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AZIMUTH THRUSTER HYDRAULIC INSTALATIONS RELIABILITY MODEL

Summary

Based on example azimuth thruster system, basic components have been presented. Components of basic hydraulic systems of thrusters, i.e. lubricating / pitch oil system and steering oil system have been show. Basic faults in azimuth thruster hydraulic systems have been pointed out. Mathematical reliability models of hydraulis systems and example fault tree model for redundant hydraulic pump unit of thruster oil system has been presented.

Introduction

Among a variety of currently operated floating units there is a group of objects equipped with compass thrusters (azimuth thrusters or azipod propulsion). Part of this units is dynamically positioned in automatic manner (DP systems) to provide highest standards of quality, reliability and safety of operation (seabed exploring vessels, drilling vessels, floating production and offlanding units, shuttle tankers, construction vessels, dive and ROV support ships etc.), to provide social requirements e.g. minimize of noise and vibrations (ferries, cruise ships, yachts, pleasure boats etc.) and for special purposes (warships, ice breakers, research vessels etc.) [1]. Proppeler drive is ussualy carried out by means of electric motor, more rare with use of combustion engine. Generally proppelers of compass thrusters are with controlled pitch proppeler (CPP system) and with controlled azimuthal position of thrust (steering system). Energetic fluid in power subsystems is ussually hydraulic oil. Example azimuth thruster system with presented location of power subsystems in general structure are given in fig. 1.

Proppeler pitch change is carried out by means of pitch and lubrication hydraulic oil system. Example instalation of pitch oil is presented in fig. 2.

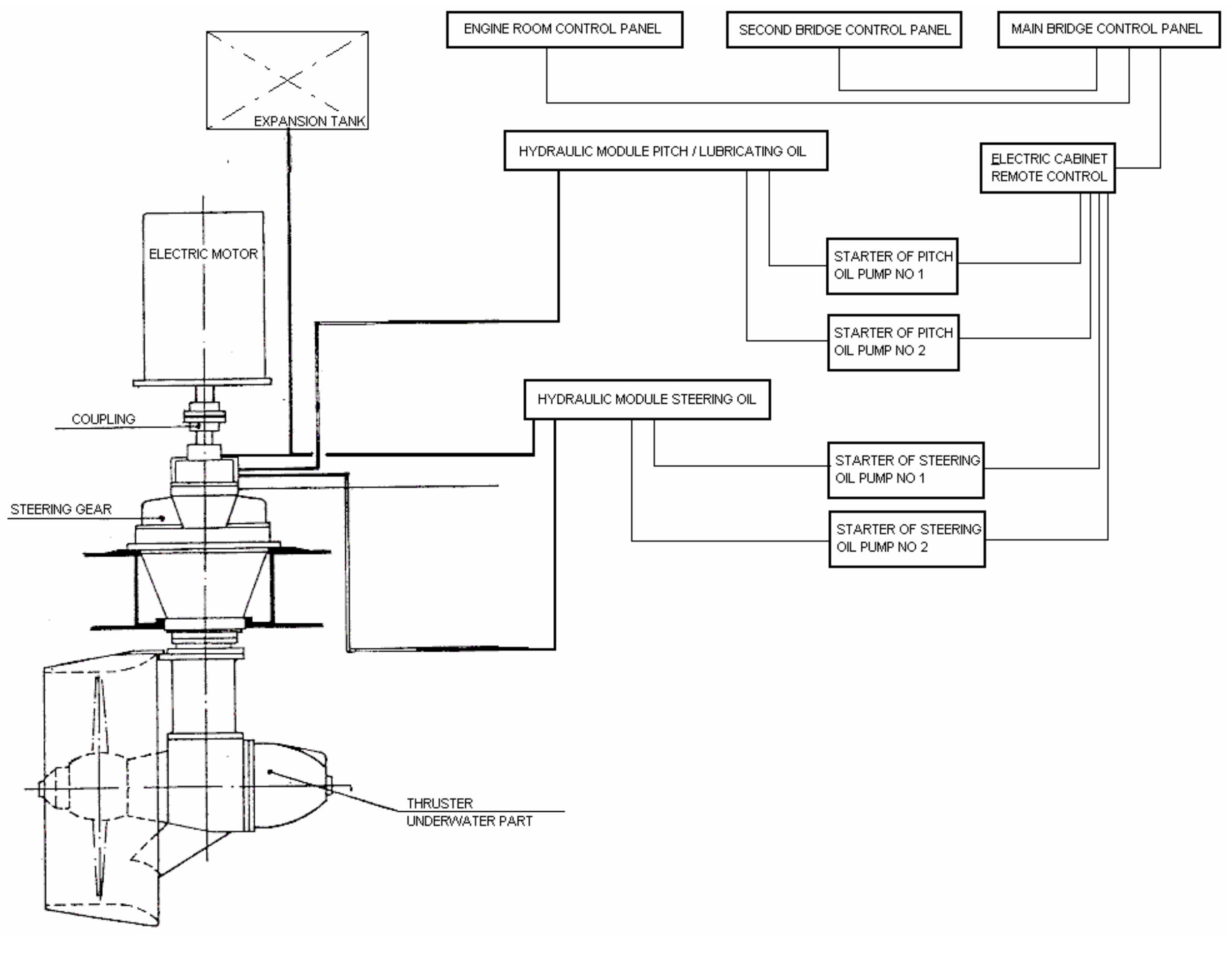

Fig. 1. Main components of example azimuth thruster system

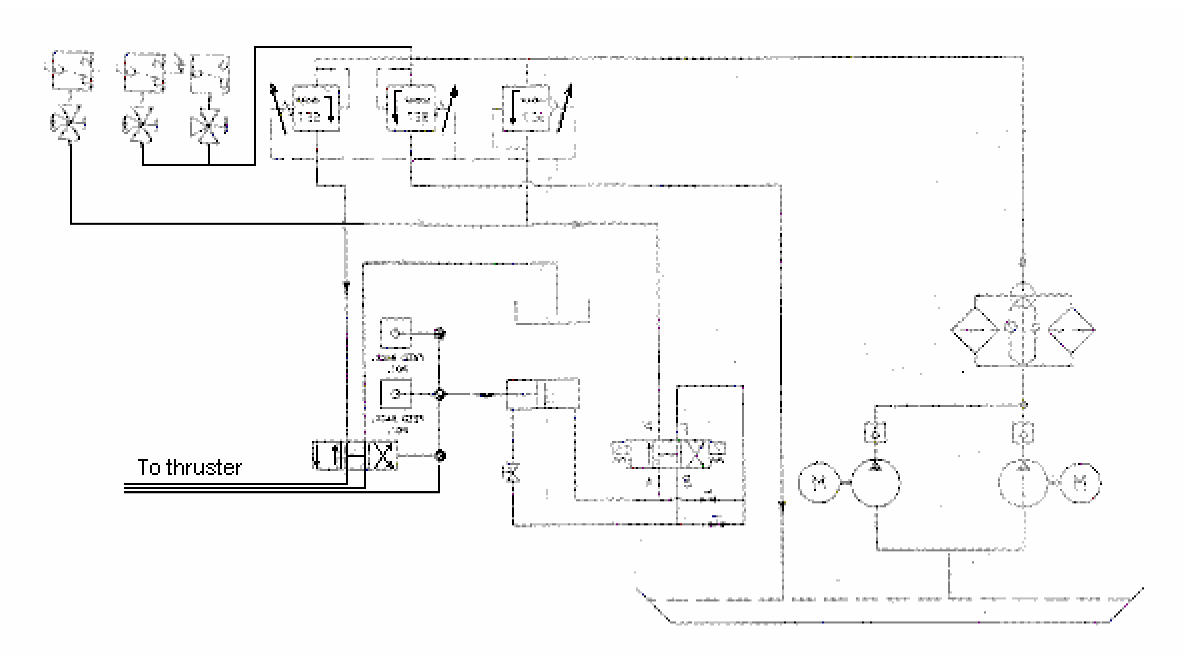

Fig. 2. Example hydraulic module of azimuth thruster pitch / lubricating oil

Steering of propeller (change of its azimuthal position) is carried out by means of steering oil hydraulic system. Example instalation of steering (propeller azimuthal position change) oil is shown in fig. 3.

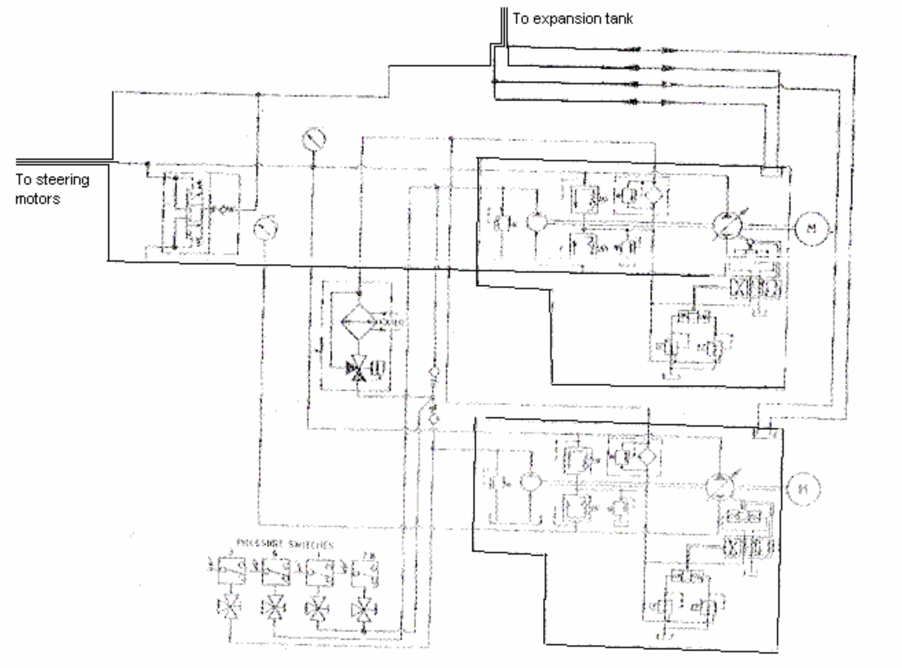

Fig. 3. Example hydraulic module of azimuth thruster steering oil

2. Faults of azimuth thruster and its subsystems

There is neccessary of up state of particular subsystems for proper ooperation of whole azimuth thruster system. Main failure nodes of system are ussualy evaluated in Failure Mode and Effect Analysis (FMEA) and some of its are analysed during DP trials.

Main nodes analysed in FMEA connected with azimuth thrusters and its subsystems are pointed out in table 1. with lower occurance probability but major consequences for DP system (high severity) are breakdowns of whole thruster (connected with fault of electric mothor or mechanical failure of thruster) or common cause events connected with down state of one main opower plant. With minor consequences for DP operations (according to system redundancy) but much higher probability are electrical and hydraulic systems faults. According to higher faults occurance frequency, there is important to evaluate of probabilistic analysis of occurance possibility for this systems (esspecially for hydraulic systems).

Table 1. Selected fualts in azimuth thruster system

failure of one azimuth thruster and two bow thrusters	Major severity for DP system; low probability – 1 failure /(10 ÷ 100) years
failure of a main propulsion engine and one azimuth thruster	Major severity for DP system; medium probability – 1 failure /(1 ÷ 10) years
malfunction of one DP system propeller	Major severity for DP system; medium probability – 1 failure /(1 ÷ 10) years
Failure of main power e.g. 660V supply	Major severity for DP system; medium probability – 1 failure /(1 ÷ 10) years
Failure of a hydraulic pump	Minor severity for DP system; medium probability – 1 failure /(1 ÷ 10) years
Failure of supply for the control system, e.g. 24V DC	Minor severity for DP system; low probability – 1 failure /(10 ÷ 100) years
Loss of the signal for propeller pitch control	Minor severity for DP system; low probability – 1 failure /(10 ÷ 100) years
Loss of the feedback signal of propeller pitch or azimuthally position	Minor severity for DP system; low probability – 1 failure /(10 ÷ 100) years
Failure of feedback circuit for DP system computer	Minor severity for DP system; low probability – 1 failure /(10 ÷ 100) years

In presented hydraulic systems, elements which can generate faults are hydraulic valves – sliders, hydraulic actuators – power pistons and motors (internal or external leakages, blocking of elements, failures caused by dirties in the oil etc.), piplines (fracture, connection damage, broken seals), circulation pumps (pump components wearing, drop of oil rate or loss of delivery pressure) and oil filters (dirties in the oil due to not proper exploatation). In general hydraulic systems faults are caused by friction wearing, fatigue process, ageing, corrosion, deformations and fractures of material [4].

3.Modeling of hydraulic systems reliability

In the general case, there is possible to find subsytem with serial reliability structure (selfcleaning filters, termostatic valves, hydraulic sliding and relif valves, tanks and oil coolers) and components in parallel reliability structure with cold spare (circulation pumps with associated stop valves, filters and control devices) in the hydraulic steering oil systems and proppeler pitch / lubricating oil systems [3].

Reliability of hydraulic proppeller pitch oil system at moment *t* for presented example is given by formula:

$$R_{pitch}(t) = \prod_{i=1}^{m} R_i(t) \prod_{j=1}^{n} R_j(t) = R_S(t) \prod_{j=1}^{n} R_j(t) \qquad (1)$$

where:

$i=1,2 \dots m$ – components belongs to serial reliability structure,

$j=1,2 \dots n$ – components belongs to parallel reliability structure with cold spare (circulation pumps, filters).

$R_S(t)$ – reliability function of serial reliability substructure in the system at moment *t*.

Reliability of *j*-th structure with cold spare at moment *t* is equal to:

$$R_j(t) = R_0(t) \sum_{Z=0}^{1} \frac{[-\ln R_O(t)]^Z}{z!} \qquad (2)$$

where:

R_0 – reliability of given subsystem in the structure with cold spare at moment t.

In case of simmillar configuration of steering oil system, there is possible to use same form of reliability model, according to formula (1). If there is not any separated oil filters (each pump has its own filter) in the system, equation can be reduced to form with given reliability of pumps set unit $R_T(t)$:

$$R_{steering} = R_T(t) \prod_{i=1}^{m} R_i(t) \qquad (3)$$

It is possible to observe, that presented structures can be modeled by two elements structure, combined with substitute component of serial reliability structure of the system, and substitute component of circulation pumps with associatted devices and stop valves (not belongs to serial reliability structure of the system). In this case there is possible to analyse whole serial reliability structure in global manner. This method has been presented in [5].

This assumption can make analysis more simple and allowed to estimation of reliability characteristics of serial structure and redundant pump units (witch from reliability engineering pont of view are almost always in parrallel reliability structure with cold spare). Ussually system is consist of two pumps with same construction and work parameters, so there is possible to take assumption that this two units have same time to failure T_0 i T_1 distribution for subsystems elements. If switch-over time for pumps is equal to zero, for failure rate functions of units $\lambda_0(t)=\lambda_1(t)$, reliability function this subsystem is given by formula (2).

In the real situation time of stand-by pump swith-over is higher then zero, and swith-over subsystem can be also in the down state during standing by and during activation on demand. There is also real possibility of stand-by pump fault duribng waiting for operation (e.g. by means of short circuit in electrical instalation or common cause failure).

For modeling of subsystem with non-zero switch-over time and real (lower then one) value of reliability function of pump switch-over unit, there is necessary introduce an additional events in the model. Example model of this kind [2] has been presented in form of fault tree in fig. 4. In this model is considered possibility of system fault connected with loss of pressure on pumps delivery *T*, what is generated by main pump breakdown *P1* and unavailable of stand-by pump. Selection of main and stand-by pump is contratual, both pumps are same according to construction and in given times periods its functions are exchanged, i.e. one of its is main (working) pump and another one is stand-by pump. This strategy allow to keep both pumps in well technical condition. Fault of stand-by pump is generated by stand-by pump breakdown during stand-by *P2a* (with event probability equal to $P_1(t)$) e.g. short circuit in electrical system, and during starting up of pump on demand *P2b* (with event probability equal to $P_2(t)$) e.g. connected with non proper renewal of pump.

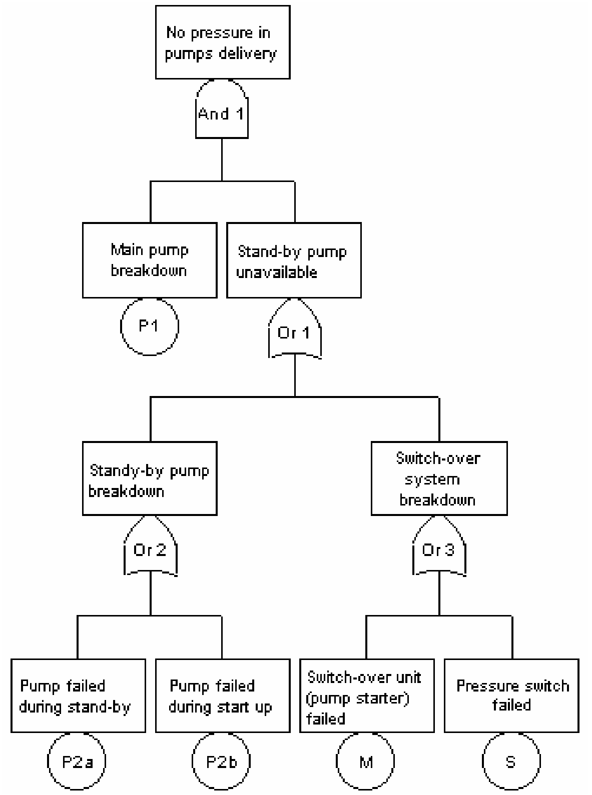

Fig. 4. Fault tree for real redundant pumps unit

Unavailability of stand-by pump at moment t can be connected with componnents other then pump, i.e. switch-over system: pressure switch or pressure transmitter failed S (with event probability equal to $P_3(t)$) or switch-over unit failed e.g. contactor or relay M (with event probability equal to $P_4(t)$).

This model can be presented in the logical form:

$$T = P1 \cap (P2a \cup P2b \cup S \cup M) \tag{4}$$

For *OR1* gate with statistically independent input events, probability of fault event generation is given by Poincare formula:

$$P_{OR1}(t) = P(\bigcup_{i=1}^{i=4} E_i) = \sum_{i=1}^{4} P_i(t) - \sum_{i=1}^{3}\sum_{j=i+1}^{4} P_i(t)P_j(t) + \sum_{i=1}^{2}\sum_{j=i+1}^{3}\sum_{k=j+1}^{4} P_i(t)P_j(t)P_k(t) - P_1(T)P_2(t)P_3(t)P_4(t) \tag{5}$$

After assumption that system is non-repairable (analysis is performed up to the firs system down), unreliability function of system $F(t)$ is equal to unavailability function of system $Q(t)$, what for presented model for statistically independent basic events is giving equation:

$$F_T(t) = F_{P1}(t) \cdot P_{OR1}(t) \tag{6}$$

Reliability of redundant pump unit for presented example is given by formula:

$$R_T(t) = 1 - F_T(t) = 1 - F_{P1}(t) \cdot P_{OR1}(t) \tag{7}$$

According to formula (1), reliability of given hydraulic system of azimuth thruster can be presented in form:

$$R_{sys}(t) = R_S(t) \cdot R_T(t) \tag{8}$$

Final conclusions

One of redundant component grup in azimut thrusters subsystems are pump units (electric motor, proper pump, additional equipment). This systems are according to classification societies rules and International Maritime Organisation directiions, are to be redundant for incrise reliability and safety of its operation. It is esspecially important for dynamic posiotioned vessels.

Very important in azimuth thruster hydraulic systems operation is proper preventive and planned maintenance, i.e. control of levels in expansion tanks, filters cleaning, pumps delivery pressure and control pionts pressure observation, electrical current (load) of pump motors observation etc.

According to pracitce, faults of azimutth thrusters hydraulic systems are quite offen and are practically not avoidable. Causes of this evens can be very different, i. e. construction and manufacturing faults, given material properties of system components, not properly done maitenance etc. This all points are providing that reliability analysys of this systems are very important for safety of operation many flkoating units. Presented in material models can be helpful in performing of azimuth thruster hydraulic systems reliability analysis.

Literature

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MODEL NIEZAWODNOŚCIOWY INSTALACJI HYDRAULICZNYCH PĘDNIKA AZYMUTALNEGO

W materiale przedstawiono budowę przykładowego systemu pędnika azymutalnego. Przedstawiono budowę podstawowych systemów hydraulicznych pędnika, tj. systemu oleju smarnego / sterowania skokiem śruby oraz systemu zmiany kierunku siły naporu śruby. Przedstawiono podstawowe niezdatności mogące wystąpić w podsystemach oleju hydraulicznego pędnika azymutalnego. Zaprezentowano drzewo uszkodzeń dla redundantnych układów pompowych w podsystemach hydraulicznych pędnika oraz przedstawiono matematyczne modele niezawodnościowe dla podsystemów hydraulicznych i ich podstruktur.