INTEGRATING AND COMBINING EVERY INFORMATION CARRYING PARAMETER IN CONDITION MONITORING

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ABSTRACT

For more than three decades, the benefits of condition monitoring have been known. Why, then, hasn't it become more widespread over every industry that apply rotating machinery? Possible answers to this question may be found in the fact that the traditional systems require vibration expertise to operate and to interpret the outputs. Experts are difficult to get, and their results often come too late so they, in a sense, represents post mortem diagnosis. System alarms are not robust, and result in false or missing alarms. Or, the information achieved from the systems was not properly utilised by the operating staff and maintenance department.

To get full benefit from the condition monitoring technology, the systems ahould be an integrated part of the complex systems that already are used in a modern plant, and that not only vibrations, but also other signals from machines, which carry information on machinery component health are included in the monitoring and diagnostic process.

In a modern context, condition monitoring systems must fulfil a set of requirements before we can expect it to be accepted by operators. In this paper we shall introduce a system sufficiently functional, open and user friendly to meet the current requirements from the industries that may benefit from condition monitoring.

1. INTRODUCTION

Whenever a fault on a machine component starts to develop, the physical behaviour of this component is changed. Monitoring specific physical parameters from machine components enables us to decode the behavioural changes, and possibly identify failure modes. For example, we have known for several decades that mechanical component faults on dynamic machinery causes changes in dynamic forces. We also know that dynamic forces are mapped into vibrations, and that these vibrations can effortlessly be measured and analysed for changes. Such changes can be used to identify components that are failing.

This is, in fact, the technology which we generally know as *vibration monitoring*. In that respect, vibration monitoring appears to be the ideal tool to monitor the health of machine components, and therefore it must be the perfect tool for machinery operators to assess the health of their assets.

So with these perspectives in mind,, we who design and market condition monitoring systems may ask ourselves: “If we are so clever, why aren't we rich?”

The answer to this question is not simple, but there are a number of possible reasons why condition monitoring, until now, has been less successful than expected: First, the early systems required vibration expertise to operate and interpret, expertise that was difficult to get, and results often came too late so they, in a sense, became post mortem diagnosis, while the system alarms were not robust – resulting in false or missing alarms. Secondly, the information derived from the systems was not properly utilised by the operating staff and maintenance department, possibly because the procedures and processes did not allow for adaptation and integration of the information, disbelief, and lack of knowledge. In order to change the situation to enable operators and system providers to benefit from the condition monitoring technology, these systems must constitute an integrated part of the complex systems which already are implemented in a modern plant and which share the existing information to maximal extent.

The benefit of executing *condition monitoring* is primarily to acquire component condition information to be used in *condition based maintenance*, with the goal of reducing the level time based maintenance, and secondly, to catch ill conditioned components before they break and cause unplanned outages.

Key requirements for a successful condition monitoring system are robustness and reliablity. It has to openly integrate with the existing plant systems and share information with other systems in an optimal sense. Furthermore, the organisation of the plant has to reflect the maintenance strategy, and has the processes that must be defined for how to act on incoming condition information.

2. INTEGRATING CONDITION MONITORING

Traditional condition monitoring is often perceived as vibration monitoring. Generally, vibration monitoring is used for machinery protection in the sense that if the vibration level exceeds a predefined limit, the protection system trips the machine. Potentially, vibration data can be processed, in parallel to the protection function, to get some condition information and to trend possible developments. However, this process is rather passive and requires human interaction or intervention.

2.1. Vibration Monitoring vs. Condition Monitoring

While vibration monitoring is watching for quantitatively increased levels, condition monitoring is concerned with qualitative changes in quantitative signatures. Saying “changes”, we must also specify how to measure specific changes, and in relation to what! Here we touch upon a very important issue, an issue which often becomes the Achilles' heel of a system; namely appropriate reference values or *baselines*. To detect even small changes we must ensure a collection of baselines to represent every significant operational condition per machine in the plant, which by itself requires a more or less complex set of measurements.

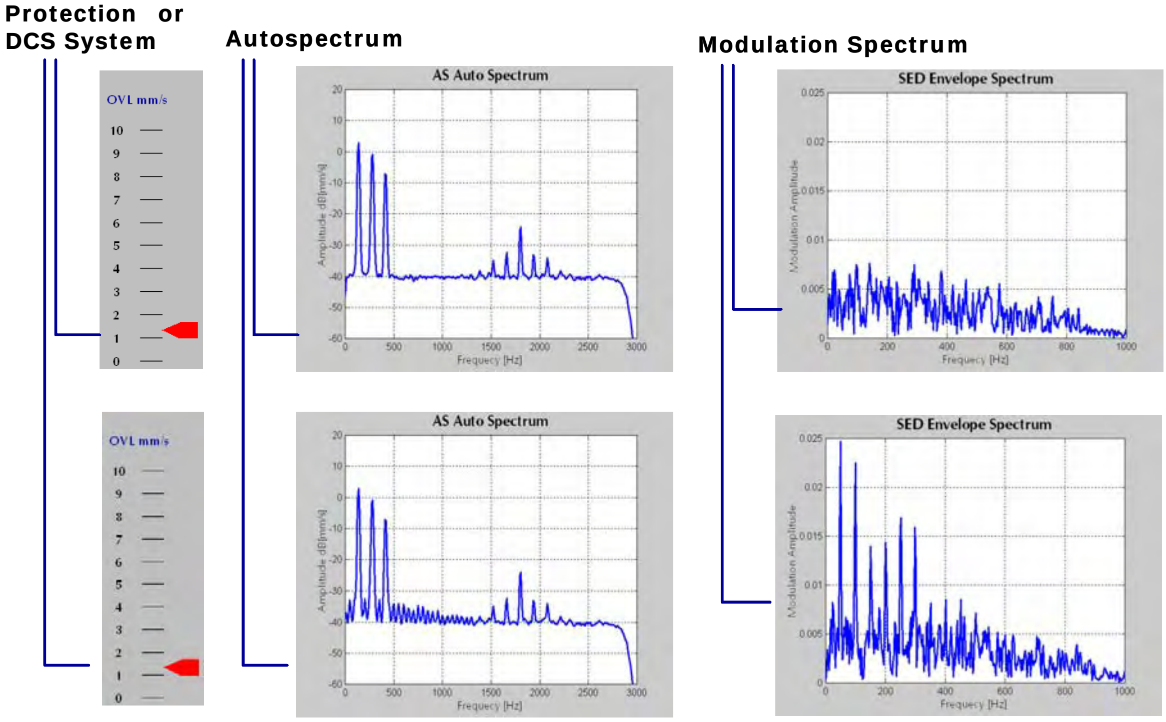


Figure 1. Illustration of the difference between quantitative and qualitative monitoring

Figure 1 illustrates the above discussion showing observations for a rolling element bearing, representing respectively a healthy state, and a state of developed outer race fault. As shown, the vibration level (overall) shows no difference. Looking at the autospectrum the difference is very subtle and would never provide sufficient information to represent a significant signature change. By extending the signal processing to estimate amplitude modulation in a specific frequency band, a significant change is clearly observed, and readily usable in a detailed diagnosis.

A lesson we may learn from the presented example is the fact that vibration monitoring, as such, is not able to detect a bearing fault. The autospectrum shows why: the overall level (1.2 mm/s) is totally determined by the first shaft harmonics, and changes appear two orders of magnitudes below the overall level (0.01 mm/s). from this observation we may draw the conclusion that in condition monitoring we are not looking for the vibration, but for the health information that a vibration signature may carry along, and that advanced signal processing is the tool to extract this information of interest, which in practice may be buried deep in otherwise irrelevant information (noise).

2.2. Other condition information carrying parameters

Not only vibrations, but many other signals from machines carry information on machinery component health. For example, we may use pressure, temperature, strain, power, speed, ambient conditions (barometric pressure and humidity) timing, composition in lubrication oil (oil analysis), thermo-graphical images, etc. Furthermore, for thermo machinery, we may extract health parameters from standard measurements related to a thermodynamic model of the machine, where also performance parameters can be derived, tracked and used for diagnostics.

2.3. Stand-alone vs. Integrated System

Signals from other physical parameters can be acquired directly from appropriate sensors, as is the case in stand-alone systems. But often such signals are available from other plant systems, and it is more economical when imported from these. The point, however, is that the condition monitoring system must be able to make an easy integration with other systems to provide extended functionality within an cost efficient frame.

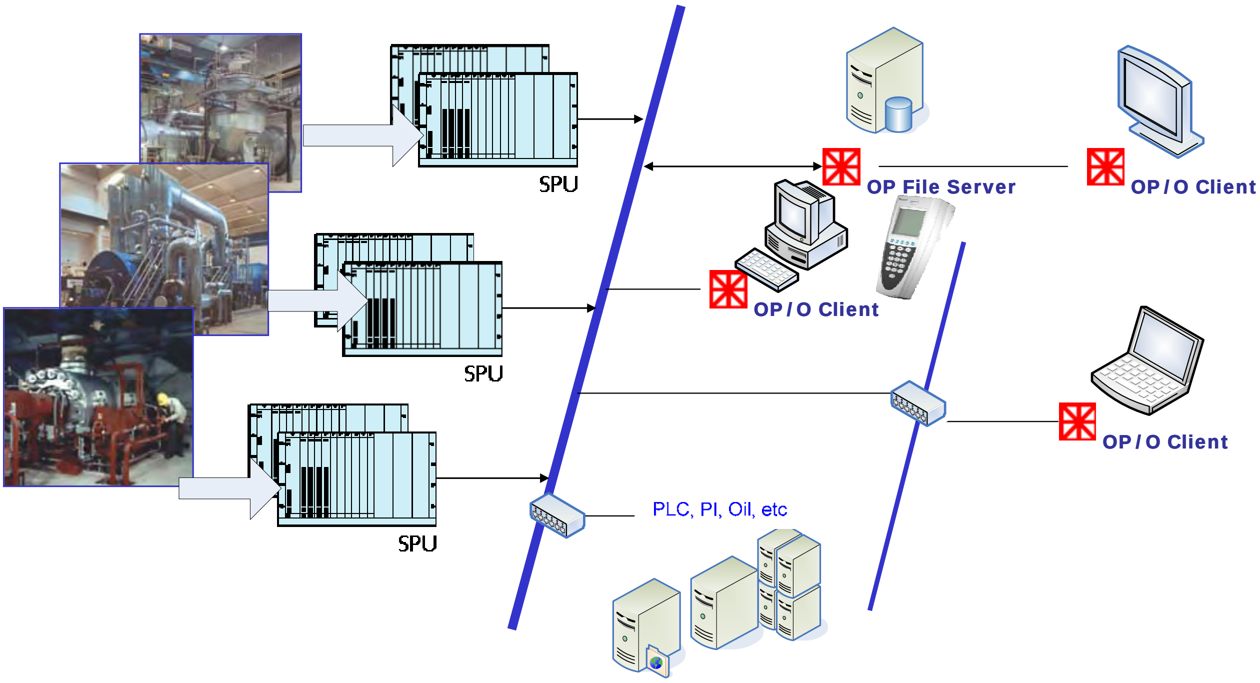


Figure 2. Example of OPENpredictor™ (OP) integrated condition monitoring system solution

Figure 2 shows an example of system integration. The centre of the system is the database server OPENpredictor™ (OP) file server, where data is gathered from the Signal Processing Units (SPU) of the basic condition monitoring system and via network connections acquire data from PLC, PI historian, ModBus, Oil analysis reports, etc., and then integrates this information into the database. The amalgamated information is then used in the diagnostic functions and predictions, and made available to local and remote users from client applications.

Figure 3 shows how the application modules are integrated in a modern condition monitoring system, the OPENpredictor™, and also shows a magnitude of possible hooks to future application modules.

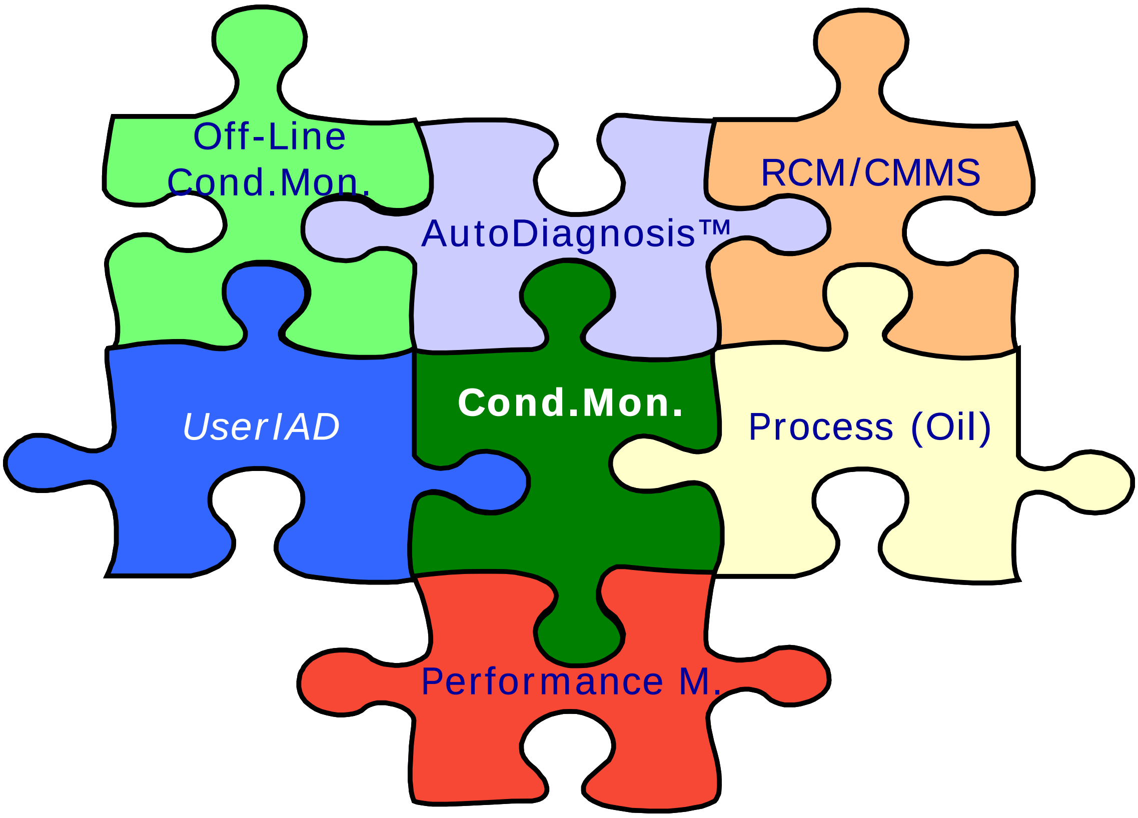


Figure 3. Integrated application modules in the OPENpredictor™ condition monitoring system with open hooks to future application modules

3. FROM CONDITION MONITORING TO AUTOMATIC DIAGNOSIS

What kind of output is desired from a condition monitoring system? Shall it be graphs, numbers, traffic lights, ☺, or something else? Possibly, the ideal output would be no-output, meaning that the condition of all the monitored equipment is fine.

Previous systems would basically produce alarms, graphs and trends. However, an alarm is rarely a robust parameter. An alarm is generally associated with one sensor, meaning that if this sensor fails the result would be a false alarm or a missing alarm. A much more robust approach would be alarms based on clusters of sensors, and even better, to provide the operator with an automatic diagnosis (AutoDiagnosis™) in clear text for every fault at an early stage; specifying which component, fault description and a prediction on when the fault is expected to develop to a critical stage.

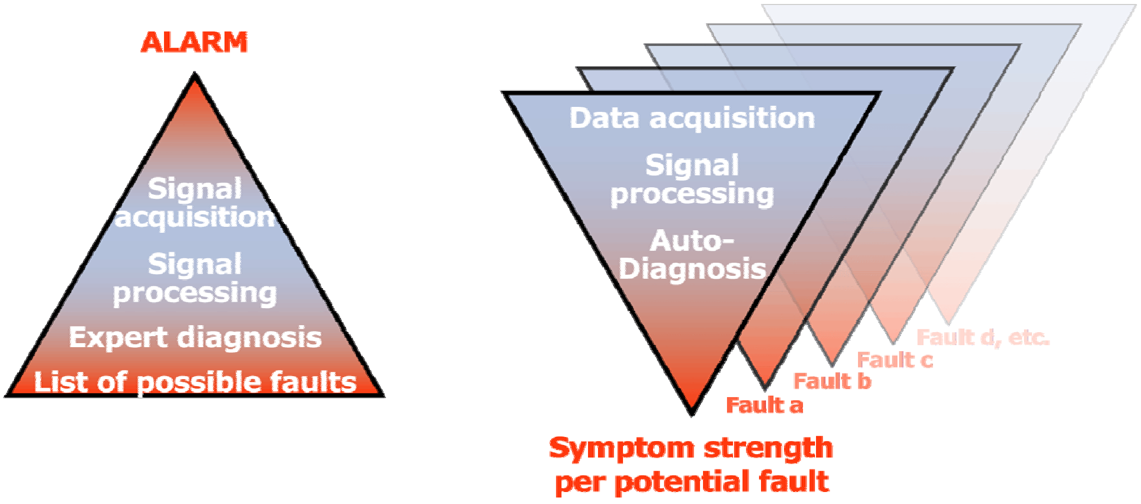
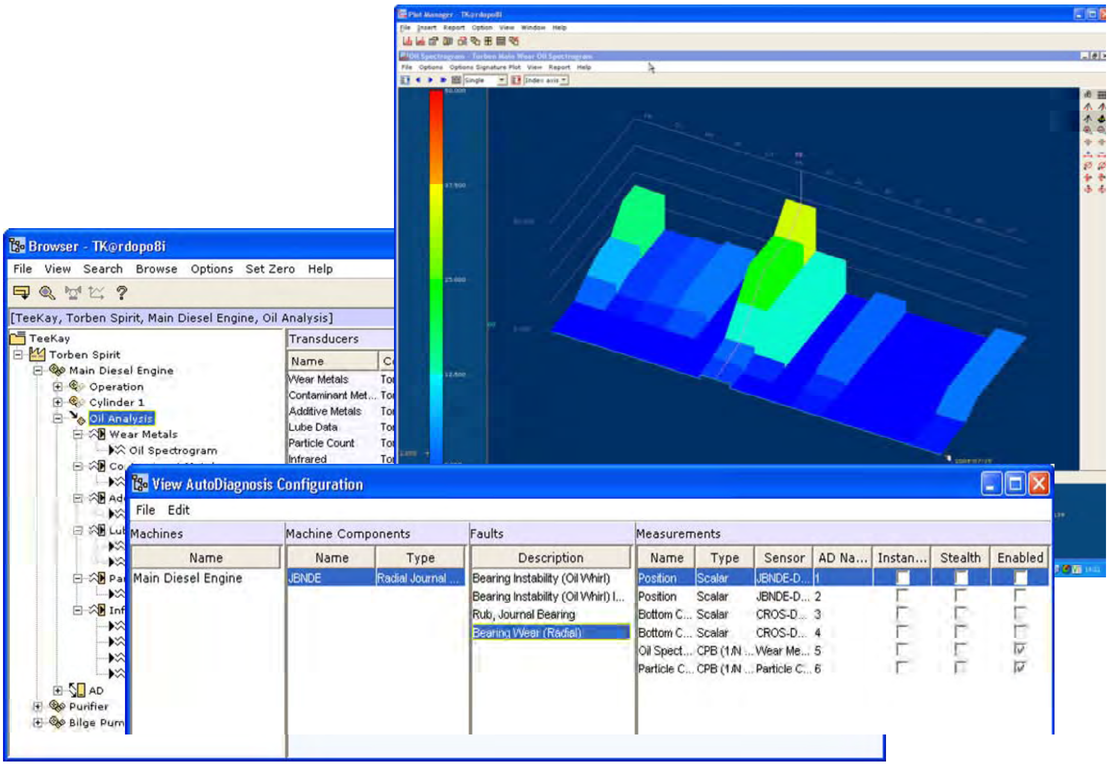


Figure 4. Comparison of traditional diagnosis and AutoDiagnosis™ as implemented in OPENpredictor™

Figure 4 shows a comparison between the traditional diagnostic approach and the approach implemented in OPENpredictor™. For the traditional approach we use a pyramid to illustrate the model, and may say that the onset of a diagnostic task most often is an alarm from the protection or condition monitoring system. To identify the cause of the alarm it may be necessary to acquire more data, and to carry out signal processing for manual analysis by an expert, who, possibly, will come up with a number of fault candidates. This approach is not appropriate in a modern plant operating context. Firstly, if the alarm is genuine, the fault must be corrected without lead time, and if the alarm is false it may result in an unnecessary outage. Secondly, as experts, who can execute machinery diagnosis are today rarely part of the staff in a modern plant, external consultants must be called to assist. Therefore, in the process of designing OPENpredictor™ we turned the traditional pyramid upside down. Today, the onset of system configuration is the definition of every potential component fault that may be anticipated in the particular plant (this count thousands). For each of these potential faults, all the data required/available is acquired and processed to a level where an automatic diagnosis (AutoDiagnosis™) can be accomplished, providing, as an output, the current *symptom strength* per fault. Naturally and most possibly, more than 95% of the potential faults will exhibit symptom strength zero, and the rest will show strengths between 0 and 1. Also, a prediction on when the strength is expected to be 1, is provided. Strength 1 means that the fault has developed to a critical level and that inspection/maintenance is required.

Another advantage of turning from *alarms* to *diagnostics* is the fact that the robustness and reliability is dramatically increased. False trips from protection systems caused by a single failing sensor can be rejected from the diagnostic function that is based on information from a collection of sensors, and the diagnosis is put valid/confident, and alarms/warnings issued, only when consistency between sensors exists,.



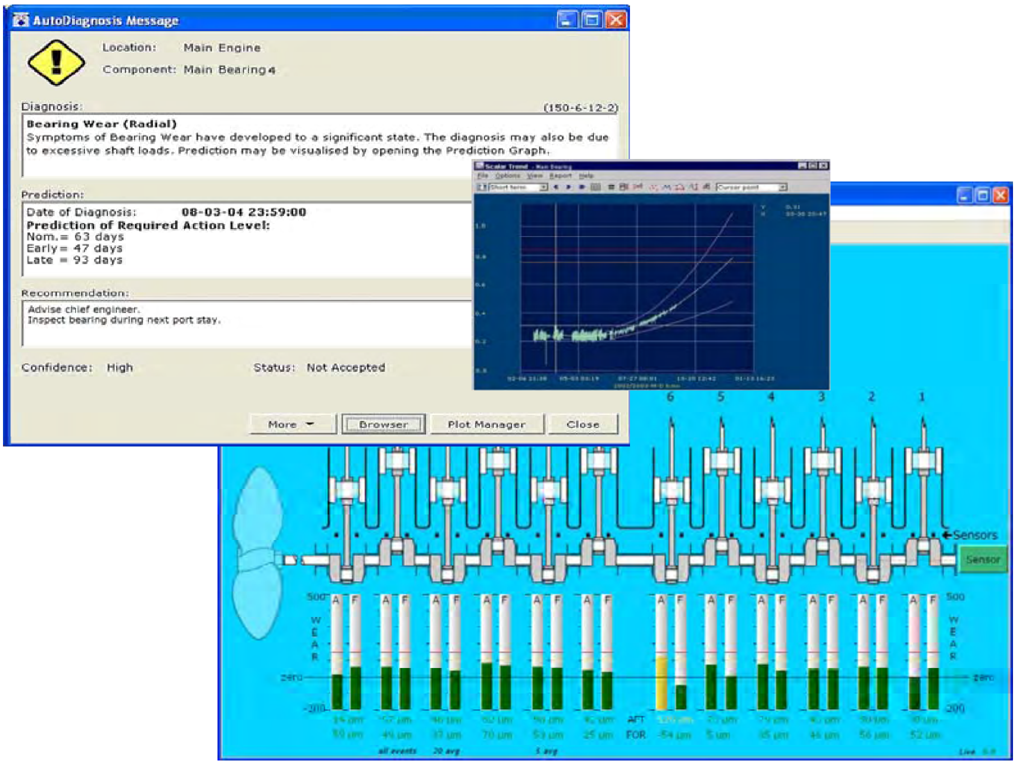
Machines
Name
Main Diesel Engine

Machine Components	
Name	Type
JBNDE	Radial Journal ...

Faults
Description
Bearing Instability (Oil Whirl)
Bearing Instability (Oil Whirl) I...
Rub, Journal Bearing
Bearing Wear (Radial)

Name	Type	Sensor	AD Na...	Instan...	Stealth	Enabled
Position	Scalar	JBNDE-D...	1	☐	☐	☐
Position	Scalar	JBNDE-D...	2	☐	☐	☐
Bottom C...	Scalar	CROS-D...	3	☐	☐	☐
Bottom C...	Scalar	CROS-D...	4	☐	☐	☐
Oil Spect...	CPB (1/N ...	Wear Me...	5	☐	☐	☑
Particle C...	CPB (1/N ...	Particle C...	6	☐	☐	☑

Figure 5. Example on how oil analysis is included in the diagnosis of wear in fluid film bearing, demonstrating integration and AutoDiagnosis™



Location: Main Engine
Component: Main Bearing 4

Diagnosis: (150-6-12-2)
Bearing Wear (Radial)
Symptoms of Bearing Wear have developed to a significant state. The diagnosis may also be due to excessive shaft loads. Prediction may be visualised by opening the Prediction Graph.

Prediction:
Date of Diagnosis: **08-03-04 23:59:00**
Prediction of Required Action Level:
Nom.= 63 days
Early= 47 days
Late = 93 days

Recommendation:
Advise chief engineer.
Inspect bearing during next port stay.

Confidence: High
Status: Not Accepted

Figure 6. Illustrations of output from OPENpredictor™: Mimic with graphical presentation of accumulated wear on fluid film bearings and a diagnostic message in clear text with prediction

4. ON THE ROAD TO CONDITION BASED MAINTENANCE

First and foremost, a requirement for condition based maintenance is reliable condition monitoring. Secondly, a maintenance strategy, probably based on *Reliability Centred Maintenance* analysis, must be defined to ensure that the condition information is utilised.

The fundamental principle now is to discontinue the traditional time based preventive maintenance, and only carry out maintenance when it is needed, with all the benefits of saving outage time, spare parts and man hours, and to avoid inspection related faults.

In a condition monitoring system that provides automatic diagnosis, the attention is mainly given to the type of fault the system is able to identify. However, information that is even more valuable is when *no fault* is currently identified; hence, operation can uninterruptedly be continued!

Finally, a hint to the organisation that considers implementing condition monitoring: Condition monitoring systems only provide information! Not before this information is utilised through well defined processes in the organisation, the full benefits are achieved.

5. CONCLUSION

In a modern context, condition monitoring systems must fulfil a set of requirements before we can expect it to be accepted by operators:

- The system must have sufficient condition coverage to catch all potential machinery faults in an early stage
- The fault diagnosis must provide an early warning allowing the maintenance staff sufficient lead time for optimal planning
- It must run in the background and only requires operator interaction when action is needed
- It must be integrated with existing plant information systems to utilise all available data and improve diagnoses
- The system must present itself with a simple graphical interface, so that operators do not need to relate to numbers
- The system must provide sufficient tools for the diagnostic expert to verify diagnoses from the system and to assess failure modes
- The system must be open and easy to integrate with current and future information, control and monitoring systems

If these, and possibly other, requirements are fulfilled, the technology of condition monitoring will have a much more prosperous future than ever before. The condition monitoring technology is *coming into age*, and is apparently on the way to become a requirement from the industry, or turning our push into a welcome pull.