SELECTED PROBLEMS EXPLOITING THRUSTERS ON DYNAMIC POSITIONING VESSELS

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Abstract
The aim of this project is to investigate the problems associated with current controllable pitch thrusters that are operated on dynamic positioning vessels. Work covers some component parts of a thruster and examines their failure mechanism. The paper is highlighting ways of improvement of thrusters' reliability during their operation.

Key words: *tunnel thruster; azimuth thruster.*

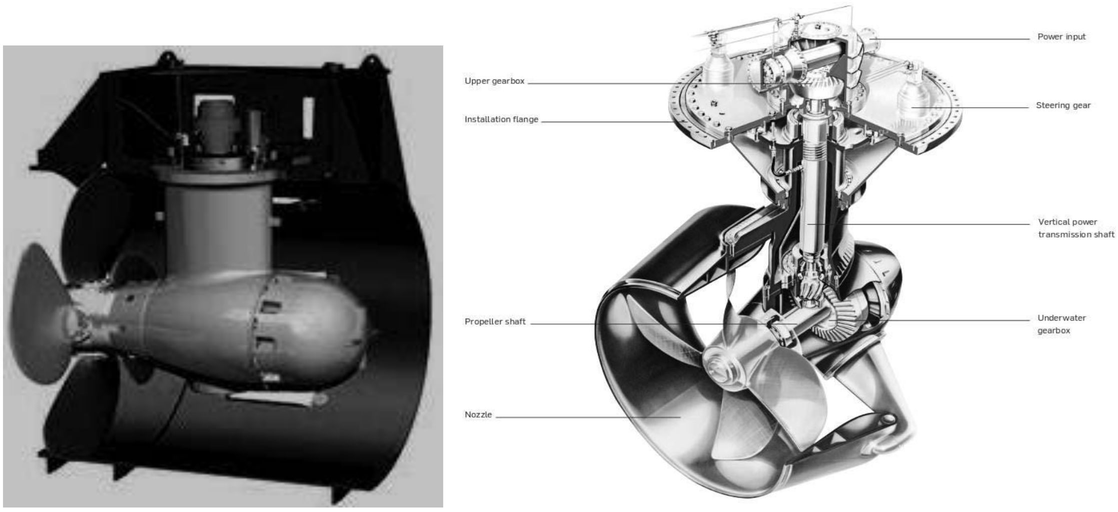
INTRODUCTION

Contemporary thrusters are used throughout the marine and offshore industry as a means of vessel propulsion, manoeuvring and dynamic positioning. Thrusters are available in two formats (*Kołodziejski, M. & Matuszak, Z., 1997*):
- fixed pitch propellers that are powered by DC electric motors, thrust is adjusted by means of variable speed and direction of electric motor. This kind of machinery is rather rarely met on offshore installations and that is why it will not be subject of this project;
- controllable pitch propellers that are powered by AC electric motors. They are running with approximately constant speed, thrust is adjusted by changing of pitch.
Both types of thrusters have a propeller of either fixed pitch or controllable pitch construction, however the controllable pitch assembly has been favoured due to its speed of response and is the subject of this study.
Vessels operators have increasingly expressed concern over the number of failures that have been experienced on dynamic positioning vessels. The overwhelming majority of failures require the thruster to be removed from its location in the vessel hull and brought to the surface for repair. This entails the implementation of an underwater removing mechanism if incorporated in the design, or for the vessel to go into dry dock (*The International Marine Contractors Association, Report No GM-01768/02-0695-2167: Failure Modes of CCP Thrusters*).

Tunnel thrusters

Tunnel thrusters are rigidly mounted inside a tunnel which runs athwartship in the bow or stern of a vessel. Figure 1a shows a diagram of a tunnel thruster. Tunnel thrusters are most commonly driven by an AC constant speed motor. There two types of drive configuration, an **L**- drive and an **Z**-drive An L-drive has the AC motor situated directly above the thruster unit and its drive shaft is located vertically into the thruster which is in turn located to the propeller shaft via a bevel gear arrangement, hence the drive system is an 'L' shape when viewed from the side.
A **Z**-drive is similar to an L-drive except that the AC motor is not situated vertically above the thruster hence a horizontal shaft is required which is connected to the vertical drive shaft via another bevel gear, giving a 'Z' shape arrangement. The vertical drive shaft is located in the thruster unit together with bearings and is connected to the pinion of the lower gear with a crowned tooth coupling. The drive is then transmitted through the pinion and gear and into the propeller shaft. The propeller shaft rotates the hub which in turn rotates the blades. The propeller shaft is supported with bearings and is hollow to allow the pitch control mechanism to run along its length. The lower gearbox id flooded with oil and is sealed in front of the propeller hub and protector with rope guards. The pitch control is actuated by a horizontal piston which operates a sliding yoke mechanism. By moving the position of the blade locating shoe the pitch of the propeller blades is altered. The blades are sealed with single O-

ring. There is a mechanical linkage feedback mechanism which allows a potentiometer to continuously provide the blade pitch angle to control the processor.



a) b)

Fig. 1 a) Tunnel thruster (*https://www.marinelink.com/news/introduce-steerable359425 [access 5.04.2017*]); b) Schematic diagram of an azimuth thruster (*https://proyectosnavales.com/2015/10/07/azipod-mermaidpod-esipod-y-otros-pods/ [access 5.04.2017]*).

Azimuth Thrusters

Azimuth thrusters are essentially the same as tunnel thrusters with similar subsea design with one major difference, the ability to rotate through 360 degree about the drive shaft centre line. Figure 1b presents diagram of azimuth thruster. Azimuth thrusters are mounted on the underside of the vessel's hull or pontoons, and their position optimised for performance and minimum interference. They are usually driven in the same way as tunnel thrusters with an AC motors and an 'L' or 'Z' drive configuration. The thruster is normally rotated by two or more hydraulic motors which turn the upper steering gear. The main mechanical difference in operating conditions for an azimuth thruster compared to a tunnel thruster is its lack of circumferential rigid mounting around the propeller blades and its increased exposure to the rigours of a marine environment. The combination of these two elements contributes towards the greater susceptibility of azimuthing thrusters to failure.

Retractable azimuth thrusters

The main drawback with azimuth thrusters is the increase in the draught of the vessel due to the thrusters protruding below the vessel. To overcome this a retractable azimuth thruster was designed and manufactured. The unit is identical to a non-retractable azimuth thruster with the exception of the capability to be pulled up into the vessel's hull. The thruster is lowered via either hydraulic actuators or screw rods, and the thruster has a telescopic drive shaft to accommodate the change in position. On the base of the thruster nozzle there is the plate that fits into the hull to create a smooth hull form for when the vessel is not utilising it. The increased number of moving parts and the lengthened drive shaft leads to a retractable thruster being a little more prone to failure and most of them cannot be repaired from inside the hull when the thruster is retracted.

MATERIALS AND METHODS

Mechanical components and their possible failures

Drive shaft and crowned tooth coupling

The drive shaft runs vertically down the thruster transmitting torque from AC motor to the propeller shaft via a bevel gear. The shaft is held in place with bearings and connected to the bevel gear pinion with a crowned tooth coupling. The shaft is hollow and runs in an oil flooded environment.

The crowned tooth coupling should last the design life of the thruster if the maintenance procedures are followed. There have been incidents of the coupling being subjected to excessive wear due to lack of lubrication. This has been caused by insufficient application of grease to the coupling. The coupling is susceptible to vibration induced problems, which is enhanced by misalignment, hence it is crucial that the manufacturer aligns the system correctly and keeps vibration to a minimum. It is also subjected to a very rapid acceleration due to start-up on zero pitch. The thruster must be at zero pitch when the motor is started, if not then the coupling undergoes an enormous loading very rapidly. Zero pitch is sometimes hard to adjust and it may wander with time.

The drive shaft and coupling require little attention as they are generally reliable components. Their maintenance must not be neglected as this will lead to failure. It is essential that when the thruster is opened up during repairs the drive shaft is inspected for cracking. This should be part of the detailed checking procedure undertaken at every thruster overhaul and repair.

Bearings

The possibility of a bearing failure is often reduced by the frequency of thruster repairs and the ensuing re-builds for other reason. When the thruster is re-built new or refurbished bearings are installed as the original ones are usually damaged or displaced during dismantling. This then leads to the scenario of many vessels never reaching their bearing design life, hence artificially reducing the failure rate. However bearings have failed and do require the attention.

A thruster has several bearing which support the drive and propeller shafts. They are all of roller bearing construction but differ in size enormously, from the small lower drive shaft bearing to the very large upper steering gear bearing. Adequate lubrication is essential to sustain bearing life, yet there have been several incidents of bearing failure where sufficient lubrication was applied. It is also necessary to note that when a bearing fails it can damage other components from metal fragments, or even entire rollers, circulating the system.

There have been several cases of bearing failing as they approach, but have not exceeded, their design life. Bearing are often changed because the thruster is being overhauled for another reason, providing an ideal opportunity for expert inspection of the bearings that are replaced to compare wear and damage with known utilisation. By acknowledging that there is fault in a particular design the remaining vessels with similar designs can be informed and preventative action taken

Insufficient axial float of the propeller shaft may cause friction welding problems on some thrusters. Axial float corresponds to axial movement of the propeller shaft fore and aft. If the axial flow is not adequate then the locating bearings of the propeller shaft are subjected to the thrust loading rather than the thrust bearing. This can result in bearing running very hot causing friction welding to occur. The axial float of the shaft must be adequate to ensure that each bearing receives no more than its designated loading. Bearings have also failed due to too much axial float, so this parameter is critical and must be corrected at the outset. The shaft float requires careful design and correspondingly meticulous quality control during manufacture.

Bearing can overheat and run hot due to a lack of lubrication or if subjected to an oscillating load which is perpendicular to the plane of rotation. If the thruster has a significant vibration problem it can manifest itself as a bearing failure. If bearings overheat the contact surface will break down, otherwise known as pitting, causing metal fragments to circulate the system.

The biggest factor in all thruster failures is the seepage of water into a thruster unit. When a bearing runs in oil contaminated with seawater a range of problems occur. Water in oil creates a kind of water-oil sludge which tends to settle where the circulation is poor. Bearings which are in such locations are prone to gathering sludge and then rely on it to provide lubrication. The sludge is a poor lubricant and is detrimental to the running of the bearing. A bearing running with insufficient lubrication will run hot and begin to break down. Once a bearing has lost its surface hardness the break down is rapid and severe, and is accelerated by corrosion. Corrosion is caused by the seawater in the oil that attacks the bearing causing ‘black bearing’, which is the result of the combination of corrosion and overheating. To reduce the number of bearing failures the water ingress has to be stopped. Once this has been achieved the frequency of thruster failures due to bearing failures will decrease dramatically.

Gears

The failure of the bevel gear in the lower gearbox has a major influence on vessel downtime. They are susceptible to overloading, pitting, cracking and having teeth broken, all of which leads to catastrophic failure and costly repairs. As with bearing the prominent factor in gear failure is water ingress and its associated problems. The bevel gear is located in the lower gearbox and transmits the drive from the vertical drive shaft to the horizontal propeller shaft. It has helical teeth and the ratio is critical to the design of the thruster as it governs the size of the lower gearbox, which is significant for the hydrodynamic drag. To obtain maximum efficiency the motor speed wants to be high whereas the propeller blade speed wants to be low, hence the lower gearbox must optimise thrust efficiency and minimise drag.

Pitting of gears

Pitting of the surface of the gears is the most common cause of gear failure. Although the gears may not physically break they will require replacement which is costly and time consuming, compounded by the long lead times required to obtain new gears. The pitting of the gears is caused by inadequate lubrication and the generation of hot spots. The combination of heat and pressure between the meshing gears leads to the break down of the surface causing pitting. The lack of lubrication can be due to water in the oil or insufficient oil circulation, and usually combination of both. If the water is present in the unit it tends to gather at the base of the gear box and as the gear rotates it passes through this water and then meshes with the pinion, hence it meshes with water and oil causing hot spots to develop. Over time this repeated excessive and high pressure will cause pitting to occur. Pitting will occur on gears over a period of time, especially when run in marine environment and prone to water contamination. However, it should not manifest itself before the design life of the gears has been reached. In some thruster units it has appeared only a few months after installation. The primary solution to the problem is to remove the water from the oil and prevent the water from leaking into the lower gearbox. In addition to this the gear alignment must be accurate and the vibration levels of the lower gearbox must be negligible, as these factors will accelerate any rear wear problems. There have been a few incidents of heavy pitting where there was no indication of water ingress, the reason for this is unknown and requires further investigation. All these leads to the question why is there inadequate lubrication, and why is water allowed to enter the thruster and remain undetected? The poor lubrication can be easily blamed on water in the oil but it is a fundamental design fault in all thrusters. There is inadequate provision for complete circulation of the oil with the gears running in old, stagnant, un-filtered and water contaminated oil. Perhaps the oil needs additional pumping around the gears and a low take off point to properly monitor its condition. There is no point in analysing oil from the header tank when it is nothing like the oil around the gears where real damage occurs. The dichotomy between oil quality at the sampling tap and around the gears is enormous, and one which leads to neglect and failure. This is design fault which should be addressed immediately and rectified on all thrusters. Without comprehensive oil circulation around the gears and good oil sample analysis it is clear that a thruster failure will tend to always be diagnosed as inadequate lubrication even if this is only a secondary cause.

Broken teeth

Gear teeth can break due to fatigue or overloading which is usually caused by under design and occasionally due to material fault which went undetected. There have been several incidents of teeth breaking resulting in thruster failure and in some cases damage to other components through the broken teeth circulating the system. If the lower gearbox is subjected to high levels of vibration, fatigue problems will arise in the gears. Vibration can be transmitted down the drive shaft from the motor, or from the varying hydrodynamic forces as the thruster moves in the waves. This could lead to gear failure in the form of broken teeth through shock loading. However, the most common cause of broken teeth is due to a power overload. Gears that are under designed are likely to fail as they are not capable of withstanding the forces involved. This situation will arise when the vessel specification and workload are under estimated. An overload situation will also arise if the thruster is started with the blades not at zero pitch. This will put a huge load on the thruster and consequently the gears. If The blades strike floating debris the subsequent loading on the gears can be considerable and this has caused teeth to break.

RESULTS AND DISCUSSION

Problems associated with lubrication of thrusters' components

If a thruster is correctly designed, installed, and operated, then its reliability depends heavily on oil quality. Without sufficient lubrication and cooling the subsequent effects on the thruster can be catastrophic. It is of paramount importance when running thrusters to keep the oil clean and free of contamination. It follows that the design should enable competent engineers on board to maintain oil quality with relative ease. If the on board maintenance is carried out according to the manufacturers instructions and water ingress takes place, the responsibility rests on the manufacturers. The oil system on a thruster is vastly different from a normal mechanical device as the lubricating oil and hydraulic oil is the same. In other words oil that lubricates the meshing gears teeth also controls the hydraulic components. This inherently leads to problems as the oil chosen is a compromise between hydraulic oil and gear oil. The oil is contained in a local tank which is pressurised by a small header tank well above the water line at the deepest draft to give an overpressure in the gearbox. The oil is fed from the local tank to the thruster, circulated around the unit, and then returned to the tank through filters to remove any dirt. Overpressure provided by header tank is supposed to refrain water from leaking to the thruster unit through the seal. Water and oil do not mix, and once water has gained access to an oil lubricated system the water forms a kind of sludge which has a tendency to settle where circulation is poor. The sludge has no beneficial lubrication properties and only causes damage to the thruster. The water reduces the oil’s capacity to lubricate and cool, allowing hot spots to develop on gears and bearings which leads to their eventual failure. It also causes hydraulic causes as the sludge can cause control valves to stick leading to control problems. The water usually enters the thruster through the propeller shaft seal despite the over pressure. The oil will normally become dirty from its operation in the lower gear box. The meshing gear will produce tiny metal fragments, the water introduces salt into the oil, and any oil degradation from overheating will also produce solid particles. Dirty oil offers substandard lubrication and cooling, increases wear rates, and causes hydraulic valves to stick. The reduced ability of the oil to function correctly leads to, or increases the risk of, the failure of other components. If the oil is overheated it will break down and its lubrication property will diminish. Excessive heating of the oil can be caused by the misalignment of components generating hot spots, poor circulation through the gearbox, and insufficient cooling. The first two are the most common causes and better circulation of the oil is an area which has been identified as requiring improvement. The fundamental problem with the oil is its susceptibility to water contamination. This has to be prevented by improving sealing. However, until a suitable sealing arrangement is produced the water should be removed using separators and filtration devices. It is also essential to improve the circulation of the oil as the water is often allowed to gather in the thruster and it never really surfaces for extraction analysis and replacement. By taking the oil from the bottom of the thruster the water would be forced out allowing it to be removed. This is a practical modification that needs urgent action for all thrusters. A continuos water content check is required to monitor the level of water in the oil as at present the oil sample analysis is not frequent enough or not true reflection of the oil in the thruster. In general the results of the oil analysis are relied upon far too heavily in assessing the condition of the thruster, and this has been proved through high failure rates with the oil analysis being satisfactory. The filtration of solid particles is essential to prolong the thruster life. It is a simple and easy operation to maintain filters. It is crucial that all filters are monitored closely and replaced regularly. If unusually high quantities of dirt are found they should be investigated. However, the filters rely on good oil circulation for the particles to reach them. The oil temperature should also be monitored carefully, but just checking the oil temperature outside the gearbox is not sufficient and temperature monitoring should be carried out in the lower gearbox as well. This is because the failures caused by overheating will occur here and the sooner information is received with regards a potential problem, the sooner it can be solved. Temperature monitoring within the lower gearbox is definitely a means by which catastrophic failures can be prevented. The problems of all sensors however is that they themselves are the purveyors of bad news.

CONCLUSIONS

To reduce the thrusters’ failures the water ingress has to be stopped. Once this has been achieved the frequency of damages of bearings and gears will decrease dramatically. The requirement is to remove the water from the system, not only in an attempt to directly reduce the number of failures but also to aid clarification of the failure cause. It is very easy to lay the blame for a failure with water ingress, however once this has been removed from the equation failures must be attributed to another cause. Water ingress in some ways a convenient excuse for thruster failure, providing the manufactures with a cause without highlighting any design errors. By removing the water the lubrication will improve and the pitting of gears will be lowered. In conjunction with this oil circulation needs to be adequate to give good lubrication and cooling to the meshing gears. The only other way to reduce pitting is to upgrade the material specification. It is also essential that that the gears are aligned correctly to ensure that they mesh in the designed pattern, as incorrect meshing leads to excessive abrasive wear and eventually broken teeth. Any vibration problems should be addressed immediately as they will shorten the fatigue life of the gears. The running in of a thruster unit is critical to ensuring reliability. After every re-build they must be run in at a low load for a sustained period of time and the temptation to run to full power to resume work should be ignored. The longer the running in time the longer the life of the thruster. An extra day of running in will reduce the chance of thruster failure before a scheduled docking (*Matuszak, Z., 2010*).

ACKNOWLEDGMENT

„This research outcome has been achieved under the research project *Badanie efektywności energetycznej siłowni okrętowej w aspekcie niezawodnej i bezpiecznej eksploatacji* No 5/S/IESO/14 financed from a subsidy of the Ministry of Science and Higher Education for statutory activities".

REFERENCES

1. Kołodziejski, M., & Matuszak, Z., (1997). Comments about the dynamic positioning vessels service. Second International Conference on Marine Technology, (Odra '97) Szczecin 13-15 May 1997, 343-349.
2. Matuszak, Z., (2010) Estimation of the availability of the power-propulsion and technological system of a fishing vessel at selected operational model. *Eksploatacja i Niezawodnosc – Maintenance and Reliability*, vol. 45, no. 1, 49-58. DOI: dx.doi.org/10.17531/ein.
3. The International Marine Contractors Association, Report No GM-01768/02-0695-2167: Failure Modes of CCP Thrusters.
4. https://www.marinelink.com/news/introduce-steerable359425 [access 5.04.2017].
5. https://proyectosnavales.com/2015/10/07/azipod-mermaidpod-esipod-y-otros-pods/ [access 5.04.2017].

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