Condition based data trending to optimise maintenance on Sandown class propulsion system

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Synopsis

The day to day challenges of maintaining legacy complex warships demands an ever increasing level of support to address the through life challenges of equipment obsolescence and an increasing number of emergent defects. To improve the materiel state of the in service platforms, a greater use of technology and data analytics is now being applied optimising the maintenance and through life support of key equipment and systems.

This paper provides a case study of the Babcock Warship Technical Authority (WTA) contribution to an equipment availability review of the maintenance schedule of the Voith Schneider Propulsion (VSP) system for the Single Role Mine Hunter (SRMH) Sandown class. The paper reviews the trends from historical oil sampling and vibration monitoring data, in combination with operational defects. These trends were compared with the reliability centred maintenance tasks to optimise support. The FMECA methodology has been applied to this information to provide recommendations on (i) the amount of condition based monitoring being applied, (ii) revisions to the standard operating procedures, (iii) the logging of environmental conditions; and (iv) baselining of equipment performance. The paper also considers the work being undertaken to optimise the through life support of the equipment, covering logistics, documentation and training.

The role of the WTA is to introduce innovation and deliver intelligence lead support solutions at the waterfront to enhance the crew's ability to take ownership and maintain their platform efficiently. This case study provides an example of how data trending and analysis can optimise the maintenance routine for key equipment on legacy platforms.

Keywords: Propulsion; Maintenance; Marine Systems; CBM; Oil

Caveat

The views and opinions in this paper are those of the author and not to be construed as the official view of the Surface Ship Support Alliance or wider maritime enterprise.

1. Introduction: The Sandown VSP propulsion system

The propulsion system for a Royal Navy SRMH Sandown class comprises of two Schottel bow thrusters and two VSP units. The combination of the bow thrusters and the VSP units allow the platform to remain on station and conduct precise manoeuvring during a range of weather and tidal conditions. These characteristics are clearly essential for the operational tasking of a SRMH platform. This technical paper will focus on the condition based monitoring for the VSP units.

The power delivery to the two VSP units is provided on the Sandown class from two independent shafts. The propulsion machinery is provided by primarily two Paxman Valenta diesel engines, with additional induction motors for slow speed drive. A simplified system diagram of the arrangement is provided below.

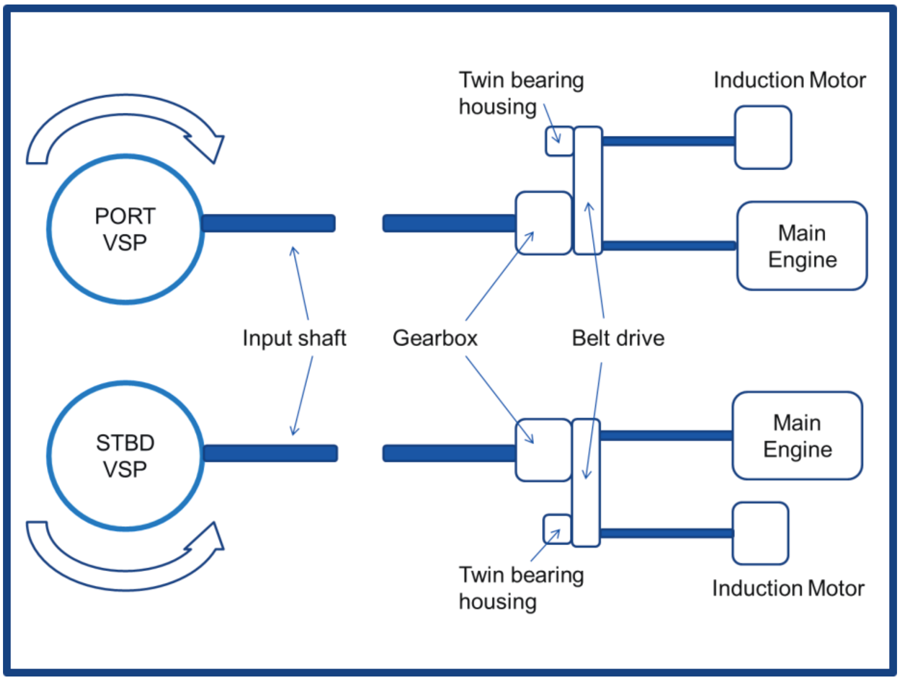

Figure 1: System diagram of power delivery arrangement for VSP units

Each VSP unit has five blades which are perpendicular to the hull and rotate on a carousel rotor casing flush to the bottom of the ship. While rotating the blades perform an oscillation motion representative of the cyclorotor operating principle. The camber blades which are rotated around the centre of the unit have variable pitch which during rotation can vary their incidence angle to the local flow. The force generated by the blade is dependent on the flow direction, blade rotation and local incidence angle. Figure 2 depicts the blade force generated at each 90 degree position over the full revolution. If the pitch of the blade is varied throughout the revolution then both the direction and magnitude of the force will change. When the cumulative effect of the forces is measured the net force can be calculated for one rotor revolution, provided by the diagram on the right. Combined across all five blades it will give the overall force from the VSP unit for one complete cycle. This, together with a second VSP unit and the bow thrusters, provides the precise steering and propulsion for the platform. The lubrication of the blade actuation gear is therefore a critical maintenance requirement in the operation of the units.

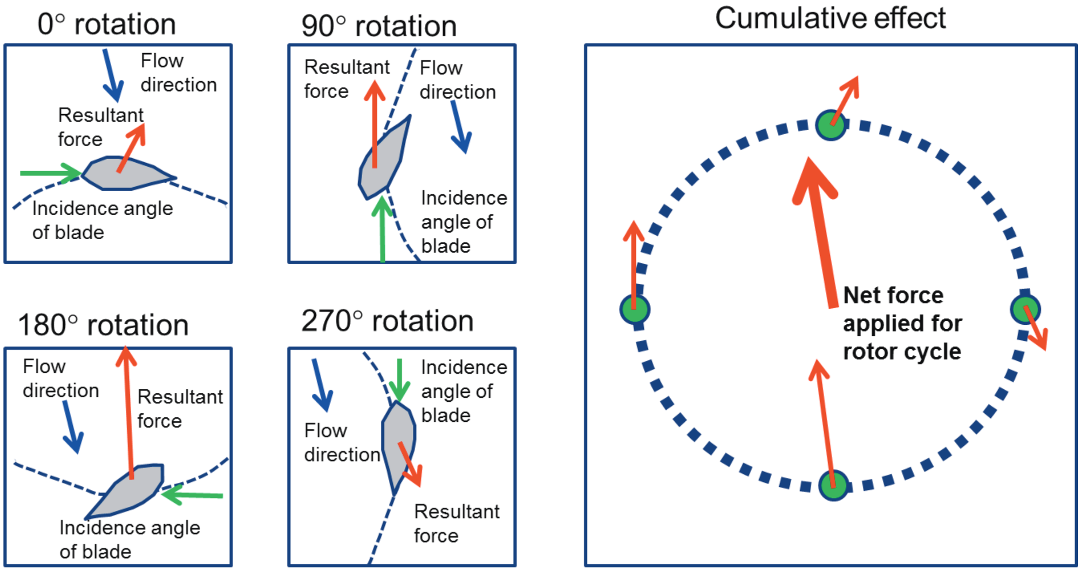

Figure 2: Generation of force from variable pitch blades in CCW cycle

The VSP oil system is self-contained, with the housing acting as the sump and any circulated oil draining back into the housing. The rotor casing compartment containing the shaft and bearings of the five blades and the blade actuating gear is filled with oil. It is maintained with a positive oil pressure with an elevated oil tank to prevent sea water ingress. Oil can also be circulated through the rotor to act as an oil-cooler because it is in contact with the sea water. Approximately two thirds of the total oil in the system is contained within the VSP housing and one third in the rotor. Each VSP contains approximately 900 litres of OEP-220 oil, which is a Transmission Lubricant containing an extreme pressure additive. [1]

2. Oil sampling

The maintenance schedule for the VSP units includes a periodic oil sample for each unit, taken by ship staff and despatched for laboratory testing. The results are published in a report which is sent to both the MoD Equipment Authority and the platform. The report consists of two pages. The first contains laboratory team comments of the sample, with the second section providing recommendations for preventative action. The second page of the report provides (i) the elemental oil analysis across a range of metallic elements, (ii) the debris found in the oil, (iii) viscosity of the oil, (iv) water content and (v) Total Acid Number (TAN). There is also an overall status provided in the report which for each unit summarises one of three statuses: (i) that no action is necessary, (ii) some action is recommended, or (iii) action is required.

While the recommendations arising from oil sample reports have proven to be beneficial, in some instances sample analysis has led to a requirement for immediate action. To establish the amount of risk being carried by each unit and become more predictive than reactive the Babcock WTA has developed a tool which trends the historical data provided by the oil sample reports.

The WTA is the industry technical capability that provides Engineering Assurance to Navy Command’s surface fleet. Its primary role is to generate the bodies of technical evidence to maintain Design Intent and provide engineering solutions and recommendations for acceptance by the MoD Warship Approving Authority (WAA). The WTA also ensures that any design change is maintained within the design intent of the platform. For the case study covered by this paper the WTA conducted a technical investigation based on oil sample trends, generate a dashboard and issue a technical report with recommendations.

2.1. Oil sample trending for preventative intervention

The oil sample trending tool developed by the WTA provides the Equipment Authority a dashboard to identify the risk being carried by individual VSP units across the Sandown class. The input to the tool is based on the oil sample reports across all the metallic components, TAN and water content. The layout of the dashboard is provided by Figure 3.

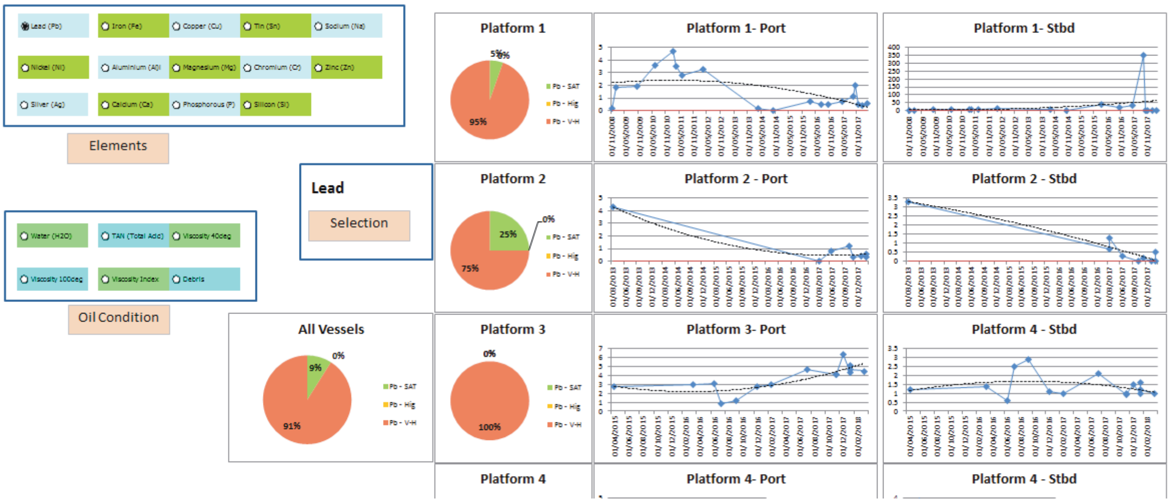

Figure 3: Dashboard created by the WTA to trend oil sample results from VSP units

The first challenge in developing the tool was to ensure the raw data was based on a specific unit rather than the platform. As part of the overhaul programme the VSP units have been interchanged between platforms in the class. Therefore the tool provides the trend of the current units fitted on an individual platform and provides the historical data of an individual unit independent of platform. For each oil characteristic under consideration the tool produces a chart and a second order polynomial trend line. An example is shown in Figure 4. When reviewing the information it is important to consider the historical maintenance conducted on the unit. For example in Figure 4 it is clear when previous oil changes have been undertaken.

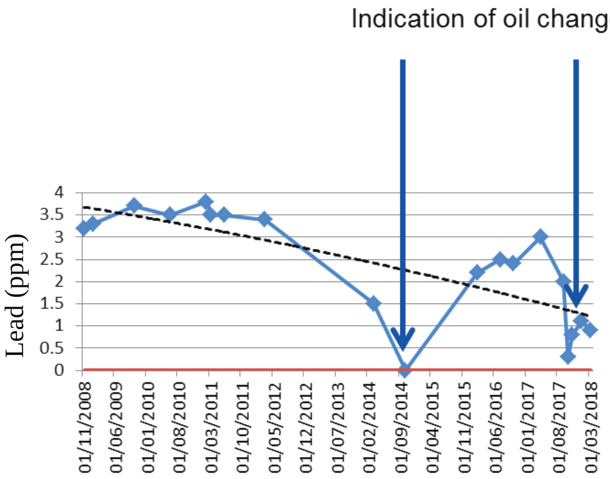

Figure 4: Overlay of maintenance activity against oil sample trends

The scaling of the data can provide a false impression of a sudden rise when the overall values remain small. For this reason the WTA received maximum permissible values of the water content in the oil and the key metallic components from the Original Equipment Manufacturer. By overlaying warning and critical maximum permissible values against the trend line provides an indication when action is required and it also allows extrapolation of the data to identify an appropriate support period to conduct remedial work without impacting the ship's operational programme.

When reviewing the trend data presented by the dashboard it is important to establish what an increased metallic element signifies in terms of deterioration of the unit. Table 1 provides a list of the main metallic elements with a brief description of what an increasing trend could signify.

Table 1: Linking an increase in the metallic elements found in the oil with degradation of asset

Metallic element	**Potential root cause**
Aluminium	Generally comes from Pistons, Turbo Bearings, Main and Rod Bearings, pumps, thrust bearings and washers, plates and Aluminium castings. Aluminium associated with silica indicates dirt. Aluminium found in hydraulic system should be generally due to dirt ingestion and in final drives can be associated with dirt or sand.*
Chromium	Generally a hard metal generated from piston rings, liners, exhaust valves, shaft plating, roller bearings, needle bearings, shafts, rods, gears, stainless steel alloys. Its presence indicates something harder is present usually silica and alumina. chromium found in hydraulic system is from cylinder rods and valve spools.*
Copper	Usually like a soft metal present in main and rod bearings, oil cooler core, clutch plates, brass and bronze bushings and roller bearing outer cage. It is found along with lead and tin, and comes from bearing or bushing.*
Iron	Mostly comes from cylinder liners, rings, crankshaft, camshaft, rods, valve train, oil pump gear, wrist pins, cast iron components and gears. Usually found as fine particles due to abrasion or wear.*
Lead	Usually a soft metal, most common related to bushings and rod bearings. engine oil which is highly oxidized can attack the bearing material, leads to increased lead readings.*

Silicon	Degradation of seal or dirt contamination in the oil sample.
Zinc	Indication of a minor contamination with another oil
Calcium	Indication of a minor contamination with another oil

*(Techenmics, 2017) [2]

The water content of the oil is also monitored as water ingress could signify deterioration of the main seals. The trending of water content should be based on the original water content of the oil when it is changed and it is important to trend the results from this baseline rather than zero. An increasing trend of sodium content in combination of an increase in water content is an indication of sea water ingress into the oil.

The TAN value is an indication of the breakdown of the lubricant. When the oil degrades it produces acidic by-products by the chemical decomposition of the base stock and additional additives when in the presence of air and heat. When the acidic content in the oil increases it can result in corrosion of components and filters due to the presence of varnish and sludge. The TAN value is therefore a strong indication of the quality of the oil, with the maximum TAN value indicating the need for an oil change. [3]

When data is being presented as trend lines it is imperative that there is consistency in the oil samples being taken. For example standardising the oil sampling point for the units and ensuring the oil in the unit has been recently heated and circulated. This mixing of the oil will reduce the likelihood of metallic debris in the oil settling on the bottom of the sump.

3. Additional condition based monitoring applications

In addition to the oil samples there are a number of other condition monitoring techniques which are reflected in a range of BS / ISO standards e.g. “BS 13373 Condition Monitoring and Diagnostics of Machines and Vibration Condition Monitoring” (BS13373, 2002, 2015, 2016). A survey of CM techniques provided by Table 2 highlighted the variety and popularity of the top four methods.

Table 2: Popularity of main conditioned based monitoring techniques

Technique	Number (Percentage)
Vibration Analysis	148 (17.3%)
Oil Analysis	113(13.2%)
Infra-red	99 (11.6%)
Human-Senses	92 (10.8%)

The current practice with respect to Condition Based Monitoring (CBM) on Royal Navy vessels is localised, i.e., “taking and recording CBM data at periodic intervals in order to determine the condition of the component being monitored, and then deciding whether the condition of the component is acceptable or not” [4]. The consequence of intermittent data recording is that only a small selection of data may be logged each month. The adoption of continuous networked remote CM system would negate the task of data collection, providing engineers with the opportunity to apply their intelligent feedback with an understanding of recent operational tasking. Furthermore, system managers could be presented with real-time data from the vessels.

An increase in the number of CBM techniques may provide a correlation or causation and further evidence to the position on the Potential-to-Functional (P-F) failure curve, as shown in Figure 5 below. This model can be broken down to three discrete groupings of the asset: (i) reliable, (ii) degenerative and (iii) unpredictable. Each state has a varying level of performance from the asset. If the maintenance is optimised this will increase the time before it transitions between these categorises.

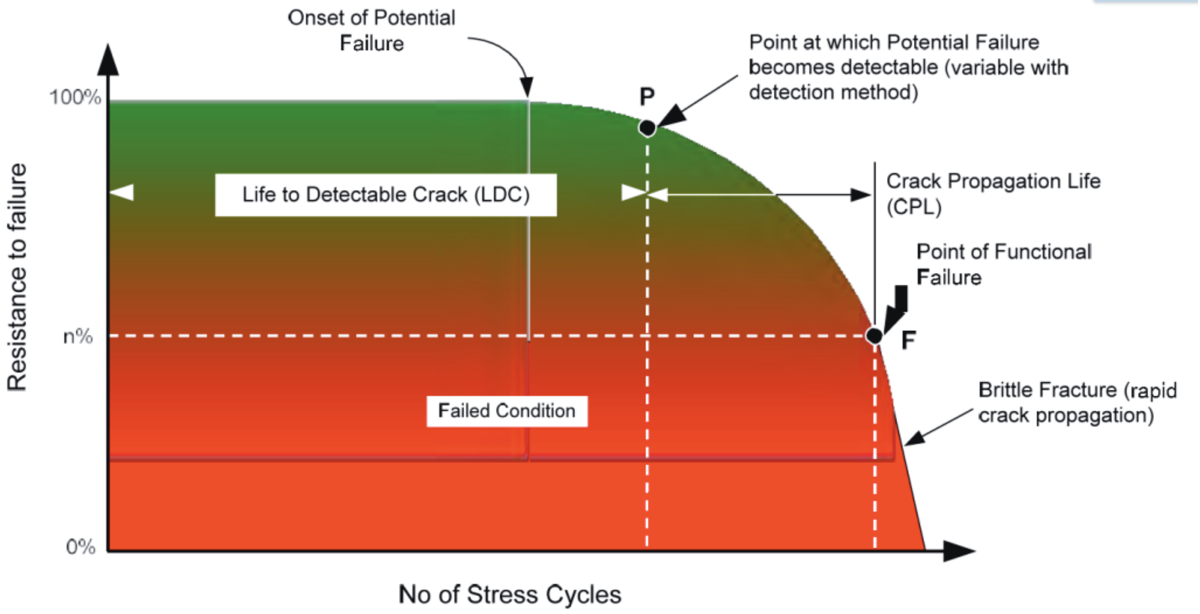

Figure 5: Example of a P-F Interval Curve (DefStan00-45, 2016)

3.1. Vibration analysis

Vibration Analysis (VA) is the monitoring of vibration generated by mechanical equipment or systems. Vibration is typically recorded on Royal Navy vessels without any record of the environmental context of temperature and humidity. Loading or speed is also not typically considered. Isolating equipment for VA may not be possible with the potential of transference of background noise. Al-Najjar states this should be as low as possible for securing high accuracy in the interpretation of the vibration spectrum [5]

For the VSP units the vibration is measured at the drive end on the horizontal, vertical and axial planes. For vibration that consists of fingered elements such as gears and roller bearings a maximum frequency equal to three times the number of fingers multiplied by the operating speed should provide the full spectrum of interest. For each set of readings the kilcocycles per minute (kcpm) is measured and the discrete values are plotted over time using previous readings to identify mechanical deterioration. The results are reviewed by the Royal Navy Condition Monitoring Assurance Team who analyse the results and provide recommendations where action is required. During the development of the oil sample trending toolset, the VA results were compared with increasing trends of metallic elements to help identify the deteriorating component.

The challenges of conducting VA of the VSP units is the number of moving parts, vibration emanating from other equipment on the platform and the position of the accelerometer on the housing and its distance from the bearing. The activity is also reliant on consistently mounting the accelerometer at the same location to minimise measurement inconsistencies.

3.2. Acoustic monitoring

The mechanical degradation of machinery produces acoustic emissions (AE) by producing an elastic wave which propagates throughout the system. Monitoring of AE is based on a high frequency range from 25 kHz to 1MHz. When rotating machinery is operational the AE monitoring device can detect a range of potential sources including grinding, a sudden impact or crushing.

There are a number of advantages of using this CBM technology on the VSP units.

- It is non-invasive.
- It detects material degradation at an earlier stage compared with other CBM technologies due to its sensitivity.
- Low frequency noise from other equipment or audible noise does not interfere with the output.
- The detection device is non-directional which allows flexibility of the placement of the sensor.

AE may suffer from signal attenuation and consequently the sensor must be close to its source. This may be an advantage, for example a sensor placed near a bearing will only detect bearing faults since fault signatures from other machine components are highly attenuated upon reaching the sensor [6]. Similar to other CBM technology the information gathered from AE monitoring to be used as part of a body of evidence from other source such as VA, oil analysis and survey reports to establish the root cause. It is also important to provide baseline AE results to allow any anomalies to be readily identified.

4. FMECA methodology applied to previous RCM studies

Reliability Centred Maintenance (RCM) was adopted by the Royal Navy in 1984 to provide efficiencies in the periodicity of the maintenance and being able to accurately assign resource to a particular repair activity. The scheduling of the maintenance cycle can either be undertaken by ship staff or base support. When base support is required the maintenance is targeted within dry docking periods or ship support periods.

Failure Modes, Effects and Criticality Analysis (FMECA) methodology identify all the potential failure modes of an equipment item or system, their severity and likelihood of occurring. As part of the investigation on the CBM techniques used on the VSP units the Babcock WTA applied a FMECA methodology on the current RCM maintenance regime for the units.

The criticality of the failure is a combination of the severity and the likelihood of its occurrence. When considering a VSP unit the severity would be based on the condition of the unit and the resulting operational impact to the platform. A significant level of severity would be considered as a failure which would result in the loss of the platform’s main propulsion system. This would require rectification of the damage before the vessel continues with operational tasking.

The probability or failure frequency is detailed in Def Stan 00-45 [7]. In this case the high criticality failures are those that are likely to occur at least once per platform lifetime. A range of functional failures is also captured by the FMECA, with the main failure being a loss of thrust to the unit. This could be a result of a range of casual factors, as captured by Table 3 [8].

Table 3: Causal factors due to loss of thrust

Casual factor	Description
Lubrication oil contamination or degradation	The local effect is that over a period of time, water will build up in the lubricating oil. Rolling element bearings will start to corrode. The bearings will start to produce excessive noise and vibration prior to catastrophic failure. The end effect being a total loss of the affected shaft and of mine hunting capability.
Wearing of the bearings	The local effect is a flaking of the bearing. Unit noise and vibration levels increase, excess debris is deposited into the oil. Continued use will lead to unacceptable noise levels and finally catastrophic failure and loss of mine hunting capability.
Actuator failures	The local effect is on receipt of the demand signal the actuator fails to move. A discrepancy between demand and achieved signals leads to loss of ahead or astern pitch control (the system fails set at the last position). The end effect is loss of mine hunting capability.

Other functional failures which were considered as part of the FMECA review included the VSP units unable to contain the oil within the acceptance leakage rate, inability to prevent sea water ingress within acceptable limits, inability to control the VSP units and finally, failure to conduct the scheduled maintenance.

The failure modes associated with the functional failures of sea water ingress and control relate to component failure such as bearings and seals. The failure to conduct the maintenance is linked to the documentation and training available to ship staff. The training aspect is also an important factor in providing consistency in the data gathering for the CBM oil sampling.

Predicative maintenance is based on the continued monitoring of these items and is a key element of the Royal Navy’s RCM policy. The maintenance is reliant on the logistics teams assessing which components are most likely to require replacing and ensuring these items are readily available when required. This strategic understanding of future demands is a key responsibility of an Integrated Logistics Support (ILS) role and should be intertwined with the RCM policy of the asset.

5. Conclusions

The level of risk being carried by individual platforms can only be accurately measured with an evidence based assessment of materiel state. If the risk becomes an issue it could impact the operational tasking of the platform from performance limitations or requirements for defect rectification work. The data trending tool for the oil samples provides a greater understanding of the condition of the VSP units and provides a compelling body of evidence to influence future support arrangements. For instance stakeholders can use this information to make informed decisions to prioritise VSP units for future overhauls or to plan interventions to prevent further degradation. As with any toolset the benefits can only be realised by ensuring (i) the quality of the data is consistent (particularly in terms of how the oil is measured), (ii) laboratory analysis is expedited to minimise latency in the analysis; and (iii) the frequency of the oil sampling is maintained.

The maintenance strategy carried in the marine industry (see Figure 6) has evolved over the last sixty years [9]. Initially it was purely reactive “run to failure” maintenance which is only cost effective until a catastrophic failure occurs. The preventive maintenance which is primarily RCM in Royal Navy platforms introduced a time driven or hours based maintenance activities, which reduce the failure rates and also prevent unnecessary replacement of components. An enhancement of the preventative maintenance schedule is predictive maintenance determined from CBM results. Supported by the WTA the data analysis of the CBM results contributes to measuring and maintaining the design intent of the equipment or system through its operational lifecycle.

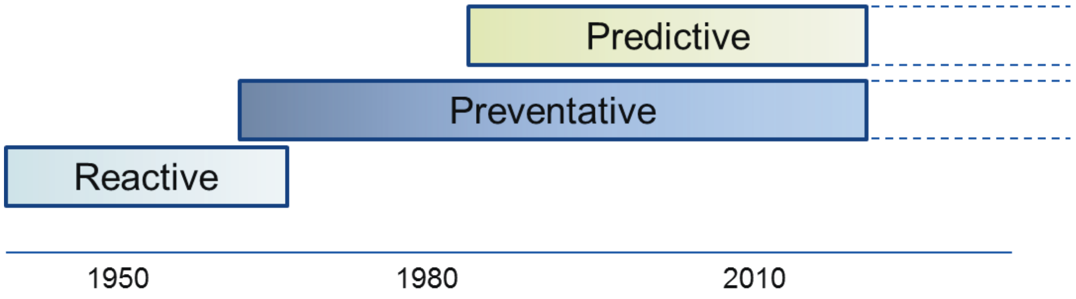

Figure 6: Maintenance strategies within the marine industry

The oil sampling should only be taken as one CBM technique which could place each unit on the P-F curve. To provide a comprehensive body of evidence to determine the materiel state of a VSP unit requires additional CBM data from VA and Acoustic Emissions. The optimised maintenance model is for the CBM data to be integrated into the preventative maintenance schedule and analysed autonomously. This would provide recommendations to either the WTA or Equipment Authority to undertake a technical review or to direct the Royal Navy maintainer to take appropriate action.

Acknowledgements

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References

[1] BR6566. (2015) BR6566(017) Voith Schneider Propulsor Type 18GH. Issued April 2015. Ministry of Defence.

[2] Techenmics. (2017) Techenomics International. Test Explanations. [ONLINE] Available at: http://www.techenomics.net/oil-fluid-analysis/test-explanations/.

[3] Spectro Scientific. Guide to measuring TAN and TBN in Oil. [ONLINE] Available at: https://www.spectrosci.com/resource-center/lubrication-analysis/literature/e-guides/guide-to-measuring-tantbn/

[4] Higgs,P.A., Parkin,R., Jackson,M., Al-Habaibeh,A., Zorriassatine,F. and Coy,J. (2004) A Survey On Condition Monitoring Systems In Industry. In 7th Biennial ASME Conference Engineering Systems Design and Analysis. July. pp.19-22.

[5] Al-Najjar,B. (2000) Impact Of Real-Time Measurements Of Operating Conditions On Effectiveness And Accuracy Of Vibration-Based Maintenance Policy - A Case Study In Paper Mill. Journal of Quality in Maintenance Engineering, Vol. 6, Iss.4, pp.275-287.

[6] Mba,D. and Rao,R.B.K.N. (2006) Development of Acoustic Emission Technology for Condition Monitoring and Diagnosis of Rotating Machines; Bearings, Pumps, Gearboxes, Engines and Rotating Structures. The Shock and Vibration Digest. Vol.38(1), pp.3-16.

[7] DefStan00-45. (2016) Using Reliability Centred Maintenance to Manage Engineering Failures Part 3: Guidance on the Application of Reliability Centred Maintenance. Issue: 3, Date: 18-Nov-2016

[8] Dr G Ford, E Adjene (2018) WTA technical report. Voith Schneider Data Analysis.

[9] NA Tomlinson (2015) What is the ideal maintenance strategy? A look at both MoD and commercial shipping best practice.