Marine Maintenance Systems and Class Surveys – Alternative Survey Arrangements

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Marine Maintenance systems are closely linked to a vessel's Classification. In order to satisfy Class requirements owners/operators must demonstrate that their vessels are properly maintained and in satisfactory condition[1]. This paper will discuss the various methods of using planned maintenance and condition monitoring to meet regulatory demands with respect to machinery survey.

A History of Marine Surveys

Owners, regulatory bodies, and those who charter vessels to carry goods have conducted marine surveys for hundreds of years. In 1760 the customers of Edward Lloyd's Coffee House formed the Register Society. The establishment was a popular meeting place for ship owners, insurance men and merchants. This was the origin of Lloyd's Register. The first Register of Ships, published in 1764, gave underwriters and merchants an indication of the condition of the vessels they insured and chartered. The early Registers outlined details such as the vessel's owner, master, tonnage, date of build and number of guns.
Through the years, marine technology has evolved from sail to steam to diesel & turbine. Main and Auxiliary machinery inspections have become a large component of Classification surveys.

Surveyable Items

Items, which require Class survey, include but are not limited to:

- hull and related structures
- main and auxiliary machinery
- emergency and safety related equipment
- shafting arrangements
- electrical equipment
- pumping systems
- pressure vessels
- heating systems
- tanks
- sea connections

All vessels have a master list of surveyable items. This list identifies surveyable equipment and the time intervals between surveys.

Survey Methods

In order to maintain Class a vessel is required to meet all the conditions imposed by Class.[2] Some of the accepted approaches of satisfying machinery Class inspections are:

Tear Down Inspection

Scheduled intervals dictate when a machine is to be opened for inspection by the Class Surveyor.

Planned Maintenance Systems

A Class approved Planned Maintenance System (PMS) allows a certified Chief Engineer to carry out inspection on specified pieces of equipment without requiring a Surveyor to be present. The records of these activities, along with all maintenance records illustrating that the PMS is being followed correctly and that machinery is operating satisfactorily, are to be evaluated by Class yearly.[3]

Condition Based Maintenance Systems

This approach uses the collection and trending of various operational parameters and diagnostic results in order to determine the condition of the machine.[4] When the condition of specified pieces of equipment are shown to have been maintained within designated parameters, credit for survey can be given without requiring the machine to be opened for inspection. The data and records are normally evaluated on a yearly basis.

The preceding was a general overview of the standard methods of maintaining Class requirements for Main and Auxiliary Machinery. Each Class society has guidelines detailing the requirements in order to qualify for alternative survey. A ship owner can apply to the Class society to have a condition monitoring and/or planned maintenance program approved as an alternative survey arrangement.

Condition Monitoring – Plant Audit

Most Class societies allow the owner/operator to determine what equipment will be monitored. This decision is usually based on such factors as the machine's criticality, replacement/repair costs and the expected costs associated with condition monitoring. Care must be taken when selecting the machines that are to be monitored. An inaccurate audit may result in useless data collection or conversely the exclusion of a critical piece of equipment. For example, a small inexpensive pump, that is easily replaced, is not included in the condition monitoring program. This conclusion is justified by indicating that the cost of including the pump in the program is greater then the replacement costs. However, the pump is a critical component and if it runs to fail, the entire system is brought to a halt, incurring an even higher cost.

The Chief Engineer conducting the plant audit should determine which equipment is to be included in the condition monitoring program, the appropriate readings and the collection intervals. The influence of process parameters on the data can play an important part in determining the machines condition. Collecting related information will allow for a more detailed and accurate picture of the machine to be developed. Information collected and trended must provide a realistic representation of the machine. The data should be collected while under normal operating procedures. Typical data collected includes vibration levels, oil analysis, operational parameters (i.e. pressures, temperatures, flows, power, RPM etc.) and physical inspections.

Although most Owners/operators are permitted to select which machines are included in the condition monitoring scheme, most Class societies have specific pieces of information that must be monitored. Below is an excerpt from Lloyd's Register of Shipping pertaining to Main Propulsion Diesels[5].

Machinery parameters to be monitored for condition based surveys

10.11.1 Main Propulsion Diesel Engine

(a) Shaft horsepower.
(b) Engine and shaft RPM.
(c) Cylinder pressures - time curves.
(d) Oil fuel injection pressure - time curves.
(e) Charge air pressure.
*(f) Exhaust gas temperatures.**
*(g) Engine cooling systems temperatures and pressures.**
*(h) Engine lubricating oil system temperatures and pressures.**
*(i) Turbo-charger RPM and vibration.**
*(j) Lubricating oil analysis data.**
*(k) Crankshaft deflections.**
(l) Main bearing temperatures.

Outlines supplied by the Class Society can aid an experienced Chief Engineer in conducting an accurate plant audit.

Condition Monitoring – Value of Trending

"…the use of trending the readings cannot be over emphasized."[6]

One of the most important, and overlooked, aspects of condition monitoring is trending. The operational and diagnostic data collected on a machine, when properly interpreted, can produce an accurate picture of the machines health. If the data is not collected at regular intervals vital information about the equipment's condition may be lost.

One of the goals of trending data is to allow for an early and realistic diagnosis of machine health. Trending will also allow for cross-reference between machines (when parameter "Y" changed what was the result on parameter "X"). It is this ability to note changes, both in the short and long term, which improves the ability to ascertain the situation.

"Whether short or long term, a monitoring strategy must recognize trends and initiate appropriate warnings."[7]

The initiation of warnings can be accomplished in a variety of ways. Three means by which warnings can be generated are:

Magnitude

Setting absolute alarms is a definitive method of ensuring that a machine runs within a set range. This is the most common method of setting alarms in a DCS. This is because a DCS usually displays an instantaneous picture of the machines condition and not an overall representation.
Another method is to set up a statistical alarm. Most of the raw data collected will produce a normal distribution in the form of a bell curve (Figure 1). This distribution contains a mean representing the normal value and a standard deviation representing a variation about the mean.[8] Statistical theory states that 95.5% of all readings collected will fall within two (2) standard deviations of the mean.[9] Alarms can be set based on this theory. This method is more accurate because it uses the actual readings to determine what is a normal value.

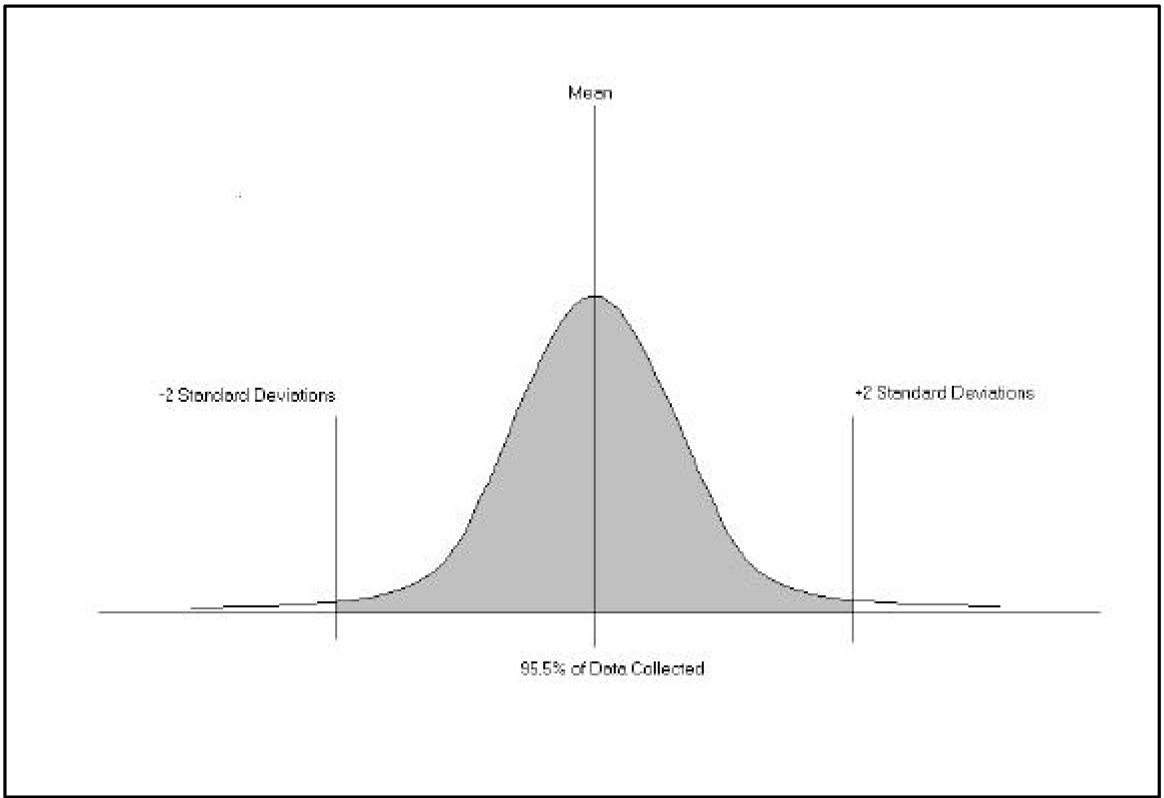

Figure 1 Normal Distribution

Change

A second method of setting an alarm is through change. This method can be accomplished through percent change from a base level or a mean.

Lube oil analysis is one area of condition monitoring that utilizes change very effectively. An example would be to set a baseline spectrography of an oil from an unused stock sample. Additive depletion can then be one of the areas monitored. When a certain level of additive consumption has occurred (change from the base) then the oil is flagged for change. This method is more accurate than changing oil by calendar dates because the actual condition of the oil is used in determining the time for change as opposed to an estimated time interval.

Rate of Change

Rate of change is very useful. A slower rate of change usually indicates that there is time to assess the machine and determine the situation prior to failure (Figure 2). A sudden change is usually a precursor to failure and can sometimes only allow a decision to be made regarding shut down. Rate of Change is also very useful in conducting Root Cause Analysis. Once a change has been noted the associated date/time can be used to inspect associated operating conditions, parameters or any other information that may provide information regarding the onset of the machines deterioration.

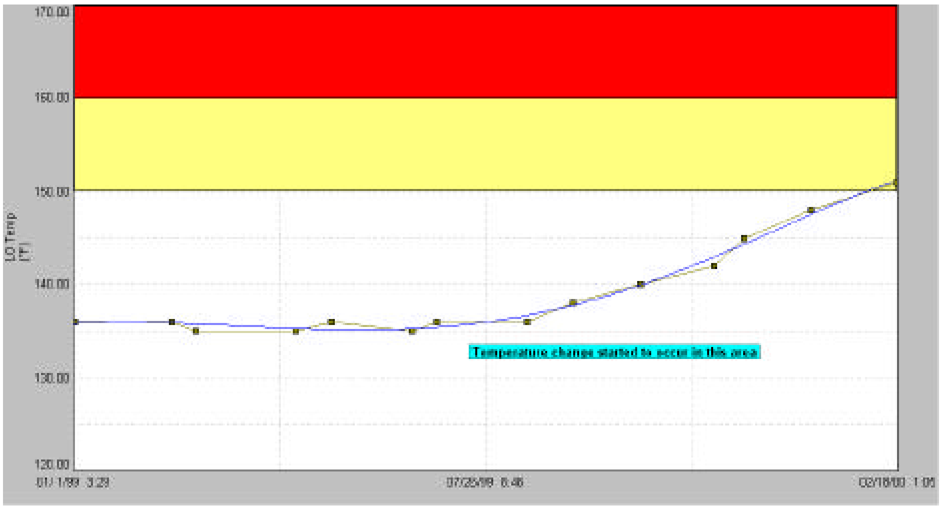

Figure 2 Temperature Trend – Rate of Change

After the alarm is triggered, trending becomes an invaluable tool in assessing the situation. The ability to look at trends allows for the determination of such things as:

- when the changes started to occur
- the rate of change
- cross correlation with other parameters (what else has occurred, does this information confirm or contradict the conclusion)
- cross reference with maintenance records (was work performed on the machine)

The information collected and trended in the condition monitoring program now has numerous uses.

- Machines with data that indicate normal performance can be credit with survey.
- Conduct Root Cause Failure analysis.
- Modify maintenance procedures or operational practices.

Condition Monitoring – An Example

Condition monitoring techniques are most advantageous when used in conjunction with one another. The following is an example of how a complete condition monitoring program can detect a potentially serious problem.

Overview: A 16 cylinder Diesel engine operating at 1500 rpm drives a 1400kW generator running at 1800 rpm through a step-up gearbox with a ratio of 1:1.1935.

Initial full spectrum vibration analysis on the Non-Drive End Bearing indicates that the gearbox is operating normally.

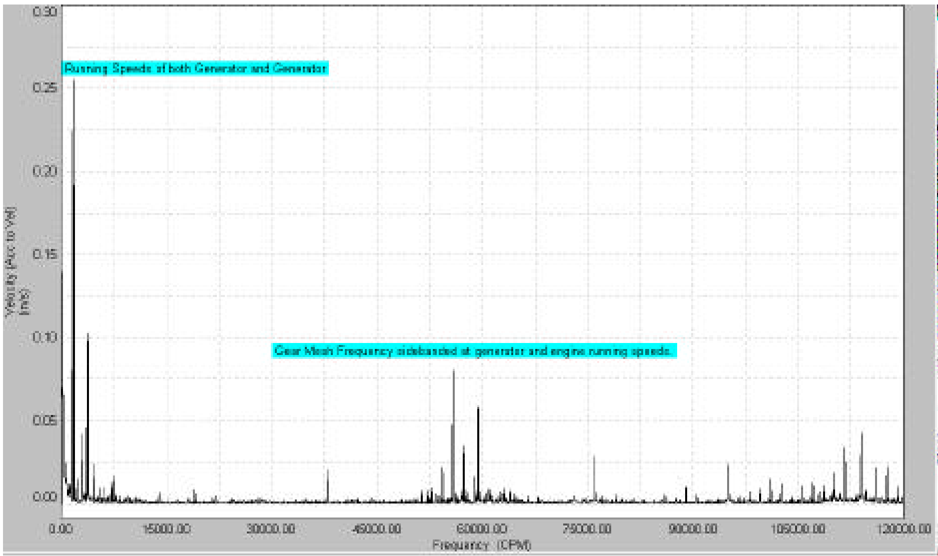

Figure 3 Initial Gear Box Spectrum

The Gear Mesh Frequency (# of teeth x RPM) is present but at an acceptable level, approximately 0.08 in/sec. Overall vibration readings are then used to develop a trend.

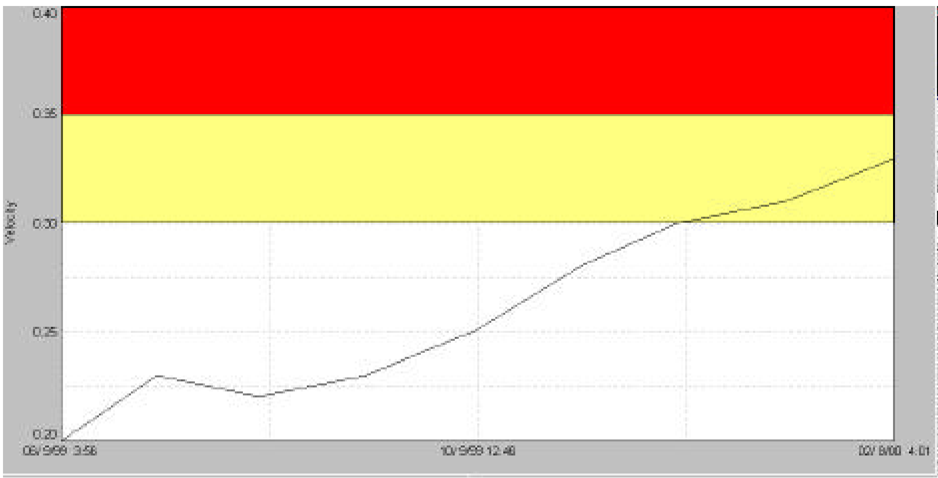

Figure 4 Overall Vibration Trend

The trend starts to gradually climb. Levels cross the caution acceptance value initiating an alarm. This would result in the use of a full spectrum analysis.

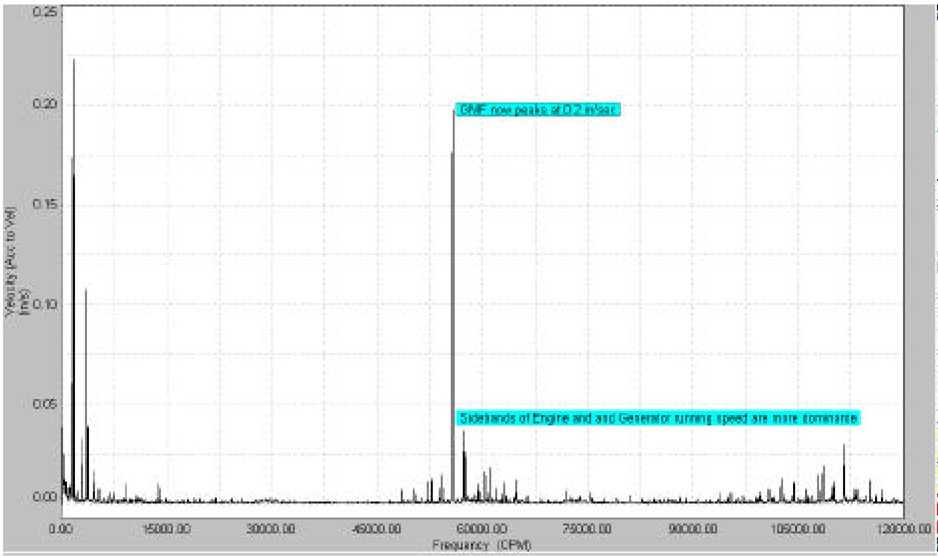

Figure 5 Second Gear Box Spectrum

The GMF has climbed to 0.2 in/sec. This increase is possibly due to a variation in load. It is important to collect data under the same conditions. With all parameters being equal, it can be concluded that the rise is not due to load variation on the Gen-Set. An investigation would now examine other available data trends.

Gear box lube oil temperature out is examined.

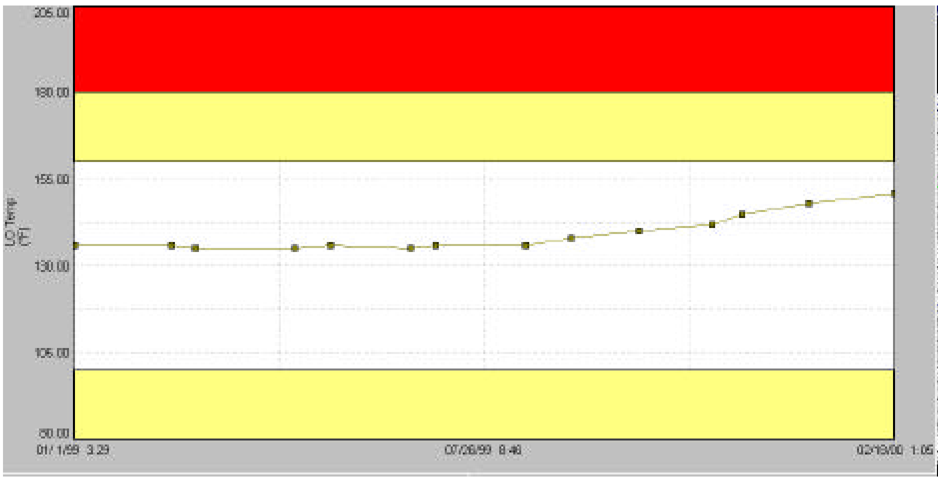

Figure 6 Lube Oil Temp Out

A slow increase in temperature can be seen. Although no alarm is triggered, it is noted that the rise started to occur prior to the increase in overall vibration.
An initial hypothesis is that increased loading on the gears (increase in lube temperature) initiated wear on the gears (increased GMF).

Examination of lube oil samples from the gear box can then be used to strengthen the hypothesis.

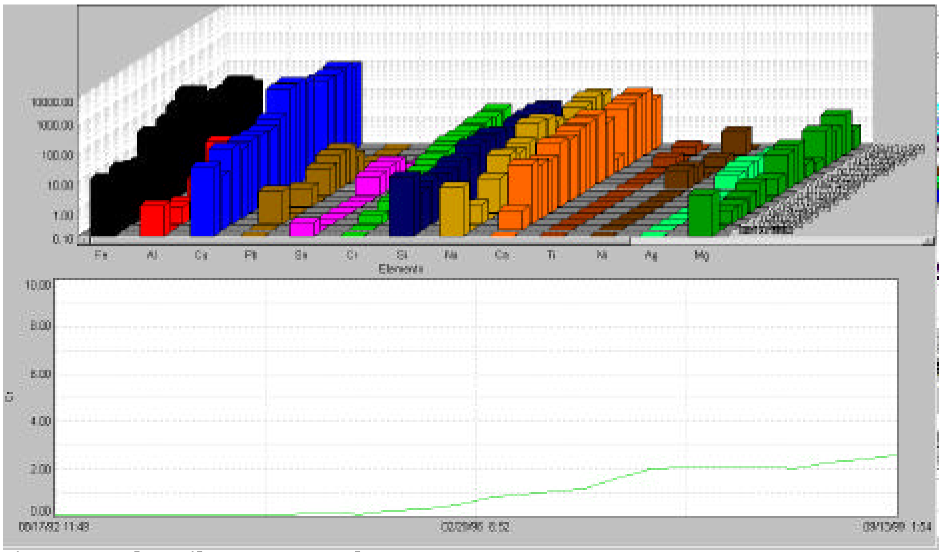

Figure 7 Lube Oil Spectrograph

A gradual climb in Chromium and Iron (constituents of the gear) is evident. The increase has started after the rise in overall vibration; this adds support to the theory of gear wear caused by increased loading.

The machine can know be shut down at a convenient time (resulting in minimal interruptions) in order to inspect the gearbox.
In this example only one trend actually triggered an alarm yet with proper data collection a potential problem can be diagnosed before catastrophic failure.

Diagnostic "Expert" System

In the preceding example the user examining the data utilized his/her expertise to diagnose that the gear was wearing.
MAINT*elligence* Monitor utilizes an expert system that allows diagnosis to be automated based on rules created by the user. An expert system is sometimes referred to as a form of artificial intelligence. The concept of an expert system is that a knowledge base is established consisting of rules (rule sets in MAINT*elligence* Monitor). The knowledge base is created using a series of IF/THEN statements that define the rule. These rules refer to the machine set-up and the condition monitoring data collected.

IF	there is a GEAR on this SHAFT,
AND	the number of GEAR TEETH is KNOWN,
AND	there is a SYNCHRONOUS PEAK between 5XRPM and 20XRPM,
AND	the PEAK is 1/2 of the GEAR MESH FREQUENCY
THEN	GEAR RESONANCE, 70%

The Inference Engine is the portion of the expert system that examines the rules in order to determine which rules have been satisfied. If the rules have been satisfied then a diagnoses is assigned to the Condition Assessment (the THEN statement in the rule).
This allows the "examination" of the data to be completed by the software. Making the process of data examination much more efficient.

Integration of CMMS and PdM Software

In the previous example the technician operating the condition monitoring program would request a work order. This would require him/her to enter a CMMS, if they have access, or ask the Chief Engineer to create a work order requesting the gear box be examined.
In an integrated system such as MAINT*elligence* the PM Task is triggered by the condition assessment generated by the "expert system". The Chief Engineer will then approve the task and issue a work order. This places the Chief Engineer at the most critical position within the system, he/she has final authority in determining if work is justified.

Benefits of Establishing an Alternative Survey Arrangement

An approved alternative survey arrangement will reduce the number of surveys conducted by Class by allowing a certified Chief Engineer to conduct surveys on certain equipment (as stipulated in the agreement with Class).

Condition Monitoring Data and Planned Maintenance records can be used to illustrate that machinery is operating within specified limits. This can reduce the number of tear-down inspection required.

A properly designed and maintained condition monitoring program will have positive effects on maintenance and operational procedures. This will increase the equipment reliability and improve the vessel's availability.

A properly designed and maintained condition monitoring program can detect potential problems prior to failure allowing for scheduled shutdowns. This results in savings in maintenance, parts and down time.

"…total maintenance workload was reduced by almost 50 percent…"[10]

"…ship's availability for service was improved from 60 to 70 percent through the reduced requirement for downtime for maintenance intervention." [10]

Optimization of operational procedures will increase efficiency.

Improved maintenance practices will reduce machine down time and maintenance costs.

[1] Det Norske Veritas. Alternative Survey Arrangements for Machinery and Automation Systems Ships and Mobil Offshore Units. Classification Notes No. 10.1. p. 4

[2] Germanisher Lloyd. Approval of Trend-Diagnosis & Condition-Monitoring Systems. V0RIE6IQ, 04/28099.

[3] Lloyd's Register of Shipping. Marine Division Survey Procedures Manual. Section: 10.6, p. 31

[4] Germanisher Lloyd. Approval of Trend-Diagnosis & Condition-Monitoring Systems. V0RIE6IQ, 04/28099.

[5] Lloyd's Register of Shipping. Marine Division Survey Procedures Manual. Section: 10.10, p. 37

[6] Lloyd's Register of Shipping. Marine Division Survey Procedures Manual. Section: 10.8, p. 33

[7] Mitchell, John, S. Introduction to Machinery Analysis and Monitoring 2nd Edition. Penwell Publishing Company, 1993.

[8] Mitchell, John, S. Introduction to Machinery Analysis and Monitoring 2nd Edition. Penwell Publishing Company, 1993.

[9] Mitchell, John, S. Introduction to Machinery Analysis and Monitoring 2nd Edition. Penwell Publishing Company, 1993.

[10] Picknell, Jim, V. The Reliability Handbook: From downtime to uptime – in no time. Chapter 3 Is RCM the right tool for you? Clifford/Elliot Publication Volume 23, Issue 6 December 1999.