ISSN: 2414-1895 DOI: 10.6919/ICJE.202207_8(7).0009

Study on Fault Diagnosis of Ship Engine Equipment based on Fault Tree Analysis Method

Lisi He, Ji Zeng, Yiting Zhan, and Chaochun Huang

School of Shanghai Maritime University, Shanghai 116023, China

Abstract

The disaster caused by the failure of the ship engine will be fatal. In order to reduce the probability of its failure, it is necessary to diagnose its equipment.This paper uses fault tree analysis method to ship engine fault diagnosis, which can be qualitative analysis of fault system and quantitative analysis, is a safe and reliable fault diagnosis method, can effectively improve the safety of ship engine system and the efficiency of engine fault diagnosis.

Keywords

Fault Tree Analysis; Fault Diagnosis; Qualitative Analysis; Quantitative Analysis.

1. Introduction

Ship engines work in harsh sea conditions, and failure is inevitable.As the core equipment of the ship, once the engine fails, it is likely to cause the ship to stop the operation, or even have safety accidents at sea, endangering the safety of the personnel on board and causing economic losses.Therefore, in order to ensure the safety and reliability of ships, it is necessary to study the equipment fault diagnosis.So far, in a large number of ship engine equipment fault diagnosis methods, fault tree analysis method[1] is a relatively mature method, and is also the most widely used method of modern ship engine equipment fault diagnosis.For the research of ship engine equipment fault diagnosis, the relevant researchers have made a substantial research.Dong Chen[2] of Harbin University of Science and Technology uses BP neural network technology and vibration, temperature and pressure analysis method to achieve low fault diagnosis accuracy to analyze the faults of the engine, etc.Zhao Wei[3] of Dalian Maritime University combined the ferrospectrum analysis method, spectral analysis method and oil monitoring and analysis method on the ship diesel generator equipment.This study proposed a set of scientific and reasonable diagnosis and monitoring scheme for diesel engine, which greatly improves the efficiency of engine fault diagnosis. However, the overall diagnosis scheme is highly comprehensive, and various monitoring methods must be combined to timely and diagnose engine faults accurately.

This paper presents ship engine equipment fault diagnosis based on fault tree analysis, a scientific and systematic intuitive diagnosis method for both qualitative and quantitative analysis.First, the fault type of the ship engine is analyzed, and then the fault tree structure is drawn. Through the relationship of the fault tree structure, the root cause of the fault is gradually introduced, and the fault diagnosis is realized.

2. Theoretical Basis of the Fault Tree Analysis Method

2.1 Basic Principle of Fault Tree Analysis Method

Fault tree analysis is a deductive analysis of equipment failure method, first prediction of the fault engine equipment, roughly give the cause of engine equipment failure, and then according to the fault

ISSN: 2414-1895 DOI: 10.6919/ICJE.202207_8(7).0009

cause classification, draw the fault tree structure, according to the logical relationship of the fault tree structure gradually deduced the root cause of engine failure and its failure rate.

The essence of fault tree analysis is a logical causal analysis method, combining the function of diagnostic equipment and structural components of a fault diagnosis model.The fault phenomenon shown by the equipment is called the "top event" of the fault tree, the indirect cause of the equipment failure is called the "middle event" of the fault tree, and the most basic cause of the equipment failure is called the "bottom event" of the fault tree.

The most important link to solve the engine equipment failure problem by using the fault tree analysis method is to determine the main fault problem[4], with the main problem as the backbone of the fault tree, that is, the top event of the fault tree.Then use qualitative analysis to split the fault system first, and then use scientific methods for quantitative analysis.Qualitative analysis refers to the analysis and research of the top events of the fault tree, transforming complex and complicated fault problems into accurate and simple small problems, and simplifying complex problems, so as to find the breakthrough of fault problems.Quantitative analysis is a scientific and reasonable analysis method based on the fault probability calculation. By calculating the failure rate of fault tree top events and analyzing the logical relationship between intermediate events and bottom events, it is analyzed to obtain the failure rate of fault tree top events.Finally, the potential safety risks in the fault tree, so as to ensure the scientific and rationality of the overall equipment fault diagnosis.

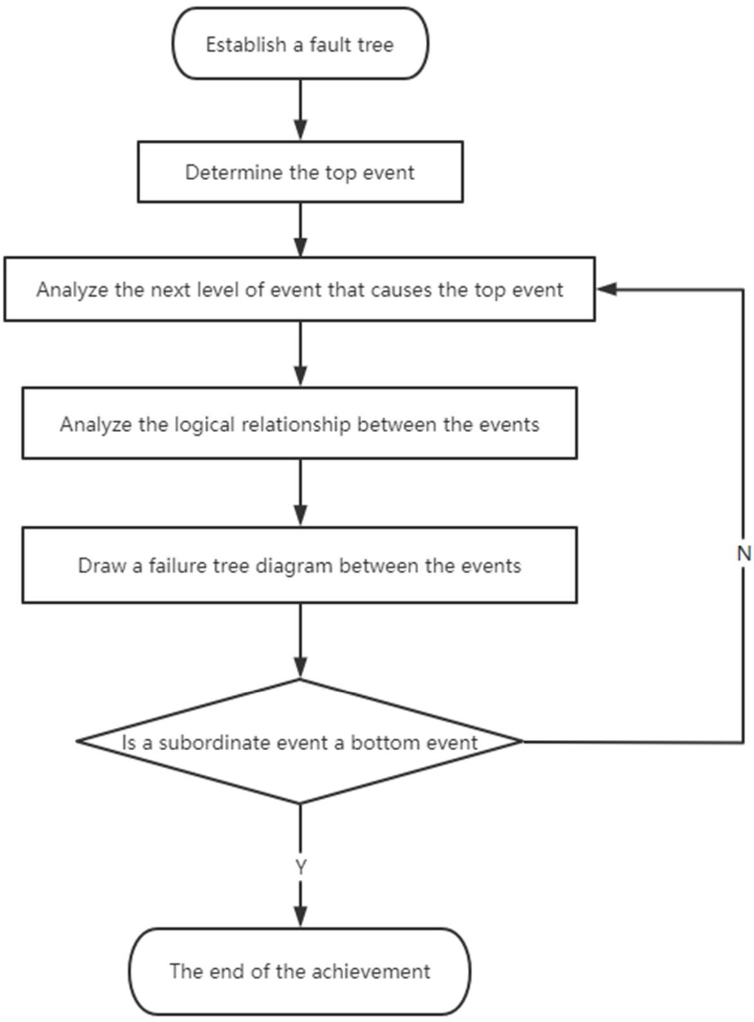

Figure 1. Failure tree building flow chart

The establishment step of the fault tree is as follows:

① determines the top event, first analyzes the most likely fault in the fault system, and then determines it as the top event according to the fault phenomenon displayed by the equipment.

② determines the intermediate event, breaks down the fault tree system layer by layer, analyzes the indirect causes of each layer, and sets it as an intermediate event.

③ determines the bottom event, analyzes the intermediate event, looks for the fault cause of each intermediate event, and sets it as the bottom event.

④ draws the failure tree, numbers each event according to the logical relationship between the top, intermediate, and bottom events obtained in the previous analysis, and then draws the failure tree map.

The steps for establishing the fault tree flowchart are shown in Figure 1.

Fault tree analysis can organically connect the various causes of failure of the host system, and clearly show the fault logic relationship between each events. It can be both qualitative analysis and quantitative analysis.

2.2 Qualitative Analysis of Fault Tree Analysis Method

The purpose of the qualitative analysis[5] is to find out the set of the most direct causes of the top events in the fault tree, namely the cut set of the events at the bottom of the fault tree.The cut set must satisfy a feature: any bottom event of a failure tree does not occur, then its top event does not occur.In the fault tree, the minimum cut set represents all possible top events in the entire fault system studied.

According to the steps of the fault tree establishment, first establish the fault tree structure diagram, as shown in Figure 2.

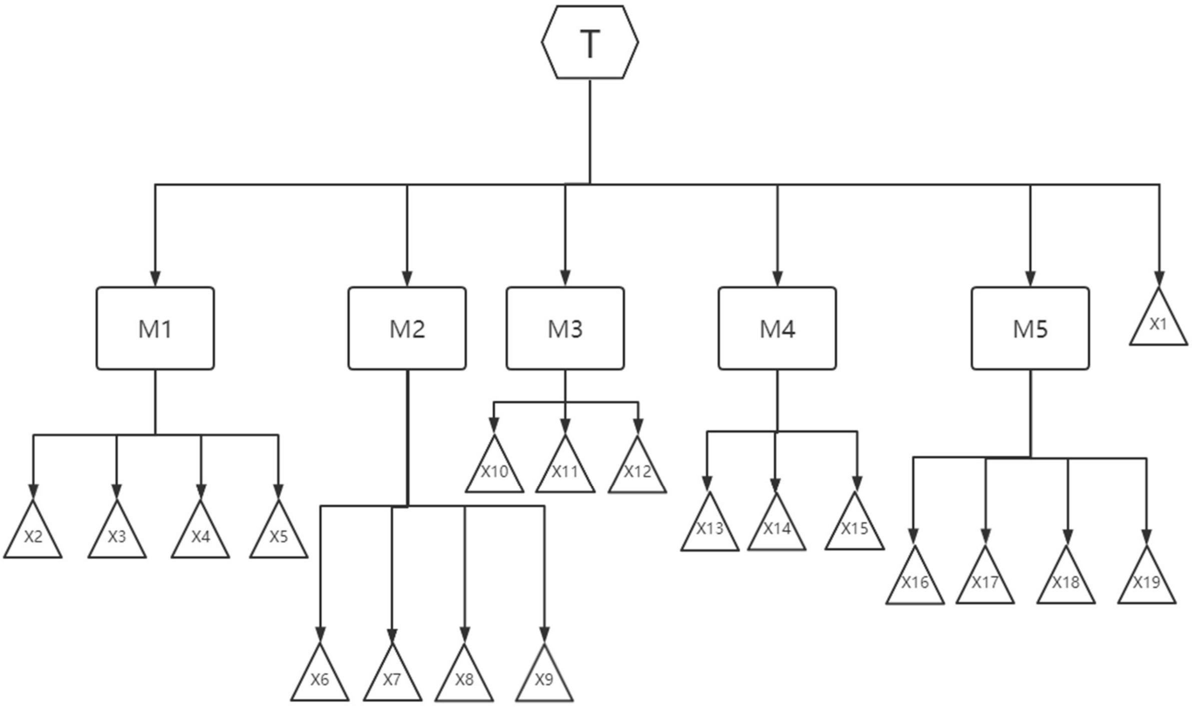

Figure 2. Fault tree structure diagram

The description of the graphical symbols in the failure tree is shown in Table 1.

ISSN: 2414-1895 DOI: 10.6919/ICJE.202207_8(7).0009

Table 1. Description of the fault tree symbol

symbol	name	meaning
	The top event	Equipment failure phenomenon
	Intermediate events	Indirect cause of the failure
	bottom event	The direct cause of the fault

According to the structure diagram of the fault tree, it can be clearly seen that in this fault system, T is the top event of the fault tree and the fault phenomenon of the equipment; the expanded M1, M2, M3, M4, M5, X1 are the intermediate events of the fault tree and the indirect cause of equipment failure; X2~X19 is the bottom event of the fault tree, which is the most basic and direct cause of equipment failure.Intermediate events can have many levels, and this paper only discusses the first-level case.

According to the logical relationship between events analyzed above, the Boolean algebraic mathematical relationship between various events is obtained:

Boolean algebraic mathematical relationships between top events and intermediate events:

$$T = M1 + M2 + M3 + M4 + M5 + X1$$

Boolean algebraic mathematical relations between intermediate and bottom events:

$$\begin{gathered} M1 = X2 + X3 + X4 + X5 \\ M2 = X6 + X7 + X8 + X9 \\ M3 = X10 + X11 + X12 \\ M4 = X13 + X14 + X15 \\ M5 = X16 + X17 + X18 + X19 \end{gathered}$$

In conclusion, the Boolean algebraic mathematical relationship between top events and bottom events is obtained:

$$T = \sum_{i=1}^{i=19} X_i$$

It is follows that the minimum cut set in the engine fault system:

$$X = \{X1, X2, X3, X4, X5, X6, X7, X8, X9, X10, X11, X12, X13, X14, X15, X16, X17, X18, X19\}.$$

2.3 Quantitative Analysis of Fault Tree Analysis Method

The quantitative analysis[6] of fault tree refers to the calculation of equipment failure occurrence probability with scientific and reliable data, mainly including the quantitative analysis of the fault incidence of bottom events and top events.

ISSN: 2414-1895 DOI: 10.6919/ICJE.202207_8(7).0009

The fault tree of the engine is analyzed quantitatively, and the failure rate of the parts corresponding to the bottom event X_i is set as λ_i, in which the failure probability of the non-processed parts is calculated and evaluated by the expert experience, and the processed parts are obtained by the failure rate provided by the manufacturer.The occurrence probability of bottom event X_i can be obtained by the failure rate of the parts in the reliability estimation results, and the calculation formula of the occurrence probability of bottom event F_i is shown in Equation (1):

$$F_i = 1 - e^{-\lambda_i t} \tag{1}$$

Among: λ_i-Part failure corresponding to bottom events;

t-Device running time / h.

The calculation formula of the failure probability of the top event F_s is shown in formula (2):

$$F_s = 1 - \prod_{i=1}^{n} (1 - F_i) \tag{2}$$

Among: F_i-Failure incidence of corresponding bottom events;

n-Number of bottom events in the fault tree.

According to the established fault tree diagram, firstly input the service time t and the failure rate λ_i and obtain the failure probability of bottom event F_i through the above formula (1), and then calculate the occurrence probability of top event F_s according to the failure probability of formula (2).

3. Application of Fault Tree Analysis in Fault Diagnosis of Ship Engine Equipment

According to the above, the most important step in applying the fault tree analysis method is the establishment of the fault tree, analyze the cause of the engine equipment fault, and establish the engine fault tree according to the fault tree establishment principle as shown in Figure 3.

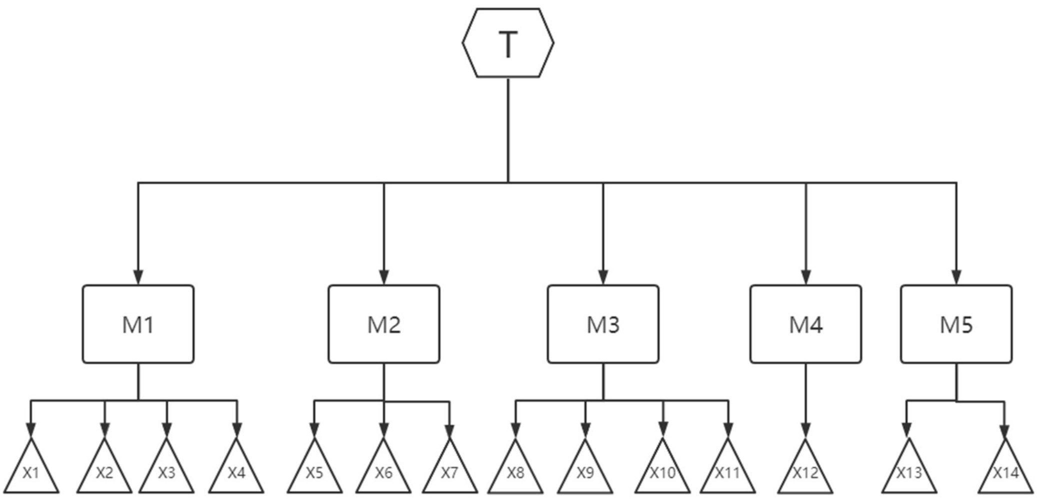

Figure 3. Engine fault tree

ISSN: 2414-1895 DOI: 10.6919/ICJE.202207_8(7).0009

The meaning of the number corresponding to the fault tree in Figure 3 is shown in Table 2.

Table 2. Fault tree number meaning

number	meaning	number	meaning
T	engine failure	X5	The Engine is in shutdown mode
M1	The generator is not stopped normally	X6	Start lock activation
M2	The engine does not respond to the start request	X7	System shutdown to check the fault
M3	Engine stall or lost load	X8	Engine overload
M4	The engine active power is too low	X9	Fuel supply is insufficient
M5	Engine reactive power is too high	X10	Insufficient pressurized air supply
X1	The injection pump is damaged	X11	Fuel link failure
X2	Remote control downtime is damaged	X12	Voltage and frequency is unstable
X3	Oil leakage	X13	The active power suddenly decreases
X4	System shutdown fails	X14	Excitation is out of control

3.1 Qualitative Analysis

On the basis of the qualitative fault analysis[7] of the fault tree, there are five indirect causes of the top event T engine fault in the fault tree: engine failure (M1), engine no response to start request (M2), engine stall or loss of load (M3), engine active power (M4), engine reactive power (M5).Among the indirect causes of engine failure, each cause has one or more direct causes of engine failure.

There are four reasons why the engine is not stop normally (M1), namely injection pump damage (X1), remote control shutdown damage (X2), oil leakage (X3), and system shutdown failure (X4).The reasons why the engine does not respond to the startup request are: the engine is in the shutdown mode (X5), the startup lock activation (X6), and the system shutdown check fault (X7).The causes of engine stall or load loss are: engine overload (X8), insufficient fuel supply (X9), insufficient pressurized air supply (X10), and fuel link failure (X11).The low active power is the unstable voltage frequency (X12).Excessive reactive power is due to a sudden decrease of active power (X13) or uncontrolled excitation (X14).

Thus one can obtain the cut set of the fault tree $M=\{M1, M2, M3, M4, M5\}$, The minimum cut set of the fault tree is:

$$X=\{X1, X2, X3, X4, X5, X6, X7, X8, X9, X10, X11, X12, X13, X14\}$$

3.2 Quantitative Analysis

After the qualitative analysis of the engine fault tree, the quantitative analysis is to calculate the probability of the engine system failure with specific numerical and scientific methods.According to the results of the qualitative analysis, the minimum cut set of the fault tree is the most direct cause of the engine system failure[8].

The minimum cut set is divided into two groups $\{X1, X2, X4, X5, X6, X7, X14\}$, one for processed parts and for non-processed parts $\{X3, X8, X9, X10, X11, X12, X13\}$ .The part inefficiency of processing equipment is provided by the processing plant, and the inefficiency of non-processed equipment is obtained based on expert diagnostic experience.The inefficiency of the equipment corresponding to the bottom event is shown in the table. Assuming that the engine running time t is 10h, the failure incidence of each bottom event is calculated according to formula (1), and the results are shown in Table 3.

Table 3. Part failure efficiency corresponding to bottom events and failure incidence of bottom events

number	failure cause	failure rate	$F_i = 1 - e^{-\lambda_i t}$
X1	The injection pump is damaged	0.036	0.3023
X2	Remote control downtime is damaged	0.0325	0.2775
X3	Oil leakage	0.0405	0.3330
X4	System shutdown fails	0.0255	0.2251
X5	The Engine is in shutdown mode	0.024	0.2134
X6	Start lock activation	0.028	0.2442
X7	System shutdown to check the fault	0.0375	0.3127
X8	Engine overload	0.022	0.1975
X9	Fuel supply is insufficient	0.029	0.2517
X10	Insufficient pressurized air supply	0.0315	0.2702
X11	Fuel link failure	0.0245	0.2173
X12	Voltage and frequency is unstable	0.0195	0.1772
X13	Active power suddenly decreases	0.026	0.2289
X14	Excitation is out of control	0.0275	0.2404

After obtaining the failure rate of each bottom event, apply formula (2) to calculate the failure rate of the top event[9]:

$$
\begin{aligned}
F_s &= 1 - \prod_{i=1}^{n}(1 - F_i) \\
&= 1 - (1 - F_1) \bullet (1 - F_2) \bullet (1 - F_3) \bullet \cdots \bullet (1 - F_{14}) \\
&= 0.9824
\end{aligned}
$$

4. Conclusion

This paper makes the diagnosis of ship engine fault based on fault tree analysis. The diagnosis principle of fault tree analysis is to analyze the fault system from top to bottom to find the fault cause. Firstly, predict the engine faults, give the fault tree diagram, then analyze the engine fault tree system layer by layer to find the minimum cut set, in the engine fault tree system, in the fault tree system, and calculate the fault rate of the top events of the fault tree using a scientific and reasonable formula. The fault tree analysis method can effectively analyze the engine fault system, which plays a substantial role in the process of engine system fault maintenance, greatly reduces the time of fault diagnosis, and improves the efficiency of engine fault diagnosis.

Acknowledgments

Natural Science Foundation.

ISSN: 2414-1895 DOI: 10.6919/ICJE.202207_8(7).0009

References

[1] Lu thriving. The Bogie System Reliability Model and the T-S Polymorphic Failure Tree Analysis [D]. Southwest Jiaotong University, 2020.

[2] Dong Chen. Research on ship engine fault diagnosis system [D]. Harbin University of Science and Technology, 2019.

[3] Zhao Wei. Research on Monitoring and Failure Diagnosis of Marine Diesel Engine [D]. Dalian Maritime University, 2006.

[4] White Green Case Day. A Quantitative Analysis Method for Configurable Dynamic Fault Tree Research [D]. Dalian Maritime University, 2020.

[5] and by Libin Wang. Diagnosis of engine overheating fault by fault tree analysis [J]. Automobile Repair and Maintenance, 2021, (04): 54-55.

[6] Haitao Zhang. Ship engine fault analysis based on on-line fluid monitoring [J]. Mechanical Design and Manufacturing Engineering, 2020,49 (03): 113-116.

[7] Luo Xinchang. Reliability analysis of diesel engine based on fuzzy fault tree and event tree [D]. Jiangxi University of Science and Technology, 2013.

[8] Chen Yuezhou, Tan Lin, Xing Weiyan, Liu Dong. A new qualitative analysis method of the fault tree [J]. Computer Engineering, 2008, (13): 67-69.

[9] Fan Yaqiong, and Haiyan, Chen. Qualitative analysis model of state event failure tree based on sequential logic [J]. Computer Technology and Development, 2017,27 (08): 12-15 + 19.