Considerations for Classification Societies
With Respect to *Vibration Condition Monitoring* (VCM)

Maryon J. (Skip) Williams, Ph.D., P.E.
Senior Engineer
Condition Analyzing Corporation

John K. McNeil
President/CEO
Condition Analyzing Corporation

Abstract

Vibration Condition Monitoring is a subset of the broader process of Condition Based Maintenance (CBM). CBM is a strategy rooted in applied scientific inquiry and resulting in empirical evidence of machine performance. Our focus is on the sub-practice of Vibration Condition Monitoring (VCM). There are benefits to performing other CBM techniques, however in our experience the specific technique of VCM is most effective in achieving the dual goals of reliable machine performance and cost-effective maintenance.

Successful Vibration Condition Monitoring (VCM) programs are characterized by careful implementation. Several areas of practice or approach critical to realizing the benefit of VCM are identified. Incentives Classification Societies could offer to increase quality and expand the use of VCM are explored, including uniform data standards, operating guidelines, and adjustments to mandatory opening practices supported by VCM data. Business benefits of VCM programs are identified. Considerations for industry and class cooperation and collaboration are addressed.

1. Conclusions for VCM Consumers

A successful vibration condition monitoring (VCM) program requires more than purchase of the hardware and data collection, but the integration with a total system. There are several areas in which practice or approach makes the critical difference in realizing benefit from a VCM program. These include: Managerial Decisions; Personnel; Technical Support; and Integration with Work Order Systems; as well as Classification Society involvement.

Managerial Decisions
Ship managers set the tone for VCM programs. A VCM program should complement, not duplicate, other maintenance strategies such as planned maintenance. A balance is needed for the Chief Engineer to adjust the maintenance while implementing company guidelines for maintenance. Reporting systems should be selected based on ease of use to distribute and act on the information.

Personnel
No system will succeed without active involvement of the crew, the ship's managers, the class society and the VCM specialists. The crew either takes the data or facilitates those who do by providing access to machines. Communication with the crew is essential for follow-up of repairs and retaking of data. A VCM program needs to be managed by specialists to set up and interpret results. Class Society surveyors need to understand the benefits of VCM.

Technical Support

The technical support function consists of setting up the measurement points, choosing baseline parameters, reviewing data collection procedures, and providing feedback as to the results. Providing an annual audit of the program to ensures continuity, compliance and adherence to the intended goals. Updating the system to reflects changes in methodology, technology. Updating the system in effects enables the database to 'learn' from actual experiences, i.e. alarm levels. Data taking and evaluation cannot be trivialized. Marine VCM has unique factors, such as hull vibration, ship operation restrictions, and class society review that can be handled by specialists with experience in the marine environment.

Integration with Existing Work Order Systems

To be used, VCM results need to be accessible to decision-makers and allows users to take ownership of the process. VCM results should be integrated with existing work order systems so that the machinery repairs are seen in the context of the VCM reports. Such integration will identify where a repair has been successful, where a repair may have created a problem, where a repair may have ruled out a cause and therefore need not be repeated. Such information is valuable in addressing warranty claim issues.

2. Conclusions for Classification Societies

The purpose of class society involvement is to ensure the safe and efficient operation of a vessel. Established rules have evolved that need to be merged with VCM methods. Evaluation of the results involves the application of standards, but also trending of the data. Engineering judgment is needed to properly evaluate a program. The class surveyor should expect to allow alternative solutions to maintenance problems and to rely on the ship's crew, the manufacturer and VCM specialist for detailed information.

VCM data is beneficial to Classification Societies because it establishes the working history and performance reliability of a given machine.

It is in the best interests of Classification Societies to promote VCM as a strategy in the maritime industry, to make more performance data available.

Establishing guidelines/regulations that are too restrictive will drive clients away from a technology beneficial to Classification Societies and ship operators.

Classification Societies could incentivize VCM as a maintenance strategy by offering benefits to the ship owner such as credits for non-opening, based on VCM results. Currently, inspection intervals are established by actuarial assessment of risk, and date to a time when planned maintenance was the most available approach. With the development of VCM in marine enterprises, an empirical assessment of risk became possible. Classification Societies can update their guidelines to reflect the scientific assessment of machine health, so appropriate flexibility is introduced into the 5-year inspection cycle.

3. Problem and Purpose

Methods of implementing Vibration Condition Monitoring programs vary, as do outcomes. As a provider of VCM services, our interest is in offering our client a successful product – in this case an effective method of marine machinery maintenance. Creating a method that can, in terms of cost and personnel, realistically be implemented in the marine industry is the core of our business.

A pioneer in application of VCM to marine industries, we have built a vast data collection of over 330,000 readings. We can now scientifically establish trends previously attainable only through probability assessment. VCM should not stand alone as a methodology, but should complement programs of planned or fixed maintenance. However it is employed, we are able to identify critical implementation considerations and approaches that are integral to success or failure.

Classification Society guidelines and practices evolved in an era of actuarial, or probability-based risk assessment. Manufacturers specify, through warranty or other device, an anticipated lifespan. The goal of machine maintenance, then as now, was to affect repairs before failure occurred. If experience showed the chances of a particular pump bearing failing increased after 3500 hours, replacement was scheduled prior to that time. This methodology still underpins planned maintenance programs, unless they are complemented by the empirical data a VCM program affords. VCM enables engineers to determine more precisely which machines require repair, when, based not on chance but on actual machine conditions. In many respects, current Classification Society guidelines and practices assume an actuarial, rather than empirical approach. To be effective in both benefitting from and supporting the advancement of VCM, Classification Society guidelines require review and repositioning.

4. Disclosure of Interest

All businesses offering the tools and techniques of Vibration Condition Monitoring have their interests. Each, in their way, profoundly affects how a VCM program is implemented, and in turn, whether it derives business benefit for the ship owner.

Some in the industry emphasize data collection devices. It is in their interest to maximize the number of devices their clients use. This impacts how data collection is delegated among personnel, and the frequency with which it is collected.

Others in the industry – including Condition Analyzing Corporation – emphasize data reliability and analysis. Our interest pursues the potential growth of VCM as a cost-effective and reliable model of maintenance planning for marine machinery. Currently, only a small percentage of the approximately 45,000 registered ships under Class utilize VCM as a significant element in their maintenance strategies. It is in our best interest for more ships to participate in VCM. Our goal is to articulate a strategy that realizes the potential business benefits of VCM.

Having VCM data available is beneficial to Classification Societies because it establishes the working history and performance reliability of a given machine. It is in the best interests of Classification Societies to promote VCM as a strategy in the maritime industry, in order to make more performance data available to ensure the safe and reliable operation of classed vessels, thus minimizing financial risk to owners and underwriters while ensuring compliance with standards

The common interest of CAC and Classification Societies in showing how successful VCM programs can be best implemented inspires this White Paper.

5. High-Level Solutions

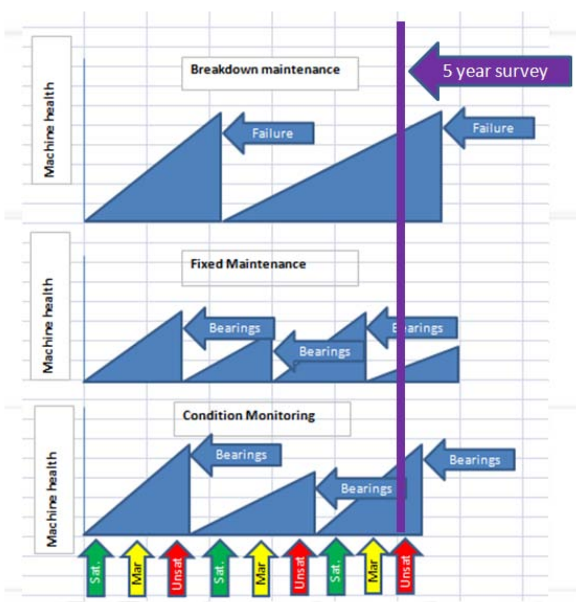
In following sections, we examine maintenance models, and ways of assessing the risk of machine failure – actuarial or probability-based methods, as well as empirical or performance-based methods. We identify incentives Classification Societies can offer to encourage greater use of performance-based maintenance decision-making.

We identify five areas in which implementation of VCM that are critical to the success of the strategy, including managerial decisions, personnel, technical support, and integration with work order systems, as well as considerations for Classification Societies.

Our chief focus in this paper is the role Classification Societies can play in ensuring the success of VCM programs, by giving incentives without over-burdensome regulations that would prevent the ship owner from engaging in VCM plan. Full appreciation of that role requires understanding where some VCM programs go wrong, and how they can be adapted to become effective. We begin, then, with a review of maintenance models.

<u>Models of Maintenance Planning</u>

Broadly, there are three approaches, or models of maintenance planning:



<u>Maintenance Models</u>

- Breakdown Maintenance - repair done when the *machine fails*;
- Planned (Fixed) Maintenance - pre-emptive repairs done after a *fixed time period*.
- Condition Monitoring - pre-emptive repairs are done *as measurements indicate*.

(Fig. 5-1)

The goal of maintenance is to ensure the safe and reliable operation of equipment. The goal of any model of maintenance is to plan the care and repair of equipment, before costly breakdown occurs.

The models and approaches to maintenance planning fall broadly into the categories outlined above. Fleet managers and ship operators choose the model which best, for them, balances risk and cost.

Actuarial (Probability-based) vs. *Empirical (Performance-based) Assessment of Risk.*

Classification Societies generally follow a 5-year cycle of periodic surveys. Under Special Continuous Survey of Machinery, 20% of machines under class are examined every year. The remaining 80% of the machinery are not subject to examination in the current year unless special conditions arise. This follows the Pareto Principle (80/20 rule).

The purpose of the 5-year review is not to determine the current health status of a given machine *per se*. Rather, it is to review the machine history for evidence that appropriate maintenance has been accomplished, and barring that, to open the machine for physical examination. If a machine passes the review, the class society usually schedules the next review for a date five years hence.

The determination of a 5-year review period is an actuarial. That is, it is based on an assessed risk that the likelihood of machine failure increases unacceptably after this time period. That assessment is itself based, in part, on manufacturer's specifications, engineering predictions, etc. The 5-year rule can also be based on the time allotted in the year to review the machines.

The current method of selecting machines is based on probability rather than evidence.

Planned Maintenance (PM) programs are built around the established 5-year review interval. The planned maintenance intervals can fall anywhere in the 5-year review cycle.

It is established knowledge among machine engineers that opening a machine at any time during its operating lifecycle can introduce mechanical anomalies. By extension, unnecessary openings can reduce the effective lifespan of the machine.

In extreme cases, opening a machine that is operating acceptably can actually introduce safety hazards where probability of failure is greatest. Known colloquially as 'infant mortality', the implication of the phrase is that the failure was preventable. The phrase illustrates in colorful language the rationale for permitting a machine operating acceptably to remain untouched at the end of its 5-year inspection cycle should other indicators (VCM) dictate so.

Condition Monitoring, in contrast, is an empirical or evidence-based method of determining machine status. While the method cannot predict when a failure will occur, it can identify when a machine is trending toward failure, suggesting necessary intervention. Similarly, an established trend of reliable performance may suggest that planned maintenance can be deferred.

Any operating machinery has an inherent risk of failure. How that risk is determined – by probability or by evidence – depends on the approach. VCM offers the empirical data to permit evidence-based risk assessment.

6. Solution Details – VCM Implementation

We identify five areas of VCM implementation which impact directly the success or failure of the program, scientifically and in terms of business benefit. Those areas are Managerial Decisions, Personnel, Technical Support, Integration with Fleet Management Systems, and Classification Society Involvement.

Managerial Decisions

Vibration Reports are addressed to the Chief Engineer and copied to senior management of the vessel operator.

Chief Engineers receive recommendations that enable him to make decisions:

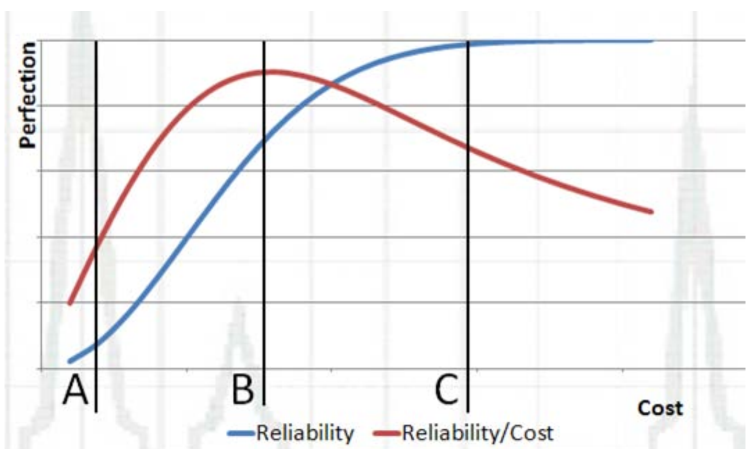
- to postpone maintenance because the monitoring indicators are acceptable; or
- to perform maintenance because the machine is unhealthy and to focus maintenance on the components requiring it.

VCM results are best used to fine-tune a fixed maintenance schedule.

Chief Engineers need the authority to deviate from a scheduled maintenance plan, when data supports the decision.

All maintenance is expensive. Using VCM as a complement to, not a replacement for, fixed maintenance allows fleet managers to defer planned maintenance with confidence, when data shows the machine is healthy. When results indicate a problem, they can take action before failure and on the offending components. Either way, ship reliability is maintained with a cost saving.

Is it always necessary to carry out planned maintenance? The evidence shows that elements of planned maintenance can be safely deferred when recommended by analysts.



There is an optimum data collection frequency. Below that threshold, reliability suffers. Beyond the threshold, quality does not significantly increase, however costs continue to rise.
(Fig. 6-1)

Is there an optimum data collection frequency or interval? For most equipment, two times per year is an acceptable collection frequency. This paradigm applies well to marine machinery where redundancy and standby time (i.e. vessel in port) reduces the overall operating hours.

Technology permits rapid collection of massive amounts and various types of data. We need to limit the data to only what is needed to make decisions, for too frequent collection of data, too many data samples, too fine the resolution and the inclusion of different types of precision monitoring technologies, leads to Data Smog.

Management needs a system that can show trends and summarize the data.

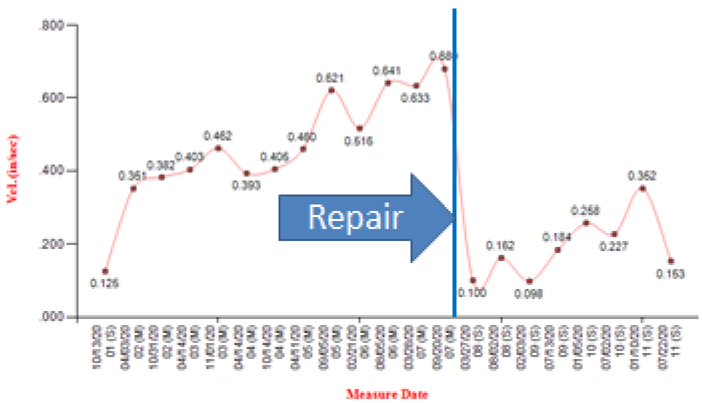
Too frequent reporting and/or too much detail is overwhelming to the person who has to read, understand, and respond to the report.

Too many recipients of copies, especially of non-essential information, clogs email systems.

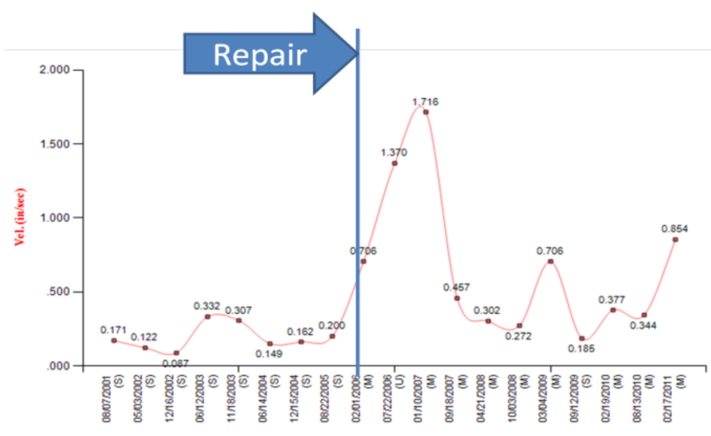
Over-reporting clouds the really important information in a haze of information that is not as critical. We call this 'Report Spam'.

Rather than facilitating the decision-making process, too much information can have opposite effect – it can distract from the process.

An effective and streamlined reporting protocol can avoid this common problem.

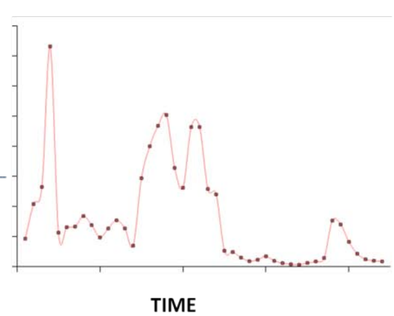


In this case, machine vibration increased gradually. Two tests per year is sufficient to detect the problem before failure occurs. (Fig. 6-2)



Here is a case where the repair increased the vibration. Why was the repair done? Was it to satisfy the 5-year Class opening rule? Was it to satisfy a fixed PM schedule from the home office? Unnecessary opening can compromise machine reliability. (Fig. 6-3)

Pt	Set_dt	O 1	Vertical	F 1,765	Horiz	Vel_bb	Axial
A	2011/05/25	0.2054		0.0889		0.0899	
A	2010/11/01	0.1065		0.0863		0.1190	
A	2010/03/22	0.1279		0.1046		0.1057	
A	2009/06/29	0.1626		0.1417		0.1567	
A	2008/12/31	0.2110		0.1182		0.2561	
A	2008/05/06	0.2870		0.2392		0.2024	
A	2007/10/28	0.3455		0.0874		0.1917	
A	2007/03/09	0.1721		0.1664		0.1735	
A	2006/09/14	0.1352		0.1148		0.1049	
A	2006/02/12	0.1048		0.1862		0.1525	
A	2005/08/12	0.1124		0.0875		0.2884	
A	2005/02/26	0.1378		0.1846		0.1370	
A	2004/10/28	0.1274		0.1650		0.1160	
A	2004/05/13	0.1580		0.1550		0.1308	
A	2004/03/23	0.1497		0.2084		0.1291	
A	2004/02/24	0.2040		0.1462		0.1749	
A	2004/01/23	0.1567		0.1056		0.1566	
A	2003/11/04	0.1612		0.1205		0.1844	
A	2003/04/16	0.2185		0.1948		0.1729	
A	2002/09/07	0.2567		0.1784		0.2985	
A	2002/04/10	0.5375		0.2032		0.2716	
A	2002/03/06	0.6179		0.2074		0.2908	
A	2001/08/07	1.0384		0.2475		0.1478	
A	2001/02/07	0.8853		0.2319		0.1429	
A	2000/05/28	0.6783		0.2154		0.1678	
A	2000/03/02	0.9819		0.2142		0.2391	
A	1999/12/28	0.9811		0.2826		0.2129	
A	1999/07/30	0.7837		0.1687		0.2189	
A	1999/04/18	0.5905		0.1852		0.1339	
A	1998/07/23	0.3127		0.1465		0.2244	



Rather than enhancing the information a decision-maker can consider, a certain volume at a certain point has the opposite effect – it distracts them. (Fig. 6-4)

Personnel

Data must be collected by experienced and qualified personnel.

VCM depends on accurate data consistently collected thoroughly and accurately. Proficiency requires extensive (and expensive) training. Only those crewmembers who have received thorough training in vibration and data collection techniques should obtain vibration readings.

The taking of data and evaluation of results cannot be trivialized.

The cost of training is a formidable expense that is easily overlooked. Attempting to train hundreds of crew members is problematic, especially when longevity and shift/crew turnovers are considered. Ship owners are likely not going to be willing to 'spend what it takes' to get and keep properly trained personnel. If the data being collected is not reliable then there is no chance for success.

ISO qualification does not necessarily prepare a crew member to collect data effectively.

Certification courses provide theoretical instruction; they are not necessarily designed for the dynamic marine environment and provide little in the way of practical application.

An effective alternative is to develop, within the fleet, a team of Internal Data Specialists who do nothing but collect this data, moving from ship to ship. This approach models the way in which outside specialists, like CAC, operate. Utilizing the Internal Data Specialist model will reduce the required manpower needed and training can be concentrated on fewer individuals who report to the experts providing Technical Support.

Technical Support

The technical support function consists of setting up the measurement points, choosing baseline parameters, reviewing data collection procedures, and providing feedback as to the results.

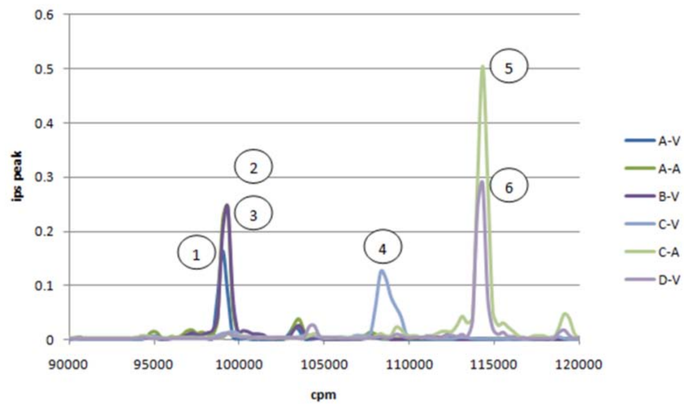
Marine VCM has unique factors, such as hull vibration, ship operation restrictions, and class society review that can best be handled by specialists with experience in the marine environment.

The data collection specialist needs a support person or Senior Analyst.

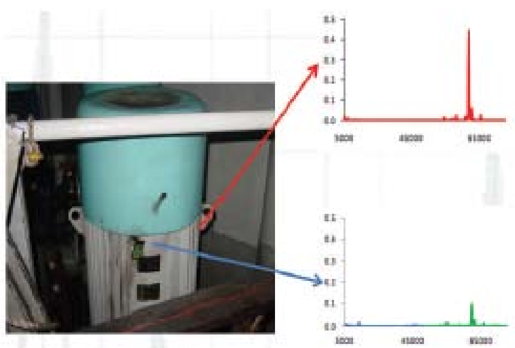
A crewman or even a full-time data collection specialist cannot be expected to completely manage a VCM program. While computer assisted processing is helpful, human analysis can more effectively detect trends and relate them to repair histories. The Senior Analyst can study fleet-wide trends, modify test parameters, and conduct testing with advanced methods such as modal testing. The Analyst can respond to feedback, anecdotal evidence, and incorporate these observations along with the empirical data into his analysis and distribute this information back to those who will benefit from it most. Additionally the information can be shared within the industry.

Communication and collaboration between the Senior Analyst and the Data Collection Specialist are essential. The Data Specialist can describe the test conditions—for example, heavy seas, load conditions and other relevant observations. The Analyst can call for more testing to be done to rule out hull vibration, faulty data, etc. This collaboration qualifies and clarifies the readings, resulting in a more thorough analysis.

The data specialist must be known to the Senior Analyst, who can be called upon to provide additional non empirical information as needed and share common knowledge between all in the technical circle.



The speed of a Turbine-driven cargo ballast pump was increasing during the test. The data collector did not notice this fact while taking data. The Vibration Analyst recognized that vibration at the gear mesh frequency indicated a possible gear problem. However, the increasing speed meant that the load on the machine was abnormal. When the machine was retested at full speed, the vibration went away and was normal. This example illustrates the importance of recording conditions as well as readings, and underscores the need for direct contact between the person collecting the data and the analyst. (Fig. 6-5)



During an audit of a ship, it was found that the crew had been taking one reading at the top of this motor in the STBD direction. The Fmax was 45,000cpm and showed no problem. If a higher Fmax had been chosen, a new vibration frequency would have been found. In fact, if a reading had been taken in the RWF direction, a bigger problem would have been found – motor bar vibration at 44X-rotation rate. This shows how the way data is collected can affect results, and underscores the need for effective crew training. (Fig. 6-6)

Integration with Work Order Systems

Placing all of the information together in a centralized location that is familiar to the users enables the users to make the most out of the information collected and reduces “report spam”.

Technological innovations have recently made VCM more user-friendly.

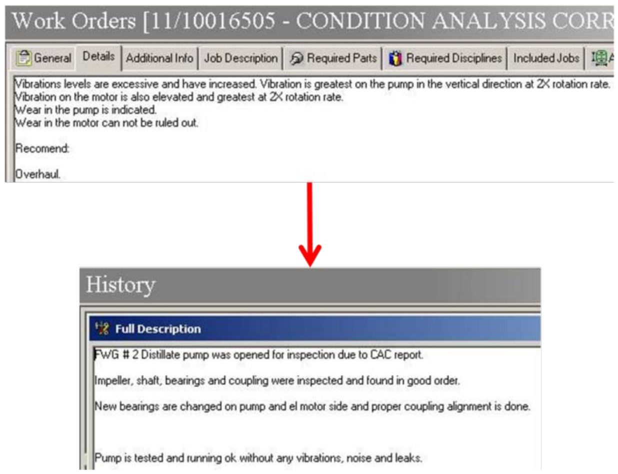
Integrating data with existing work order systems and fleet management software – capacities we have at CAC – has complementary effects: it gives the analyst ready access to repair history and it gives crew access to vibration data.

The vibration analyst needs to know the repair history.

The crew needs to have the vibration data integrated into the machinery history, and to know when to schedule data collection.

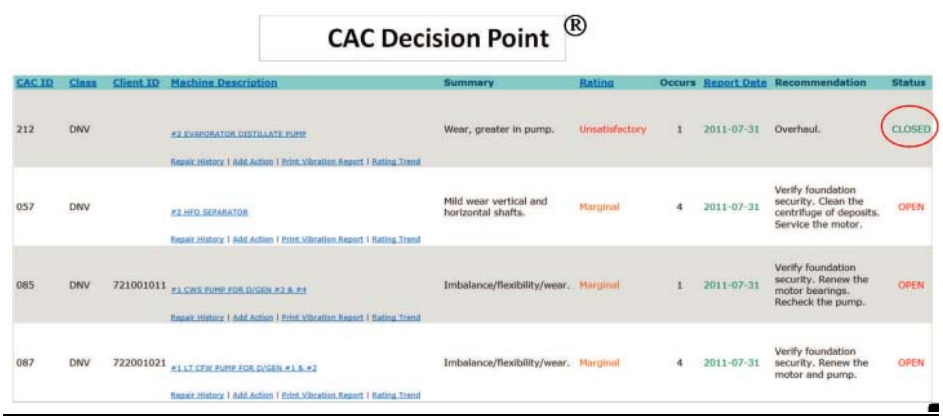
Chief Engineers, Marine Superintendents, Class Surveyors, and other decision-makers need a Summary Report that clearly shows what action needs to be taken and the condition of machines from worst to best. Too often, the machine test results are not easily available to all the parties involved, or easily interpreted quickly.

Posting to a website is an excellent way to distribute the data. It is available to anyone with Internet access and a password. A full survey report can be distributed promptly to all concerned. Items of greatest concern can be distributed virtually in real time if necessary.



At top left is a screen shot from a ship's own management software, showing the results of a vibration survey requiring action. CAC can export vibration survey reports into several fleet management software programs. The end user does not have to flip screens or learn new programs to access the data or receive alerts.

Middle left is the resulting work order, again, in the ship's own software, showing corrective action. (Fig. 6-7)



CAC Decision Point ® is a secure website containing an interactive database of over 330,000 readings which can be accessed for analytical and comparative purposes. (Fig 6-8)

7. Solution Detail – Classification Society Involvement

Classification Societies are increasingly recognizing VCM. The growth potential of the approach is great. CAC advocates that Classification Societies, through their membership in IACS, take four steps to support VCM.

Four things Class can do to help the industry reach the full potential of VCM:

- **Establish clear rules;**
- **Train ship inspectors to read and understand monitoring reports, providing an important independent perspective;**
- **Develop a reward or incentive for ships to participate in condition monitoring programs; and**
- **Consider an approved review or waived opening as the equivalent of an opening, for the purposes of the mandatory five-year visual inspection.**

Data Standards

Currently, different Classification Societies specify different data standards for VCM. The different standards evolved separately, at different times. While uniform standards should be developed, one cannot rely on strict observance of fixed criteria. Standards must recognize 1) that data trends are equally important to the absolute values of a machine reading at any given time; and 2) the real success of the program should be judged on periodic audits, to determine what problems may have been missed, or what maintenance was not necessary.

Below are summaries of the vibration standards currently used by selected IACS members, with our comments in italics:

> **DNV** refers to ISO 3954, which is not a vibration standard, and discusses criteria for running and not running that is not standard in the industry. DNV also refers to ISO 10816-3 and shows limit boundaries of 1.8, 4.5, 11.2 mm/s rms for machines above 15 kW. *The standard values are actually 1.4, 2.8, 4.5 mm/s rms (Group 2, rigid support).*
>
> **LRS** refers to the ISO 10816 (casing measurements) series of standards, but rightly say they should be applied with caution. LRS also refers to ISO 7919-1 (shaft measurements). LRS also refers to ISO 13373-1 (procedures) as well as an internal document "Ship Vibration and Noise Guidelines." *Note there is not a companion standard ISO 13373-2 (data handling).*
>
> **ABS** refers to Rules for Survey After Construction, 2009 and SNAME T & R Bulletin 3-42 "Guide for the Use of Vibration Monitoring for Preventative Maintenance"
>
> **GL** refers to ISO 13373-1:2002 (Table A.1), ISO 10816-3:1998 and VDI Guidelines 3841: 2002 in so far as the measurement location is concerned.

Considerations re: Data Standards

The scope of the standard specifically applies to ships and is based on actual machine data. The application of the standard should take into consideration the repair history, the trend of each machine, comparison of that machine with sister machines, and the ability of the machine to function to the satisfaction of the chief engineer. The criteria should not be too stringent as to require unnecessary maintenance nor so broad as to be meaningless.

Detailed analysis is best left to a specialist, and should not be embedded in the standard itself.

The first recommendation for most vibration problems is to check the foundation. Sometimes, tightening the foundation bolts will solve the problem. Sometimes, the foundation may be a serious problem, with wasting of metal. In any event, the evaluation of the foundation is a basic first step.

The determination of the rpm of the machine is extremely important. Many machines have multiple fixed speeds or are variable speed. Sometimes the speed can be deduced from the vibration. The most reliable way is for the speed of the machine to be determined independently, when the data is taken.

The magnitude of vibration indicates if there is a problem. That is, either the magnitude exceeds a standard *or* the trend has increased. The frequency of vibration indicates the source of the vibration. The frequency often relates to the speed of the machine. If a frequency found in the vibration is equal to the rotation rate or is twice the rotation rate, the analysis can change. Often, the machine component with the greatest vibration is not the source of the vibration.

At the time of data collection, the speed of the machines must be recorded. Generally, the test should be done under the normal operating conditions and/or at the greatest speed and load available. If the machine normally runs at one speed, that may be the speed used for the test. At the time of test, the surrounding conditions that may affect the vibration should be noted, including draft conditions, propeller rpm, nearby machines running, etc. Often, tests taken underway have to be repeated at the dock or at low-frequency range or with the machine off to properly diagnose the vibration from the machine itself.

It is not necessary that the same conditions be duplicated on each test, because such conditions may be impractical. Some vibration problems may be missed if one set of conditions is always chosen.

Vibration can be taken with various degrees of frequency precision (number of lines in the spectrum), with time waveforms, and with preservation of the phase relationships. Some always take two types of data on every checkpoint. However, more is not always better, and contributes to “data smog.”

What is most efficient is if one standard set of readings are taken, then more taken based on the judgment of person taking the data, i.e. different resolution, different loads, different ship speed, even with the unit off.

The selection of the correct frequency range and number of lines of data collection is critical to the analysis of data. The frequency range should be high enough to collect the frequencies of interest; the number of lines should be great enough to adequately resolve one spectral peak from another. Often more than one frequency range is required, either taken as a routine or taken as needed, based on the knowledge and experience of the person taking the data.

Most standards are guidelines and should not be relied upon to give absolute limit levels in the absence of engineering judgment. The alarm levels can be changed if 1) the vibration has been steady; 2) the vibration on machines of the same type on the same ship are similar; 3) the vibration on a sister ship is similar; 4) there have been no unscheduled repairs; 5) the machine is functioning as designed; and 6) the Chief Engineer agrees.

Alarm levels serve as warnings or guides to the expert analyst. The novice should not treat a standard as cast in stone.

The standard should be applied by the surveyor in charge. Should exceptions be granted, the reasons should be stated by the surveyor. In the event the owner disagrees with the surveyor, an appeal process should be available.

Collecting Reliable Data - Data Specialist

It is an oversimplification to assume that anybody with just minimal training can collect vibration data. It must be collected by experienced and qualified personnel. CM depends on accurate data consistently collected thoroughly and accurately.

The Data Specialist is someone who has received specialized training and possesses sufficient experience in these duties. He collaborates closely with Vibration Analysts, who assist in the data collection process. The data specialist should be able to demonstrate competencies. Only those crewmembers who have received thorough training in vibration and data collection techniques should obtain vibration readings.

It is CAC's experience that the ISO qualification does not necessarily prepare a specialist to collect data effectively with consistency. Although these certification courses provide theoretical instruction, they are not designed for the marine environment.

A commitment to constant improvement is inherent in the performance of the specialist's duties. Ongoing training, technical bulletins, safety briefings, shared experiences build knowledge base among the Data Specialists. Class should review ongoing training programs.

Role of Classification Societies in Training

IACS and its members are in a unique position to articulate a set of competencies to be recognized as qualification to provide these specialist services. They are also in a unique position to work with industry to develop effective training programs.

Training costs are not made always known to the owner when starting a program. Training costs may not be included in the cost associated with the hardware, software and implementation. Class needs to recognize that proper and adequate training is vital to the reliability of the data.

Over thirty years, CAC has, for example, developed an extensive program we use to train our specialists. Counting staff time, travel, meals, accommodations and production of training materials, we spend at least $10,000 per person for only their initial training. This can be a considerable burden if several crewmembers on each ship in a fleet are trained to an effective level of competency. The total number of ship personnel involved in the collection of data can be formidable, several hundred for a modest fleet. These training costs range in the millions and the propensity to cut costs in this regard should not be underestimated.

Everyone touching the data should be certified to do so.

Flexibility in Assigning Data Collection Duties

Current guidelines reflect the expectation that data collection will be performed either by shipboard personnel or by an External Specialist. Given the total cost of training and the operational considerations aboard a ship - shifting permanent and non-permanent crews of varying nationalities and educational backgrounds - fleets may experience increased consistency and quality while reducing costs by specializing the function among a smaller group dedicated exclusively to servicing the entire fleet. Instead of potentially hundreds of vessel personnel being involved, the number can be reduced by an order of magnitude. These individuals need not be physically present aboard each vessel at all times. Consideration of guideline expansion to enable Internal Data Specialist development within fleets may be appropriate.

Outside testing organizations – like CAC - must have Data Specialists who are trained and qualified to collect the data, skilled at performing viability testing, and expert Vibration Analysts. Each should have direct contact with the Vibration Analyst, before, during and after the vibration surveys.

For clarity, ship conditions like propeller speed and Fwd and Aft draft, environmental conditions, and other conditions that may impact the level and meaning of a given reading need to be reported. Thus, effective analysis requires data interpretation. Without consultation between the Data Specialist and Vibration Analyst, the quality of data interpretation is negatively impacted.

Data Specialists must take care that the taking of a measurement does not affect the measurement itself, such as damping vibration from the test equipment or interference by the Data Specialist himself. Consistency over time is important in data collection, as is rigour in any one machine test.

Consideration of an Internal Data Specialist team operating within the fleet may resolve some inherent challenges to reliability and consistency posed by marine operating environments and practices.

Data collection by ship's personnel should be subject to review by a Vibration Analyst to ensure:

1) data is taken at the correct locations;
2) the conditions of hull and surrounding conditions are noted as relating to vibration;
3) machine rpms are correctly determined; and
4) additional readings are taken as indicated.

The Vibration Analyst is skilled at examining the data for pattern consistency and can certify the data as accurate. In the event the data is suspect, the analyst can call upon the Data Specialist to clarify the data, re-record if possible or discard the data if necessary so as not to provide a false diagnosis. It must be possible to remove faulty or bad data records from the software otherwise statistical references will be skewed.

The vibration analysis should be compared with the repair history to determine the number of false positive and false negatives for each year.

The custody and control of data should be tracked. Personnel should be authorized to make changes, with access restricted. Changes might include deleting data, changing alarm levels, correcting machine descriptions, etc.

Strategies and Tactics to Improve Analysis

Over thirty years of providing VCM services to ships and fleets large and small, we have learned the following provide the framework within which data can be reliably collected for analysis purposes:

Machines enrolled in the condition monitoring program ought to be those considered critical to the operation of the vessel. Some machines critical to the ship may not be classed by the Society; nevertheless, their inclusion in the program is useful to data-driven decision-making.

Where available, Oil analysis results should be compared to vibration analysis results, typically by the Chief Engineer or a supervisor on the ship. It is important that vibration analysis and oil analysis be considered together.

Obviously, the vibration data collector (device) should be approved for the purpose.

The software used to display the data and analysis should be tested for accuracy. The particular nuances of marine operation – propeller induced vibration, wake action, etc – need to be taken into account in the analysis.

During any survey period, some machines may not be tested due to ongoing maintenance, ship operations, etc. The reason for not testing a machine should be noted and reviewed by the class surveyor.

The location of the vibration test points can be shown on a standard machine diagram provided by a testing company. Testing should be done on each bearing location in three directions- horizontal, vertical, and axial

Locating the test positions must be done by qualified personnel.

When the ship's crew takes data, machine markings should be used. The markings can be painted, or can be an affixed tags or blocks. Blocks add significantly to the implementation and ongoing costs. Blocks are seldom 'permanent' and require ongoing maintenance/reattachment. Blocks cannot be placed in all locations due to physical restraints. These factors tend to limit their use to fewer test locations than is desirable.

The use of magnetic pickups is acceptable for routine vibration surveys given the frequency range typically encountered in shipboard machinery. Placement of vibration pickup should be on heavy metal components closest to the bearings. It is not vital to place it in the exact same spot.

In general, taking all available test points adds to the reliability of the data. Doing so does not increase significantly data collection time and storage requirements.

The vibration analyst should have access to the repair history of machines when evaluating the vibration. There are many purposes for reviewing the repair history: to determine what repairs are successful; to determine if a repair has resulted in no improvement (or made conditions worse); possibly to eliminate repair as a solution option; or possibly to identify bad parts or service suppliers.

Results of repairs, root cause of failures and the vibration history preceding these events can be made available to the vessel, fleet, to industry and to the classification society. Sharing of information relevant to successful repairs benefits all.

Ideally, repair records and results would be available automatically in the same system as the vibration history. It is desirable the repair history be exported from the fleet management software for use by the vibration analyst. It is also desirable that there be an exchange of information between the fleet management software (already used and familiar to the Chief Engineer) and vibration results. Both the Chief Engineer and the Vibration Analyst benefit from the ready transfer of information.

A suitable repair history identifies the date of the repair, who did the repair, and the items repaired, by component. The repair history should be made available to the Class Society, and Vibration Analyst, as a matter of course.

Machine Ratings

Machine Ratings presented to the surveyor should distinguish machines in distress from those working well but developing problems from those operating reliably without unusual or unacceptable wear or stress. A minimum of three categories is acceptable. Too numerous a set of categories unnecessarily complicates decision-making based on the rating.

Vibration ratings should not be confused with machine priority. A low-priority machine can have a severe vibration rating and not receive (or require) the same attention as a high-priority machine with a moderate rating.

Open-and-Inspect Requirements

As stated previously, under Special Continuous Survey of Machinery rules, 20% of machines under class are examined every year. The remaining 80% of the machinery are not subject to examination in the current year unless special conditions arise.

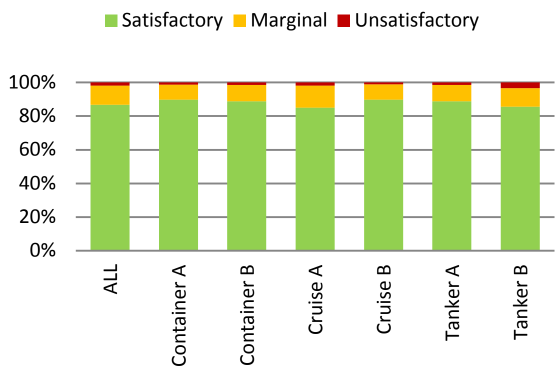
One presumes this is an application of the Pareto Principle, which essentially states that 80% of effects come from 20% of causes, and is known therefore as the “80/20 rule”

For example, in a group of 50 machines, only ten machines will be specified for opening inspection this year. Of those ten, only two will present conditions that, in the end, will justify opening the machine.

The same principle applies to the machines not opened for inspection: of the 40 such machines in the sample, eight may be expected to be at risk. These risks are unknown unless Condition Monitoring is used to determine the *actual* risk status (as opposed to its *actuarial* risk status) of the machines in question.

It is necessary to consider the relationship of the 5-year open-and-inspect requirement to actual machine incident or failure. If evidence cannot support the assumption that 20% of the machines are at risk, then the mandatory open-and-inspect interval of 5 years should be re-evaluated.

Indeed, an evidence trend we present below indicates that marine machinery actually performs, on aggregate, closer to an 87:13 ratio of acceptable: problematic performance:



Results of over 330,000 readings taken over 30 years, rated by CAC's 3-scale measure of machine health and reliability:

2% unsatisfactory;
11% marginal;
87% satisfactory
(Fig. 7-1)

Clarifying Conditions of Waiver

Given the appropriate historical performance data record, as established by a Condition Monitoring (CM) program, Classification Societies can and do grant waivers extending the opening requirement. In so doing, Classification Societies effectively extend the operating lifespan of the machine in question. They are also acknowledging the scientific validity of VCM data.

Classification Societies acknowledge that CM provides for evidence-based assessment of risk, and express qualified support for increased use of CM as a method of maintenance planning and accountability.

Class Surveyors and CM Data

To evaluate CM data effectively, Class Surveyors need to be apprised of class machines that have exceeded CM criteria for service. Those cases require resolution.

After the case is resolved, the machine should begin a new 5-year review cycle, not continue in the same one. Adjusting the 5-year review cycle is a departure from current practice. However the adjustment should be feasible with computerized scheduling and makes sense in the life for the machine. The Surveyor should continue to be apprised of those machines and components which have performed satisfactorily for the 5-year interval, so that reviews can be completed.

The class surveyor requires review guidelines to follow, but should not be expected to be an expert in vibration analysis.

Optimum Testing Intervals

There are two types of monitoring systems, periodic and continuous.

While it could be said that the best method is ubiquitous signal processing of all bearing points in all directions with data constantly being reviewed by skilled specialists, it is impractical in terms of implementation, maintenance and cost.

Periodic monitoring by its very nature implies that data is taken on some sort of schedule. This schedule of data collection can be varied for a wide range of reasons including machine criticality, current operating condition, cost factors, etc

For the purpose for class society involvement, Vibration Spectra analysis should be obtained a minimum of twice per year. It is arguable that more frequent testing may improve reliability it is not always going to detect a failure that gives little warning.

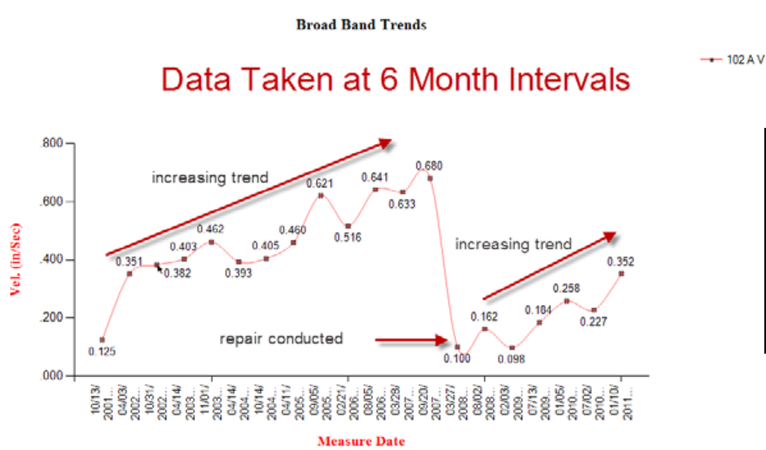
At a certain point, there is minimal real benefit of increased testing yet the cost continues to increase.

Continuous testing may be needed for 'mission critical' machines, as failure can occur rapidly, when it occurs. It may also be advantageous to outfit mission critical machinery with a shut-down feature that engages in the event of failure.

Continuous installations must be properly setup and maintained on an ongoing basis. The proper monitoring parameter and the discrete frequencies and ranges as well as appropriate alarm levels must be established prior to installation of the system. The parameter being monitored must be made known to the Chief Engineer. False alarms as well as missed warnings will rapidly lose favor with vessel personnel.

Data collected semi-annually during a 5-year inspection cycle yields a total of ten data sets to inform the class surveyor's decision whether or not to grant a waiver.

The following graph depicts actual machine data obtained on a semi-annually over a period of 10 years. The graph clearly depicts the increasing trends which prompted repair. Following repair, levels clearly decline near 'baseline' levels, until another increasing trend is detected.



This graph shows, *for a typical machine of typical reliability*, how data taken semi-annually is sufficient to identify critical trends. More frequent data collection would be superfluous, and would add costs. (Fig 7-2)

A pool of more datasets (*i.e.* obtained on a quarterly basis) would not yield significantly more information for the class surveyor. Any improved reliability perceived by the ship owner to collect data more frequently should be voluntary. Insisting on more frequent data collection drives costs toward the 'cost break point'.

Class should not be involved in routine data collection. Their interest is to provide incentives for ship owners to collect data that would benefit them during annual surveys.

Toward an Appeal Process

While the class surveyor should have discretion to grant a waiver based on VCM, a review and appeal process can resolve a dispute over his decision. Both the review and appeals process could become a revenue stream for the society.

An appeal process might contain two elements:

1. Peer review process
   a. In the event that that the class surveyor is uncertain about granting the waiver, he/she could request a peer review of the data. Peer Reviewers could include knowledgeable industry and Classification Society professionals.
   b. Peer Reviews should be directed to the surveyor in charge, who remains the ultimate arbiter.
2. Appeal process
   a. In the event that vessel engineers disagree with the decision of the surveyor, an appeal to peers nominated or identified by the Classification Society would provide a formal method of resolving the dispute..
   b. Appeal decisions should also be directed to the surveyor-in- charge, who remains the ultimate arbiter.

As initiators of an appeal, fleet owners should compensate the Classification Society for appeal costs.

8. Business Benefits

Benefits of Evidence-Based Maintenance

VCM benefits both the Classification Society and the owner. Both are provided an incentive to reduce the risk of catastrophic failure, and an evidence-based method of assessing that risk. The owner can eliminate unnecessary interventions to realize significant costs savings, while the Classification Society receives a virtual view of the machinery annually, throughout the 5-year inspection cycle – an enhanced view of machine status.

By reviewing the machine data on an annual basis, Classification Societies can require that a machine be brought into proper operating condition (between scheduled inspections) *before* failure occurs, often by minor corrections or adjustments to the machinery.

Benefits

1. Non-opening credit - demonstrable cost and timesaving to the client. This element is key in appealing to the owner to engage in VCM in the first place.
2. Improved machine reliability. This element is key to the Society approval.
3. Focused Maintenance. Permits owner to concentrate on the machine components needing attention rather than a complete overhaul of the machine. This element is key to both Owner and Society to reduce problems created with maintenance actions.

Complementing Planned Maintenance with VCM Data

VCM should complement planned maintenance programs. Indeed, by depicting actual operating conditions, VCM can allow fine-tuning of planned maintenance to respond to need, before failure occurs, while minimizing costly unnecessary interventions.

To achieve flexibility operationally, Chief Engineers must be permitted by the ship managers to adjust a planned maintenance schedule, based on evidence of satisfactory or unsatisfactory machine performance. Fleet Managers should be encouraged by IACS members to trust the science of VCM. The ship operators and the Classification Society should have confidence that maintenance methods chosen reduce risk and increase machine reliability. When indicated, the Chief Engineer can call upon VCM experts.

When condition monitoring indicates that a periodic maintenance item (such as bearing change) can be postponed, for example, the Chief Engineer should have the discretionary authority to defer issuing a work order for a reasonable period of time. These short extensions can add up in the long run without significantly increasing risk, provided the VCM justifies the action.

For the company, taking the evidence-based decision to defer maintenance extends the maintenance interval. Each extension of the interval eliminates unnecessary maintenance costs, and effectively defers inevitable costs, without increasing risk. This makes engineering and economic sense.

9. Summary

Condition Based Maintenance and Vibration Condition Monitoring benefit both regulators and owners by providing empirical data on the health of the machine. Classification Societies have an interest in obtaining a virtual view of the machinery condition. It is in their best interest to promote more widespread use of CBM/VCM methods. Incentives to the ship owners in the form of clear conditions of waiver, and flexibility in the opening intervals (currently set at 5 years) could inspire greater participation by owners.

Management decisions respecting testing intervals, and the adjustment of planned maintenance based on VCM data set the stage for the success or failure of a program. The Chief Engineer requires the ability to alter scheduled maintenance based on data, for a program to achieve maintenance savings for an owner.

Thorough training and cost-effective deployment of data collection personnel realize potential program success. We believe it is best, both in terms of data integrity and cost-effectiveness, to specialize the function.

A program can only be effective if the data that is obtained is timely and accurate. Data integrity is a vital necessity. So, too, is collaboration. For this reason, programs need to be structured to enable the vibration analyst to communicate directly with the person who took the reading. It is also important to note a variety of environmental and operating conditions to provide context.

No one size fits all; each ship owner should be free to select the method that best suits their maintenance philosophy, and to structure their program in a way that, for them, makes economic sense.

Classification Societies should be concerned with quality data; it should not concern Classification Societies how an owner manages its collection, day-to-day. The ship owner should realize two chief benefits from a VCM program: limited risk of unexpected machine failure; and non-opening credits from the Classification Societies.

Classification Societies play a vital role in inspecting machines, ensuring safety and reliability, and protecting the investment of owners and underwriters. VCM data could be used to help identify machines for opening and inspection. How Classification Societies incorporate the information gained from VCM in evolving guidelines, rules and practices is an important question. As a corporation with a shared interest in the promotion and growth of VCM, CAC is poised to collaborate with IACS and its members in providing the regulatory environment in which VCM can best benefit both industry and Class.

Bibliography

American Bureau of Shipping. (July, 2004). *Guidance Notes on Reliability-Centered Maintenanance.* Retrieved from http://www.eagle.org/eagleExternalPortalWEB/ShowProperty/BEA%20Repository/Rules&Guides/Current/132_ReliabilityCenteredMaintenance/Pub132_RCM_GN

American Bureau of Shipping. (2003). *Guide for Surveys Based on Preventive Maintenance from Rules for Survey After Construction 2010 Part 7.* Retrieved from http://www.eagle.org/eagleExternalPortalWEB/ShowProperty/BEA%20Repository/Rules&Guides/LinkedGeneralGuideTitles/Current/Part7RulesforSurveyAfterConstruction

American Bureau of Shipping. (24 February 2009). *Letter to Kieran Lynch, CAC from J. Riva.* New York.

ANSI/ASA. (2009). *ANSI/ASA S2.28-2009 American National Standard Guide for the Measurement and Evaluation of Broadband Vibration of Surface Ship Auxiliary Rotating Machinery* . Retrieved from http://asastore.aip.org/shop.do?cID=8&pID=552

Det Norske Veritas. (2008, October). *Guidance for Condition Monitoring.* Retrieved from http://exchange.dnv.com/Publishing/CN/CN10-2.pdf

Germanischer Lloyd. (2008, February 15). *Rules for Classification and Construction, Chapter 17 Guidelines for Machinery Condition Monitoring.* Retrieved from http://www.gl-group.com/infoServices/rules/pdfs/english/schiffst/teil-1/kap-17/englisch/inhalt.pdf

Lloyd's Register. (2010, February). *Condtion Monitoring of Marine Machinery.* Retrieved from http://www.webstore.lr.org/products/49-condition-monitoring-of-marine-machinery.aspx

Society of Naval Architects and Marine Engineers. (1987) Guide for the Use of Vibration Monitoring for Preventative Maintenance (SNAME T & R Bulletin 3-42)

Appendix I: Graphic References and Examples

The following graphs display actual data examples collected at 6-month intervals. In a 5-year cycle, the surveyor could make judgments based on the historical records and the recommendations of the vibration analyst.

Point A

Date	Vertical		Horizontal		Axial		RPM	FWD Draft	Aft Draft	Prop. RPM
	Vel. In/Sec	Vel. Graph	Vel. In/Sec	Vel. Graph	Vel. In/Sec	Vel. Graph				
07/01/2010	0.227		0.132		0.076		893	12.00	6.00	0
01/04/2010	0.258		0.153		0.051		893	8.00	8.00	0
07/10/2009	0.184		0.107		0.063		893	8.05	8.07	72
02/02/2009	0.098		0.046		0.079		893	7.80	7.80	0
08/02/2008	0.162		0.055		0.076		893	8.30	6.50	0
03/24/2008	0.100		0.066		0.038		893	8.40	7.50	0
09/20/2007	0.680		0.290		0.143		893	7.80	8.00	0
03/26/2007	0.634		0.235		0.101		893	7.92	7.63	0
08/05/2006	0.641		0.279		0.077		893	8.20	7.80	75
02/19/2006	0.516		0.198		0.068		893	8.00	8.00	0
09/02/2005	0.621		0.205		0.077		893	8.80	7.80	0
04/10/2005	0.460		0.191		0.073		893	8.70	7.70	0

This data shows that, following a period of elevated vibration, levels were reduced. The surveyor should be in a position to question why the data diminished. Records proving repairs should be made available.

Providing all appropriate records are in order, this machine would be a candidate for a waiver.

Point B

Date	Vertical		Horizontal		Axial		RPM	FWD Draft	Aft Draft	Prop. RPM
	Vel. In/Sec	Vel. Graph	Vel. In/Sec	Vel. Graph	Vel. In/Sec	Vel. Graph				
07/01/2010	0.031		0.095		0.126		1740	12.00	6.00	0
01/04/2010	0.054		0.044		0.069		1740	8.00	8.00	111
07/10/2009	0.054		0.027		0.107		1740	8.05	8.07	80
02/02/2009	0.030		0.039		0.068		1740	7.80	7.80	124
08/02/2008	0.087		0.073		0.122		1740	9.00	6.50	130
03/24/2008	0.085		0.067		0.187		1740	8.40	7.50	0
09/20/2007	0.059		0.070		0.095		1740	7.80	8.00	0
03/26/2007	0.101		0.108		0.204		1740	7.92	7.63	130
08/05/2006	0.092		0.089		0.140		1740	8.20	7.80	138
02/19/2006	0.050		0.078		0.118		1740	8.00	8.00	0
09/02/2005	0.077		0.104		0.155		1740	8.10	7.60	0
04/10/2005	0.043		0.098		0.213		1740	8.00	7.70	0

This data, taken at 6-month intervals, shows an even trend throughout the machine's operation. This machine would be a candidate for a waiver.

Date	Vertical		Horizontal		Axial		RPM	FWD Draft	Aft Draft	Prop. RPM
	Vel. In/Sec	Vel. Graph	Vel. In/Sec	Vel. Graph	Vel. In/Sec	Vel. Graph				
11/16/2010	0.698		0.339		0.621		1740	8.20	8.20	132
05/02/2010	0.161		0.188		0.197		1746	8.20	8.20	105
11/02/2009	0.101		0.128		0.220		1746	8.04	7.90	127
04/24/2009	0.095		0.100		0.119		1746	5.00	5.00	85
11/04/2008	0.061		0.069		0.078		1746	8.20	7.80	124
05/18/2008	0.033		0.052		0.059		1746	8.00	8.00	0
11/29/2007	0.115		0.144		0.079		1746	8.00	8.30	125
06/06/2007	0.073		0.110		0.098		1746	7.90	8.00	130
03/01/2007	0.0		0.0		0.0		1746	0.00	0.00	0
06/11/2006	0.053		0.085		0.036		1746	8.20	8.20	0
10/02/2005	0.041		0.048		0.051		1746	8.10	8.20	0
02/18/2005	0.294		0.211		0.477		1746	8.07	8.03	127

This data, taken at 6-month intervals, shows an increasing trend throughout the machine's operation, culminating in a significant increase. This machine would be a candidate for an opening.