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Cable Laying Vessels: A Review Of The Classification, Statutory And Station Keeping Aspects

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INTRODUCTION

Section 1 of the paper provides an overview of the development of cable laying vessels from their earliest designs to those of the present day; particular reference is made to four Maersk vessels which recently entered into Lloyd's Register (LR) Class. This section continues with a review of the differences between modern cable laying vessels and general cargo vessels before considering how cable layers differ as a ship type. Section 2 addresses the relationship between vessel operational / design characteristics and the applicable Classification and Statutory requirements. The paper moves on in Section 3 to consider the use of dynamic positioning during cable laying and the proprietary DP systems which are available to facilitate these operations.

Section 4 focuses on the more popular, yet more onerous, LR DP(AA) notation (IMO Class 2 equivalent), identifying the design requirements for the proprietary DP control system and the ship's engineering systems. Section 5 builds upon previous sections, discussing the requirement for a Failure Mode and Effects Analysis (FMEA) to be conducted and the subsequent functional testing during sea trials. The final section provides an overview of the key issues presented within the paper; particular emphasis is given to the relationship between vessel operational characteristics / design and the relevant Statutory and Classification requirements.

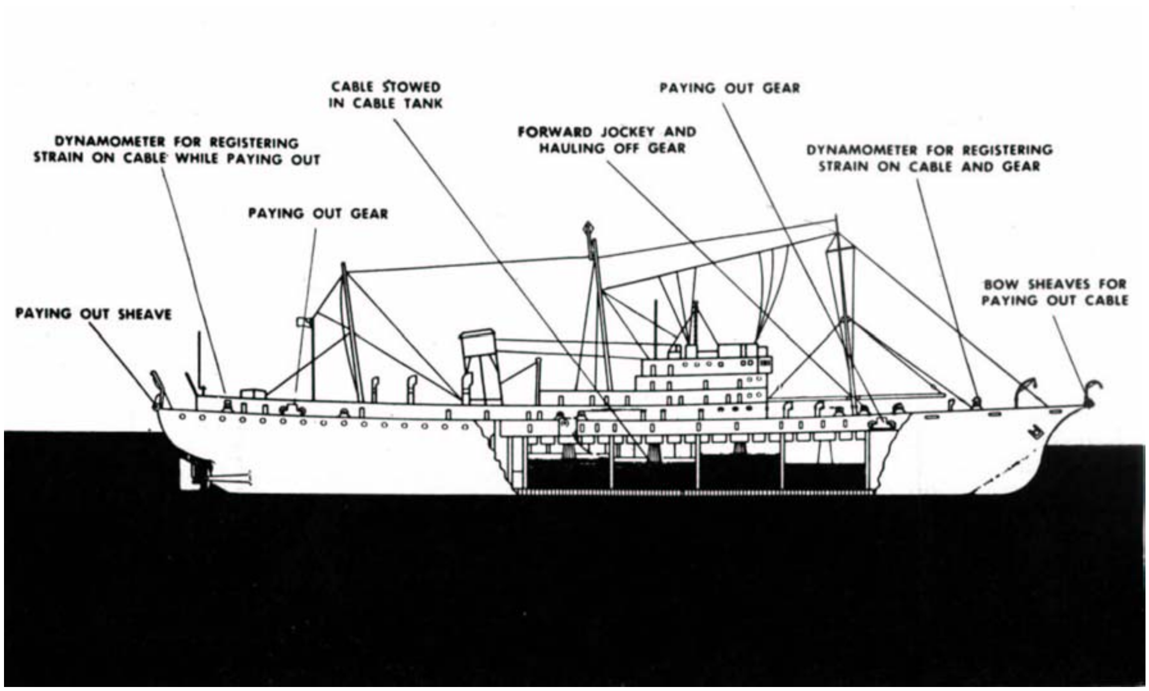

Figure No. 1: HMTS Monarch

1.0 BACKGROUND

A good example of an earlier design of cable laying vessel was His Majesty's Telegraph (HMTS) Monarch (Figure No. 1) constructed in the early 1940s at the Swan Hunters shipyard for the British Post Office. At the time of build, it was the largest cable layer in the world (8,056 gross tons), with the capability to lay and repair submarine telegraph cables, utilising a total cable capacity of 2,000 miles. Historically, a distinction was made between cable layers and cable repairers – purely based upon size. Most cable repair ships could lay approximately 500 miles of cable when repairing a cable fault, whereas cable laying ships could lay up to 2,000 miles of new cable and also, if required, perform cable repairing functions on existing cables.

The complement of the HMTS Monarch comprised the master, thirty officers and one hundred and seven men - laying and repairing cables was a very labour intensive activity.

Figure No. 1 illustrates the almost symmetric arrangement of the ship: sheaves; paying out gear; and dynamometer located fwd. and aft. Much of the equipment e.g. cable gear would have been steam driven – almost all vessel loads / systems are now either completely or partially dependent upon some form of electrical power supply. Of course, the older vessels would not have had any form of DP capability. The introduction of the first LR Rules for Dynamic Positioning in 1982, does however provide us with an indication as to when vessels started to develop dynamic positioning capabilities. With respect to the structure of the vessel, it can be seen that the accommodation and wheelhouse decks are located above the cable tanks – introducing the possibility of racking. In contrast with modern cable laying vessels, deck loads would have been small in comparison. The recent boom in the telecommunications sector has resulted in a sharp increase in the number of newbuild cable laying vessels and conversions from other

Figure No. 2: Maersk Recorder (Courtesy of Maersk Shipping)

suitable ship types. Over 28% of the world's fleet of cable laying vessels are classed by Lloyd's Register (113 ships – 746,269 GT). Ongoing newbuilding projects include a vessel for Asean Pacific at the Jurong shipyard in Singapore, with the possibility of a second. Four newbuild cable laying vessels (constructed for Maersk in Germany) entered into Lloyd's Register Class between the end of 2000 and the beginning of 2001, the Maersk Recorder (Figure No. 2) was the first in the series.

Perhaps the first feature for comparison between old and new cable laying vessels is the cable tank capacity. Modern vessels have a capacity of up to 5,000 kilometres; this is due, in part, to the fact that old submarine telegraph cables were bulkier than today's fibre optic cables, but also due to the increased number and size of cable tanks.

The following features are typical for a modern cable laying vessel:

- A-frame for deploying the plough (ensuring that in shallow waters the cable is dug into a trench);
- cranes for general loading / unloading and moving the cable tank hatch covers;
- winches:
  - large linear winch for controlling the cable,
  - towing winch for controlling the plough;
  - capstan winch for retrieving the cable.
- containers on deck to house the cable repeater boxes;
- purpose built rooms for joining cables, testing cables and controlling the plough;
- one set of sheaves: pick-up/laying of the cable is from the stern only;
- less crew – far less labour intensive (Maersk Recorder had a complement of 60 (14 crew and 46 special personnel);
- additional generating capacity to supply the large electric loads, e.g. thrusters, which are necessary for dynamic positioning;
- dynamic positioning controller – the use of position referencing systems and the controlled use of active thrust help to ensure that cable tension is not exceeded and that the intended cable route is followed to within precise limits.

The DP(AA) notation (IMO Class 2) is increasingly becoming the notation of choice for DP vessels. The various DP configurations will be discussed later in Section 3, illustrations are provided in Figure No. 4. It is apparent from Figure 2 and the above list that the deck loads have increased dramatically. Therefore, not only will the deck plating and supporting structure have to be selected accordingly but the effects of the large open spaces (cable tanks) on the vessel's racking strength will have to be carefully considered. Having developed an appreciation as to the design of modern cable laying vessels, we can now examine the differences which exist between cable laying vessels and their nearest cousin: general cargo ships. The primary differences are operational, and by implication design.

Operation

From an operations point of view, it is necessary that cable laying ships carry a large number of special personnel, in addition to the crew, performing specialised activities: laying and repairing (joining) cables, testing cables and controlling the plough, far more than would be found on any normal general cargo ship. The implications of this will be examined in Section 2.

Design

With respect to the general structure, the major difference relates to the large cable tank spaces which raise potential problems concerning not only racking strength, but also localised strength issues at the double bottom, and with respect to the vessel's global longitudinal strength. As for the engineering design, where the vessel is to be assigned the DP(AA) notation, engineering systems are to be tolerant to a single fault in any active component. For this to be demonstrated, it is required that an FMEA be performed. The FMEA should be conducted at a stage which allows the results to be taken into account when finalising the vessel's design. A more detailed account of the operational and design aspects particular to cable laying vessels will be discussed in Section 2, along with a summary of notations often associated with cable laying vessels.

2.0 OPERATIONAL/DESIGN CHARACTERISTICS vs. CLASSIFICATION AND STATUTORY REQUIREMENTS

This section discusses in more detail how the operational and design characteristics of a cable laying vessel influence the applicable Classification and Statutory requirements.

Statutory

In general, a cable laying vessel would be subject to the normal cargo ship requirements of SOLAS, provided it was carrying not more than twelve passengers. The main concern from SOLAS would be the potential effects upon the vessel's stability from flooding of one of the large cable tanks, either as a result of impact damage or due to downflooding from the deck openings in heavy weather. However, the SPS (Special Purpose Ship) Code is often considered more appropriate. It provides an international standard of safety for the ship and its personnel, which is equivalent to that provided by SOLAS, whilst facilitating operations specific to that ship type. In the event that a cable laying vessel (500 gross tonnage and above) were to carry more than 12 special personnel (personnel required for particular operations: cable loading / laying / repairing / testing / ploughing) then it can be categorised as a special purpose ship - provided the National Authority decide to invoke the IMO SPS Code. However, the SPS Code has, as yet, only been adopted by a few National Administrations.

The SPS Code does not treat special personnel as passengers; they are expected to be able bodied, knowledgeable of the ship layout and to have received some training in safety procedures. Therefore, the ships upon which they are carried need not be considered or treated as passenger ships. It is worth noting that a special purpose ship can carry up to 50 special personnel before having to consider:

(i) the stability effects of flooding the machinery space (as a result of damage impact); or

(ii) the SOLAS fire protection and life saving appliances requirements for passenger ships.

At present, some cable layers comply with the Offshore Supply Boat Code; the damage stability requirements of which are less onerous. In the event of heavy weather, there is the potential for significant quantities of sea water to enter a cable laying vessel via penetrations in the weather deck - this would adversely affect the loadline (reserve buoyancy of the ship). Suitably rated and positioned cranes are therefore necessary for moving the hatch covers into place. Furthermore, the cable laying procedure should cater for such an event, e.g. the cable may be cut and buoyed off and the hatches associated with each deck penetration closed / sealed, preventing the ingress of water. The number of penetrations of the weather deck should be minimised and capable of being made weathertight, such that the loadline aspects are not adversely affected, and without placing any restrictions on the vessel's operations (allowing cables to pass). It is common practice to have large hatch coamings to prevent sea water / spray entering the tanks, deck scuppers to allow sea water to be drained effectively and even a cable tank bilge system. However, these matters fall outside the statutory loadline aspects.

Structural

It is generally accepted that the size of the cable tank tends to be maximised, resulting in minimal amounts of room for supporting structure at the side of the cable tanks. Cases have been experienced where the cable tank has not been integrated into the ship structure, hence not providing structural support. More specific issues relating to racking, localised and global strength are discussed in more detail below. Cable laying vessels may be considered in many ways to have similarities with ***ro-ro ships***. The combination of large open spaces (cable tanks), the restrictions on transverse structure (transverse bulkheads) and heavy loads (deckhouse superstructure, deck cranes and winches) above, may result in the need for a comprehensive finite element study to determine the racking strength of the ship's structure. This is not a Rule requirement, however, a finite element analysis can be as straightforward as the standard direct structural calculations. Localised strengthening may be required in the double bottom (due to the weight of a fully loaded cable tank). Double bottom strength needs to be investigated in a similar way to that of ***bulk carriers*** (taking account of hydrostatic pressure on outside and load on inside), to determine the location of any additional structure. The spacing of transverse and longitudinal members is to ensure a uniform distribution of load under the tank. Cable laying vessels may be too short to have any significant global strength concerns. More specifically, they seldom have the torsional problems associated with ***container ships***, due to their intact decks. The Maersk ships mentioned earlier had four intact decks: tank top; tween deck; platform deck and the main deck. With respect to longitudinal strength, due to the laying of cable, the vessel's deadweight will reduce and the hull form will change from 'sagging' (when fully loaded), to 'hogging' (when unloaded). However, the variation in deadweight can be catered for with reference to the on-board loading instrument, and by performing ballasting, ensuring that the vessel's longitudinal strength is not exceeded. It is a Class requirement that all cargo ships (incl. cable laying vessels) of length greater than 65m have an approved loading instrument on-board to calculate bending moments and shear forces. A more economic way to respond to the recent market demand for cable laying vessels has been to convert existing vessels. Vessels suitable for conversion tend to have a large flat aft. end, e.g. trawlers and offshore supply boats, in such cases cable tanks are constructed on the existing deck. Alternatively, ro-ro ships with their existing large open internal spaces are a good option. Whilst presenting a more timely and economical solution, conversions may however prove to be problematic depending upon the amount of steelwork removed to accommodate the cable tanks and depending upon the inherent strength of the vessel. For example, the racking strength of the vessel may be adversely affected. It is easier with newbuild constructions to design around potential structural problems.

Engineering

In many respects the single fault philosophy that we associate with the FMEA has been inherent within the classification Rule requirements for many years, particularly with respect to essential services. All LR class vessels (not small ships) are to have split bus bars, with barrier protection. Essential services that are required to be duplicated are to be supplied from opposite sides of these bus bars. Their cables are to be separated throughout their length as widely as practicable without the use of common feeders, transformers, converters, protective devices or control panels and circuits. So that any single fault will not cause the loss of both essential services. Whether a service is considered to be essential will depend upon the ship type, its design and configuration of engineering systems. The LR Ship Rules provide a list of services which may be considered to be essential, these are expanded upon by the Rules for DP Ships to include the following:

- electrically driven thruster units;
- generator and thruster control equipment;
- reference systems; and
- environmental sensors.

Therefore, in addition to compliance with the existing single fault requirements regarding loss of essential services,
if the vessel is to be assigned the DP(AA) notation, the engineering systems are to be configured such that a single fault in any active component will not result in the loss of position. This will be discussed at length in Section 4.

Class Notations

It would be remiss to discuss Classification without mentioning some of the notations which are common to cable laying vessels. For navigation safety, these include Navigation Arrangements for Periodic One Man Watch (NAV1) and Integrated Bridge System (IBS), on the machinery side the most common is the Unattended Machinery Spaces (UMS) notation. It is interesting to note that such notations either require certain type of failure to be designed out or require mitigating measures to be in place to control failures. For example, in the case of the IBS notation, it is required that in the event of a single failure of an operator interface, all functions of the Integrated Bridge System are to remain available. In addition integrated display and control functions are to be of an ergonomic design, hence reducing the likelihood of human error arising or failures escalating due to misinterpretation. The UMS notation incorporates requirements which manage, to an extent, the escalation of a failure. For example, machinery alarms are to be relayed to the bridge such that the navigation officer of the watch is made aware when:
(i) a machinery fault has occurred;
(ii) when it is being attended to; and
(iii) when it has been rectified.
It would be considered normal for a cable layer to operate in UMS whilst also in DP, as the cable laying operation is not considered safety critical, unlike that of a diving support vessel. There are a series of Class notation which relate to dynamic positioning. The two most popular DP notations for cable laying vessels are DP(AM) and DP(AA), these relate to IMO classes 1 and 2. LR's equivalent to IMO Class 3 is the DP(AAA) notation, which is by far the most onerous notation for dynamic positioning.

DP is now considered necessary for cable laying in order to ensure that a constant and acceptable level of tension is placed upon the cable during laying / repairing (joining). It also assists with charting the position of the cable on the sea bed. With a notation such as DP(AA), the ship engineering systems and the DP control system will be tolerant to a single fault - minimising interruptions to the cable laying operation and hence reducing downtime. New constructions of cable laying vessels show a definite preference for the DP(AA) notation. The main feature of a ship assigned a DP(AA) notation is that engineering systems (machinery / piping / electrical and control) which are essential for dynamic positioning are to be configured such that a single fault in any active component will not cause the loss of position. Furthermore, the dynamic positioning control system for a DP(AA) vessel will, in the event of a controller fault, automatically changeover to the second controller without interruption. Hence, the owner / operator can be confident that whilst operating in DP the vessel will be tolerant to the majority of likely single faults. It is a Class requirement that this be verified by way of an FMEA on the ship systems (ideally providing an input to the design of the vessel) and verified by functional testing during sea trials to the satisfaction of the attending LR Surveyor.

3.0 DYNAMIC POSITIONING AND CABLE LAYING

Dynamic positioning is a computer assisted manoeuvring system that keeps a ship on station exclusively by means of active thrust. It is the role of the DP system to keep the vessel within an area of operation as defined by set points for heading and position specified by the operator. These limits will be specified in relation to the mode of operation. The ability to stay in position will be heavily dependent upon the number, rating and position of the thrust units. The environmental conditions will also play a significant role. A DP system controls only three of the six modes of motion: surge, sway and yaw, by controlling the pitch and/or rpm of the thrust units against the prevailing wind, sea current and wave forces, see Figure No. 3.

The dynamic positioning system works on the basis of input signals from position reference systems (indicating actual position), these are fed to the controller where they are compared with the desired position. Based upon the resulting error signal, the controller produces an output signal to the thruster units to reduce the error to zero. The system allocates the optimum amount of thrust to whichever thruster units are available. In the context of cable laying operations, there are different uses for the various reference systems:

(i) DGPS is the main reference system in use, especially for surface laying over long distances, deep water makes the use of other reference systems difficult;

(ii) acoustic reference systems tend to be used when ploughing, mainly to indicate the subsea position of the plough and the burial position of the cable;

(iii) taut wire and DGPS are used for maintaining the vessel in a fixed position whilst cable joining / repairing in shallow water, or for landing shore ends, when the cable is pulled ashore from the vessel. As would be expected, the configuration and redundancy of equipment / components in proprietary DP control systems is indeed focused towards meeting the requirements of IMO classes 1-3 and hence the requirements for the LR DP notations. Figure No. 4 provides examples of the various configurations available on the market.

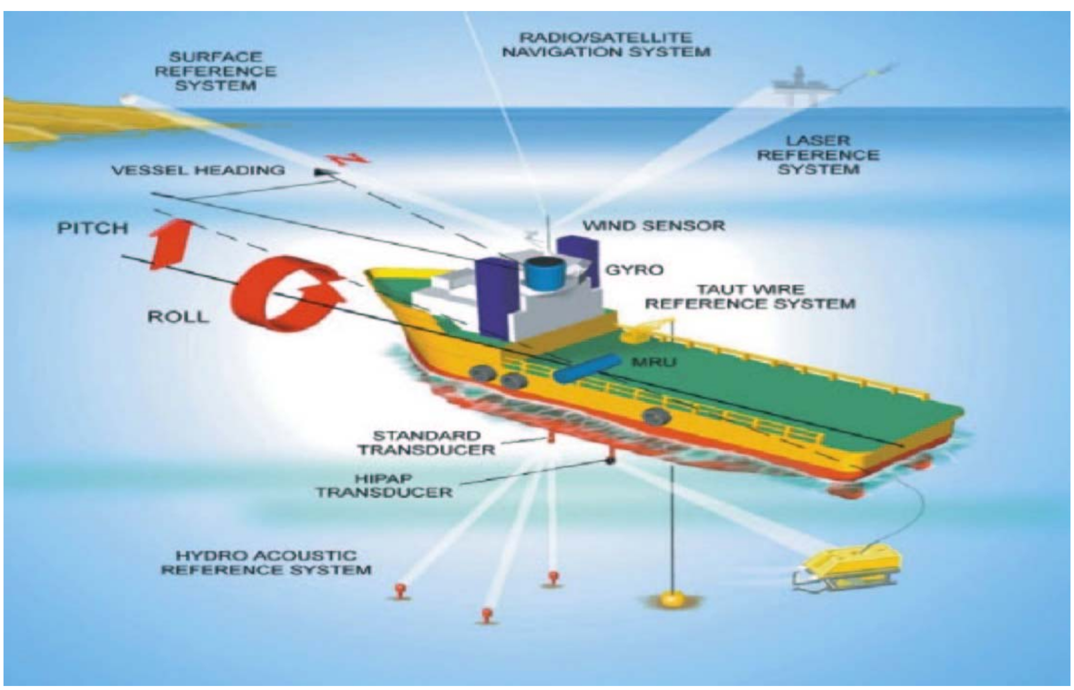

Figure No. 3: Modes of Motion, Surge, Sway and Yaw (Courtesy of Kongsberg-Simrad)

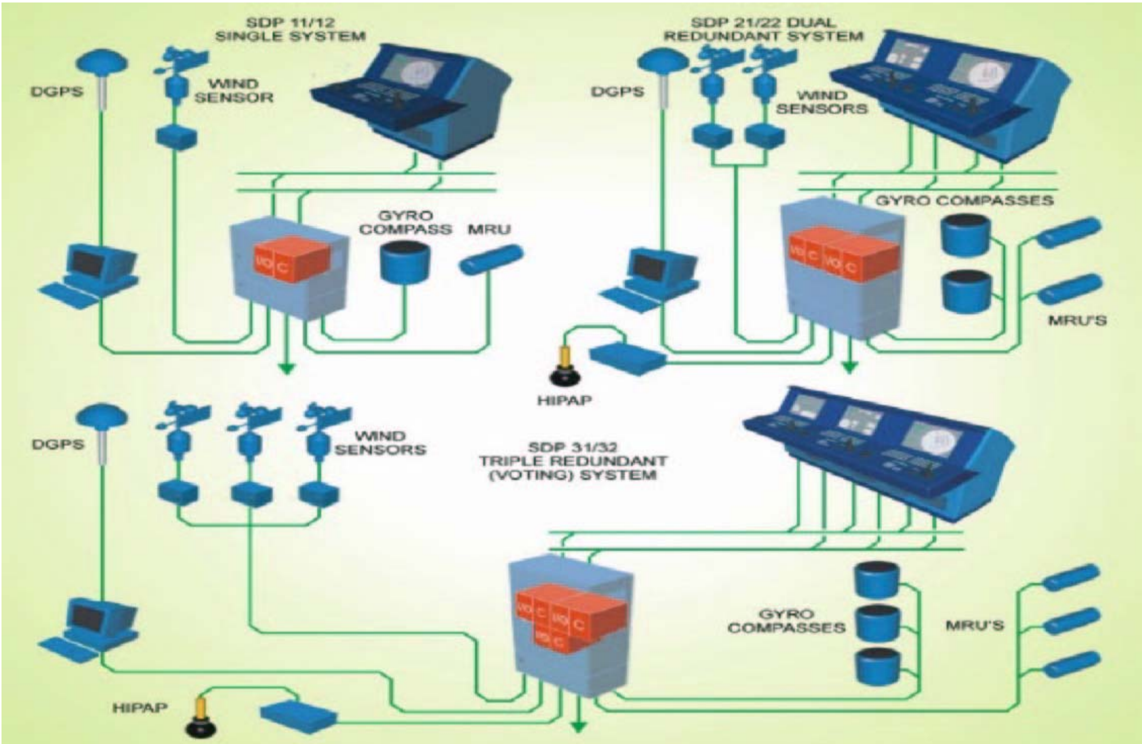

Figure No. 4: Proprietary DP Control Systems (Courtesy of Kongsberg-Simrad)

Perhaps the most noticeable difference is the level of redundancy offered by the system components: the controller, position referencing units and environmental sensors. The performance of the control system however depends upon the following:
(i) response to variations in environmental forces acting upon the vessel;
(ii) ability to filter out unwanted effects (first order wave forces and high frequency wind components); and
(iii) the available thruster power (transverse and azimuth thrusters and CP propellers).

4.0 DESIGN REQUIREMENTS FOR THE DP(AA) NOTATION

The standard DP(AA) control system has two automatic controllers, these are arranged to operate independently, such that a failure in one will not affect operation of the other. In the event of a failure of the working controller, the standby unit takes over automatically without manual intervention, and without any adverse affect upon the ship's station keeping performance. Further components of a DP(AA) installation which require redundant units (three of each) include: position reference systems; gyro compasses and vertical reference units.

There are specific requirements for engineering systems in a DP(AA) ship. This includes cables, pipes and other components essential for the correct functioning of the DP system, located and protected such that the risk of fire and mechanical damage is minimised. Generation and distribution arrangements are to be such that no single fault will result in loss of more than 50% of the generating capacity, or of any duplicated essential services.

Engineering systems (power, control and thruster systems and other systems necessary for dynamic positioning) are to be provided and configured such that a fault in any active component or system will not result in the loss of position. This is to be verified by means of an Failure Mode and Effects Analysis (FMEA), assessing components such as: prime movers; generators; switchgear; gearing; pumps; fans; thrusters; valves (where power actuated) and by functional tests performed during sea trials. The FMEA will be covered in more detail in Section 5.

5.0 FAILURE MODE AND EFFECTS ANALYSIS

The Failure Mode and Effects Analysis (FMEA) is an established technique for examining the potential failure modes associated with a system and investigating the likely failure effects. The structure of the FMEA lends itself to the systematic and rigorous examination of engineering systems. Whenever an FMEA is conducted, it is essential that it is performed by qualified and experienced individuals in accordance with an International Standard, e.g. IEC 60812, utilising worksheets to record the assessment.

The worksheet in Figure No. 5 includes the standard content of an FMEA, but also allows for an assessment of criticality. The criticality analysis, whilst not required by Class, is one method by which critical failure modes can be identified and ranked, hence providing the basis for the functional test schedule, which is performed during sea trials. The test schedule should be considered as an extension of the written FMEA, based upon the design aspects which are identified as weak / sensitive to the introduction of a single failure, or where the failure effects have a degree of uncertainty. The strength of the test schedule lies in its ability to reveal (during operational conditions) the dynamic nature of a system's response to failures, either demonstrating that the response is consistent with expectations and acceptable, or, unacceptable, hence providing the opportunity for design modifications to mitigate the unwanted failure effects. Whilst it is important that the test schedule covers the key failure modes, it is equally important that the sequence of failure modes is given due consideration, such that the true causes and effects are revealed.

It is the objective of the test schedule to introduce single failures into the system; key failures tend to result in the loss of a consumer's ability to perform a specific 'function'. As indicated in Section 1, the dependence upon an electric supply for consumer power and control result in the majority of tests consisting of the disconnection of circuit breakers, fuses or switches.

SECTION 6: DISCUSSION

Cable laying vessels may initially be considered as cargo vessels, however, as their operational characteristics and design become more specialised the associated Classification and Statutory requirements become more onerous, to the extent that the cable layer is far removed from the general cargo vessel. The differences become more apparent when a cable laying vessel is assigned the DP(AA) notation, due to the careful consideration required for the engineering design: duplication of essential services, segregation of supplies and most importantly, consideration of the effects of component failure. The production of an FMEA and the subsequent functional tests provides a high degree of assurance that these matters have been carefully considered and suitable measures incorporated into the vessel's design.

Equipment Name	Function	Ident. No.	Failure Mode	Failure Cause	Failure effect		Failure Detection	Alternative Provisions	Failure Probability	Criticality Level	Remarks
					Local	End					

Figure No. 5: Failure Mode, Effects and Criticality Analysis (FMECA) Worksheet

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