Propulsion Condition Monitoring Service

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Fig. 1 – PCMS advisory monitor.

In August 2010, Wärtsilä introduced its Propulsion Condition Monitoring Service (PCMS) for all types of propulsion machinery. This service aims to provide the customer with up-to-date and in-depth information about the condition of his propulsion equipment.

With the information provided by PCMS, the customer has a solid foundation for determining his operational and maintenance costs and for verifying his business models. This in turn enhances operations, minimises asset risks, and ultimately reduces the lifecycle costs of the customer's assets. PCMS supports existing CBM solutions for engines and other machinery.

To provide this service, a PCMS system consisting of the following items has to be installed onboard the vessel:

- PCMS advisory monitor
- One or more PCMS cabinets, each with the following as standard:
  - 6 accelerometers (50kHz)
  - 4 pressure (50Hz) transmitters
  - 2 temperature transmitters
  - oil monitoring unit
  - torque (100Hz) measurement system.

The number of inputs can be changed depending on the specific requirements of the customer.

Accelerometers are used to monitor the condition of mechanical parts, such as gears and bearings, but can also detect for example, blade damage. One PCMS system can process up to 16 accelerometers simultaneously.

Lubrication- and hydraulic oil is monitored by measuring temperature, the oil-water saturation, and any oil contamination.

The PCMS advisory monitor is the next evolutionary step in vessel automation. The interface gathers and shows information from all the PCMS cabinets on the vessel. It gives real-time and trend values, and advises the operator in case of irregularities. It has been developed to detect the operational states by real-time comparisons of parameters from multiple sources. For example, the vibration measurements are linked to the operational condition of the vessel. If an operational state causes severe vibration, the PCMS will advise how to rectify this unwanted situation.

The advisory monitor sends a data package to the propulsion CBM (Condition Based Maintenance) centre on a daily basis. There the data is automatically processed, and in the event of irregularities the propulsion specialist will take action. Once a month, the customer receives a PCMS report describing the condition of his equipment.

To effectively analyse data and to ensure that no important events are overlooked, a large part of the data analysis is automated.

State detection

An important part of the data analysis is carried out on board, which means that the results become immediately available to the operator.

State detection is a common concept for monitoring systems. Elementary state detection detects if a certain logical operation is true at a given time. For example, if the state is defined to check if the lubrication oil temperature exceeds 70°C, when the lubrication oil does indeed exceed this temperature, the event is recorded and the operator is informed.

For the PCMS service, propulsion specialists have defined over 200 different →

Fig. 2
– PCMS cabinet.

states that represent undesirable conditions. Each state consists of a logical operation, a description and an advisory message.

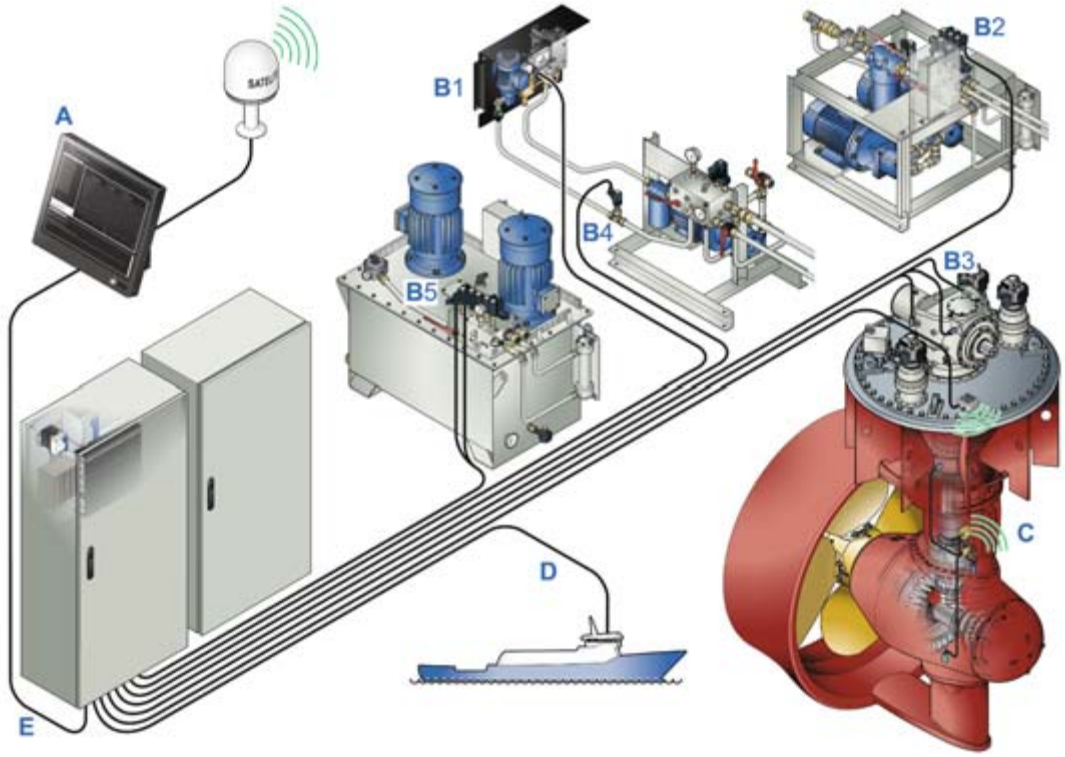
Examples of methods used for these logical operations are:

- Greater than (or equal)
- Less than (or equal)
- In range
- Table rule
- Trend rule.

It is also possible to define customised logical operations to fulfil specific customer requirements. States are not only defined to detect damage but also to prevent it. For instance if a certain manoeuvre causes high vibration levels, the PCMS Advisory Monitor will not only report the high vibration levels but also advise to carry out the manoeuvre at lower speed or with smaller steering angles.

Triggered spectrum storage is another state detection process within the PCMS scope. When the vibration intensity at any

Fig. 3 – Overview of PCMS system for a steerable thruster.



A - PCMS advisory monitor
B - PCMS sensors
B1 - Oil monitoring unit in lubrication system
B2 - Pressure transmitters in pitch system
B3 - Externally mounted accelerometers
B4 - Temperature transmitter in lubrication system
B5 - Pressure transmitters in steering system
C - Internally mounted accelerometers
D - Monitoring of nautical parameters through IAMS or GPS devices
E - PCMS cabinet

frequency increases more than 10%, an additional spectrum is stored. This ensures that all events are captured and that the propulsion specialist knows exactly when and why they occur.

Vibration analysis

Vibration analysis for machinery is based on the fact that specific elements in the rotating parts of any machine will produce forces in the machine that will cause vibration at specific frequencies. One of the most important forcing frequencies is the RPM of the shaft, this is because any rotor will always have a certain amount of residual imbalance. Other typical forcing frequencies are:

- Blade pass frequency
- Bearing inner- and outer-race fault frequencies
- Gear mesh frequency
- Electric motor rotor-bar-frequency and line-frequency.

Most forcing frequencies vary linearly with the propeller's RPM, and as such can be expressed in orders of the propeller's RPM. Identifying forcing frequencies is the most elementary form of vibration analysis.

A frequency spectrum can be created by applying a Fourier transformation to a time signal. Figure 6 shows a frequency spectrum with bearing inner-race fault frequencies. The forcing frequencies of the bearing inner-race are visible as peaks in the spectrum.

The PCMS system is also able to detect new peaks unrelated to known forcing frequencies.

To accurately analyse trends in frequency spectra comparison is only made between spectra that are measured under the same operating condition. The operating condition of propulsion equipment is determined by multiple parameters. For a steerable thruster these are load, pitch and RPM. PCMS uses a multi-dimensional matrix of configurable size that defines the operating condition. Thereby ensuring that a correct comparison is always made. Figure 5 shows an example of such a matrix. Many condition monitoring systems only measure RPM and vibrations, which can lead to misperceptions, faulty conclusions and loss of valuable information.

Pattern recognition

Not all faults can be determined merely by looking at forcing frequencies. For example, both angular and parallel misalignments →

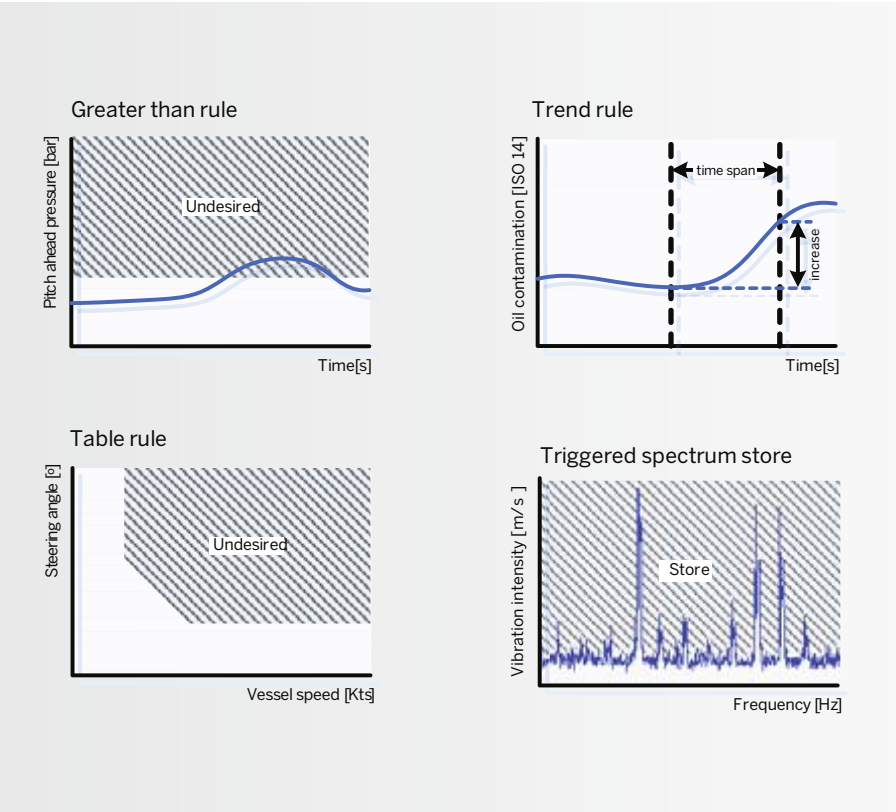


Fig. 4 – State detection methods.

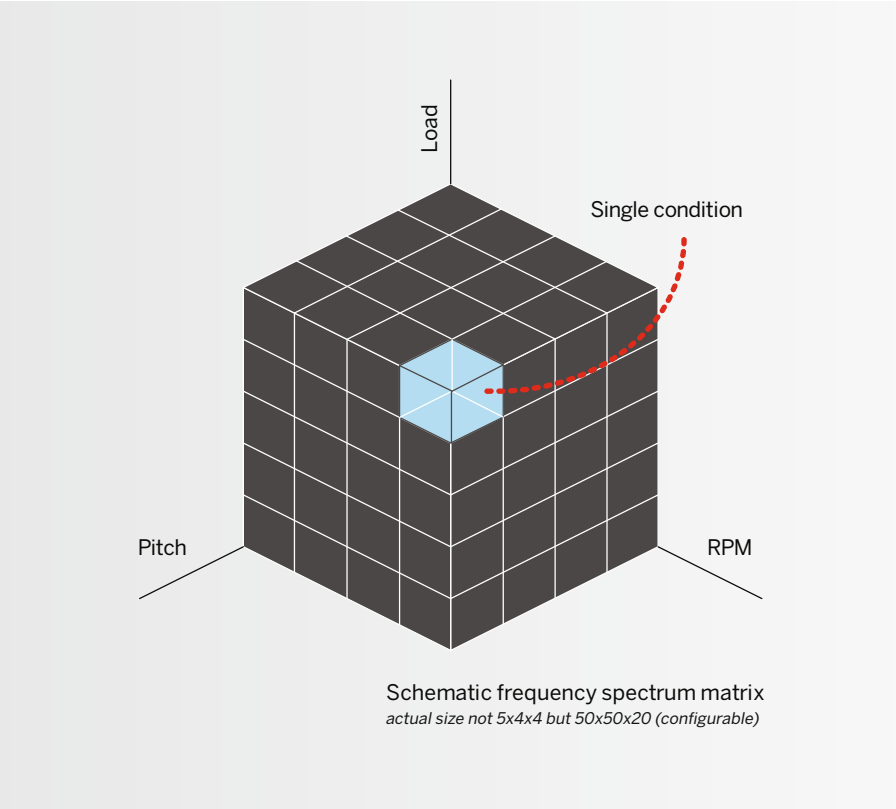


Fig. 5 – Frequency spectrum matrix.

will create peaks at 1x, 2x and 3x the shaft frequency. The difference, however, is that in the case of parallel misalignment, the peak at 2x shaft frequency is the highest, whilst for angular misalignment the peak at 1x shaft frequency is the highest.

Pattern recognition algorithms scan the frequency spectra for predefined faults such as:

- Types of misalignment
- Types of looseness
- Gear tooth wear and gear misalignment
- Different stages of bearing failure
- Electric motor broken rotor bars
- Electric motor eccentric rotor.

Cepstrum analysis

Cepstrum analysis basically comes down to taking a frequency spectrum of a frequency spectrum. A normal spectrum is created by applying a Fourier transformation to a time signal. The Fourier transformation creates a spectrum and allows the analyst to see the dominant frequencies in the time signal. Cepstrum analysis in turn shows the dominant frequencies in the spectrum itself.

This operation exposes frequencies, which might have a low intensity but which do have harmonics in the spectrum.

Cepstrum analysis is particularly useful for the early identification of bearing faults. During the early stages of bearing faults, vibration is generated with a very low energy content. Cepstrum analysis identifies the harmonics, thereby making the bearing fault clearly visible to the data analyst.

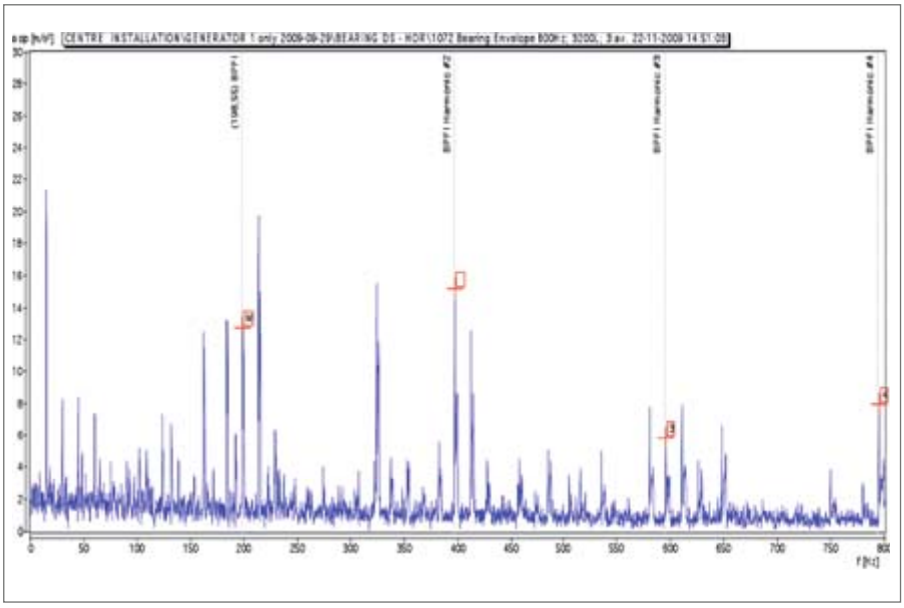


Fig. 6 – Inner-race bearing fault frequencies in spectrum.

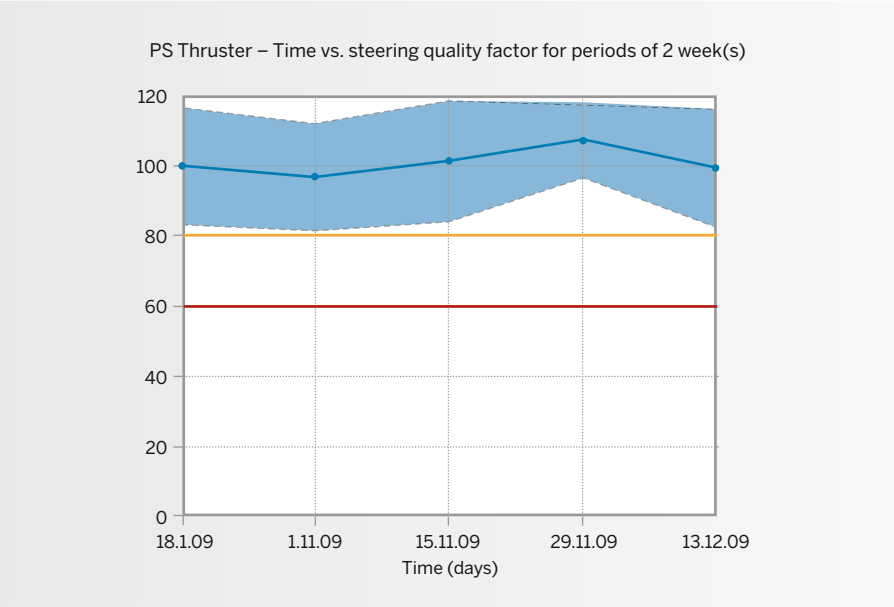


Fig. 7 – Quality factor of a steering system.

Periodic reports

Each month the operator receives a report describing the condition of his machinery.

The report contains:

- Findings and recommendations
- List of all detected states
- Quality factors for subsystems
- Operational profiles.

The findings and recommendations are written by a propulsion specialist who is also ISO certified (18436.2) for vibration analysis. Recommendations can vary from changing a filter to exchanging a gear set.

The report also contains an overview of all states that have occurred during the last period, and an analysis on how to prevent these states from re-occurring.

Quality factors are numbers, normalised to 100, representing the behaviour of different subsystems.

Quality factors are defined for:

- Pitch system
- Steering system
- Retraction system
- Bearings
- Gears
- Propeller.

For hydraulic systems, the factors take into account pump- and actuating pressures, as well as control loop performance. For bearings, gears and the propeller, they are based on vibration analysis.

Quality factors allow the operator to quickly review the condition of his propulsion machinery and make note of any trends that occur over time.

The periodic report also describes the operational profile of the vessel and equipment by giving load and steering angle distributions, and by stating the running hours of different components. Figures 8 and 9 show respectively a load

distribution versus time, and versus steering angle.

Based on the operational profile and the running hours, decisions can be made regarding maintenance intervals and the replacement of components.

Installation

The installation of a PCMS system takes 2–3 days, depending mainly on the amount and the length of the sensory cables. When no accelerometers are mounted internally (C in Figure 3), there is no need to go into dry-dock for installation.

Full system tests are carried out on all PCMS systems before installation.

Class societies

Class societies, such as DNV, state that thruster condition monitoring (CM) is intended to replace visual internal inspections of the thruster. With the PCMS, the operator can therefore eliminate the need to enter dry dock for visual inspection of the thruster at prescribed intervals.

CONCLUSION

Prior to the official release, several PCMS system were already sold. The first vessel to be outfitted with the final product was the Fjord Fairstar. A PCMS system is installed on each steerable thruster of this semi-submersible. The internally mounted accelerometers for the thrusters were extensively tested on the SSVC Thialf.

The PCMS service gives the operator or remote asset manager a firm basis upon which to make operational- and maintenance decisions.

The system detects faults at an early stage, thus reducing the risk of consecutive damage. The availability of both the machinery and the vessel itself will, therefore, be increased and their lifecycles will be extended.

The Propulsion Condition Monitoring Service is now available for the following types of propulsion machinery, and is not restricted to Wärtsilä equipment alone:

- Controllable pitch propellers
- Steerable thrusters
- Transverse thrusters
- Electric pods
- Water jets.

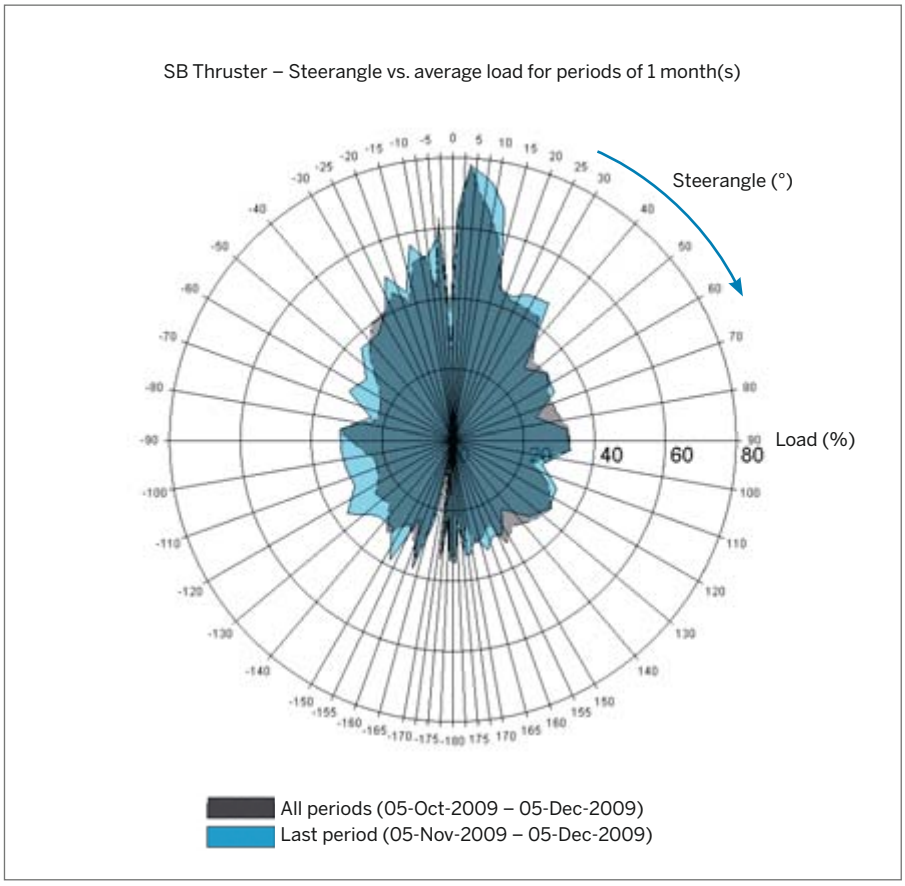


Fig. 8 – Load distribution versus time.

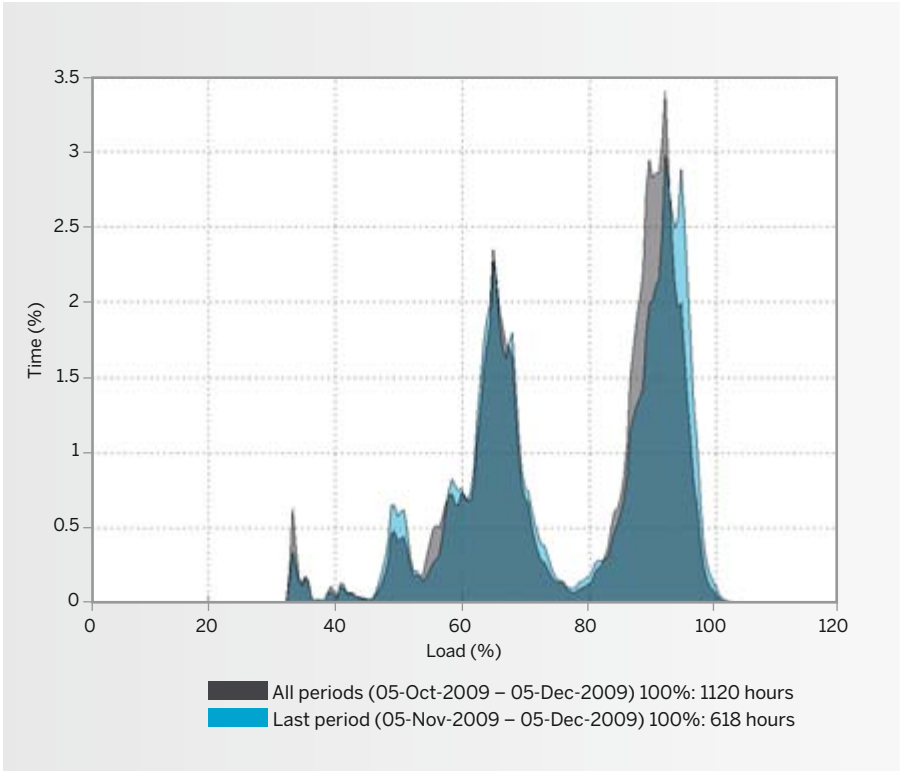
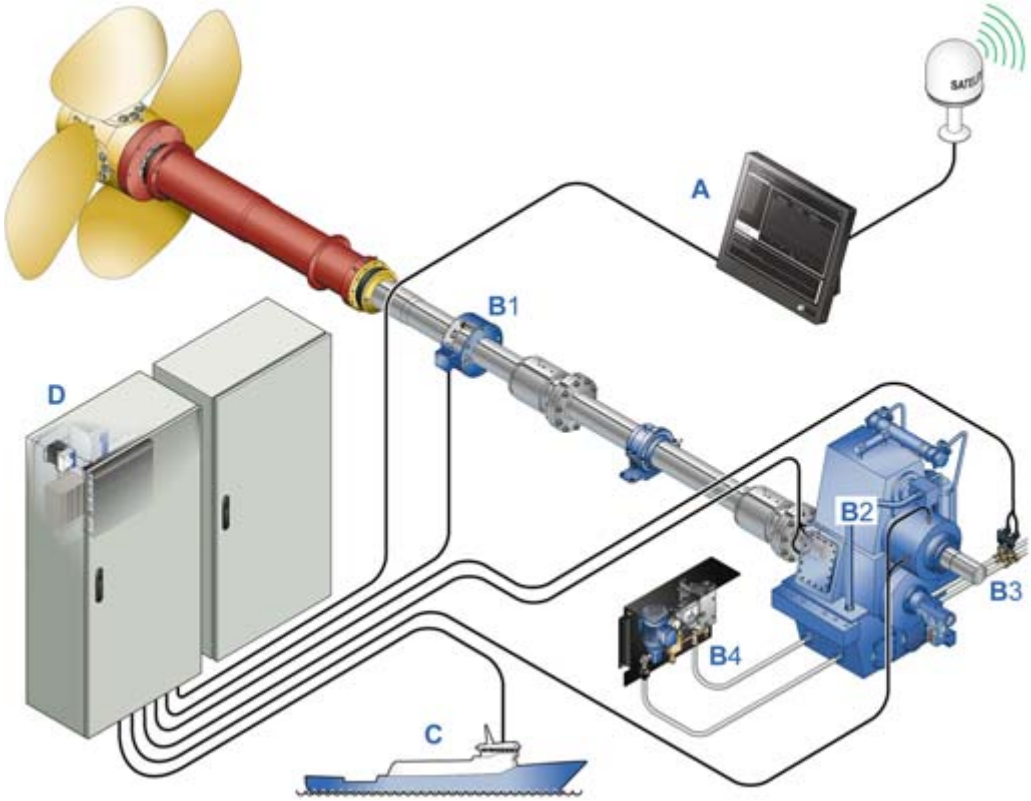


Fig. 9 – Load distribution versus steering angle.



A - PCMS advisory monitor
B - PCMS sensors
B1 - High speed torque measurement system
B2 - Accelerometers
B3 - Pressure transmitters in pitch system
B4 - Oil monitoring unit in lubrication system
C - Monitoring of nautical parameters through IAMS or GPS devices
D - PCMS cabinet

Fig. 10 – PCMS system for controllable pitch propeller.

Fig. 11 – The internally mounted accelerometers have been tested extensively on the SSCV Thialf.