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Case Report

Assesment of Marine Propulsion System Reliability Based on 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, marine propulsion system reliability assessment.

Keywords: Fault Tree Analysis Method (FTA), Reliability Assessment, Propulsion System, Marine, 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. The reliability of Marine propulsion System have been studied quite a lot over the years ([3], [4], [6]). A number of accidents and damages are caused by the failure problem. The failure rate distribution can refer to Table 1.

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

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.

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

Summary of related methods for risk Analysis and Management:

- Safety and Review Audits,
- Check list,
- What-if,
- Hazard and Operability Study (HAZOP),
- Probabilistic Risk Analysis (PRA),
- Preliminary Hazard Analysis (PrHA),
- Failure Modes and Effects Analysis (FMEA),
- Failure Modes Effects and Criticality Analysis (FMECA),
- Fault Tree Analysis (FTA), and
- Event Tree Analysis (ETA).

Each method is suitable in certain stages of a system's life cycle. The characteristics of commonly used methods are shown in Table 2.

Table 2. *Risk Assessment Methods [2].*

Method	Scope	Type of Analysis
Safety/Review Audit	Identify equipment conditions or operating procedures that could lead to a casualty or result in property damage or environmental impacts.	Qualitative
Checklist	Ensure that organizations are complying with standard practices.	Qualitative
What-If	Identify hazards, hazardous situations, or specific accident events that could result in undesirable consequences.	Qualitative
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.	Qualitative
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.	Quantitative
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.	Qualitative
Failure Modes and Effects Analysis (FMEA)	Identifies the components (equipment) failure modes and the impacts on the surrounding components and the system. This is an inductive modeling approach.	Qualitative
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.	Quantitative
Fault Tree Analysis (FTA)	Identify combinations of equipment failures and human errors that can result in an accident. This is a deductive modeling approach.	Quantitative
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.	Quantitative

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

Most of the research on propulsion system reliability has focused on FTA method, because it has many advantages over the remaining methods. 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 [10].

A fault tree analysis can also understand 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. Currently, it is considered fuzzy dynamic fault tree analysis as a new method to study the Fuzzy Reliability ([1], [8], [9]).

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.

The typical faults of main engine are show in Figure 1 (x2, x6, x7, x8, x9, x10, x11, and x12). Unless they happen, the marine main engine won't lose working ability.

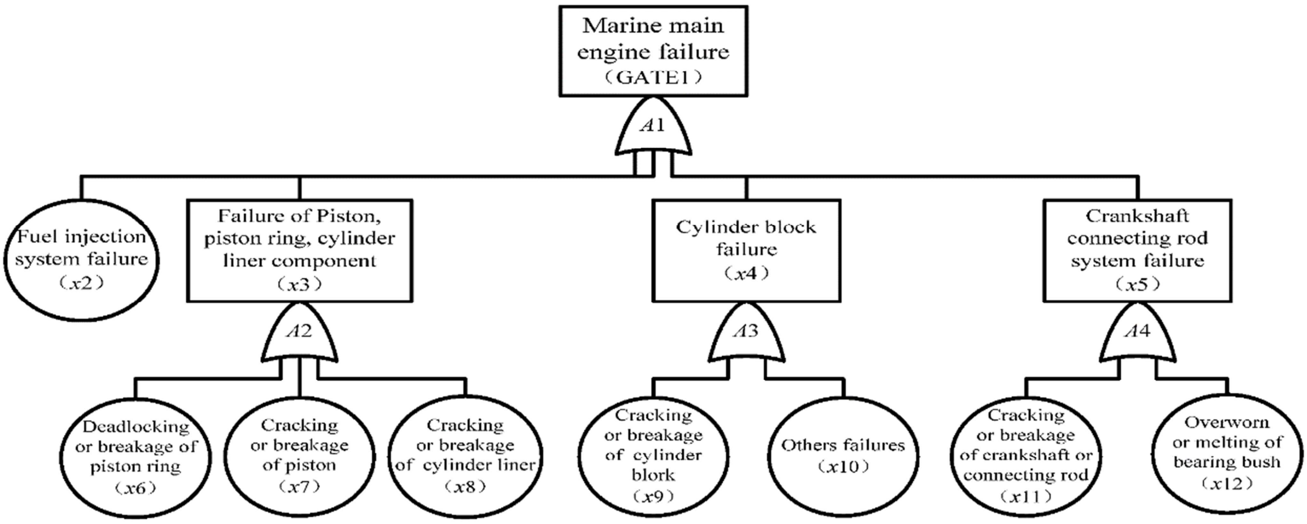

Figure 1. *Fault tree models for Marine Main Engine [7].*

According to integrated analysis meticulously, the typical failure modes, heir accumulative failure probabilities of the main engine are gained as shown in Table 3.

Table 3. *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

As the calculation results above, 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.

Marine diesels have a similar model.

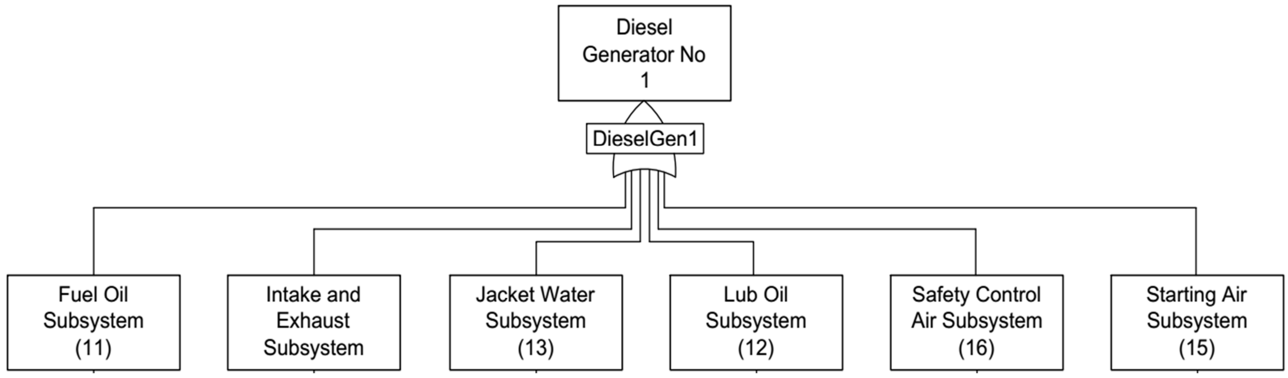

Figure 2. *Fault tree model for diesel generator [5].*

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.

The studies 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.

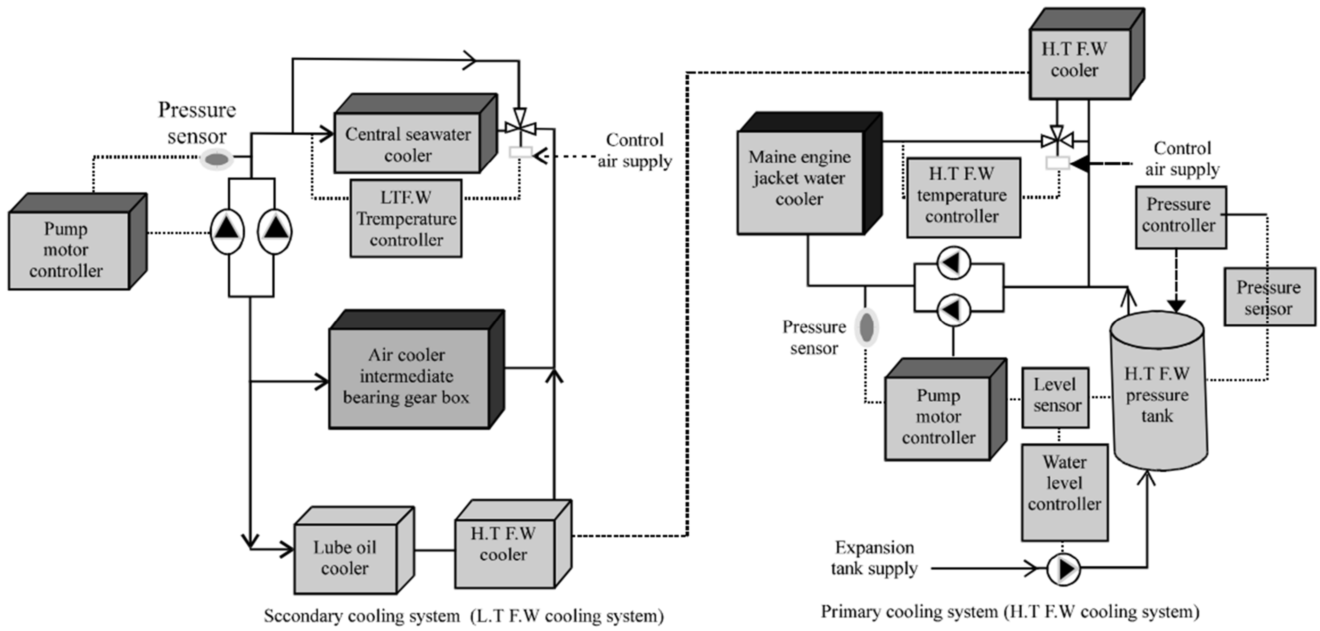

Figure 3. *Components include in the analysis of jacket water cooling system [1].*

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. 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.

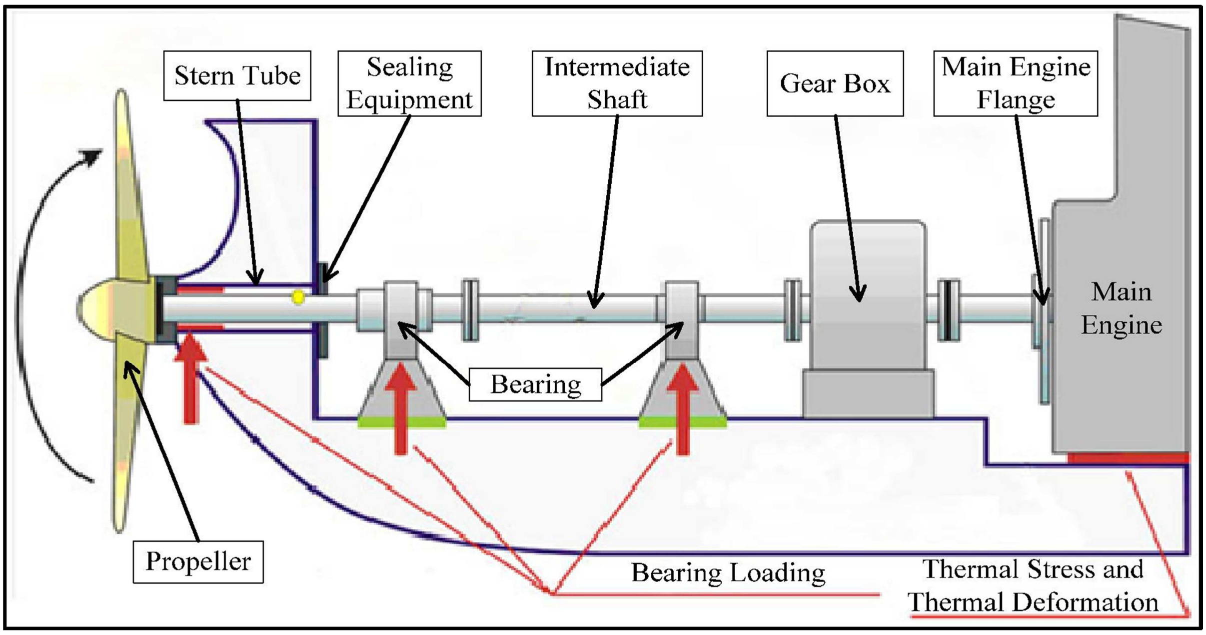

Figure 4. *The structure sketch map of the marine propulsion system [7].*

A function flow diagram 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 (Fig. 5)

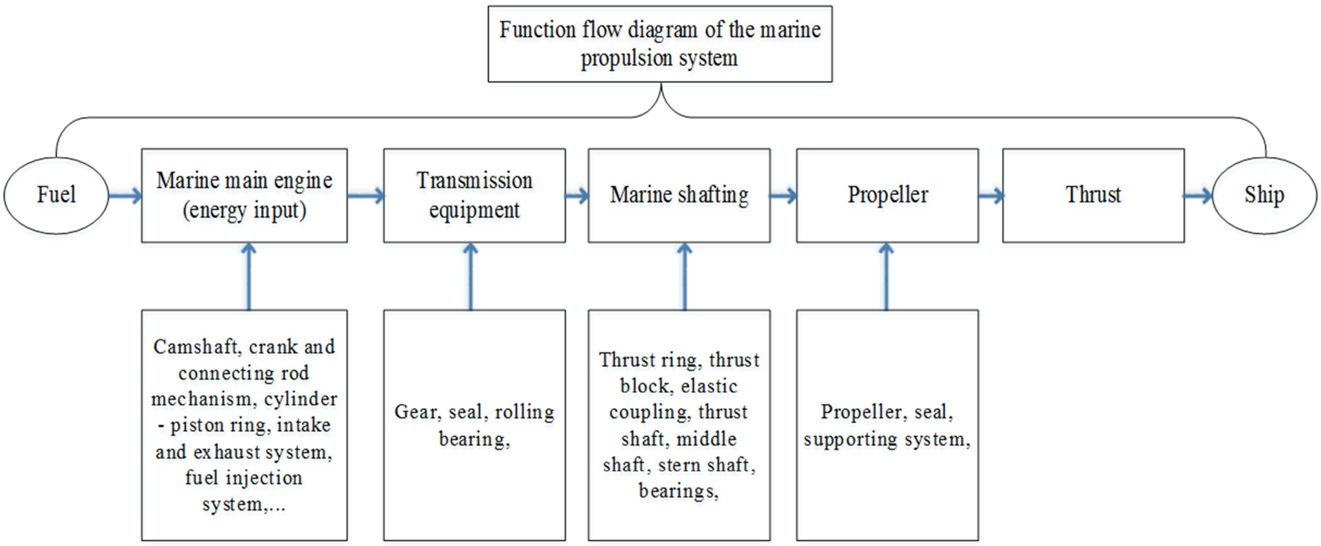

Figure 5. *Function flow diagram of the marine propulsion system [7].*

Based on the function flow diagram of 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 marine shafting has the faul tree as presented in Fig. 7.

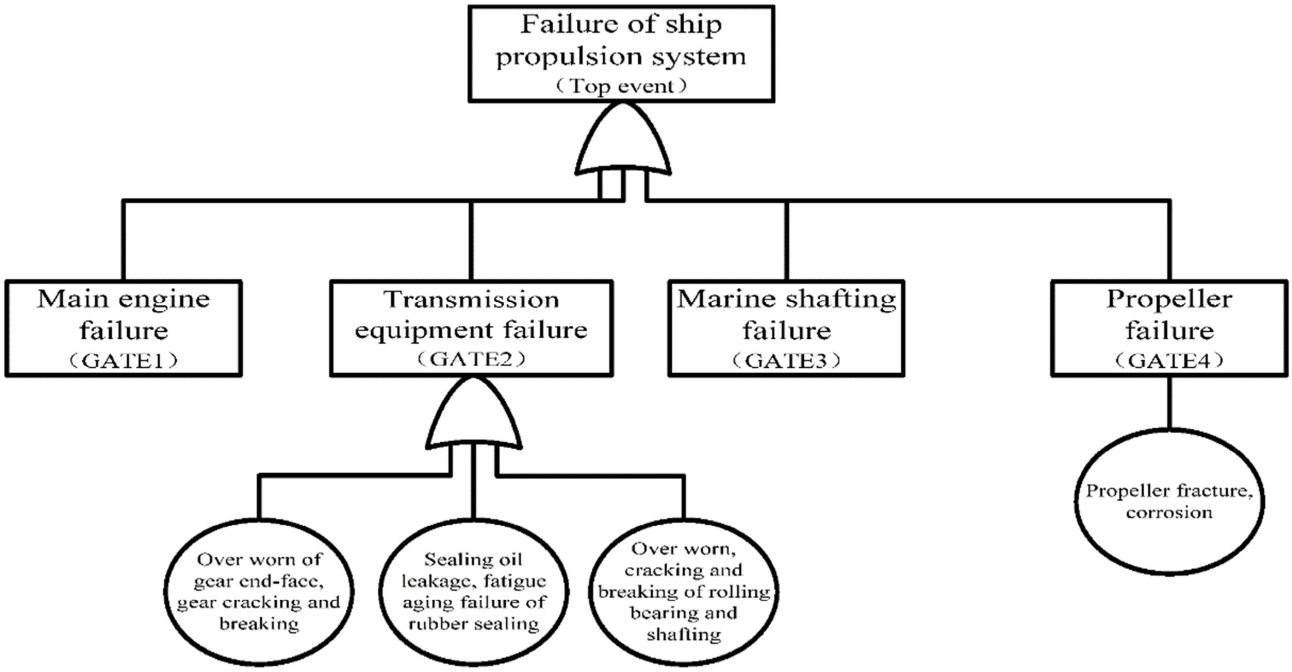

Figure 6. *The fault tree of the marine propulsion system [7].*

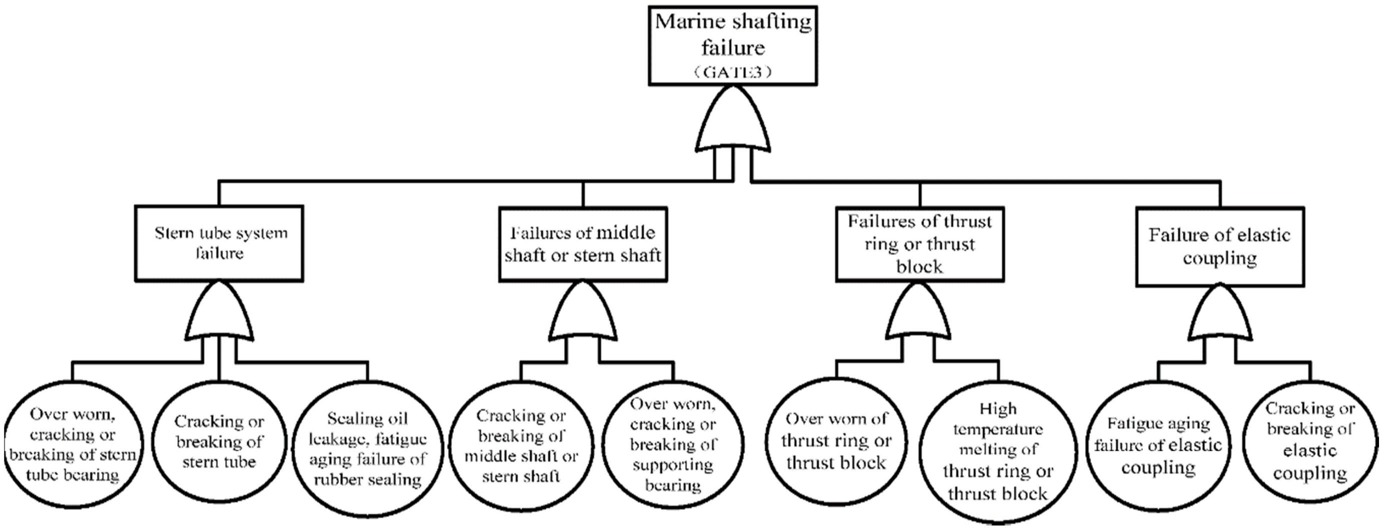

Figure 7. *The fault tree of the marine shafting [7].*

5. Comment & 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.

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Biography

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