Tasneef®
Life Environmentally Optimized

Guide for the Application of the Condition Based Maintenance within the Planned Maintenance Scheme

Effective from 1 January 2016

Emirates Classification Society (Tasneef)
Aldar HQ 19th Floor,
Al Raha Beach, Abu Dhabi, UAE
Abu Dhabi, United Arab Emirates

Phone (+971) 2 692 2333
Fax (+971) 2 445 433
P.O. Box. 111155
info@tasneef.ae

GENERAL CONDITIONS

Definitions:

"*Administration*" means the Government of the State whose flag the Ship is entitled to fly or under whose authority the Ship is authorized to operate in the specific case.

"IACS" means the International Association of Classification Societies.

"*Interested Party*" means the party, other than the Society, having an interest in or responsibility for the Ship, product, plant or system subject to classification or certification (such as the owner of the Ship and his representatives, the ship builder, the engine builder or the supplier of parts to be tested) who requests the Services or on whose behalf the Services are requested.

"*Owner*" means the registered owner, the ship owner, the manager or any other party with the responsibility, legally or contractually, to keep the ship seaworthy or in service, having particular regard to the provisions relating to the maintenance of class laid down in Part A, Chapter 2 of the Rules for the Classification of Ships or in the corresponding rules indicated in the specific Rules.

"Rules" in these General Conditions means the documents below issued by the Society:

(i) Rules for the Classification of Ships or other special units;
(ii) Complementary Rules containing the requirements for product, plant, system and other certification or containing the requirements for the assignment of additional class notations;
(iii) Rules for the application of statutory rules, containing the rules to perform the duties delegated by Administrations;
(iv) Guides to carry out particular activities connected with Services;
(v) Any other technical document, as for example rule variations or interpretations.

"*Services*" means the activities described in Article 1 below, rendered by the Society upon request made by or on behalf of the Interested Party.

"Ship" means ships, boats, craft and other special units, as for example offshore structures, floating units and underwater craft.

"*Society*" or *"TASNEEF"* means Tasneef and/or all the companies in the Tasneef Group which provide the Services.

"*Surveyor*" means technical staff acting on behalf of the Society in performing the Services.

Article 1

1.1. The purpose of the Society is, among others, the classification and certification of ships and the certification of their parts and components. In particular, the Society:
(i) sets forth and develops Rules;
(ii) publishes the Register of Ships;
(iii) issues certificates, statements and reports based on its survey activities.

1.2. The Society also takes part in the implementation of national and international rules and standards as delegated by various Governments.

1.3. The Society carries out technical assistance activities on request and provides special services outside the scope of classification, which are regulated by these general conditions, unless expressly excluded in the particular contract.

Article 2

2.1. The Rules developed by the Society reflect the level of its technical knowledge at the time they are published. Therefore, the Society, although committed also through its research and development services to continuous updating of the Rules, does not guarantee the Rules meet state-of-the-art science and technology at the time of publication or that they meet the Society's or others' subsequent technical developments.

2.2. The Interested Party is required to know the Rules on the basis of which the Services are provided. With particular reference to Classification Services, special attention is to be given to the Rules concerning class suspension, withdrawal and reinstatement. In case of doubt or inaccuracy, the Interested Party is to promptly contact the Society for clarification.
The Rules for Classification of Ships are published on the Society's website: www.tasneef.ae.

2.3. The Society exercises due care and skill:
(i) in the selection of its Surveyors
(ii) in the performance of its Services, taking into account the level of its technical knowledge at the time the Services are performed.

2.4. Surveys conducted by the Society include, but are not limited to, visual inspection and non-destructive testing. Unless otherwise required, surveys are conducted through sampling techniques and do not consist of comprehensive verification or monitoring of the Ship or of the items subject to certification. The surveys and checks made by the Society on board ship do not necessarily require the constant and continuous presence of the Surveyor. The Society may also commission laboratory testing, underwater inspection and other checks carried out by and under the responsibility of qualified service suppliers. Survey practices and procedures are selected by the Society based on its experience and knowledge and according to generally accepted technical standards in the sector.

Article 3

3.1. The class assigned to a Ship, like the reports, statements, certificates or any other document or information issued by the Society, reflects the opinion of the Society concerning compliance, at the time the Service is provided, of the Ship or product subject to certification, with the applicable Rules (given the intended use and within the relevant time frame).
The Society is under no obligation to make statements or provide information about elements or facts which are not part of the specific scope of the Service requested by the Interested Party or on its behalf.

3.2. No report, statement, notation on a plan, review, Certificate of Classification, document or information issued or given as part of the Services provided by the Society shall have any legal effect or implication other than a representation that, on the basis of the checks made by the Society, the Ship, structure, materials, equipment, machinery or any other item covered by such document or information meet the Rules. Any such document is issued solely for the use of the Society, its committees and clients or other duly authorised bodies and for no other purpose. Therefore, the Society cannot be held liable for any act made or document issued by other parties on the basis of the statements or information given by the Society. The validity, application, meaning and interpretation of a Certificate of Classification, or any other document or information issued by the Society in connection with its Services, is governed by the Rules of the Society, which is the sole subject entitled to make such interpretation. Any disagreement on technical matters between the Interested Party and the Surveyor in the carrying out of his functions shall be raised in writing as soon as possible with the Society, which will settle any divergence of opinion or dispute.

3.3. The classification of a Ship, or the issuance of a certificate or other document connected with classification or certificate on and in general with the performance of Services by the Society shall have the validity conferred upon it by the Rules of the Society at the time of the assignment of class or issuance of the certificate; in no case shall it amount to a statement or warranty of seaworthiness,

structural integrity, quality or fitness for a particular purpose or service of any Ship, structure, material, equipment or machinery inspected or tested by the Society.

3.4. Any document issued by the Society in relation to its activities reflects the condition of the Ship or the subject of certification or other activity at the time of the check.

3.5. The Rules, surveys and activities performed by the Society, reports, certificates and other documents issued by the Society are in no way intended to replace the duties and responsibilities of other parties such as Governments, designers, ship builders, manufacturers, repairers, suppliers, contractors or sub-contractors, Owners, operators, charterers, underwriters, sellers or intended buyers of a Ship or other product or system surveyed.

These documents and activities do not relieve such parties from any fulfilment, warranty, responsibility, duty or obligation (also of a contractual nature) expressed or implied or in any case incumbent on them, nor do they confer on such parties any right, claim or cause of action against the Society. With particular regard to the duties of the ship Owner, the Services undertaken by the Society do not relieve the Owner of his duty to ensure proper maintenance of the Ship and ensure seaworthiness at all times. Likewise, the Rules, surveys performed, reports, certificates and other documents issued by the Society are intended neither to guarantee the buyers of the Ship, its components or any other surveyed or certified item, nor to relieve the seller of the duties arising out of the law or the contract, regarding the quality, commercial value or characteristics of the item which is the subject of transaction.

In no case, therefore, shall the Society assume the obligations incumbent upon the above-mentioned parties, even when it is consulted in connection with matters not covered by its Rules or other documents.

In consideration of the above, the Interested Party undertakes to relieve and hold harmless the Society from any third party claim, as well as from any liability in relation to the latter concerning the Services rendered.

Insofar as they are not expressly provided for in these General Conditions, the duties and responsibilities of the Owner and Interested Parties with respect to the services rendered by the Society are described in the Rules applicable to the specific Service rendered.

Article 4

4.1. Any request for the Society's Services shall be submitted in writing and signed by or on behalf of the Interested Party. Such a request will be considered irrevocable as soon as received by the Society and shall entail acceptance by the applicant of all relevant requirements of the Rules, including these General Conditions. Upon acceptance of the written request by the Society, a contract between the Society and the Interested Party is entered into, which is regulated by the present General Conditions.

4.2. In consideration of the Services rendered by the Society, the Interested Party and the person requesting the service shall be jointly liable for the payment of the relevant fees, even if the service is not concluded for any cause not pertaining to the Society. In the latter case, the Society shall not be held liable for non-fulfilment or partial fulfilment of the Services requested. In the event of late payment, interest at the legal current rate increased by 1.5% may be demanded.

4.3. The contract for the classification of a Ship or for other Services may be terminated and any certificates revoked at the request of one of the parties, subject to at least 30 days' notice to be given in writing. Failure to pay, even in part, the fees due for Services carried out by the Society will entitle the Society to immediately terminate the contract and suspend the Services.

For every termination of the contract, the fees for the activities performed until the time of the termination shall be owed to the Society as well as the expenses incurred in view of activities already programmed; this is without prejudice to the right to compensation due to the Society as a consequence of the termination.

With particular reference to Ship classification and certification, unless decided otherwise by the Society, termination of the contract implies that the assignment of class to a Ship is withheld or, if already assigned, that it is suspended or withdrawn; any statutory certificates issued by the Society will be withdrawn in those cases where provided for by agreements between the Society and the flag State.

Article 5

5.1. In providing the Services, as well as other correlated information or advice, the Society, its Surveyors, servants or agents operate with due diligence for the proper execution of the activity. However, considering the nature of the activities performed (see art. 2.4), it is not possible to guarantee absolute accuracy, correctness and completeness of any information or advice supplied. Express and implied warranties are specifically disclaimed.

Therefore, except as provided for in paragraph 5.2 below, and also in the case of activities carried out by delegation of Governments, neither the Society nor any of its Surveyors will be liable for any loss, damage or expense of whatever nature sustained by any person, in tort or in contract, derived from carrying out the Services.

5.2. Notwithstanding the provisions in paragraph 5.1 above, should any user of the Society's Services prove that he has suffered a loss or damage due to any negligent act or omission of the Society, its Surveyors, servants or agents, then the Society will pay compensation to such person for his proved loss, up to, but not exceeding, five times the amount of the fees charged for the specific services, information or opinions from which the loss or damage derives or, if no fee has been charged, a maximum of AED5,000 (Arab Emirates Dirhams Five Thousand only). Where the fees charged are related to a number of Services, the amount of the fees will be apportioned for the purpose of the calculation of the maximum compensation, by reference to the estimated time involved in the performance of the Service from which the damage or loss derives. Any liability for indirect or consequential loss, damage or expense is specifically excluded. In any case, irrespective of the amount of the fees charged, the maximum damages payable by the Society will not be more than AED5,000,000 (Arab Emirates Dirhams Five Millions only). Payment of compensation under this paragraph will not entail any admission of responsibility and/or liability by the Society and will be made without prejudice to the disclaimer clause contained in paragraph 5.1 above.

5.3. Any claim for loss or damage of whatever nature by virtue of the provisions set forth herein shall be made to the Society in writing, within the shorter of the following periods: (i) THREE (3) MONTHS from the date on which the Services were performed, or (ii) THREE (3) MONTHS from the date on which the damage was discovered. Failure to comply with the above deadline will constitute an absolute bar to the pursuit of such a claim against the Society.

Article 6

6.1. These General Conditions shall be governed by and construed in accordance with United Arab Emirates (UAE) law, and any dispute arising from or in connection with the Rules or with the Services of the Society, including any issues concerning responsibility, liability or limitations of liability of the Society, shall be determined in accordance with UAE law. The courts of the Dubai International Financial Centre (DIFC) shall have exclusive jurisdiction in relation to any claim or dispute which may arise out of or in connection with the Rules or with the Services of the Society.

6.2. However,

(i) In cases where neither the claim nor any counterclaim exceeds the sum of AED300,000 (Arab Emirates Dirhams Three Hundred Thousand) the dispute shall be referred to the jurisdiction of the DIFC Small Claims Tribunal; and

(ii) for disputes concerning non-payment of the fees and/or expenses due to the Society for services, the Society shall have the

right to submit any claim to the jurisdiction of the Courts of the place where the registered or operating office of the Interested Party or of the applicant who requested the Service is located.
In the case of actions taken against the Society by a third party before a public Court, the Society shall also have the right to summon the Interested Party or the subject who requested the Service before that Court, in order to be relieved and held harmless according to art. 3.5 above.

Article 7

7.1. All plans, specifications, documents and information provided by, issued by, or made known to the Society, in connection with the performance of its Services, will be treated as confidential and will not be made available to any other party other than the Owner without authorization of the Interested Party, except as provided for or required by any applicable international, European or domestic legislation, Charter or other IACS resolutions, or order from a competent authority. Information about the status and validity of class and statutory certificates, including transfers, changes, suspensions, withdrawals of class, recommendations/conditions of class, operating conditions or restrictions issued against classed ships and other related information, as may be required, may be published on the website or released by other means, without the prior consent of the Interested Party.
Information about the status and validity of other certificates and statements may also be published on the website or released by other means, without the prior consent of the Interested Party.

7.2. Notwithstanding the general duty of confidentiality owed by the Society to its clients in clause 7.1 above, the Society's clients hereby accept that the Society may participate in the IACS Early Warning System which requires each Classification Society to provide other involved Classification Societies with relevant technical information on serious hull structural and engineering systems failures, as defined in the IACS Early Warning System (but not including any drawings relating to the ship which may be the specific property of another party), to enable such useful information to be shared and used to facilitate the proper working of the IACS Early Warning System. The Society will provide its clients with written details of such information sent to the involved Classification Societies.

7.3. In the event of transfer of class, addition of a second class or withdrawal from a double/dual class, the Interested Party undertakes to provide or to permit the Society to provide the other Classification Society with all building plans and drawings, certificates, documents and information relevant to the classed unit, including its history file, as the other Classification Society may require for the purpose of classification in compliance with the applicable legislation and relative IACS Procedure. It is the Owner's duty to ensure that, whenever required, the consent of the builder is obtained with regard to the provision of plans and drawings to the new Society, either by way of appropriate stipulation in the building contract or by other agreement.
In the event that the ownership of the ship, product or system subject to certification is transferred to a new subject, the latter shall have the right to access all pertinent drawings, specifications, documents or information issued by the Society or which has come to the knowledge of the Society while carrying out its Services, even if related to a period prior to transfer of ownership.

Article 8

8.1. Should any part of these General Conditions be declared invalid, this will not affect the validity of the remaining provisions.

INDEX

1 PURPOSE AND APPLICATION

The purpose of this Guide is to provide indications concerning some of the most useful condition based maintenance (CBM) techniques:

- vibration monitoring
- lubricating oil analysis
- thermography.

This Guide applies to all types of ships for the application of CBM within the Planned Maintenance Scheme (PMS) according to Part F, Ch 1, App 7 of the Rules for the Classification of Ships.

It is primarily intended for Designers, the technical staff of ship Owners or independent consultants and Surveyors.

2 THEORY UNDERLYING THE DETERMINATION OF CBM TASK INTERVALS

CBM is the process of extracting prognostic information from machines to indicate their actual wear and degradation and the relevant rate of change (i.e. trend), on the basis of which the maintenance tasks can be adjusted flexibly in accordance to their actual status. The cost effectiveness of the CBM approach is related to the criticality of the monitored items, the reliability of the CBM techniques in providing valuable information and the ease of interpretation of the results and their trends.

CBM task intervals, in theory, are determined based on the expected P-F interval. The concept of P-F interval illustrates the relation between the CBM task frequency and the mechanism of deterioration, but in practice it is often impossible to obtain a true mathematical function that describes the process. What follows is reported only qualitatively, for explanatory purposes.

Figure 1 shows this general process. It is called the P-F curve, because it shows how a failure starts and deteriorates to the point at which it can be detected (the potential failure point "P"). After this point, if the problem is not detected and corrected, the deterioration continues (often at a higher rate) until it reaches the point ("F") of functional failure, i.e. when the item ceases to perform its defined function.

The P-F interval is therefore the amount of time (or the number of stress cycles) that elapses between point P and point F.

The concept of P-F interval drives the minimum frequency with which the predictive task should be carried out. Obviously, the lower the checking interval with respect to the P-F interval, the earlier the potential failure will be detected before it becomes a functional failure.

The P-F interval can be measured in any units relating to exposure to stress (running time, units of output, stop-start cycles, etc), but it is most often measured in terms of elapsed time. For different failure modes, the P-F interval exhibits wide variations according to the physical nature of the deterioration.

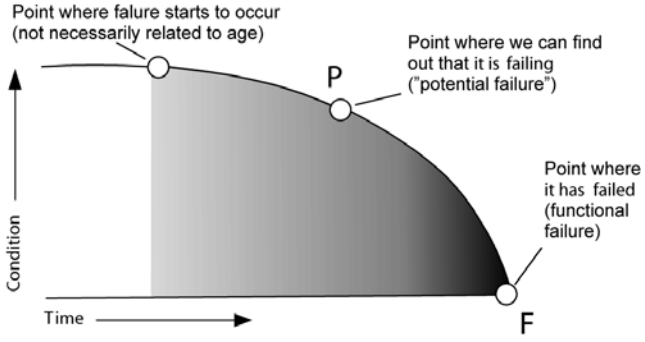
If the P-F interval is known, a good choice for the checking interval is approximately half the P-F interval. The rationale for this choice is that such an interval allows for the task to detect the potential failure before the functional failure occurs, while providing a net interval of at least another half the P-F interval to fix it. However, it is sometimes necessary to select a checking interval that is some other fraction of the P-F interval, to allow for the wide uncertainties surrounding its knowledge, and depending on the criticality of the function that the item is providing.

If the P-F interval is too short to practically predict a potential failure, or if the net P-F interval is too short for any sensible action to be taken once a potential failure is discovered, then the condition based task is not appropriate for the failure mode under consideration.

Indeed, the amount of time needed to respond to any potential failures which are discovered also influences CBM task intervals. In general, it needs to be understood whether these potential failures require immediate or delayed actions, if the actions are of preventive or corrective nature, etc.

The amount of time needed for these responses also varies, from a matter of hours (say until the end of an operating cycle), minutes (to clear people from a space in an emergency) or even seconds (to shut down a machine or process which is running out of control) to weeks or even months (say until a major overhaul).

Figure 1



3 OVERVIEW OF CBM TECHNIQUES

3.1 General

An overview of CBM techniques is reported below.

There may be alternative names for the techniques mentioned herein, particularly when a proprietary technology is used (e.g. SPM™, Spike energy ™).

The Fixed/Portable Equipment column indicates whether the hardware that the technique uses is fixed (usually, it is a part of the equipment being monitored), or portable (usually, it is carried to the equipment and removed after data acquisition). In some cases, the hardware may be fixed or portable according to the application of the equipment being monitored.

It is underlined that the simultaneous use of various aspects of condition monitoring data can provide a better picture of the condition of a machine than the reading of the data separately. Further elements for diagnosis can be obtained by checking other parameters along with those that show the abnormality, or by analysing the performance of similar machinery on other ships in the fleet.

3.2 Vibration Monitoring

3.2.1 Introduction

Vibration monitoring involves the acquisition of vibration data, which can then be checked for trends over a period of time. It focuses more on detecting changes in vibration behaviour rather than measuring any particular behaviour in isolation. Changes in vibration behaviour may occur for a variety of reasons, a non-exhaustive list of which is:

- Wear
- Imbalance
- Misalignment
- Looseness
- Bearing damage
- Resonance
- Fatigue
- Deformation of a shaft
- Defects in transmission means
- Cavitation.

Vibration measurements for CBM purposes may vary from simple to complex and can include continuous or periodical measurements. Spectrum analysis is generally more suitable for steady state conditions, whilst waveform analysis is more suitable for transient situations. Other proprietary techniques are more useful to detect very specific failures, like wear or insufficient lubrication of roller bearings or gears.

Vibration monitoring systems can be made of instruments permanently installed on machines (with continuous or periodical data reading) or portable instruments used to record data manually at preselected locations on a machine at periodical intervals using a portable tool for spot measurements.

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 (‘baseline’ conditions), including sea and weather conditions.

3.2.2 Vibration Parameters

The main types of vibration measurements that are normally used for CBM of shipboard rotating machinery are:

a) Vibration measurements made on the non-rotating structure of the machine, such as bearing housings and casings: the typical parameter is root mean square (r.m.s.) velocity in units of millimetres per second (mm/s). For gearing and high speed machines (steam and gas turbines), peak acceleration is also often used and expressed in units such as metres per second (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 (typically peak or peak-to-peak displacement) is measured in µm.

   As mentioned above, special techniques are often used for CBM of rolling bearings to integrate the more general vibration monitoring. Various techniques, such as shock pulse analysis (SPM™), Spike energy™, Kurtosis factor and Acceleration crest factor, can be used to indicate the status of the bearing.

3.2.3 Vibration Measurements

As far as possible, vibrations should be measured on bearing housings and never at freely vibrating surfaces. Measurements should normally be taken in axial and radial planes with reference to the shaft axis and always in the direction of minimal stiffness of the structure. 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.

Intrinsically safe equipment is always to be used in explosive environments (the pump room in an oil tanker, for example).

3.2.4 Standardisation of the measurement

Since CBM is based on the assessment of the trend of the measured values over time, it is imperative that the acquisition of such measures should be carried out by a procedure as standard as possible:

- To facilitate consistency, the measurement points for portable monitoring systems should be clearly marked and identified using a consistent convention. In particular, to avoid errors in the identification of the point, systems should be used to automatically identify the measurement points, such as bar code placards, frequency radiotransponders or similar devices that can be read by the portable instruments.
- Repeatable and accurate vibration measurements on stationary parts require adequate contact between the transducer and the vibrating surface. Fixed transducers may be mechanically connected or bound to the machine in such a way as to avoid unreliable measures caused by undue stress or motion. If portable systems are employed, it is to be ensured that a positive means of contact is used.

  The most common types of transducers used for vibration monitoring are:

  a) Accelerometers, the outputs of which 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 parts of the machine.

     As for type (a) transducers, accelerometers should be used having a minimum sensitivity of 100 mV/g, to guarantee the solidity and the reliability of the application.

     In the configuration of the vibration measurement acquisition, the selection of a range of 2-1000 Hz should be used with a minimum resolution of 1600 lines for rotating machinery with speed up to 3500 rpm, or a range of 2-5000 Hz with a minimum resolution of 3200 lines for machinery rotating at higher speed.

     The use of the Hanning type window is also recommended, allowing an optimal proportionality of the vibration amplitudes to the various frequencies in the standard applications.
- To facilitate consistency, it is also important that, as far as possible, the measurement should always be carried out in the same operating conditions; should this not be fully practicable, it is necessary to record parameters suitable to give indications of the operating conditions of the machine at the moment of the measurement (e.g. % of load, absorbed power, flow, pressure etc).

3.2.5 Calibration

Calibration of the instrumentation used for CBM measurements is to be carried out annually by the Manufacturer or by an authorised service supplier.

In general, a ± 10% tolerance for the required amplitude and frequency range of the measurement is acceptable. During the annual audit of the CBM records, the Tasneef Surveyor will verify that the calibration certificates are regularly updated.

3.2.6 Baseline Measurements

'Baseline vibration data' is intended to mean those data obtained when the machine is operating at its predominant (i.e. most commonly employed) load conditions in a stable and acceptable manner. All subsequent measurements will be compared to these baseline values to detect vibration trends. For new or freshly overhauled equipment, an initial operational time period (break-in) should be allowed before baseline measurements are taken. After break-in, baseline data for a piece of equipment in steady state operation can still be acquired and used as a reference point to detect future changes.

Baseline data of a piece of equipment should consist of a comprehensive set of measurements necessary and sufficient to define its vibratory profile. Even for baseline data acquisition it is necessary to record parameters suitable to give indications of the actual operating conditions of the machine at the time of measurement (e.g. % load, absorbed power, flow, suction and delivery pressure, shaft rotational speed etc). Subsequent periodical measurements need only be taken to detect changes and, if deemed necessary, the baseline measurement procedures may be repeated to help determine the cause of the changes.

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

3.2.7 Vibration Analysis

The two most common types of vibration analysis are broadband vibration and frequency spectrum analysis, which are described in [3.2.8] and [3.2.9].

3.2.8 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 graphically in trend plots to show changes in machine condition over time.

Various international standards (such as ISO Standards 10816, 7919, 13373-1) specify the acceptable broadband vibration values for different types of machines. Tab 1, obtained from the aforesaid sources, provides the vibration limits of rotating machinery (e.g. centrifugal pumps) driven by separate electric motors of various sizes.

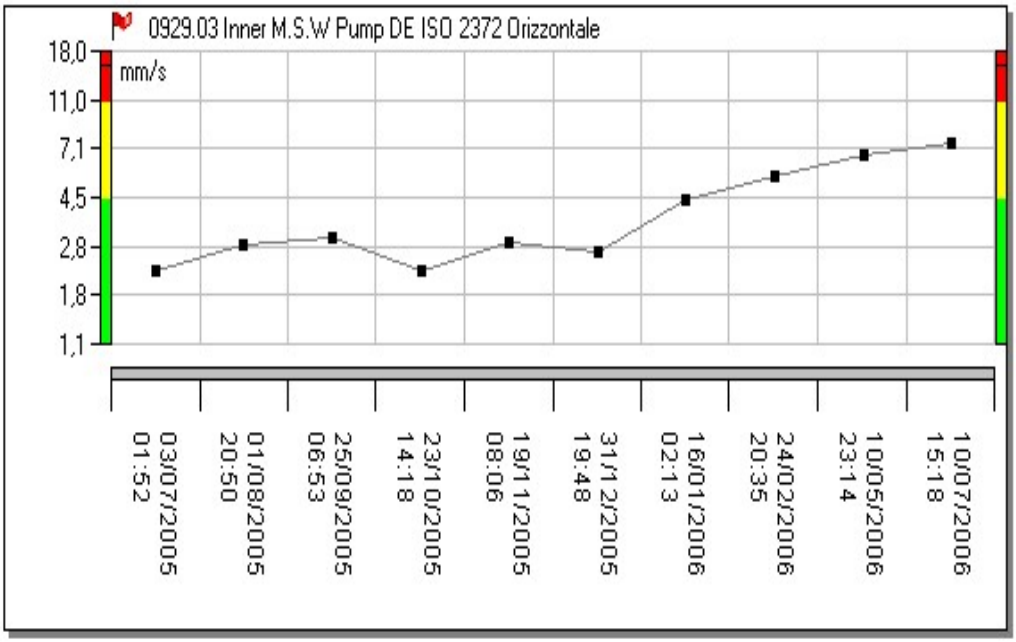
However, such absolute limits, although set by international standards, are not related to the operating environment of the machinery.

Therefore, they should be used as guidance, and CBM should be mostly based on the rate of change of vibration levels rather than on singular values, and trend plots are used to present this information. Figure 2 shows a typical trend plot for a motor driven pump.

Table 1: Vibration limits for electric motor driven rotating machinery

	Small Machinery < 15 kW	**Medium Machinery 15 - 75 kW**	**Large Machinery > 75 kW**	
			Rigid foundations	**Flexible foundations**
	Limit (mm/sec rms)	**Limit (mm/sec rms)**	**Limit (mm/sec rms)**	**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: Typical plot of vibration readings



3.2.9 Frequency Spectrum Analysis

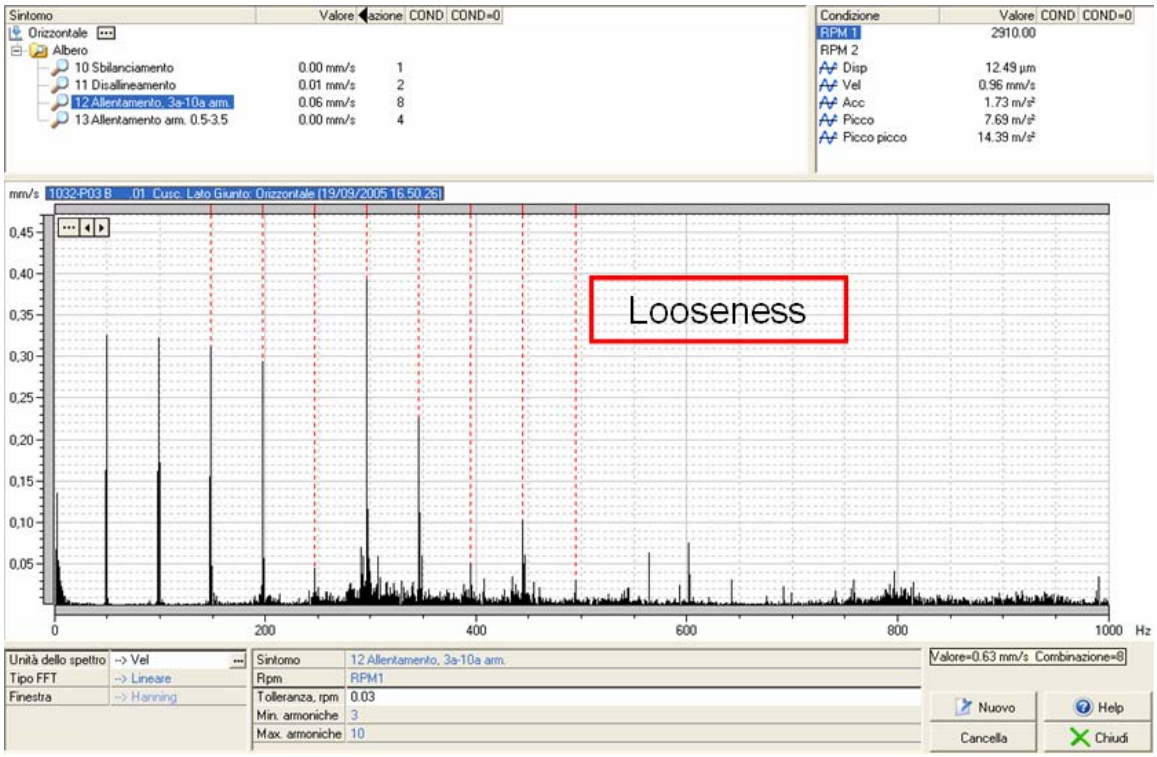
Because different types of machinery problems generate vibration at different frequencies, it is very useful to break down a vibration signal into individual frequency components. The amount of vibration occurring at any particular frequency is called the amplitude of vibration at that frequency. A plot 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.

Fig 3 shows a typical frequency spectrum.

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 [3.2.10].

Figure 3: Typical vibration signature



3.2.10 Typical interpretations of the causes of vibration at specific frequencies

a) Imbalance

In all machines. Imbalance, due e.g. to soft foot. A line at 1X, the fundamental frequency, is generally present in the spectrum of rotating machines. It occurs predominantly in radial directions.
The amplitude is significant.

Figure 4

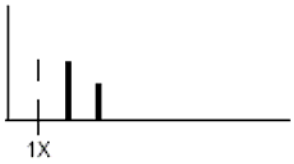
1 line at 1X
Frequency range: >1X

b) Misalignment

In all machines with couplings, belt drive. High values in axial direction. In general, two types of misalignment exist, namely:
- parallel misalignment, which is revealed by high values in radial directions
- angular misalignment, which is revealed by high values in axial direction.

Vibrations due to eccentricity have similar characteristics to those due to imbalance and misalignment.

Figure 5

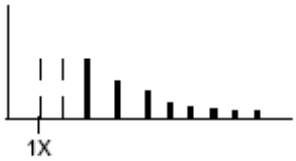


1 lines at 2Xand 3X
Frequency range: >3X

c) Looseness, 2 - 10 Harmonic (H)

In all machines. Structural looseness, excessive bearing play. Typically, the following components may be affected: assembly machine screws, bearings with excessive radial tolerance.

Figure 6

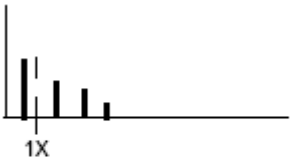


7 lines at 3X – 10X
Frequency range: >10X

d) Looseness, 0,5 - 3,5 H

In all machines. Structural looseness, excessive bearing play. Typically, the following components may be affected: assembly machine screws, bearings with excessive radial tolerance.

Figure 7



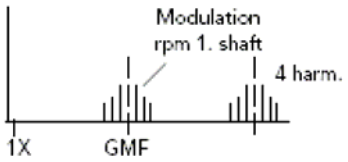
4 lines at 0.5X, 1.5X, 2.5X, 3.5X
Frequency range: 4X

e) Gear damage

In gear boxes. Look for 3 sidebands of the gear mesh frequency (GMF), modulation with the rpm of this shaft, plus 4 harmonics. The GMF itself is usually present. The appearance of sidebands (and harmonics) shows damage.

Input number of teeth of driving wheel.

Figure 8



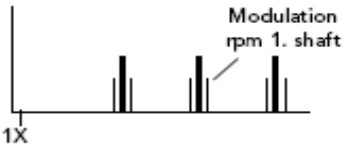
4 times 6 lines at 1X*Z – 4X*Z
(X and Z for shaft 1)
Frequency range: >4X*Z (2X*Z)

f) Gear alignment

In gearboxes. Look for 1st to 3rd harmonic of GMF (2nd and 3rd should be higher than 1*GMF), with 1 sideband, modulation with the rpm of the shaft.

Input number of teeth of driving wheel.

Figure 9



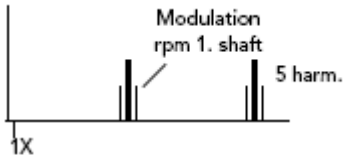
3 times 3 lines at 2X*Z – 3X*Z
Frequency range: >3X*Z

g) Gear assembly

In gearboxes. Look for the GAPF (gear assembly phase frequency), which is a fraction of GMF.

Input the assembly phase factor NA.

Figure 10

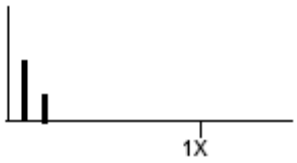


5 times 3 lines at $1X*Z/N_A$ – $5X*Z/N_A$
Frequency range: $>5X*Z/N_A$ ($3X*Z/N_A$)

h) Hunting tooth (HT)

In gearboxes. Look for the hunting tooth frequency HTF (one faulty tooth on Z1 meets a faulty tooth on Z2).

Figure 11

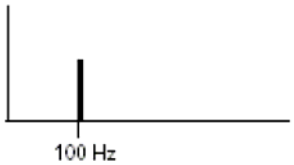


2 lines at $1X * N_A / Z2$, $2X * N_A / Z2$
Frequency range: below X

i) Eccentric stator, 50 Hz

In electric motors. Look for the double line frequency. This line is due to magnetostriction, always present, with normal amplitudes depending on motor design. Increased amplitudes can be due to an uneven stationary air gap between rotor and stator. Can even be a sign of soft foot, a warped base, loose iron, or shorted stator laminations.

Figure 12



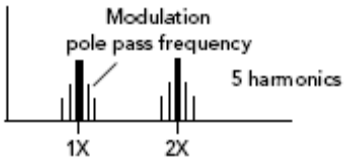
1 line at 100 Hz

j) Rotor faults, 50 Hz

In electric motors. Look for 1X and 5 harmonics with 2 sidebands, modulation with the pole pass frequency, which is the slip frequency multiplied by the number of poles.

Look for the double line frequency. Sidebands can be due to an uneven rotating air gap between rotor and stator. Can even be a sign of soft foot, a warped base, misalignment etc.

Figure 13



5 times 5 lines at 1X – 5X
Frequency range: >5X

k) Vane or blade faults

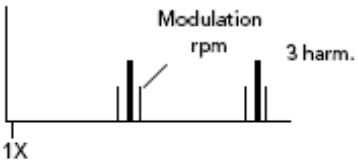
In pumps, irregular gap between rotating vanes and stationary diffusers; impeller wear ring seized on shaft, failed diffuser vane welds.

In fans, broken or damaged blades, irregular dirt layer.

Pump cavitation: Broadband high noise level above BPF.

Flow turbulence: High random vibration below 1X, high noise level above BPF. Look for the blade pass frequency (BPF), which is significant in pumps, fans and compressors. Rpm modulation, 3 sidebands.

Figure 14



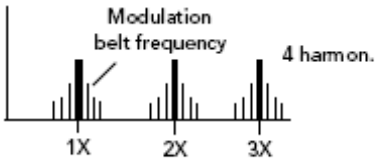
3 times 3 lines at 1X*Z – 3X*Z

Frequency range: >3.5X*Z

l) Belt problems

In belt transmissions. Look for the 1X to 4X modulated with the belt frequency (BPF), 3 sidebands.

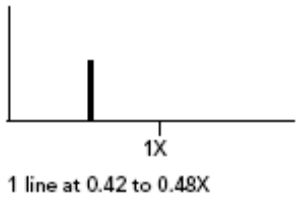
Figure 15



3 times 7 lines at 1X – 3X
Frequency range: >4X

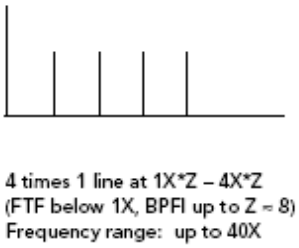
m) Oil whirl
In journal bearings. Look for oil whirl frequency, 0,42 to 0,48X.

Figure 16



n) Bearing damage BPFO, BPFI, BSF, FTF
In rolling bearings. Look for damage to outer race, inner race, rolling elements or cage.

Figure 17



where:
FTF = Fundamental Train Frequency
BSF =Ball Spin Frequency
BPFO =Ball Pass Frequency Outer race
BPFI = Ball Pass Frequency Inner race

$$FTF := \frac{1}{2}\cdot\left(1 - \frac{d}{D}\cdot\cos\right)\cdot Rps$$

$$BSF := \left(\frac{D}{2\cdot d}\right)\cdot\left[1 - \left(\frac{d}{D}\cdot\cos\right)^2\right]\cdot Rps$$

$$BPFO := N\cdot FTF$$

$$BPFI := N\cdot(Rps - FTF)$$

Rps = Shaft rotation, rounds per second
d = Rolling element diameter
D = Pitch diameter
N = No. of rolling elements
Φ = Contact angle

3.2.11 Minimum Technical Characteristics of the Measurement Instrumentation

To diagnose the operating conditions of machinery with accuracy, the following features are imperative:

- frequency range of operation sufficiently wide as to include the typical frequencies of the most common mechanical defects related to the machinery being monitored: the instrumentation can be considered satisfactory if it can carry out measurements from a minimum of 3÷100 Hz up to at least 3÷5 kHz
- resolution such that the frequency can be ascribed to the corresponding mechanical defect, in an accurate and unambiguous manner; for this purpose, the minimum satisfactory resolution is 3200 lines.

3.2.12 Minimum Frequency of Measurements

In any case, to obtain significant trends at least four measurements per year should be taken at sufficiently regular intervals. A higher frequency should be established on the basis of the criticality of the machine, in terms of safety and/or economy. More details according to the machinery type are reported in Pt F, Ch 1, App 7, [6.3] and [6.4] of Rules for the Classification of Ships.

3.3 Lubricating Oil Monitoring

The main objectives of lube oil analysis are:

- to monitor the rate of change of lubricant condition parameters;
- to ensure that the oil remains in an acceptable operating condition; and
- to detect the onset of failure mechanisms.

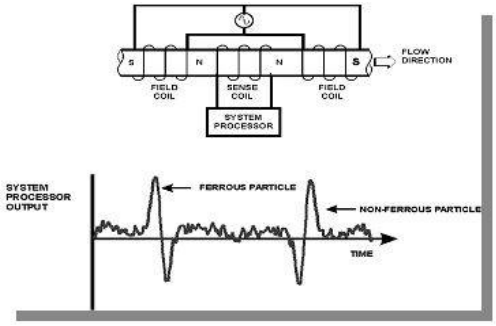
The sample is to be kept free of contaminants and to belong to the oil actually in contact with the lubricated parts.
The analysis is to be performed by the equipment supplier or by specialised laboratories authorised by the supplier.
Tab 2 provides the general correspondence between the parameter and the condition to be checked.
As an alternative to lube oil analysis for pods and gas turbines, a fixed analyser allowing continuous oil debris monitoring can be fitted in the section from the oil return line to the filter, provided that it does not affect the oil flow in any way.
The working principle of such devices is based on the detection of the mass of (ferrous and non-ferrous) metal particles in the lube oil flow, through the variation of the magnetic field caused by the passage of the metal particles through a coil, as shown in Fig 18.

Table 2

Parameter	Condition to detect
Viscosity	Increase or decrease
Flashpoint	Decrease
Water concentration	Presence of salt or fresh water
Alkalinity	Increase or decrease
Strong acid	Presence
Acidity	Increase
Insoluble substances	Increase
Metals	Increase
Microbial concentration	$\geq 10^4$
Particle count	Increase

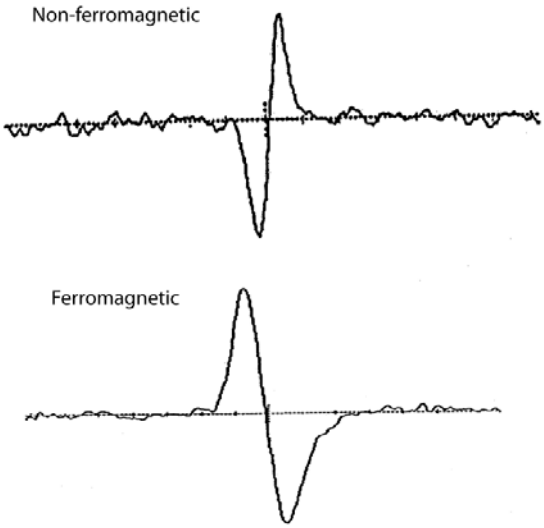
(*) particularly important for hydraulic systems with requirements of high oil cleanliness

Figure 18



Every particle has a different coupling level with the magnetic field when it crosses the sensitive zone, and this turns into a characteristic output signature, as shown in Fig 19:

Figure 19



The amplitude and the phase of the output signal are used to identify the size and nature of the particle. The amplitude is proportional to the particle mass for ferromagnetic materials, and to the surface area of the particles for non-ferromagnetic conductive materials. The signal phase of ferromagnetic materials is opposite to that of non-ferromagnetic materials.

The output signal is normally elaborated in a control unit that yields the following information, which can be stored for subsequent analysis and records:

- particle number and size
- total mass
- particle rate
- comparison of the actual status with pre-set thresholds
- alarm indications
- distribution of the particle size.

As an example, the following figure shows the different trending behaviour of the diffusion of metal particles in two bearings with different levels of wearout, low (see Fig 20) and high (see Fig 21).

Figure 20

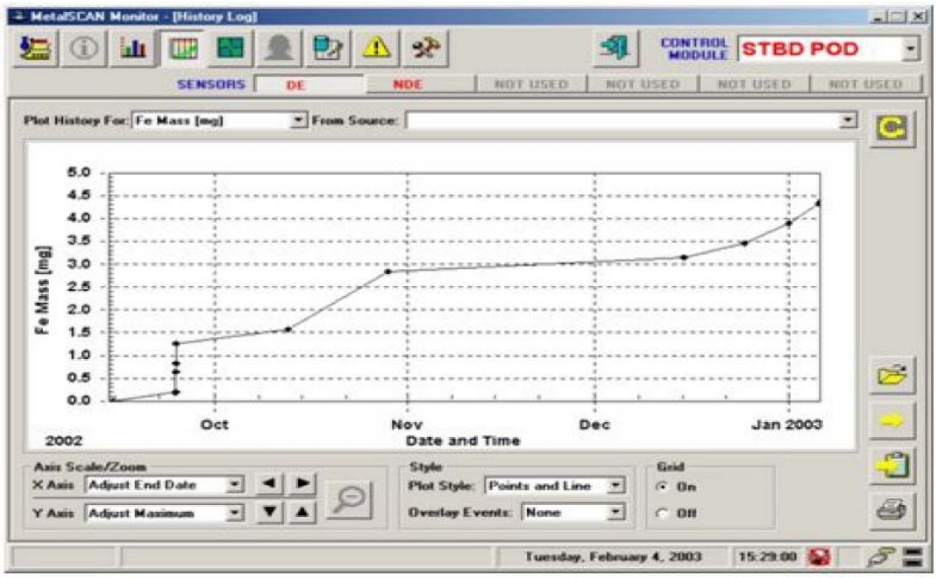
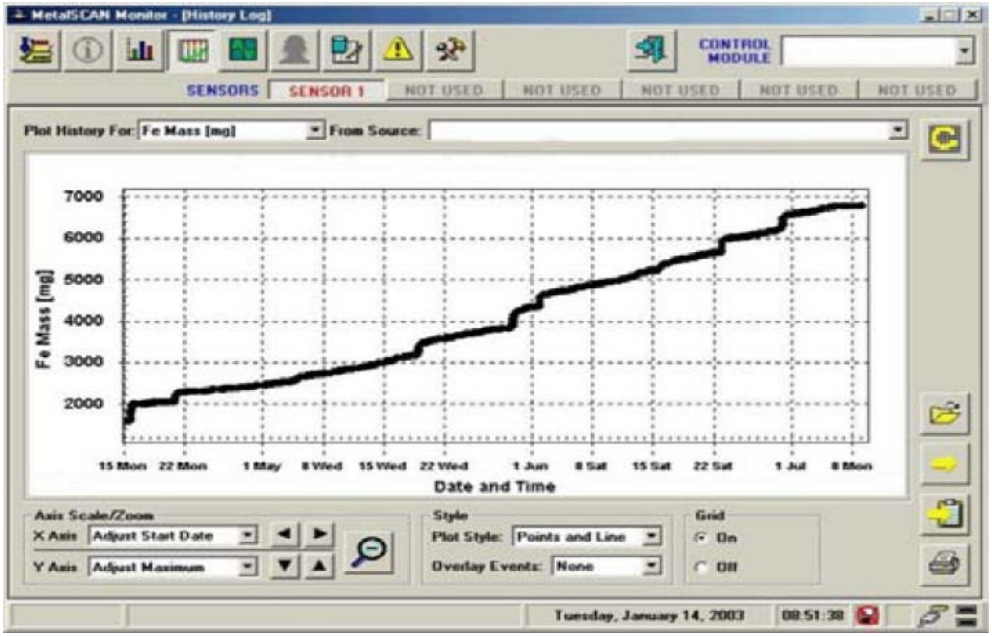


Figure 21



3.4 Thermographic inspection criteria

The purpose of the thermographic inspection is to:

- evaluate the operating condition of a selected item of equipment.
- isolate the locations of “hot spots“ and recommend necessary corrective measures.

When a scan performed with the infrared camera reveals a potential problem, a thermogram and temperature are to be taken.

Absolute surface temperature measurements of the target are to be taken, and ambient or background measurements are to be detected within the surrounding target area to indicate relative temperature rise.

A thermogram is known as an infrared photograph and is obtained by videotaping the image from the infrared camera.

A means of assessing severity of temperature in evaluating the maintenance scheduling is presented in Tab 3. The degree of temperature rise and criticality of the particular equipment or process involved should determine the final decision as to priorities and order of maintenance.

The personnel in charge of the thermographic inspection are to hold a qualification corresponding to level 2 of EN 473 or ISO 9712, or alternatively the second level of SNT TC 1A if issued by a recognised body.

Reference: ISO 7726 “Ergonomics of the thermal environment - Instruments for measuring physical quantities”.

Table 3

TEMPERATURE RISE ΔT	REMARKS
1°C ≤ ΔT ≤ 10°C	Corrective measures required during the next scheduled maintenance period
10°C < ΔT ≤ 20°C	Corrective measures to be scheduled on a priority basis
20°C < ΔT ≤ 30° C	Corrective measures required as soon as possible
Above 30°C	Corrective measures required immediately