ATLANTIS PRESS
Advances in Engineering Research, volume 204
Proceedings of the 2021 10th International Conference on Applied Science, Engineering and Technology (ICASET 2021)

Research on Fault Diagnosis of Marine Refrigeration System Based on Fault Tree Analysis

Zhao-qiang Li[1, a*], Xue-gang Zhao[1, b], Zhi-qiang Zhao[1, c] and Bao-cheng Lu[1, d]

[1] *Binzhou Polytechnic, Binzhou, Shandong 256600, China*
[*]*Corresponding author. Email: 474637466@qq.com*

ABSTRACT
Aiming at the fault phenomenon of "the temperature of food cold storage does not meet the standard" in the fault of ship refrigeration system, based on the analysis of its possible fault factors, a fault tree model is established, which can improve the speed of finding and troubleshooting; At the same time, based on the fault tree model, the influencing factors of the top event of the model are classified and sorted by using the analytic hierarchy process, and the target layer, criterion layer and index layer are divided. According to the relevant data, the weighted assignment of each influencing factor is carried out, and the modeling calculation is carried out by using the AHP calculation software to obtain the influence weight of each fault factor on the top event, some suggestions on the management of marine refrigeration system are put forward.
Keywords: *Fault Tree Analysis, Analytic Hierarchy Process, Ship Refrigeration System, Diagnosis*

1. INTRODUCTION

Modern ocean going ships have large tonnage and long sailing time, so they need to carry a large amount of food, so they also need to be equipped with cold storage for food storage. In addition, ocean going ships sail in different navigation areas around the world, with changeable climate and temperature. In order to improve the comfort of crew and passengers, they also need to be equipped with air conditioning devices. At present, the most common refrigeration method used in ships is compression refrigeration, and piston compression is mainly used in compressors.

Marine engineers have systematically studied the ship's refrigeration system during the competency training of marine ship crew, but it is only limited to the study of theoretical knowledge and the training of simple disassembly and assembly operation skills. Once the refrigeration system on the ship fails, because there is no maintenance experience and scientific fault diagnosis method, most crew members overhaul the refrigeration equipment through the instructions. What they can do is generally to supplement the refrigerant and replace the filter element. They cannot effectively eliminate complex faults, which affects the stable operation of the ship's refrigeration and air conditioning system. In this paper, the fault tree analysis method is used to diagnose the fault of marine refrigeration system, in order to provide a reference for the fault diagnosis, maintenance and repair of marine refrigeration system.

2. THE PRINCIPLE OF REFRIGERATION SYSTEM OF SHIP FOOD COLD STORAGE

As shown in Figure 1 below, it is the schematic diagram of the refrigeration system of a ship's catering cold storage. The refrigeration system is powered by com28 open piston refrigeration compressor and started by multi-stage unloading. The refrigerant is R22 Freon, with a high-temperature vegetable warehouse (3 ℃ ~ 5 ℃) and a low-temperature meat warehouse (- 23 ℃ ~ 26 ℃). The condenser is cooled by seawater, the evaporator is air-cooled, and two fans with power of 80W are installed.

In this system, the normal temperature liquid refrigerant flickers and evaporates in the evaporator, absorbs the heat in the cold storage, and then enters the piston refrigeration compressor through the suction valve. After the compression of the compressor, the refrigerant changes from low-temperature gaseous state to high-temperature gaseous state, enters the condenser from the discharge valve, and becomes normal temperature liquid after being cooled by seawater in the condenser, Through the throttling and depressurization of the expansion valve, it becomes low-pressure wet steam and enters the evaporator to evaporate and absorb heat again, so as to complete a working cycle.

During the operation, it is found that the refrigeration system can operate normally, but the temperature of the low-temperature warehouse cannot be reduced to the set value within the specified time. The refrigeration effect cannot meet the design requirements for two reasons: one is that the heat load of the cold storage is too large, and the other is that the refrigeration capacity is insufficient. However, there may be many reasons for the faults in the above two aspects, which need to be eliminated one by one, which is very time-consuming and laborious.

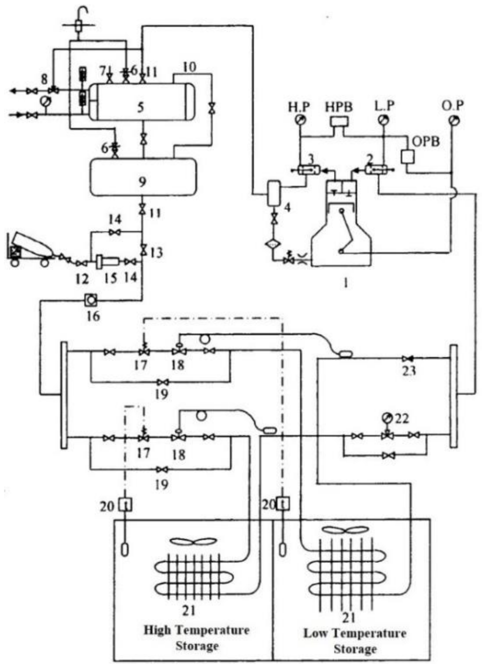

Fig. 1 Schematic diagram of refrigeration system of a ship's food cold storage

1-Compressor; 2-Suction valve; 3-Discharge valve; 4-Oil separation equipment; 5-Condenser; 6-Safety valve; 7-Vent valve; 8- Water volume regulating valve; 9-Reservoir; 10-Balance pipe; 11-Stop valve (13 and 14 are the same); 12-Filling valve; 15-Drying filter; 16-Liquid sight glass; 17-Liquid supply solenoid valve; 18-Thermal expansion valve; 19-Manual throttle valve; 20-Temperature controller; 21-Evaporator; 22-Evaporation pressure regulating valve; 23-Check valve.

3. BUILD FAULT TREE MODEL

3.1. Introduction to fault tree model

Fault tree analysis, or fault tree analysis, can also be abbreviated as FTA. It is a failure cause analysis method deduced from top to bottom. It mainly uses the low-order events combined by Boolean logic to analyze the causes of faults or failure phenomena in a system. Fat usually takes the most unexpected fault or failure phenomenon in the system as the top event for analysis, and then analyzes the secondary intermediate event leading to the top event around the top event, and so on until the lowest event leading to the failure is found down, At the same time, these events are connected by logical "and gate" and "or gate", and the fault tree model is constructed.

3.2. Construction of fault tree model for unqualified temperature of food cold storage

3.2.1. Determination of top event

We take a ship's "food cold storage temperature does not meet the standard" as the top event of the fault tree model. Under the top event, there are two subtrees: too large heat load of the cold storage and insufficient cooling capacity of the system, which are decomposed down in turn until the end event.

3.2.2. Determination of system boundary conditions

The function of system boundary is to clearly divide the boundary between the studied system and other systems, and then limit the boundary problem of fault tree research. In this paper, the boundary conditions of ship food cold storage are analyzed until the faulty parts, but the following factors are no longer studied carefully: faults outside the ship refrigeration system; Influence of human factors; "Congenital" faults caused by the design and installation of cold storage; Refrigerant failure; Drive motor failure; Impact of severe weather and ship environment, etc.

3.2.3. Construction of fault tree model

Based on the above top events and system boundaries, we build a fault tree model as shown in Figure 2 and table 1.

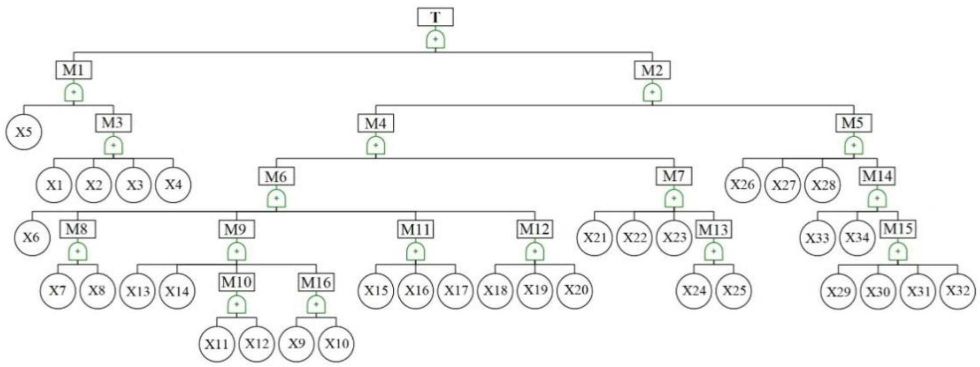

Fig. 2 Fault tree of unqualified food cold storage temperature

Table 1 Fault tree event symbols and names

Symbol	Fault Event
T	The temperature of food cold storage does not meet the standard
M1	Large heat load of cold storage
M2	Insufficient cooling capacity of the system
M3	The insulation effect of cold storage decreased
M4	Suction pressure too low
M5	Suction pressure too high
M6	High suction superheat
M7	The heat exchange capacity of evaporator decreases
M8	The condensing effect of condenser is too strong
M9	Poor flow of low-pressure pipeline
M10	Pipeline ice plug
M11	Expansion valve failure
M12	Too much oil in the system
M13	Evaporator fan failure
M14	Compressor speed decrease
M15	Drive motor speed drops
M16	Dirty and blocked pipeline
X1	Damaged insulation
X2	Damp failure of thermal insulation materials
X3	Poor sealing of cold storage door
X4	Excessive heat dissipation of drain hole
X5	New food has a lot of calories
X6	Insufficient refrigerant
X7	Large condensate flow
X8	The sea water temperature is too low
X9	Dirty filter
X10	High oil content of refrigerant
X11	Water in refrigerant
X12	Desiccant failure
X13	The liquid supply solenoid valve is damaged
X14	The liquid pipe valve is not fully opened
X15	Improper position of expansion valve
X16	The expansion valve is adjusted too tightly
X17	Expansion valve damaged
X18	Excessive oil addition
X19	The cylinder or piston ring is severely worn
X20	The piston oil scraper ring is installed reversely or broken
X21	Severe frosting of evaporator
X22	The evaporation pressure regulating valve is too tight
X23	Some parallel evaporators are disabled
X24	Motor fault
X25	Blade failure
X26	Leakage of compressor exhaust valve
X27	Compressor capacity regulating mechanism failure
X28	Compressor cylinder clearance is too large
X29	Power frequency drop
X30	Low supply voltage
X31	Drive shaft or pulley failure
X32	Motor bearing damaged
X33	Compressor piston jamming
X34	Compressor bearing failure

4. QUALITATIVE ANALYSIS OF FAULT TREE OF UNQUALIFIED TEMPERATURE IN FOOD COLD STORAGE OF REFRIGERATION SYSTEM

The structure of the fault tree is mainly composed of logic gates such as "and gate", "or gate" and "not gate". If the above basic events are independent events, we can use the Boolean algebra algorithms such as sum, product and complement of each event to calculate the fault function of the fault tree system.

In order to find out the most fault prone unit element of the refrigeration system, that is, the minimum cut set, minimum path set and structural importance of the fault tree model are obtained.

According to the result of the fault tree, according to the result of the fault tree, we've worked out from the result of the fault tree. According to the result of the fault tree, we've worked out the result of the fault tree. According to the result of the fault tree. According to the result of the fault tree, we've worked out that the minimal cut set of the fault tree is{X1} 、{X2} 、{X3} 、{X4} 、{X5} 、{X6} 、{X7} 、{X8} 、{X9} 、{X10} 、{X11} 、{X12}、{X13}、{X14}、{X15}、{X16}、{X17}、{X18}、{X19}、{X20}、{X21}、{X22}、{X23}、{X24}、{X25}、{X26}、{X27}、{X28}、{X29}、{X30} 、{X31} 、{X32} 、{X33} 、{X34}. It can be seen that for the refrigeration system, any of the above faults may lead to the substandard food cold storage of the refrigeration system. For newcomers to the marine engineer post, there is no way to start with similar faults, and further quantitative analysis is needed.

5. QUANTITATIVE ANALYSIS OF FAULT TREE OF UNQUALIFIED TEMPERATURE IN FOOD COLD STORAGE OF REFRIGERATION SYSTEM

We transform the fault tree model of unqualified food cold storage temperature into analytic hierarchy process model, arrange the independent events according to their failure rate per 10000 hours from high to low, and input the analytic hierarchy process software to obtain the corresponding fault tree model. The quantitative analysis is shown in table 2-table 11 below.

Table 2 ranking weight of elements in the middle layer to decision objectives

Ranking weight of elements on decision objectives in the first middle layer		Ranking weight of elements on decision objectives in the second middle layer		Ranking weight of elements on decision objectives in the third middle layer	
Middle layer elements	weight coefficient	Middle layer elements	weight coefficient	Middle layer elements	weight coefficient
M2	0.8571	M4	0.6429	M7	0.3214
M1	0.1429	M5	0.2143	M6	0.3214
		M3	0.1143	M14	0.0261

Table 3 Judgment matrix and weight value of criterion layer (M1, M2) relative to T

T Consistency ratio: 0.0000; Specific gravity in T：1.0000; λmax: 2.0000

T	M1	M2	Wi
M1	1.0000	0.1667	0.1429
M2	6.0000	1.0000	0.8571

Table 4 Judgment matrix and weight value of criterion layer (M3, M5) relative to T

T Consistency ratio: 0.0000; Specific gravity in T：0.1429; λmax: 2.0000

M1	X5	M3	Wi
X5	1.0000	0.2500	0.2000
M3	4.0000	1.0000	0.8000

Table 5 Judgment matrix and weight value of criterion layer (M4, M5) relative to M2

T Consistency ratio: 0.0000; Specific gravity in T：0.8571; λmax: 2.0000

M2	M4	M5	Wi
M4	1.0000	3.0000	0.7500
M5	0.3333	1.0000	0.2500

Table 6 Judgment matrix and weight value of index layer (X1, X2, X3, X4) relative to M3

M3 Consistency ratio: 0.0967; Specific gravity in T：0.1143; λmax: 4.2581

M3	X1	X2	X3	X4	Wi
X1	1.0000	0.2500	0.3333	1.0000	0.1107
X2	4.0000	1.0000	0.2500	3.0000	0.2659
X3	3.0000	4.0000	1.0000	5.0000	0.5276
X4	1.0000	0.3333	0.2000	1.0000	0.0957

Table 7 Judgment matrix and weight value of index layer (M6、M7) relative to M4

M4 Consistency ratio: 0.0000; Specific gravity in T：0.64293; λmax: 2.0000

M4	M6	M7	Wi
M6	1.0000	1.0000	0.5000
M7	1.0000	1.0000	0.5000

Table8 Judgment matrix and weight value of index layer (M14、X26、X27、X28) relative to M5

M5 Consistency ratio: 0.0444; Specific gravity in T：0.2143; λmax: 4.1185

M5	X26	X27	X28	M14	Wi
X26	1.0000	3.0000	7.0000	5.0000	0.5579
X27	0.3333	1.0000	5.0000	3.0000	0.2633
X28	0.1429	0.2000	1.0000	0.3333	0.0569
M14	0.2000	0.3333	3.0000	1.0000	0.1219

Table9 Judgment matrix and weight value of index layer (X6~X8、X14、M16、X13、M11、X11) relative to M6

M6 Consistency ratio: 0.0863; Specific gravity in T：0.3214; λmax: 8.8520

M6	X6	X7	X8	X14	M16	X13	M11	X11	Wi
X6	1.0000	3.0000	4.0000	9.0000	5.0000	7.0000	8.0000	6.0000	0.3570
X7	0.3333	1.0000	2.0000	7.0000	4.0000	6.0000	7.0000	5.0000	0.2143
X8	0.2500	0.5000	1.0000	7.0000	3.0000	5.0000	6.0000	4.0000	0.1592
X14	0.1111	0.1429	0.1429	1.0000	0.2000	0.2500	0.3333	0.2000	0.0200
M16	0.2000	0.2500	0.3333	5.0000	1.0000	4.0000	5.0000	3.0000	0.1018
X13	0.1429	0.1667	0.2000	4.0000	0.2500	1.0000	3.0000	0.3333	0.0468
M11	0.1250	0.1429	0.1667	3.0000	0.2000	0.3333	1.0000	0.2500	0.0303
X11	0.1667	0.2000	0.2500	5.0000	0.3333	3.0000	4.0000	1.0000	0.0706

Table10 Judgment matrix and weight value of index layer (X21~X25) relative to M7

M7 Consistency ratio: 0.0542; Specific gravity in T：0.3214; λ max: 5.2426						
M7	X21	X22	X23	X24	X25	Wi
X21	1.0000	3.0000	5.0000	7.0000	9.0000	0.5028
X22	0.3333	1.0000	3.0000	5.0000	7.0000	0.2602
X23	0.2000	0.3333	1.0000	3.0000	5.0000	0.1344
X24	0.1429	0.2000	0.3333	1.0000	3.0000	0.0678
X25	0.1111	0.1429	0.2000	0.3333	1.0000	0.0348

Table11 Judgment matrix and weight value of index layer (M14、M15、X33、X34) relative to M14

M14 Consistency ratio: 0.0313; Specific gravity in T：0.0261; λ max: 3.0326				
M14	X34	X33	M15	Wi
X34	1.0000	0.3333	0.1429	0.0853
X33	3.0000	1.0000	0.2500	0.2132
M15	7.0000	4.0000	1.0000	0.7014

At the same time, in order to ensure the accuracy of matrix calculation, the consistency of each matrix table is checked, which is qualified and effective.

Therefore, we get the weight value and histogram of the influence of various factors in the standard layer and index layer on the unqualified temperature of the cold storage, as shown in Table 12 and figure 3.

Table 12 Influence weight of each fault factor on top event

Failure Factors	Weight Coefficient	Failure Factors	Weight Coefficient
X21	0.1616	X11	0.0227
X26	0.1195	X24	0.0218
X6	0.1147	M15	0.0183
X22	0.0836	X13	0.0150
X7	0.0689	X1	0.0127
X3	0.0603	X28	0.0122
X27	0.0564	X25	0.0112
X8	0.0512	X4	0.0109
X23	0.0432	M11	0.0097
M16	0.0327	X14	0.0064
X2	0.0304	X33	0.0056
X5	0.0286	X34	0.0022

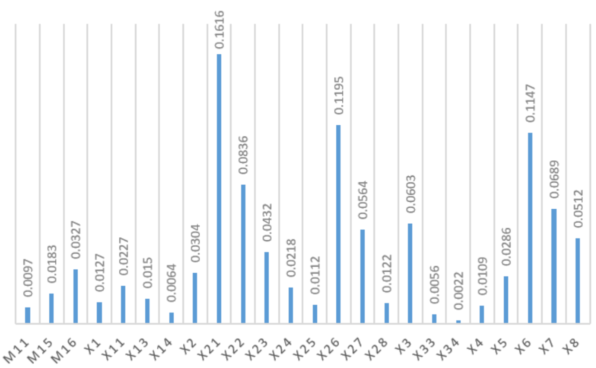

Fig. 3 Histogram of influence weight of each fault factor on top event

It can be clearly seen from the figure that the first five fault factors that are most prone to failure are severe frost on X21 evaporator, leakage of x26 compressor exhaust valve, too tight X22 evaporation pressure regulating valve, insufficient X6 refrigerant and too large X7 condensate flow. Therefore, special attention should be paid to the factors that have a great impact on system failure in daily maintenance, For example, defrost the evaporator of the cold storage frequently to ensure that the fan is not affected, and check the flow and temperature of condensate in time. After the fault occurs, according to the fault phenomenon, combined with the fault tree, we can quickly find the relevant factors.

6. CONCLUSION

There are many fault finding methods for marine mechanical equipment system. On the one hand, the fault diagnosis method based on fault tree model can make qualitative analysis on the system. Secondly, combined with analytic hierarchy process, it is also convenient to have a more intuitive understanding of the proportion of influencing elements in the system. The combination of the two can not only ensure the accuracy of failure fault diagnosis, At the same time, it can also simplify the search process of failure fault. Saving manpower and material resources and improving the speed of troubleshooting are conducive to improving the safety and economy of ships.

REFERENCES

[1] Zhu Daqi, Yu Shenglin. Diagnosis Approach Based on Minimal Cut Sets of Fault Trees[J]. Journal of Data Acquisition & Processing,2002(03):341-344.

[2] XU Rong , CHE Jian-guo , YANG Zuo-bin，ZUO Xiao-yong. The Fault Tree Analysis and Its Application in the system Reliability Analysis [J]. Command Control & Simulation,2010,32(01):112-115.

[3] GAO Jian Feng, ZHENG Yu, NI Kai, LI Yanju. Analysis of the Causes of Liquefied Gas Leakage Accidents in Tank Truck Area Based on Fault Tree-Analytic Hierarchy Process [J] Oil-Gas Field Surface Engineering, 2021,40(03):44-49.

[4] WEI Yong. Fault Tree Analysis for the Tripping of the Circuit Breaker in Normal Power Plant of Ship [J]. SHIP＆OCEAN ENGINEERING,2008(04):22-24.

[5] WU Qian-qian, WANG Zhi, DONG He. Fault tree analysis and its application to marine diesel fault analysis [J]. Machinery Design & Manufacture, 2009(01): 77-78.

[6] H. Zu, Y. Chang, H. Li, et. al., Modulating the Transport Properties of Metal Oxide Nanofibers Transistors by Controlling the Grain Size. IEEE Electron Device Letters. 42.6(2021)855-858.

[7] P. Xu; N. Na; S. Gao; C. Geng, Determination of sodium alginate in algae by near-infrared spectroscopy, Desalination and Water Treatment, 168(2019)117-122.

[8] P. Xu, N. Na, Study on Antibacterial Properties of Cellulose Acetate Seawater Desalination Reverse-Osmosis Membrane with Graphene Oxide, Journal of Coastal Research, 105(2020)246-251.

[9] H. Li, P. Xu, D. Liu, J. He, H. Zu, J. Song, J. Zhang, F. Tian, M. Yun and F. Wang, Low-voltage and fast-response SnO2 nanotubes/perovskite heterostructure photodetector, Nanotechnology, 32(2021)375202.

[10] L. Huang, Z. Xiong, X. Zeng, Z. Zhao, Y. Cao, Y. Xia. The Synthesis and Characterizations of Water-soluble Two-photon Polymerization Photoinitiator and Its Applications for 3D Hydrogel Microfabrication, Journal of Applied Science and Engineering Innovation,7(2020)8-12.