. Some lubricants are specifically designed for sterntubes and can accept a higher water content. Lloyd's Register will advise suitability for such products via Product Verification.

2. Microscopic analysis of the particles may be recommended to identify the failure process and, where applicable, non-metallic bearing or seal material.

3. Oil ageing. Oxidation characteristics such as TAN (Total Acid Number) depend upon the type of oil used. Hence no recommended value is listed. Instead observation of any trends (such as viscosity and change in colour etc.) based on sequential analysis should be made.

Additional guides to the general condition of the sternbush and screwshaft are:

- Records of the sterntube oil consumption, which provide an indication as to the effectiveness of the sternbush seals.
- Records of running temperature that provide confirmation that the operational parameters of the screwshaft have been satisfactory.
- Wear down measurements to confirm that sternbush wear is within acceptable limits.

4.6 References

- IACS Recommendation No.36 – *Recommended procedure for the determination of contents of metals and other contaminants in stern tube lubrication oil*.
- ISO 4406 *Hydraulic fluid power – Fluids – Method of coding the level of contamination by solid particles*.
- NAS 1638 *Cleanliness Requirements of Parts used in Hydraulic Systems*.
- SAE AS 4059 *Aerospace Standard – Cleanliness Classification for Hydraulic Fluids.*

■ Section 5
Lubricating Water Monitoring (Closed Fresh Water System Lubricated Sterntube)

5.1 General

Analysis of lubricating fresh water is essential for assessing the condition of the screwshaft bearings. Lubricating fresh water tests should be carried out and are to form part of the requirements for assignment of descriptive note Shipright SCM (Screwshaft Condition Monitoring), whereby withdrawal of the screwshaft from the stern bearings is not required at the normal five-yearly cycle. Sampling, testing and trend analysis of the lubricating fresh water should be carried out at intervals not exceeding 6 months. Records should be made available on board for the review of the attending Surveyor.

Each analysis should include minimum parameters such as:

- Metal contents as applicable (presence of material of the shaft and liners used), refer to *Ch 2, 5.3 Metal content values*.
- Corrosion inhibitors in fresh water (pH or equivalent alkalinity indicators) indicating the degree of passivation of the system against corrosion, *see Ch 2, 5.4 Corrosion inhibitors*.
- Salinity indicators or equivalent indicators i.e. total conductivity, *see Ch 2, 5.5 Salinity indicators*.
- Contents of bearing material particles, *see Ch 2, 5.6 Presence of bearing particles*.

The record of the extent of make-up water in the system should also be made available.

5.2 Sampling procedure

The lubricating fresh water sample should be taken at its normal service conditions, i.e. with a rotating shaft and the system at service temperature.

The sample is to be drawn from the same agreed position in the system which should be positively identified. Care should be taken to ensure that the sample is representative of the lubricating fresh water within the sterntube. Flushing of the sampling points should be done to ensure removal of trapped debris which could affect the result of the water sample.

The sample, unless supervised by a Surveyor, is to be collected under the direct supervision of the Chief Engineer.

5.3 Metal content values

The metal content values of expected contaminants should be considered taking into account the chemical composition of the shaft and liner materials.

Suggested upper limits are given below for guidance:

Metal	Limit value
Iron	25 ppm
Chromium	5 ppm
Nickel	5 ppm
Copper	40 ppm
Silicon	30 ppm

The upper limits shown are for guidance only as it is more important to have a usable number of sequential results to enable any trends to be identified. When the above table is used in combination with the three most recent analysis results, it should assist in making a reasoned estimate of the condition of the screwshaft or liner.

In case of shafts provided with a corrosion protection system, the possible presence of further contaminants should be evaluated in accordance with the instructions of the shaft/system manufacturer.

5.4 Corrosion inhibitors

The fresh water used for shaft lubrication may be treated, according to the provisions of the system manufacturer, by means of corrosion inhibitors that limit the risk of oxidation of the shaft and/or liners. The characteristics and contents of such inhibitors may vary; hence no recommended value is listed.

However, a significant indicator that may be used as guidance is the pH value of the sample or an equivalent indicator of alkalinity. The lower limit of the pH value of the water that may be assumed as guidance is 11.

5.5 Salinity indicators

In order to evaluate the possible contamination of the fresh water with salt water (e.g. leakages from the outboard seals) the following indicators should be considered.

Suggested upper limits are given for guidance:

Chloride	60 ppm
Sodium	70 ppm

5.6 Presence of bearing particles

The bearings used in fresh water lubricated propulsion shafting systems are typically made of synthetic material and could have a composite structure consisting of specifically selected polymers and additives having mineral or synthetic origins.

The possible presence of synthetic material in the fresh water sample may indicate the deterioration of the bearing or onset of bearing failure.

Mechanical filtering of the water sample, e.g. by means of a paper micro-filter, may allow a first quantitative analysis of the content of macro parts. This shall be taken before the filters, if any are fitted in the system.

Microscopic analysis of the particles may be recommended to identify the non-metallic bearing material in the sample.

5.7 References

IACS Recommendation No. 143 – *Recommended procedure for the determination of contents of metals and other contaminants in a closed fresh water system lubricated stern tube*.

■ *Section 6*
Thermography

6.1 Introduction

Every surface with a temperature above absolute zero emits some infrared radiation. Thermography is a technique of detecting the infrared radiation emitted by a body to produce a thermal map of its surface. The temperature variation is indicated in different colours or in shades of grey. The image thus produced is called a thermogram and is a very useful condition monitoring aid for both electrical and mechanical equipment when used to identify hot spots (or cold spots in electric circuits). Identifying areas of equal temperatures (isotherms) in the baseline images and detecting variations by subsequent trending can provide very early warning signs of equipment failure.

The main advantages of thermography are as follows:

- It is a non contact measurement technique.
- Measurement can be made with the equipment under operational load.

6.2 Practical issues

There are two ranges of the infrared band, which are utilised by typical cameras:

- Long wavelength 8 to 14 microns, suitable for low temperatures (below ambient).
- Short wavelength 2 to 5 microns, suitable for higher temperatures (above ambient).

Emissivity of an object is a measure of its ability to emit radiation. The emissivity of a black body (perfect emitter and absorber) is 1. Cameras have to be programmed with the emissivity factor of the object being measured. The temperatures measured will only reflect the true temperature if the emissivity correction is accurate.

A thermographic camera is relatively easy to use and the results are easy to interpret. However there are several details that the user should be aware of in order to obtain the best results.

- Thermal sensitivity:

The smallest change in radiation level that the instrument is capable of registering expressed in terms of temperature.

- Temperature range:

Temperature measurement from –40°C to 2000°C is possible with modern cameras.

- Environmental temperature:

The range of temperature in which the camera may be safely operated.

- Thermal resolution:

The smallest difference in temperature possible to be expressed between two measurements.

- Spatial resolution:

A measure of the fineness of detail directly proportional to the number of pixels representing the image.

- Accuracy:

A measure of the difference between the true temperature and the measured temperature.

- Spot size ratio:

The ratio that expresses the maximum distance the camera can be from a target of a given size and still maintain temperature measurement accuracy.

The quality of the thermal image can be affected by several factors such as:

- Extraneous radiation from surrounding objects and bright sunlight.
- Shape (angular relation to the camera) and surface condition.
- Excess humidity in the measuring environment (rain or condensed steam).
- Presence of insulation material between camera and target.
- Distance between camera and target.

6.3 Typical thermographic images

Figure 2.6.1 Overheated relay on a switchboard

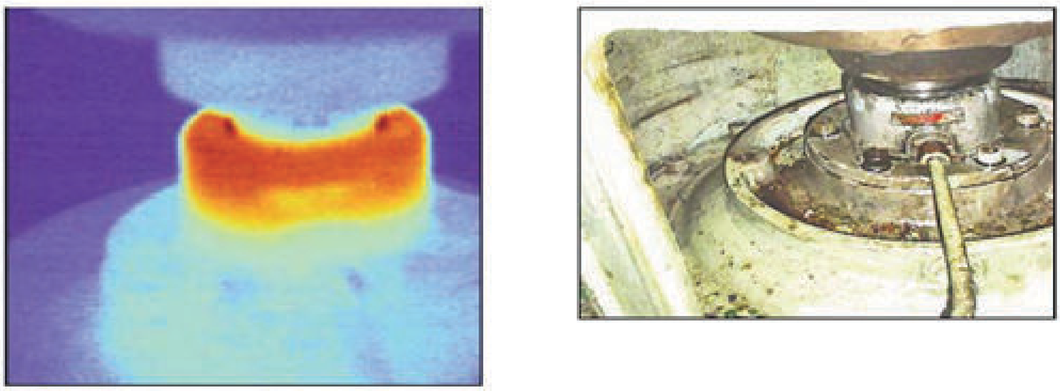

Figure 2.6.2 Overheated pump bearing

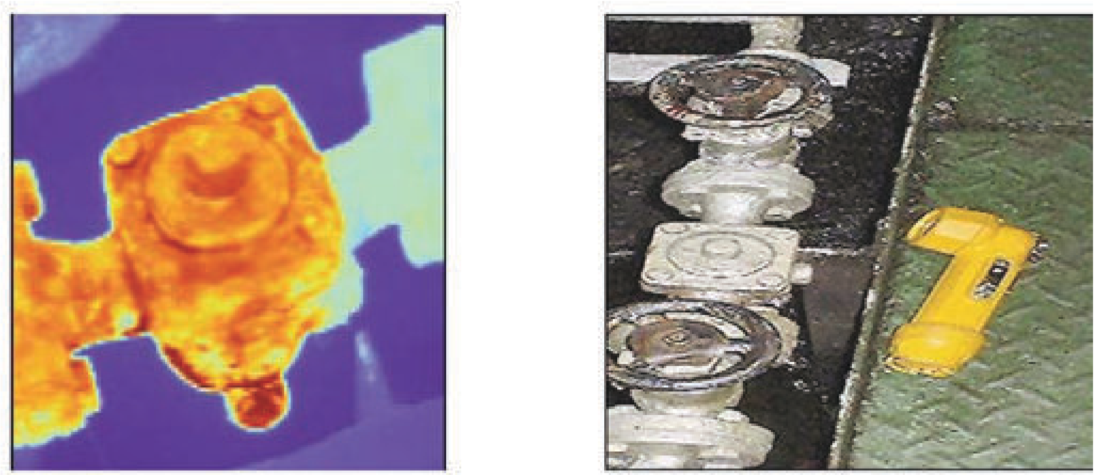

Figure 2.6.3 Steam trap in good order

6.4 References

ISO 7726: *Ergonomics of the thermal environment - Instruments for measuring physical quantities.*

■ *Section 7*
Guidance on Condition Based Maintenance

Machinery Condition Based Maintenance is described in *Figure 2.7.1 Condition monitoring procedure flowchart* which is extracted from BS ISO Standard ISO 17359.

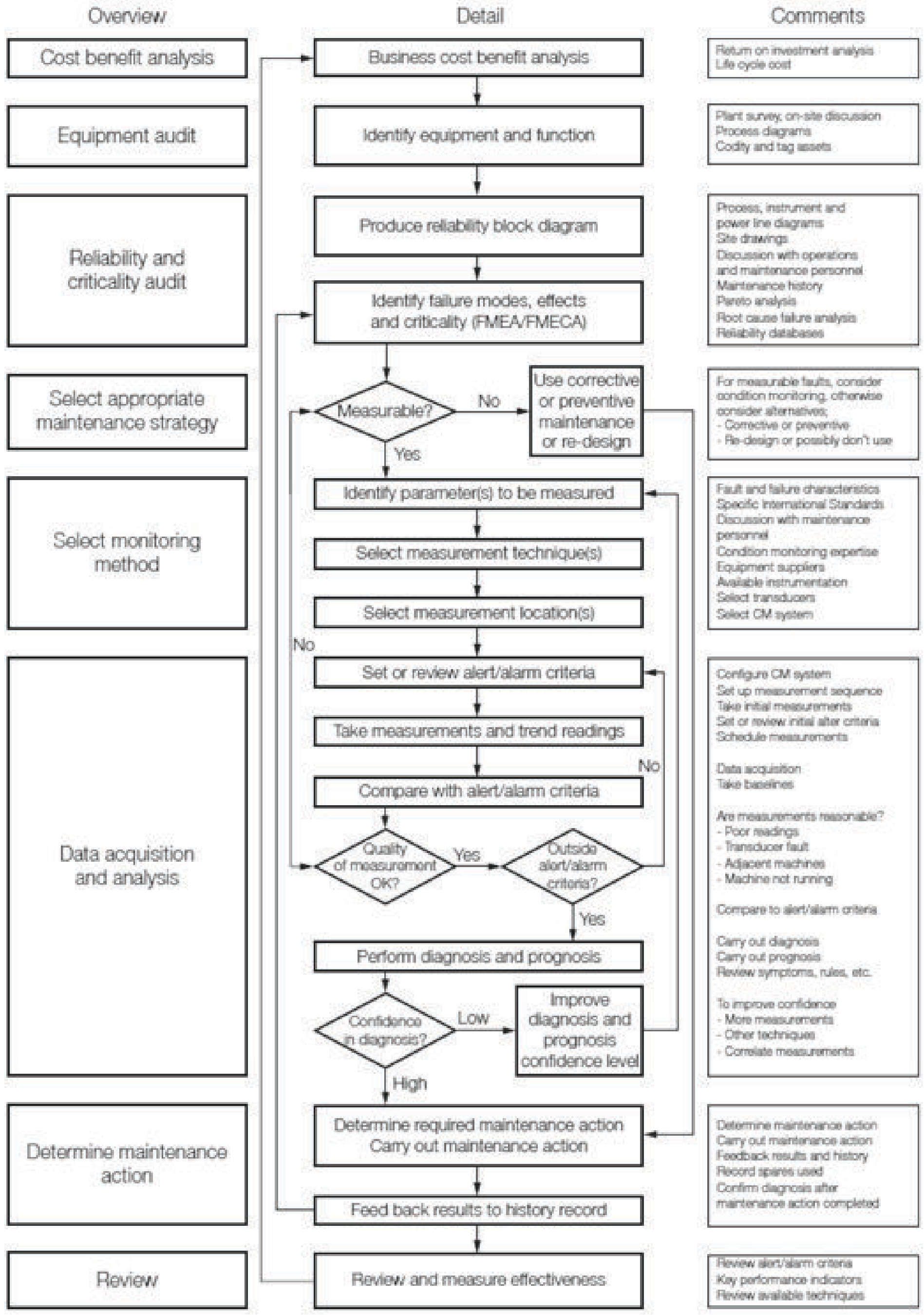

Figure 2.7.1 Condition monitoring procedure flowchart

7.1 Introduction

Condition Based Maintenance increases the flexibility of a well designed maintenance system. It is dependent on identifying the criticality of a machinery asset. Condition Monitoring provides the basis of planned actions based on trend analysis and maintenance strategies triggered by the values obtained during monitoring.

7.2 Criticality assessment

Criticality is a product function of failure probability and consequences. Criticality of Failure and its consequences should consider issues such as:

- Cost of down-time or lost service costs for any asset.
- Asset failure rates and mean time to repair.
- Asset redundancy reduces criticality.
- Consequential or secondary damage to asset.
- Replacement costs, including lead time delays.
- Cost of asset maintenance or spares.
- Life-cycle costs.
- Cost of monitoring system (including the training, interpretation of data and trends).
- Safety, environmental and business costs.

Criticality categorises or weights failure in terms of each asset, which assigns a probability of failure to the means and consequences of the failure. This process is central to Condition Based Maintenance because it provides a priority rating for assets under control. Criticality assessment is to be carried out in accordance with a recognised international standard such as IEC60812.

7.3 Identification of measurable parameters

Following the analysis of asset criticality the design of the MCBM scheme should consider which measurable parameters can be used to reliably monitor the condition of the asset. The following should be considered:

- The measurable parameter.
- The measurement technique.
- The location of the measurement.
- The trend that the measurements are expected to follow.
- The alert and alarm trigger criteria needed to protect the asset from failure.

If an asset has no measurable symptom an alternative maintenance strategy is to be adopted. For example, Air Receivers currently have no satisfactory method which would provide an adequate means of Condition Monitoring, and therefore would remain an item which must be surveyed.

Contents

Associated Forms and Documentation Chapter 3

Section 1
Checklist for Approval of Machinery Planned Maintenance Schemes

Lloyd's Register

Machinery Planned Maintenance Scheme (MPMS)
and Machinery Condition Monitoring (MCM)
Approval Checklist

Ship Name: ____________________ LR Number: ____________

Machinery Planned Maintenance Scheme

General	✓	Comments
Formal request for approval submitted to Lloyd's Register	❑	
Continuous Survey Machinery (**CSM**) cycle in use	❑	
Language of the scheme is English	❑	
The scheme is based on computerised system with arrangements for backing up data at regular intervals. Access limited to Chief Engineer or other authorised persons.	❑	
Items to be submitted to Lloyd's Register	✓	Comments
A general description of scheme	❑	
Name and version number of planned maintenance software *e.g. Amos M&P 05.4.40*	❑	
Numbered index of items, which includes all CSM items on 'Master List of Surveyable Items' and cross references to Master List numbers (*See* Note 1)	❑	
Sample maintenance job descriptions	❑	
Maintenance intervals for each item (*See* Note 1)	❑	
Examples of reporting and recording procedures. These should include: • details of inspections and maintenance carried out on a specific item over a specified time interval • the condition as found • any repairs effected • a list of spare parts used	❑	
Special arrangements for crankshaft and bearings	✓	Comments
For ships fitted with a single main engine, are special arrangements requested for the Chief Engineer to survey the main engine crankshaft and bearings?	❑	
If the answer to the previous question is yes, confirm that details of engine condition monitoring have been submitted.	❑	

Machinery Condition Monitoring
(only in association with a Machinery Planned Maintenance Scheme approval)

Items to be submitted to Lloyd's Register	✓	Comments
Name and version number of condition monitoring (PC based) software	❑	
Name and type of condition monitoring hardware *e.g. 'Vibscanner Data Collector'*	❑	
Numbered index indicates items on either preventive or condition based maintenance (*See* Note 1)	❑	
Description of monitoring methods, frequency of monitoring and limiting values of acceptable condition	❑	
Method and frequency of calibration for instrumentation	❑	
Specific requirements for vibration monitoring systems:	❑	
• Able to display trends of overall vibration level over time	❑	
• Able to display FFT frequency spectrum	❑	
• Details of training given to personnel undertaking measurements	❑	
Initial set of 'baseline' measurements (*See* Note 1)	❑	

Version 6.01 (05/12/2014)

Lloyd's Register

Machinery Planned Maintenance Scheme (MPMS) and Machinery Condition Monitoring (MCM)

Approval Checklist

Note 1
Where an identical machinery planned maintenance scheme is to be implemented on one or more of an operator's ships, the initial application should include all the details requested. Subsequent applications need only include the items indicated.

Note 2
If the planned maintenance software has been approved using Lloyd's Register's *Software Conformity Assessment (SCA)* system, refer to the ShipRight Procedure "Machinery Planned Maintenance and Condition Monitoring – Linked Supporting Service" for details of information to be submitted.

Note 3
If the RCM (Reliability Centred Maintenance) descriptive note is applied for, refer to the ShipRight Procedure "Machinery Planned Maintenance and Condition Monitoring – Linked Supporting Service" for details of information to be submitted.

Version 6.01 (05/12/2014)

Section 2
Certificate of Operation of an Approved Machinery Planned Maintenance Scheme

Certificate no:
Page 1 of 3

Certificate of Operation
of an approved Machinery Planned Maintenance Scheme

Name of ship   LR number

Operator[1]

This is to certify that the operator of the above named ship has been granted a special arrangement for dealing with machinery surveys in conjunction with an approved Machinery Planned Maintenance Scheme.

The arrangement has been granted provided that the conditions for approval of the Machinery Planned Maintenance Scheme are complied with, together with the conditions listed on page 2 of this document, and is valid until cancelled in writing either by the certifier or the operator. It will automatically be cancelled if the operator of the ship changes.

Chief Engineers participating in the Scheme may carry out examinations of selected machinery items listed under the approved Machinery Planned Maintenance Scheme. A list of applicable machinery items is included on page 2.

Details

Name and version number of planned maintenance software:

The scheme **does/does not*** include **Condition Monitoring/Condition Based Maintenance*** of selected machinery.

Main Engine Crankshaft and Bearings
1. Special arrangements **have/have not*** been agreed for the examination by the Chief Engineer.

ShipRight descriptive note **MPMS/MCM/RCM/MCBM*** assigned.

This certificate is to be presented to Surveyors at the time of the annual audit of the approved Machinery Planned Maintenance Scheme.

Clients that arrange for items of machinery to be credited for survey based on examinations by Chief Engineers shall indemnify and hold Lloyd's Register harmless against any claim, loss, or liability including any legal costs or other expenses relating to any negligent or other act or omission of the Chief Engineer while acting within the conditions contained in this document.

Any dispute, claim, or litigation between the Lloyd's Register Group and the Client arising from or in connection with this application shall be subject to the exclusive jurisdiction of the English courts and will be governed by English Law.

Date of issue

Surveyor to

A subsidiary of Lloyd's Register Group Limited

[1] *Operator may be the Shipowner or Manager responsible for the day-to-day operation and maintenance of the ship.*
** Delete as appropriate*

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Certificate no:
Page 2 of 3

A. Conditions for carrying out examination under the approved Machinery Planned Maintenance Scheme

The Machinery Planned Maintenance Scheme as submitted for approval must be adhered to and the conditions listed in the ShipRight Procedures are applicable.

Chief Engineers are to carry out examinations under the conditions of the scheme. Items of machinery which may be examined by the Chief Engineer are given below:

Main Propulsion Diesel Engines:
(a) Cylinder covers.
(b) Valves and valve gears.
(c) Cylinder liners.
(d) Pistons and piston rods.
(e) Connecting rods, crossheads, top end bearings and guides, gudgeoned pins and bushes.
(f) Crankshafts and bearings in multiple engine installations. *Crankshafts and bearing in single engine installations* ***only*** *where special arrangements have been agreed.*
(g) Fuel injection pumps and fuel booster pumps.
(h) Scavenge pumps, blowers and air coolers.
(i) Turbocharger.
(j) Detuners, dampers and balancer units.
(k) Camshaft and camshaft drive.
(l) Main engine thrust bearing.
(m) Governor.

Auxiliary Diesel Engines:
(a) Complete unit including coolers and pumps (*See* below).

Auxiliary Steam Turbines:
(a) Complete unit including coolers and pumps (*See* below).

Auxiliary Machinery:
(a) Main engine driven pumps e.g. bilge, lubricating oil and cooling water.
(b) Independently driven pumps (and associated motors and cables where insulation resistance readings are supplied), e.g. bilge, ballast, fresh water, sea-water cooling, lubricating oil and oil fuel transfer.
(c) Main engine fresh water and lubricating oil coolers.
(d) Low pressure heaters used in high viscosity fuel systems of internal combustion engines.
(e) Main and auxiliary condensers/drain coolers
(f) Air compressors and their safety devices.
(g) Forced or induced draught fans.

Steering Machinery:
(a) Steering gear pumps.

Shafting:
(a) Intermediate shafts.

Pressure Plant:
(a) Adjustment of exhaust gas boiler safety valves under steam.

Deck Machinery:
(a) Windlass and windlass machinery.

Refrigerated Cargo Installations:
(a) Reciprocating refrigerant compressors.
(b) Brine pumps.
(c) Condenser cooling pumps.
(d) Liquid refrigerant circulating pumps.

Ships for Liquefied Gases:
(a) Reciprocating refrigerant compressors.
(b) Reciprocating cargo gas compressors.
(c) Condenser cooling pumps.
(d) Circulating pumps (where fitted).

With regard to stand-by units, for example auxiliary engines and main lubricating oil pumps, it will be the responsibility of the Chief Engineer, in consultation with the Master in their joint capacity as representatives of the Operator, to ensure that such items are only opened up for examination under favourable conditions so that no hazard, including fire, to the ship or cargo would result from breakdown of a working unit.

The number of auxiliary generator sets must be such that all services essential to the propulsion and safety of the ship, together with preservation of the cargo, can be supplied when any two of the sets are not working. One of these two sets could then be overhauled while the other remains available as the stand-by set.

Satisfactory records of maintenance carried out together with details of minor or routine repairs and spare parts fitted are to be available on board. The records are to be prepared in the English language and to be available for examination upon request by Surveyors. Any machinery parts that have been replaced by spares are, where possible, to be retained on board until examined by the attending Surveyors. Condition data such as bearing clearances, crankshaft deflections and cylinder liner gaugings are to be kept on board for examination by Surveyors.

Main Engine Crankshaft and Bearings
1. Where special arrangements have been agreed for the Chief Engineer to carry out the examination of the main engine crankshaft and bearings, the inspections are to proceed as follows:

- The top and bottom halves of the main bearings are to be removed for inspection. Bridge gauge readings before removal and after replacement of bottom halves are to be recorded where facilities are provided, otherwise the crown thickness of the bearings are to be measured and compared with engine designer's recommended limits.
- Crankpin bearing top and bottom halves are to be examined and clearances recorded, or crown thicknesses compared with designer's recommended limits. Crankpins, journals and webs are to be carefully examined for cracks especially at the fillets and in the vicinity of oil holes.
The Chief Engineer is to keep records of the condition monitoring measurements and inspections as specified in the following Table:

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Certificate no:
Page 3 of 3

Method	Requirement
Performance Monitoring	Continuous or periodic monitoring of: • Shaft horsepower • Engine and screwshaft rpm • Cylinder pressure – time curves • Charge air pressure • Exhaust gas temperatures • Engine cooling system temperatures and pressures • Engine lubricating oil system temperatures and pressures • Turbo-charger rpm and vibration • Main bearing temperatures and/or crankcase oil mist densities
Lubricant Analysis	• Regular sampling, laboratory testing, analysis and assessment of lubricant
Visual Inspection	• Periodic inspection of crankcase and at the edges of the bearings for signs of wiped or broken white metal • Periodic inspection of shrink fit reference marks (if applicable) • Periodic inspection of bedplate structure, inside and out
Physical Measurement	• Periodic measurement of crankweb deflection readings • Periodic measurement of bearing clearances

The confirmatory survey carried out by Lloyd's Register at the time of the Annual Audit will comprise:

- A review of the condition monitoring records specified in the Table above.
- A check of bearing clearances, where possible.
- A check for signs of wiped or broken white metal in the crankcase and at the edges of bearings.
- A check of shrink fit reference marks, if applicable.
- A check of the bedplate structure, inside and out.

B. Requirements for maintaining the approval of the Machinery Planned Maintenance Scheme

Annual Audit

Surveyors will carry out an annual audit held concurrently with the Classification Annual Survey. At this time the machinery records and documentation will be examined in sufficient depth by the Surveyors to ensure that the Scheme has been operated correctly and that machinery has functioned satisfactorily since the previous audit. The records should indicate that all scheduled maintenance has been carried out. Any items not dealt with as per the schedule will be discussed with the Chief Engineer. As part of the audit the Surveyors will carry out a general examination of the machinery. As far as is practical, machinery to be credited for survey will be examined under working conditions. If the Surveyor is not satisfied with the operating condition or any aspect of the scheme's operation he may request that items be opened out for inspection.

Damages

Machinery items suffering damage, defect or breakdown to an extent that may affect the safe operation of the ship or which could invalidate the conditions for which class has been assigned, are to be reported to the Lloyd's Register Group without delay. This requirement over-rides all other terms of the Scheme. (See Rules & Regulations for the Classification of Ships, Part 1, Chapter 2, 1.1.5)

Repairs

All machinery repairs, which may be required in order that the ship retains its Class, are to be carried out under the supervision and to the satisfaction of Surveyors. (See Rules & Regulations for the Classification of Ships, Part 1, Chapter 2, 3.4)

Form 1488 (2016.10)

Section 3
Certificate of Operation (Office) of an Approved Machinery Condition Based Maintenance Scheme

Certificate no:
Page 1 of 1

Certificate of Operation (Office)

of an Approved Machinery Condition Based Maintenance (MCBM) Scheme

Operator[2]
Address

This is to certify that the operator above has been granted a special arrangement for dealing with machinery surveys in conjunction with an Approved Machinery Condition Based Maintenance (MCBM) Scheme, for ships operating with the descriptive note ShipRight MCBM.

The arrangement has been granted provided that the conditions for approval of the Machinery Condition Based Maintenance (MCBM) Scheme are complied with, and is valid until cancelled in writing either by the certifier or the operator. It will automatically be cancelled should the operator cease to operate ships with the descriptive note ShipRight MCBM.

Details

Name and version number of planned maintenance software:

This certificate is to be presented to Surveyors at the time of the intermediate and renewal office audits of the approved Machinery Condition Based Maintenance (MCBM) Scheme. The intermediate audit should be carried out between the second and third anniversary of the initial or renewal audit.

A copy of this certificate should be retained aboard each participating ship in the scheme for presentation to the surveyors at the annual shipboard audit.

Clients that arrange for items of machinery to be credited for survey based on examinations by Chief Engineers shall indemnify and hold Lloyd's Register harmless against any claim, loss, or liability including any legal costs or other expenses relating to any negligent or other act or omission of the Chief Engineer while acting within the conditions contained in this document.

Any dispute, claim, or litigation between the Lloyd's Register Group and the Client arising from or in connection with this application shall be subject to the exclusive jurisdiction of the English courts and will be governed by English Law.

Date of issue

Date of expiry

Surveyor to

A subsidiary of Lloyd's Register Group Limited

Intermediate Office Audit

Date

Surveyor

[2] *Operator may be the Shipowner or Manager responsible for the day-to-day operation and maintenance of the ship.*

Form 1480 (2014.01)

■ *Section 4*

Audit Checklist for an Approved Machinery Planned Maintenance Scheme

Audit Checklist

For an approved **Machinery Planned Maintenance Scheme.**

The scheme may include special arrangements for Chief Engineers to survey main engine crankshafts and bearings, and may incorporate Machinery Condition Monitoring or a Machinery Condition Based Maintenance scheme

Report No:

Page 1 of 3

Name of ship	LR number	Surveyor's signature	Date of Audit

For annual audits mark 'X' to indicate 'yes' and 'O' to indicate an outstanding action in the appropriate block for each item. If an item is not applicable mark 'N/A' in the appropriate block.

1.	To be completed at each Audit and in conjunction with the Classification Annual Survey.	X, O, N/A
	Documentation:	
1.1	Confirm that the ship's *Certificate of Operation* for the Scheme remains valid.	---
1.2	Confirm that the planned maintenance software being used is that which is stated on the *Certificate of Operation*.	---
1.3	Examine the maintenance records for each item of machinery to be credited for Class. Confirm that:	---
	a) Maintenance has been carried out, or supervised, by a Chief Engineer.	---
	b) Each item of machinery is included in the list of items that may be surveyed under the terms of the approved Machinery Planned Maintenance Scheme (refer to the ship's *Certificate of Operation*).	---
	c) Confirm that all scheduled maintenance has been carried out. An explanation is to be obtained from the Chief Engineer for any items not dealt with. Overdue items are to be dealt with at the time of the audit.	---
	d) Confirm that the maintenance records give details of repairs carried out and spare parts used. Written details should be provided of any defect, breakdown or malfunction of essential machinery, including the main cause of failure.	---
	PMS Interactive (if applicable):	
1.4	Confirm whether or not PMS Interactive is being used by the Operator. Items reported using PMS Interactive will have an 'I' (Interim) assigned, on acceptance, to be changed to 'C' (Confirmatory) and the assigned dates are to be aligned with the Chief Engineer's or Operator's report date.	---
	General:	
1.5	General examination of the machinery items to be credited for Class, under working conditions where practical. Where possible, examine any machinery part that has been replaced due to damage.	---
	Special Arrangements for the Survey of Main Engine Crankshafts and Bearings for Single Engine Installations (if applicable):	
1.6	Confirm that the ship's *Certificate of Operation* for the Scheme includes the provision for Chief Engineers to survey the main engine crankshaft and bearings. OEM Extended time between overhauls are acceptable and may be valid.	---
1.7	Undertake a general examination of the crankcase, including:	---
	a) an examination of the bedplate structure, inside and out;	
	b) signs of wiped or broken white metal in the crankcase and at the edges of bearings;	
	c) an examination of shrink fit reference marks, if applicable.	
1.8	Check main bearing and crankpin clearances, where practical.	---
1.9	Review condition monitoring records.	---
1.10	Review the records of work undertaken on the crankpins, journals and bearings.	---
1.11	Examine records of main bearing wear down and crankweb deflections and compare with engine designer's allowable values. Witness the taking of crankweb deflection readings if considered necessary.	---

Audit Checklist

For an approved **Machinery Planned Maintenance Scheme.**

The scheme may include special arrangements for Chief Engineers to survey main engine crankshafts and bearings, and may incorporate Machinery Condition Monitoring or a Machinery Condition Based Maintenance scheme

Report no:

Page 2 of 3

Name of ship	LR number	Surveyor's signature	Date of Audit

2.	Machinery Condition Monitoring (if Applicable, in addition to Section 1)	X, O, N/A
2.1	Confirm that the ship's *Certificate of Operation* for the Scheme includes the provision for the use of Machinery Condition Monitoring.	---
2.2	Confirm that condition monitoring instrumentation such as vibration measuring equipment, is regularly checked and calibrated in accordance with manufacturer's recommendations.	---
2.3	Examine condition monitoring records and trend data such as vibration levels, oil analysis results, performance criteria, etc. Review action taken if specified limits have been exceeded. Review the trend characteristics of the monitored parameters.	---
2.4	If considered necessary, witness confirmatory measurements on available running machinery for comparison with the ship's records. List the machines checked in this manner in Section 4.	---

3.	Machinery Condition Based Maintenance (if Applicable, in addition to Section 1)	X, O, N/A
3.1	Confirm that the ship's *Certificate of Operation* for the Scheme includes the provision for the use of Condition Based Maintenance.	---
3.2	Confirm the Operator's approved MCBM Plan is on board and in use, all procedures being followed and records retained as required. Feed back from the office concerning the operation of the scheme reviewed.	---
3.3	Review training records and authorisations for participating ship's staff, or 3rd party service supplier, required for the monitoring, inspection and interpretation of monitoring results and operation of the condition based maintenance scheme, as defined in the MCBM Plan.	---
3.4	Confirm that a copy of the operator's current *Certificate of Operation (Office)* is retained aboard and Office audits are not overdue.	---
3.5	Confirm that any condition monitoring instrumentation used as part of the Condition Based Maintenance Scheme, such as vibration measuring equipment, is regularly checked and calibrated in accordance with manufacturer's recommendations.	---
3.6	Examine condition monitoring records and trend data for items being maintained and to be credited on the basis of condition monitoring, such as vibration levels, oil analysis results, performance criteria, etc. The records should indicate where acceptable limits have been exceeded (if applicable) and what action was taken. Review actions taken if specified limits have been exceeded. Review the trend characteristics of the monitored parameters.	---
3.7	Compare planned and actual maintenance activities. Deviations from the approved MCBM Plan discussed with the Chief Engineer and the proposed corrective action reviewed and found in order. (List details in Section 4).	---
3.8	If considered necessary, witness confirmatory measurements on available running machinery for comparison with the ship's records. List the machines checked in this manner in Section 4.	---
3.9	Confirm that the inspection, maintenance and monitoring records give details of repairs carried out and spare parts used. Written details should be provided of any defect, breakdown or malfunction of essential machinery, including the main cause of failure.	---
3.7	Confirm that items due for survey that are being examined under conventional Continuous Survey of Machinery (CSM) as a maintenance strategy within the Machinery Condition Based Maintenance Scheme, have been examined and found satisfactory. List these items in Section 4.	
3.8	Deficiencies in the operation of the scheme have been identified, either from the maintenance records or from the general condition of the machinery, a further Audit has been requested and a Condition of Class imposed. (In the event of serious deficiencies, a report should be forwarded to the Classification Committee in London recommending that approval of the scheme be withdrawn)	---
3.9	The inspection, maintenance and monitoring records have been examined in sufficient depth to establish that the Machinery Condition Based Maintenance Scheme is operating correctly and that the machinery remains functioning satisfactorily.	---

Form 2100MPMS (2014.01)

Audit Checklist

Report no:

For an approved **Machinery Planned Maintenance Scheme.**

The scheme may include special arrangements for Chief Engineers to survey main engine crankshafts and bearings, and may incorporate Machinery Condition Monitoring or a Machinery Condition Based Maintenance scheme

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Name of ship	LR number	Surveyor's signature	Date of Audit

4.	Machinery items subjected to examination as part of the audit to be listed below:	
	Machinery item	Remarks

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Section 5
ShipRight MCBM Audit Checklist - Office

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ShipRight MCBM Audit Checklist - Office

For a ship Operator's Office running a Machinery Condition Based Maintenance Scheme in association with a fleet of ships assigned the Descriptive Note ShipRight MCBM.

Date of Audit:		Operator's Name and Address
Type of Audit:	Intermediate/Initial/Renewal	
No. of participating ships on the MCBM Sceme		

Mark 'X' to indicate 'yes' and 'O' to indicate an outstanding action in the appropriate block for each item.
If an item is not applicable mark 'N/A' in the appropriate block.

1	To be completed at each Office Audit	
1.1	Confirm all the Operator's ships participating in the scheme have an up to date Machinery Survey status	---
1.2	The Operator's MCBM Plan(s) have been reviewed, including any documented amendments carried out since the previous audit, and found in order. Quality control and documentation control standards are defined and fit for for the purpose of maintaining classed machinery in accordance with the rules.	---
1.3	Review office records of reviews of ships' maintenance reports and any controls put in place to ensure compliance. Confirm Defect Reporting and corrective/preventative action carried out and where necessary a criticality assessment was carried out. (Complete section 3 for ships participating in the Operator's MCBM Scheme)	---
1.4	Confirm the Extended Time Between Overhauls implemented on board ships are in accordance with the Original Equipment Manufacturer's recommendations.	---
1.5	A sample of Maintenance and repair records carried out during the year prior to audit for all ships participating in the scheme indicated no items overdue for maintenance or repair.	---
1.6	If there is an isolated case of overdue maintenance/repair has the root cause been identified and appropriate steps taken to ensure the item(s) are dealt with in a timely manner? (This may include sighting of purchase requisitions for spare parts, the Operator's definite intentions for the work to be carried out, and/or a Condition of Class imposed by a surveyor on the basis of damage)	---
1.7	Supporting documentation such as delivery notes, job control records, purchase requisitions and details of deferment decisions are available in the operator's office.	---
1.8	Review training records and authorisations for participating ship's staff, or 3rd party service supplier, required for the monitoring, inspection and interpretation of monitoring results and operation of the condition based maintenance scheme, as defined in the MCBM Plans	---
1.9	Has the previous office audit report been viewed, and have any follow-up actions from that report been suitably dealt with?	---
1.10	Is the Operator's Condition Based Maintenance Scheme operating satisfactorily? (if not, consideration should be given to withdrawal of the MCBM Descriptive Note from all participating ships, the relevant Class Section DCG/PSG/TGG-Class should be informed)	---
1.11	Has the Certificate of Operation (Office) been issued or endorsed as required:- (a copy of the certificate should be provided for each ship participating in the scheme)	---
1.11.1	- Date of Issue:	
1.11.2	- Date of Expiry:	
1.11.3	- Date of Endorsement:	

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2	Report
1.1	Comments (continue on separate sheet if required):
1.2	Follow-Up Actions:

3	Ships participating in the Operator's Scheme (with Descriptive Note ShipRight MCBM)				Click here to add Participating Ships	
LR No.	Name	Remarks		LR No.	Name	Remarks

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