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DYNAMIC POSITIONING OF OFFSHORE ANCHOR HANDLING TUG SUPPLY (AHTS) VESSELS (UT 788 CD Project)

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Summary

Each vessel exposed to the forces of wind, waves and changes in sea level due to tidal streams and forces caused by the propulsion system, changes its position and heading. The basic function of the dynamic positioning system is to maintain the vessel's position and heading. This article analyses the use of the FMEA (*Failure Modes and Effects Analysis*) of dynamic positioning system of off-shore vessels which includes analysis of all subsystems connected to dynamic positioning (production and distribution subsystem of electrical power, automatics, propulsion and controller subsystems)[1]. Specifically, it is dealing with the dynamic positioning of the vessel UT 788 CD for deep anchoring, towing and platform supply, analysed in two operational modes: diesel electrical and conventional mode. According to the FMEA, the UT 788 CD vessel has met all the DP 2 class requirements for operating within the foreseeable volume in accordance with the IMO classification.

Key words: *dynamic positioning, offshore vessels, FMEA analysis*

1. Introduction

The "Eureka" ship was among the first vessels to use the dynamic positioning technology back in 1961 [2]. She was fitted with a simple analogue control system controlled via system of taut wires. The ship was 42 metres long, and along with the main propulsion also had bow and stern thrusters. By the end of the 1970s dynamic positioning had already become basic technology, and by the end of the 1980s, the number of ships fitted with the dynamic positioning system was 65. By 1985 the number went up to 150, whereas today, the number of ships using dynamic positioning system is significantly higher and continues to rise. The modern definition of the dynamic positioning says it is "a controlled computer system of automatic maintaining of position and heading of the vessel which uses its own propellers and thrusters. Position reference sensors, combined with wind and electricity sensors and gyro compass provide information to the computer maintaining the position.

Dynamic positioning may be absolute in a way that the position is set to a fixed point over the bottom, or relative to another vessel or an underwater vehicle. Also, the vessel can be positioned at a favorable angle towards wind, waves and current [3].

It can therefore be stated *that dynamic positioning (DP)* is actually new technology which appeared due to growing demand and expanding industry of oil and gas exploitation during the 1960s and the 1970s, and even today with over a thousand ships using dynamic positioning systems, most of them are used for the purpose of exploitation of oil and gas reserves. Requirements of the oil and gas industry have imposed a new demand, and exploration of oil and gas reserves at greater depths and locations characterized by severe weather conditions has contributed to a growing development of the dynamic positioning technology. Therefore, this article analyses dynamic positioning on the example of off-shore vessel for deep anchoring, towing and platform supply (UT 788 CD *Project*, Rolls-Royce design) by applying the FMEA (*Failure Models and Effects Analysis*) for the purposes of: a) detecting potential failures of the DP system components and b) identifying consequences for the system performance and evaluation of potential prevention (minimization) of those potential failures. The analysis is carried out in accordance with the standards of the 1994 IMO Guidelines for Vessels with Dynamic Positioning Systems (IMO 1994 MSC/Circ. 645).

2. The principles of Dynamic Positioning and FMEA methods

The DP system is engaged with control of the ship in the horizontal plane, with surge and sway translation motions and rotation around the vertical axes of the ship. Surge and sway translation motions refer to the ship's position, whereas rotation defines the ship's heading [4]. Steering is done by establishing the preferred (reference) value for the position and heading set by the operator. The actual position and orientation have to be measured in a way that will establish deviations from the given value. The position is measured through one or more different position reference systems, whereas information on the orientation is obtained by the gyro compass. The difference between the real (return) and reference value represents the regulatory deviations. The DP system works on the principle of minimizing deviations. The ship has to maintain its position and orientation within acceptable deviation limits during exposure to outside forces (sea currents, wind, waves…). If those forces are measured directly instantaneous compensation of the deviation can be carried out. A good example of this is the compensation of the influence of the wind power where data on the measurements are continuously obtained through wind power sensors. Also taken into consideration, apart from the wind, is the influence of sea currents which, in DP, is taken as the sum of all unspecified forces and deviations in the control unit. The DP system can automatically change position and ship's orientation at the operator's request. Some ships, such as dredgers, pipe and cable layers, have to follow a defined trail (course) during operation. In such cases the portable position reference is used.

Based on the position and orientation of the ship, the main functions of the DP system are shown on the block diagram, Figure 1.

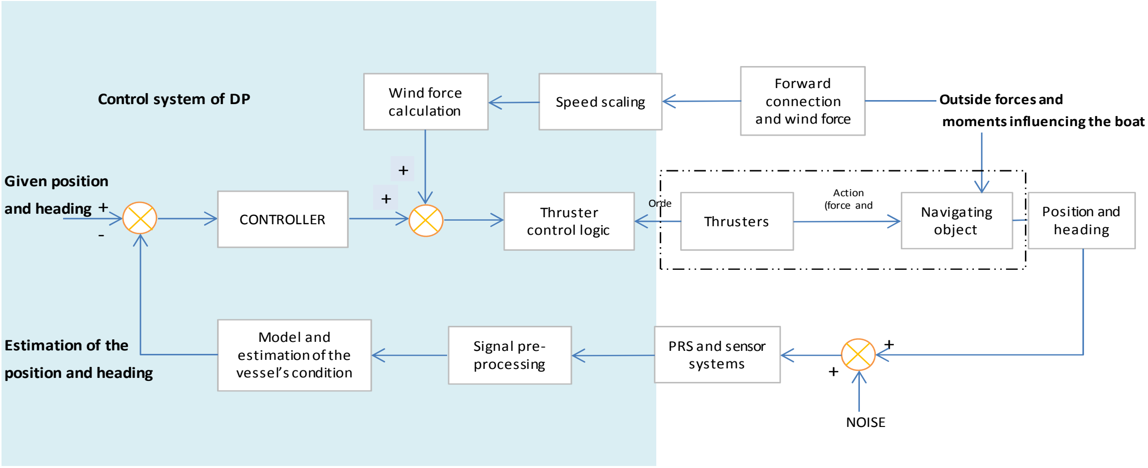

Figure 1 - Block-diagram of the DP control system

Mathematical model of the ship in the DP control computer, and filtering of measured signals enables “a memory” mode of the operation in case of losing the position reference. In such mode, the ship maintains its position on the basis of the latest gathered data from the position reference system. This type of operation can only be used for a short period of time due to the appearance of deviations in the position and heading in case of longer time intervals.

2.1. Dynamic Positioning System Classification

DP system classification is determined by the IMO document, according to whose rule book the DP systems are divided into 3 classes:

DP class 1: No redundancy. The loss of position is possible in the case of individual failure of a part of the system.

DP class 2: There is redundancy. Individual failures during active system operation cannot therefore cause a complete system failure. The loss of position does not occur in case of failure of one active component or of a subsystem such as generators, boosters, switchboards, valves etc., but can happen in the event of failure of a static (passive) components such as pipes, cables, manual pipes etc.

DP class 3: Along with all the conditions for class 2, the system has to sustain fire or flooding in each compartment without failure. The loss of position is not to occur in the event of a single failure, including subsystems exposed to fire and flooding.

Equipment class of the DP of a vessel performing specialized operations at sea must be agreed upon between the ship owner and the client on the basis of the consequence analysis in case of system failure, i.e., loss of position. DP systems have become much more sophisticated, more complex and more reliable. Computer technology has developed quickly and some ships have had the new modernized DP system installed multiple times. Along with the DP systems, other peripheral systems have also developed and ensured high redundancy levels on all vessels involved in high-risk activities.

There are other methods of maintaining the platform or ship position which include anchor handling and barge or platform anchoring to the sea bottom. Table 1 shows a comparison of the advantages and disadvantages of dynamic positioning.

Table 1.1. A comparison of the advantages and disadvantages of dynamic positioning

Advantages	**Disadvantage**
Vessel is fully manoeuvrable; no tugs are required at any stage of the operation	High production and operating costs
Quick and easy positioning on difficult location	Can fail to keep position due to equipment failure
Rapid response to weather conditions of the system	Higher day rates than comparable moored systems
Rapid response to changes in the requirements of the operation	Higher fuel consumption
Versatility within the system (i.e. track-follow and other specialist functions)	Thrusters are hazards for divers and ROVs
Ability to work in any water depth	Possibility of losing position in extreme weather conditions or in shallow waters and strong tides
Ability to complete short tasks more quickly and more economically	Position control is active and relies on human operator (as well as equipment)
Avoidance of risk of damaging seabed hardware from mooring lines and anchors	Requires more personnel to operate and maintain equipment
Avoidance of cross-mooring with other vessels or fixed platforms	
Ability to move to new location rapidly (also avoid bad weather)	

The above table clearly shows that the dynamic positioning technology is not always the best economic solution. Although mooring has many advantages, dynamic positioning is becoming the best option in many operations because the seabed is already cluttered with pipelines and other hardware, so laying anchors has a high risk of damage to pipelines or cables and other equipment.

2.2. FMEA method

With vessels fitted with DP systems, the FMEA analysis focuses on failures causing loss of the vessel's position [5]. A timely analysis is paramount. The FMEA analysis is carried out at an early stage of the development cycle to make modifications in the subsystems for fault removal more cost effective. The analysis can be carried out when the vessel's subsystems can be shown using a functional block diagram with clearly defined performance characteristics of each component. The FMEA is an iterative method of analysis which should be adapted to the development cycle of the vessel's construction project. FMEA analyses potential single failures, i.e. independent computer system components. It is not suitable for analysing faults resulting from a series of events. The diagram of the FMEA analysis is shown in Figure 2

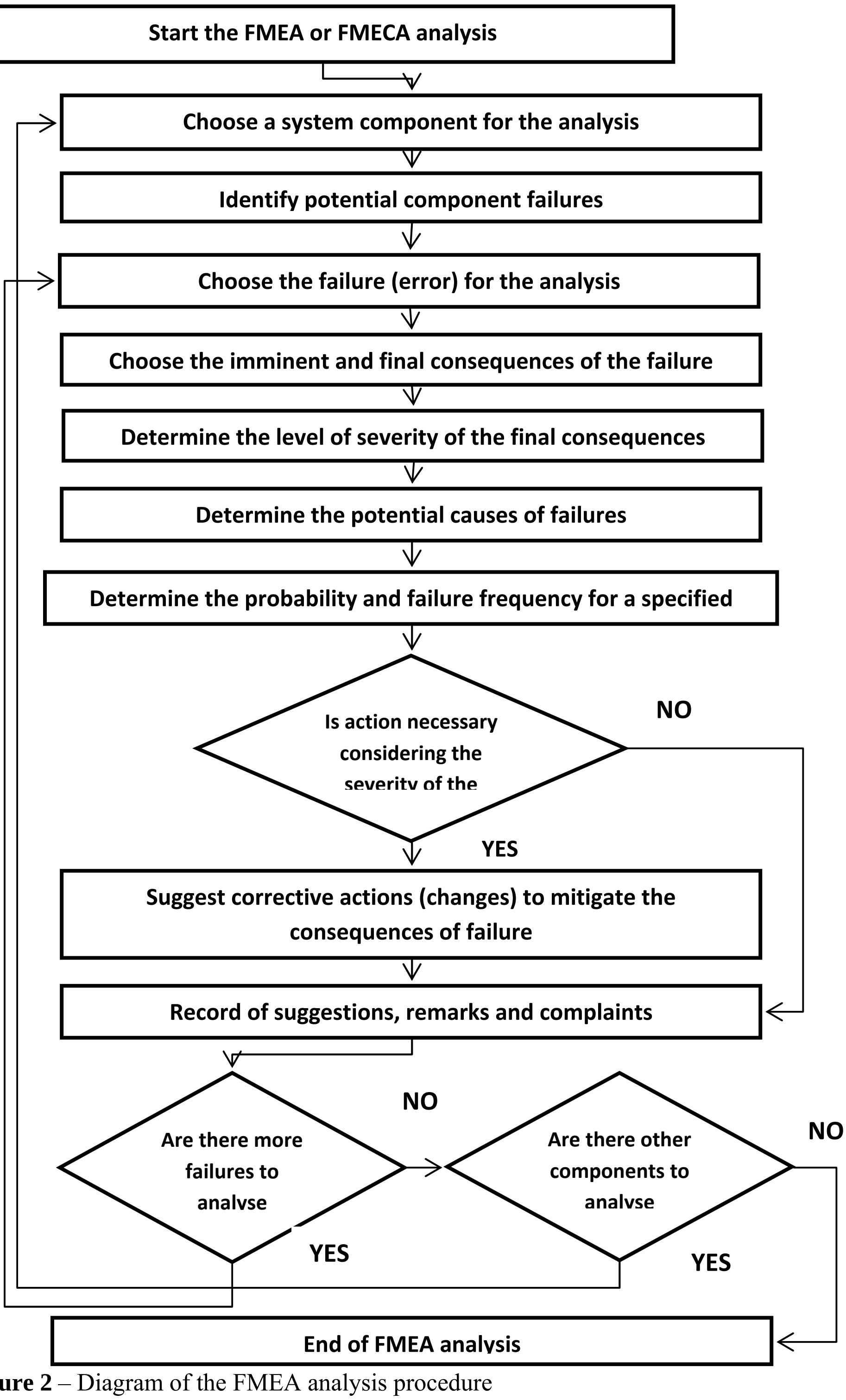

Figure 2 – Diagram of the FMEA analysis procedure

The severity of the system failure is determined on the basis of the consequences of the failure on the functionality of the analysed component, i.e. the system. In the analysis a number of factors are taken into consideration: the default performance of the system and processes, client contract demands, safety demands determined by the industry and government regulations, system demands specified in the guarantee and consequences of potential failures on the users and the surrounding of the analysed system. Table 2 shows the classification of critical failure.

Table 2 – Classification of critical failure

Class	**Criticality level**	**Consequences on the user and the environment**
4	Catastrophic	A failure which may provoke an error with primary functions and thus cause severe damage to the system and its environment
3	Critical	A failure which may provoke an error with the primary functions and thus cause considerable damage to the system and the environment. Such failures do not usually lead to serious injury (not life threatening).
2	Marginal	A failure which may limit system functions performances without any serious damage to the system, the environment or users.
1	Minor	A failure which may limit system functions performances without any serious damage to the overall system functionality. There are no consequences for the environment and the users.

Once the criticality is calculated, it is necessary to determine the probability, i.e. occurrence rating. The probability of a component failure can be rated through: data on testing the durability of a component, data on the occurrence of failures (if any) and failures of similar components (or same class of components). Therefore, the goals of the FMEA analysis are: a) detailed identification and evaluation of all unwanted failure effects within the defined limits of the analyzed system and the consequences of each failure on the different levels of the functional hierarchy; b) establishing the priorities of applying modifications to the system while at the same time maintaining the process functionality; c) failure classification according to relevant characteristics such as timely detection, testing and compensations; d) failure identification of functional system units and the probability of failure occurring and e) development of plans including modifications to the system for the purposes of mitigating or eliminating potential failures. The procedure of the FMEA analysis consists of the following phases:

1. Determining the ground rules for carrying out the analysis and planning and organising to establish the possibility of carrying out the analysis in a given timeframe - preparatory phase
2. Implementation of the FMEA analysis by using tables and other means such as logistical diagrams and deductive analysis (using Boolean logic)
3. Uniting the results and drawing up a report including analysis conclusions and references for system improvement
4. Updating the FMEA analysis in accordance with the developmental changes in the project.

The results of applying the FMEA analysis on the dynamic positioning system of offshore vessel for deep anchoring, towing and platform supply (UT 788 Project, Rolls - Royse design) are shown below.

3. Offshore vessel for deep anchoring, towing and platform supply

FMEA objectives of dynamic positioning of the vessel for deep anchoring, towing and platform supply were to: identify all system failures which result in loss of vessel position, offer references to eliminate or mitigate the impact of a failure in the DP equipment which may cause partial or complete loss of the vessel's ability to maintain position, a display of the DP redundancy, identification of potential "hidden" failures (failure in backup or standby, without an indication or an alarm) and identifying the consequences of a single failure, if the "hidden" failure had already existed – the impact of a component failure on the rest of the DP's system ability to maintain vessel's position and create direction suggestions for system modifications which would minimize the failure risk, i.e. loss of position.

3.1. Main features of the vessel

Offshore vessel for deep anchoring, towing and platform supply (UT 788CD Project, Rolls-Royce design) is structurally divided into 9 decks. Table 3 shows general data on the UT 788CD vessel.

Table 3 – General data on the UT 788 CD vessel

Loa	93.40m
Lpb	82.00m
B. Mld.	22m
D. Mld.	9.5m
Draft Light	6.5m
Draft Load	7.70m
Main Engines	2x MaK 16M32C
Auxiliary Engines	4x Caterpillar 3516C
Shaft generators	2 x AvK DSG 144 n/10W water-cooled synchronous generators, output power 5000 kVA (4000kW); 60 Hz; 690V; @750 rpm
Auxiliary generators	2 x AvK DSG 99 K0-4W water-cooled synchronous generators, output power 2790kVA (2230kW); 60Hz; 690V; @1800rpm
Emergency Generators	1 x CAT C18 DI-TA TA power 465 kW @ 1800 rpm
Bow Tunnel Thrusters	2 x Rolls Royce TT2200 DPN CP
Stern (azimuth) thrusters	2 x Rolls Royce TCNS 92/62-220
Tunnel Thrusters Aft	1 x Rolls Royce TT2200 DPN CP
Main Propellers	2 x Rolls-Royce
Steering system	2 x Tennfjord – steering equipment 2 x Rolls Royce FB-S 3300
DP system	Rolls-Royce ICON DP 2 2 x DGPS 1 x HiPAP 500 1 x CyScan
Navigational equipment	2 radars , autopilot
Communication equipment	GMDSS, VHF, UHF

The vessel is equipped with the electrical power generation system consisting of four diesel generators and two main engines with shaft generators. Only one diesel-generator is in tweendeck, while the others are on the tanktop. Stern rollers are extended up to the main propellers through the aft storage area. The emergency generator and switchboard are in a special steering room. The vessel is equipped with a power managing system (PMS) produced by “Deif”. It is also equipped with a start lock of big consumers in case of overload of the main switchboard. The propulsion system consists of two main propellers which can use diesel-electric, diesel-mechanical or combined propulsion. Also, the vessel contains three tunnel thruters (two bow and one aft) and two retractable stern thrusters (one bow and one aft). All the thrusters use electric propulsion, and the manufacturer is Rolls-Royce.

3.2. Dynamic Positioning Control System

Rolls-Royce has developed a dynamic positioning control system called ICON DP2, a double redundant system. Communication between the DP control system and vessel’s thrusters is achieved through the redundancy network and the Rolls-Royce HELICON control system. An independent control console with separate communication channel towards the thrusters is also installed.

All the components of the DP system are powered through an uninterrupted power supply (UPS), whereas in some cases backup power supply 24V is used. The DP system is divided into two uninterrupted power sources to maintain the vessel’s position and heading in the DP. The bridge is equipped with two DP control units. Each of them includes a control handle, a steering device and a 20 inch screen. Controllers of the DP operative system are placed in cabinets in a separate room. Control equipment of the DP is sometimes fitted in the chair or is inside the console on the bridge. The operator can use the manual controls to carry out the following operations: yaw , pitch and roll control, silent alarm control, choose between automatic and manual operation, taking and handing over the control, activating and deactivating the DP system. The position reference system (heading selection control) can: change vessel’s orientation, change operation mode of the control handle (automatic heading/pitching /rolling), change the settings of the DP programme interface and enable control of the DP system via graphic interface with a touchscreen.

3.3. Analysis Results

During the FMEA analysis two vessel propulsion systems have been analyzed: the diesel electric and the conventional system.

The Diesel Electric Mode

- all four diesel-generators in service, or one diesel and shaft generator on each side
- power management system set in generator mode (Diesel-electric DP 2 regime)
- switch between the 690V buses closed
- switch on the 440V bus open
- switch on the 230V bus open
- backup switchboard 690V is fed from the right main board
- all thrusters set in service
- alarm systems, management and surveillance system in normal operation

The Conventional Mode

- both shaft generators in service with a backup diesel generator
- power management system set in the conventional mode
- switch between the 690V buses open
- switch on the 440V bus open
- switch on the 230V bus open
- backup switchboard 690V is fed from the right main board
- all thrusters powered
- alarm systems, management and surveillance system in normal operation

Analysis has shown the following as the most inconvenient cases:

- mechanical failure of the main engine or the shaft generator in a conventional mode which leads to the loss of thrusters and lowering of the overall power. In this case, the diesel –powered generator is started and continues to supply the thrusters,
- electrical failure of the right or left 690V switchboard in the diesel-electric mode which causes thrusters failures which are fed from that board,
- a failure of the DP UPS (uninterrupted power supply) unit which causes the loss of redundancy of DP charging, a failure of one operational console and two DP reference systems for maintaining the position. In such cases, the vessel is no longer in accordance with the IMO DP2 class

Failures of the accompanying systems (petrol, oil, cooling and compressed air systems) are not in the high-risk category because they are different for each motor. Therefore, according to the FMEA analysis the vessel for deep anchoring, towing and platform supply UT 788CD meets all the DP2class requirements for operating within the foreseen perimeters.

4. Conclusion

The article represents an example of implementation and execution of FMEA analysis of the dynamic positioning system for the deep anchoring, towing and platform supply vessel. FMEA analysis includes data processing of all the most important potential failures of single components and their impact on the overall Dynamic Positioning system. The FMEA analysis has therefore become an integral part of vessel designing fitted with dynamic positioning system and other vessel project which require establishing the level of reliability of vessel systems in given operational conditions.

FMEA analysis has fulfilled its mission to identify failures (errors) which have a negative impact on the system as a whole and threaten worker (operator) safety. Its implementation can meet all the contract obligations towards the contractor through analysis of all project entries. There is the possibility of improving reliability and safety of the system (via modifications and quality ensuring procedures) as well as the possibility of improving system sustainability (via pointing out the parts of the system unsuitable for maintenance).

Analysis is standardized and is carried out in accordance with the International Marine Organization "IMO 1994 Guidelines for Vessels with Dynamic Positioning Systems (IMO 1994 MSC/Circ. 645)" and represents a very useful tool for optimizing dynamic positioning system configuration of vessels used for searching the undersea and diving support, repair and cable laying, hydro graphic controls, supply of oil and gas platforms, oceanographic research, control of shipwrecks, saving, pulling out, dredging and installing underwater installations and pipeline protection and other civil and military needs.

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