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Marine Propulsion System Reliability Assesment by Fault Tree Analysis

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Abstracts: Research on reliability to ensure that the operation of transport facilities is safe. This issue is always concerned by transportation operators. This article presents a number of research using Fault Tree Analysis method (FTA) to model the analysis, reliability assessment of marine propulsion system.

Keywords: Fault Tree Analysis method (FTA), Reliability Assessment, Marine Propulsion System, Reliability and Safety

1. Introduction

Reliability and safety of operation of the ships have to be carefully focused. In marine field, the fault of the marine propulsion system and the corresponding loss are not to be neglected. A number of accidents and damages are caused by the failure problem. Ayyub [2] presented the failure rate distribution of the main components as shown in Table 1.

The combination of individual elements in a system can improve or decrease the reliability of a system; therefore, the risk associated with the system is determined by using occurrence probability and consequence. When applying risk-based technology methods to system safety analysis, the following interdependent primary activities are considered: (1) risk assessment, (2) risk management, and (3) risk communication. These activities, when applied consistently provide a useful means for developing safety guidelines and requirements to the point where hazards are controlled at predetermined levels.

Three questions that a risk assessment have to answer:

(a) What can go wrong?

(b) What is the likelihood that it will go wrong?

(c) What are the consequences if it does go wrong?

In order to perform risk assessment several methods have been created presenting in section 2.

Reliability of a system can be defined as the system's ability to fulfill its design functions for a specified time. This ability is commonly measured using probabilities. Reliability is, therefore, the probability that the complementary event will occur to failure, resulting in

Reliability = 1 – Failure Probability

Based on this definition, reliability is one of the components of risk. The judgment of a risk's acceptability for the system safety can define as safety, making to a component of risk management.

Table 1. *The statistical result of the marine fault accident claims of the ships which had taken service [2].*

Compensation reason	Failure frequency	Total compensation (USD)	The average compensation (USD)
The main engine	232 (41.6%)	69744.597 (45%)	300.623
Manipulate gear	66	15636.563	236.918
Auxiliary diesel engine	120	27257.436	227.145
The boiler	65	18138.065	279.047
The propulsion shaft	63 (11.3%)	17798.483	282.516
Others	12	2559.295	213.275
Total	558	151134.439	270.85

Here are some of the related methods are summarized in section 2. Then, in section 3, introducing some of FTA studies for the marine propulsion system and system of marine power plant in general. Finally, a FTA model in the marine propulsion system analysis is presented in section 4.

2. Risk Assessment Methods

Barlow and Proschan (1972) presented the statistical theory of reliability and life testing [3]. After that, Vasely et al (in 1981) published the handbook on FTA [8] and Ayyub et al prersented the risk analysis and management for marine systems [2] in 2002.

Summary of related methods for risk Analysis and Management as following:

- *Safety and Review Audits*: Identify equipment conditions or operating procedures that could lead to a casualty or result in property damage or environmental impacts;
- *Check list*: Ensure that organizations are complying with standard practices;
- *What-if*: Identifiy hazards, hazardous situations, or specific accident events that could result in undesirable consequences;
- *Hazard and Operability Study (HAZOP)*: Identify system deviations and their causes that can lead to undesirable consequences and determine recommended actions to reduce the frequency and/or consequences of the deviations;
- *Probabilistic Risk Analysis (PRA)*: Methodology for quantitative risk assessment developed by the nuclear engineering community for risk assessment. This comprehensive process may use a combination of risk assessment methods;
- *Preliminary Hazard Analysis (PrHA):* Identify and prioritize hazards leading to undesirable consequences early in the life of a system. Determine recommended actions to reduce the frequency and/or consequences of the prioritized hazards. This is an inductive modeling approach;
- *Failure Modes and Effects Analysis (FMEA):* Identify the components (equipment) failure modes and the impacts on the surrounding;
- *Failure Modes Effects and Criticality Analysis (FMECA):* Identifies the components (equipment) failure modes and the impacts on the surrounding components and the system. This is an inductive modeling approach;
- *Event Tree Analysis (ETA):* Identify various sequences of events, both failures and successes that can lead to an accident. This is an inductive modeling approach; and
- *Fault Tree Analysis (FTA):* Identify combinations of equipment failures and human errors that can result in an accident. This is a deductive modeling approach;

Each method is suitable in certain stages of a system's life cycle.

Chybowski in 2002 has worked on auxiliary installations' fault tree model for operation analysis of vessel's power plant unit [4]. Dong Conglin et al in 2013 have published the reliability research on marine propulsion system based on FTA [5].

Aung et al (2014) have analyzed the marine diesel engine jacket water cooling system based on FTA with fuzzy point of view [1]. Before this, could be mentioned the works of Kumar et al (2006) and Li et al (2012) about the fuzzy reliability of a marine power plant [6] and fuzzy dynamic FTA [7]

Next section will introduce some of FTA studies for the marine propulsion system and system of marine power plant.

3. Introducing Some of FTA Studies for the Marine Propulsion System

Fault tree analysis (FTA) is a logical and graphic method being widely used to evaluate the reliability of complex engineering systems from both qualitative and quantitative perspectives

A fault tree analysis can be understood as an analytical technique, whereby an undesired state of the system is specified (usually a state that is critical from a safety standpoint), to find all credible ways in which the undesired event can occur, in the context of environment and operation, the system is then analyzed. The fault tree itself is a graphic model of the various parallel and sequential combinations of faults that will result in the occurrence of the predefined undesired event. The faults can be events that are associated with component hardware failures, human errors, or any other pertinent events which can lead to the undesired event. A fault tree thus depicts the logical interrelationships of basic events that lead to the undesired event-which is the top event of the fault tree.

It is necessary to know that not all of possible system failures or all possible causes for system failure are a fault tree model. Thus a fault tree cannot be understood as a quantitative model. A fault tree is tailored to its top event which associates for some specific system failure mode, and it just includes those faults that contribute to this top event. Moreover, these faults are not exhaustive-they cover only the most credible faults as assessed by the analyst.

3.1. Fault Tree Analysis for Marine Main Engine

According to Table 1, easy to see that marine main engine failure is one of the biggest reasons for marine accidents, its fault accident rate is 78.6% among the marine propulsion system fault accidents.

According to integrated analysis meticulously, the typical failure modes (from [2]), heir accumulative failure probabilities of the main engine are gained as in Table 2.

The typical faults of main engine have shown in Fig. 1 (x2, x6, x7, x8, x9, x10, x11, and x12). Unless they happen, the marine main engine would not lose working ability.

Table 2. *The accumulative failure probabilities of the marine main engine operating for different times [2].*

The parts of marine main engine	Typical faults	500 h Accumulative failure probabffity	1000 h Accumulative failure probability	1500 h Accumulative failure probabffity
The crankshaft connecting rod system	Over worn or melting of bearing bush	0.015	0.031	0.048
	Deadlocking or breakage of piston ring	0.005	0.011	0.012
Piston, piston ring, cylinder liner component	Cracking or breakage of crankshaft or connecting rod	0.020	0.042	0.065
	Cracking or breakage of piston	0.003	0.006	0.010
	Cracking or breakage of cylinder liner	0.003	0.007	0.010
Cylinder block	Cracking or breakage	0.003	0.007	0.011
	Others failures	0.008	0.016	0.025
Fuel injection system		0.010	0.021	0.032

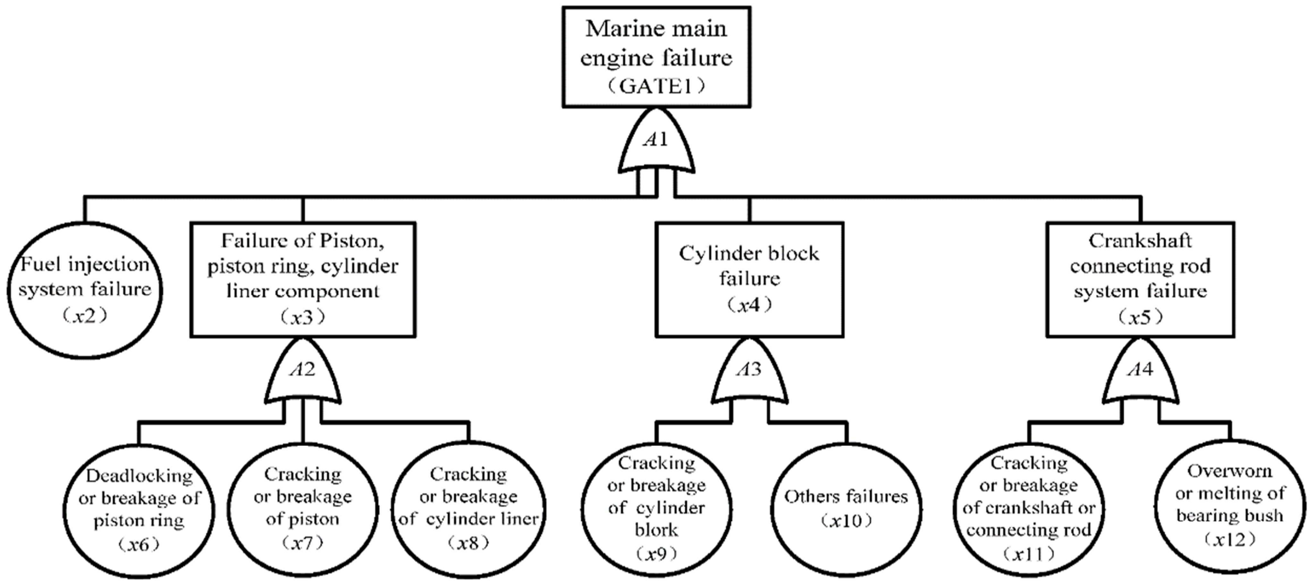

Figure 1. *Fault tree models for Marine Main Engine [5].*

As the calculation results, within a period of time, FTA is appropriate for the reliability of the marine engine system. But it cannot reflect the whole life due to the marine engine system is consisted of different kinds of parts whose failure probability is different with one another. The failure probability of the marine engine system is influenced by the failure probabilities of key parts, such as the cylinder liner-piston rings failure, the crankshaft failure, the injecting system failure and so on. People may repair or replace them for several times in the whole life of the marine engine system. Those are also appropriate to assess the reliability of the marine propulsion system. So, for assessing the comprehensive reliability of the marine propulsion system, besides the failure probabilities of the parts and the marine propulsion system, it is important to pay more attention to the relationship between the application life of the parts and the whole life of the marine propulsion system.

3.2. Fault Tree Analysis for Marine Power Generation

Major industries and technologies using FTA consist of: aircrafts, nuclear systems, transit systems, space projects, robotic systems, missile systems, torpedoes, etc. In marine and offshore industries method were used to oil platforms and ships safety (ro-ro, tankers). This method can by also evaluated to marine power plants operation analysis. In this situation is available to create universal model of auxiliary installations (MAI) for marine engines [4].

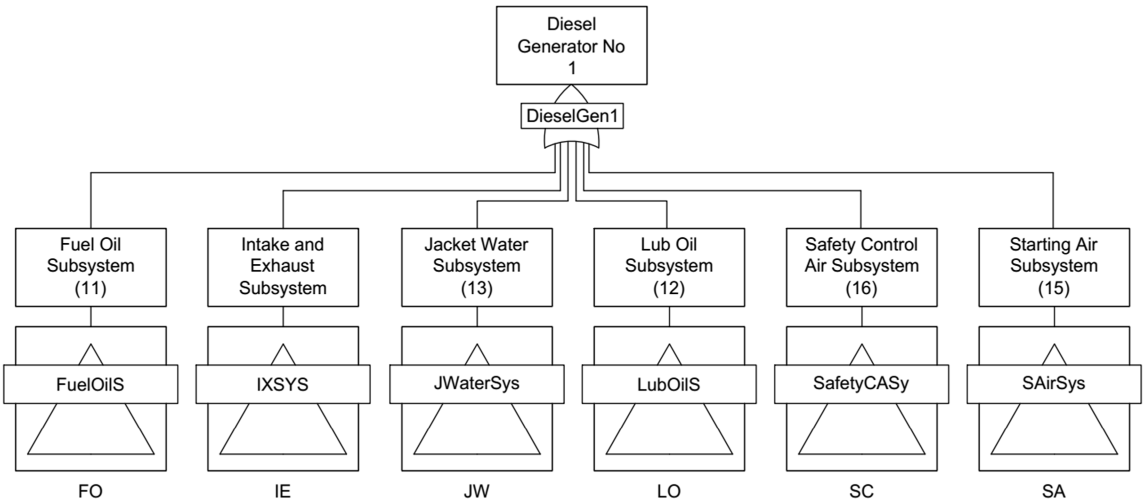

Figure 2. *Fault tree model for diesel generator [4].*

MAI model can be difficult in computing for many combinations of events, that is important to decreasing it. Each marine installation contains many elements in serial structure and series-parallel blocks (in given decomposition level). It is important to utilize computer code for finding of minimal cut sets for presented model. With more generic decomposition level (such as pump with related valves can be treat as one element) the problem of model will be solved more quickly. Operation analysis of marine power plant systems can use presented MAI model as part of project and bring up other methods.

3.3. Fault Tree Analysis for the Marine Diesel Jacket Water Cooling System

Cooling systems and temperature control systems are important to hold on the temperature of engine and to ensure the long life of the parts using in diesel engine. There are two main types of cooling system on board, that are sea water cooling system and fresh water cooling system also known as central cooling water system. Fresh water central cooling system can be divided into two subsystems (low and high temperature fresh water cooling system).

Jacket water cooling system is a high temperature fresh water cooling system and the safe and smooth operation of this system is based on the operation conditions of both sea water and fresh water cooling system [1].

The studys dedicated that, the reliability of jacket water cooling system is affected by fails of control supply air, which is the event should be most concerned in the analysis of the reliability of system. To improve the reliability of cooling water system, availability of supply air system should be well maintained and monitored, because it is the most repeated event of the system.

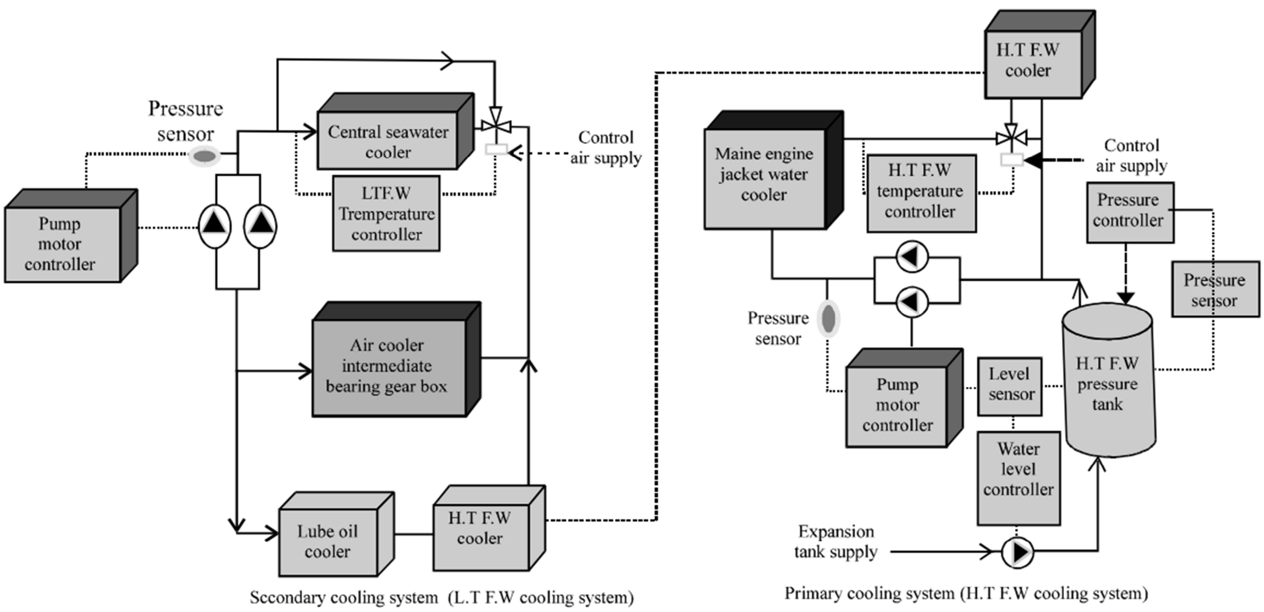

Figure 3. *Components include in the analysis of jacket water cooling system [1].*

4. FTA Model in the Marine Propulsion System Analysis

As mentioned in section 3, following is the fault tree analysis model apply to the marine propulsion system consist of model for all the marine propulsion system and particular consideration for marine propeller system [5]. As shown in Fig. 4, generally, a marine propulsion system includes following main parts: main engine, driving device, marine shaft and propeller. The main engine is the impulsion machine engine of the marine propulsion system. The function of the driving device is connecting or parting the energy that the main engine transfers to the marine shaft and the propeller. The marine shaft plays an important role in transferring the energy to the propeller. The propeller promotes the ship to sail.

A function flow diagram (in Fig. 5) is the cornerstone to study the reliability model of the marine propulsion system. It is necessary to make a function flow diagram of the marine propulsion system to show the relation between the function of the marine propulsion system and the function of the parts.

Based on the function flow diagram the marine propulsion system and the division principles of the fault tree, the fault tree of the marine propulsion system is described specifically in Fig. 6 and Fig. 7.

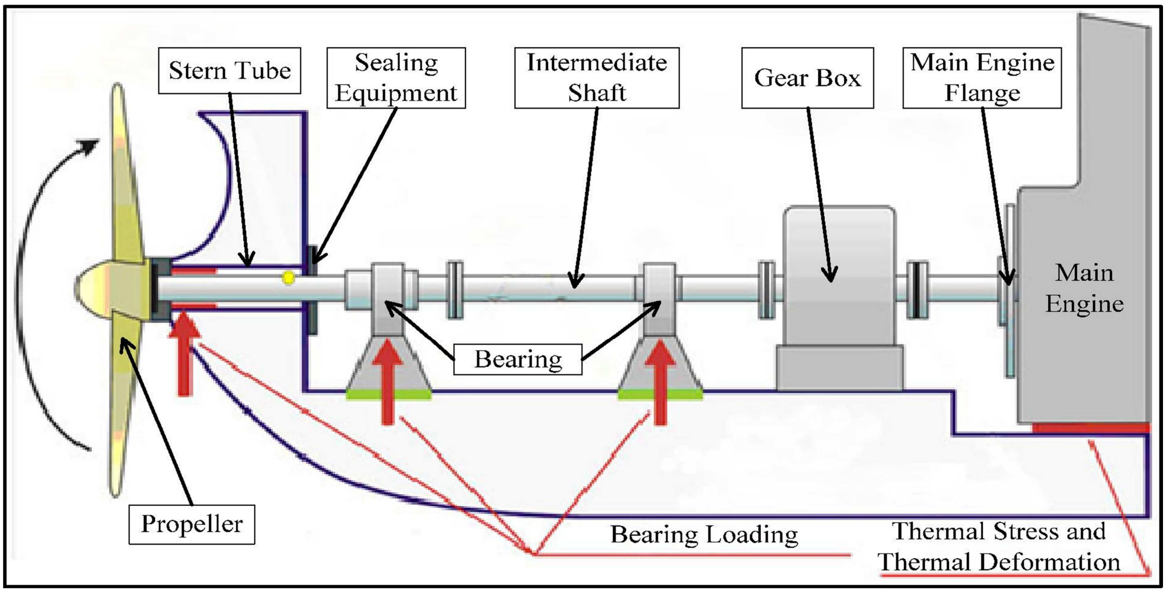

Figure 4. *The structure sketch map of the marine propulsion system.*

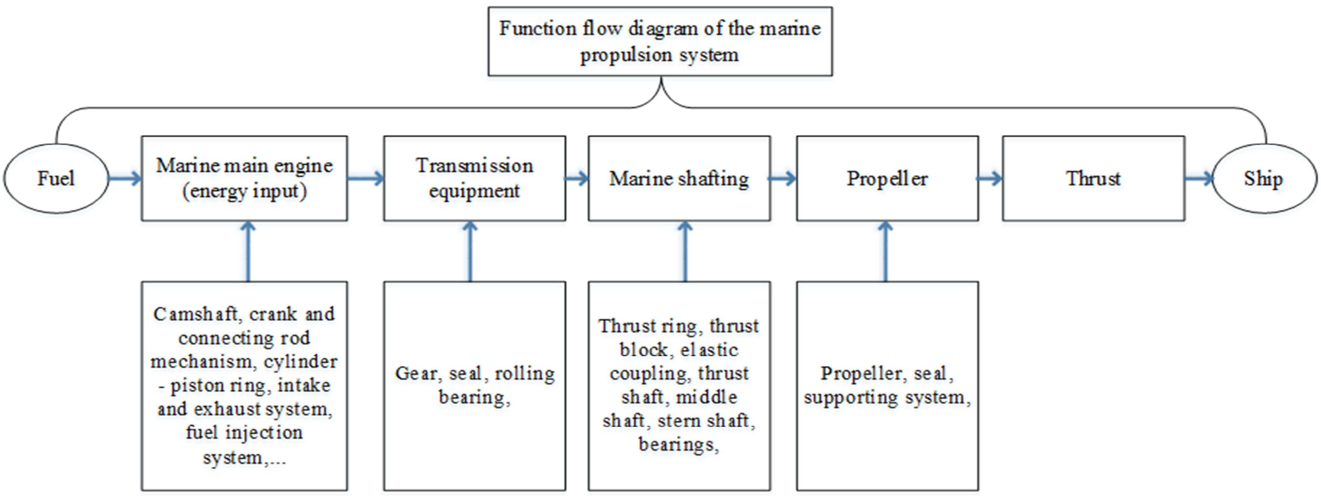

Figure 5. *Function flow diagram of the marine propulsion system.*

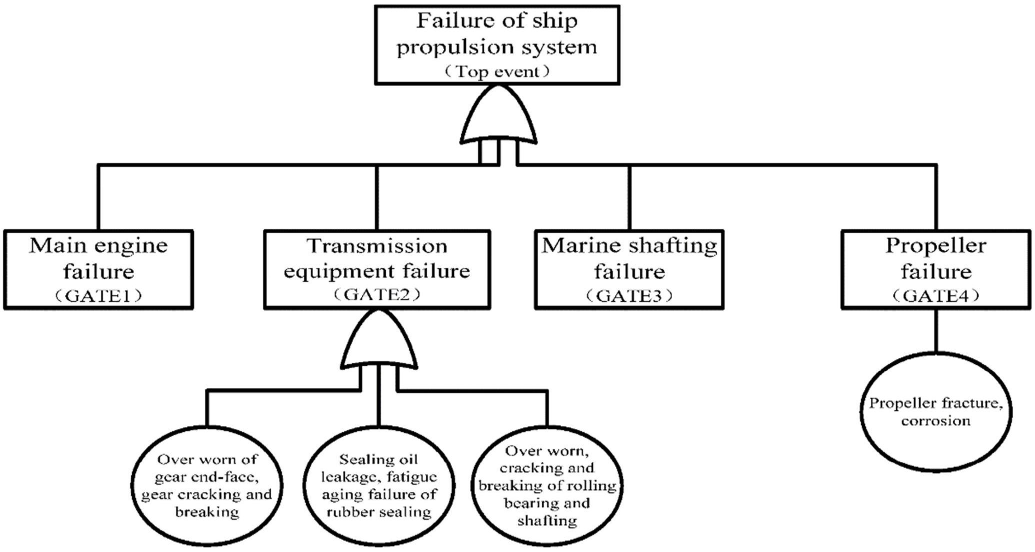

Figure 6. *The fault tree of the marine propulsion system.*

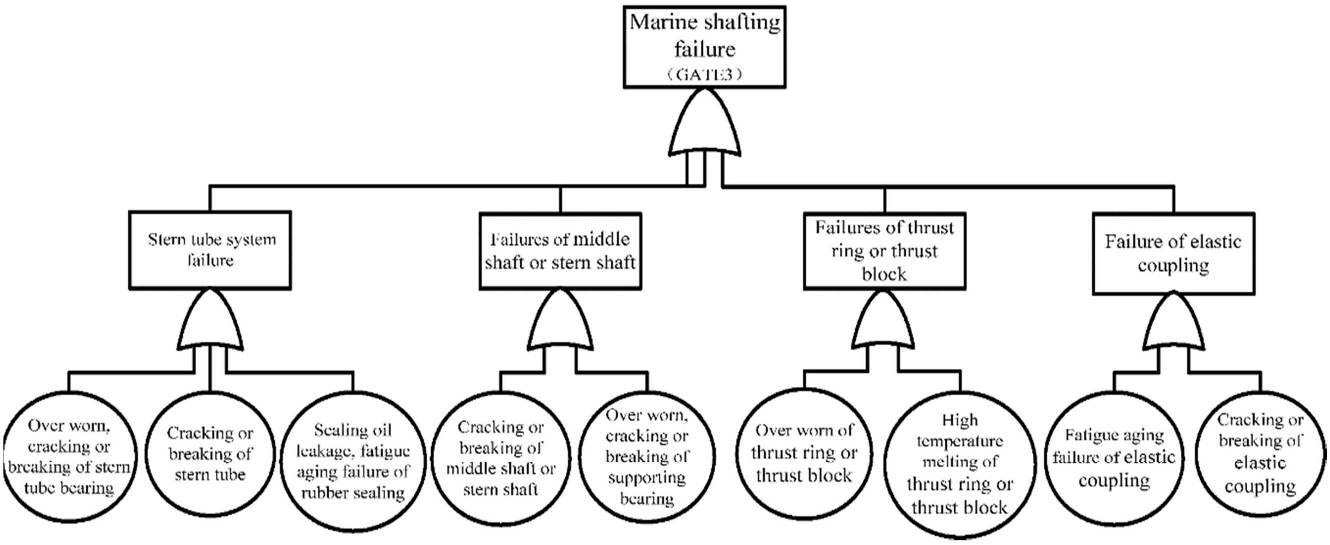

Figure 7. *The fault tree of the marine shafting.*

5. Comment and Conclusion

FTA analysis model as above (4) is proposed to the marine propulsion system over a period of time, however it cannot reflect the whole life cycle of system. In other hand, this method is also suitable for assess reliability of the marine propulsion system.

Failure analysis of the marine propulsion systems is carried out by using different reliability analysis methods from design stage to operation stage in order to obtain high reliable of the marine propulsion system. In doing these analysis, to get the exact value of failure probability of the basic components (basic events) is the most challenging problem for engineers. The failure probability of basic components (basic events) and the reliability of the marine propulsion system depends on factors such as ship mobility, states of loading and weather conditions. The theoretical data of the comprehensive reliability can guide for finding the methods or countermeasures to improve the reliability, safety and efficiency of the marine propulsion system, which is very valuable for the ships completing their missions satisfactorily.

The model has some following advantages and limitations:

The advantages of this method are allowed to indicate the damage elements, assess the quantity and quality of elements of system on reliability point. It is one of the first method is used to identify the source of the failure and simplify the reliability the process of determining the reliability of complex systems. Besides, this method also has some limitations such as: take a lot time and facilities; suitable for marine propulsion systems in a while, therefore, we cannot assess the whole system due to the details in the propulsion system have specified life cycles and maintenance time each other.

Probability of the detail whose risk is highest will determine to the whole propulsion system. In additional the relationship among the details for the propulsion system is also necessary to pay attention.

Aknowledgements

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Biography

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