Analysis and research on engine room fire based on accident cases

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Abstract

Based on 100 actual cases of ship engine room fire accidents, this paper mainly analyzes the causes of engine room fire in the accident cases, and draws a fishbone diagram of engine room fire causes, analyzes the time of engine room fire, ship position, fire extinguishing measures, loss and casualties, and puts forward the measures to prevent engine room fire.

1. Introduction

With the development of world economy, shipping industry is developing well, and water transportation is increasingly busy. At the same time, the frequency, loss and casualty of ship fire accidents are increasing. According to relevant research data, ship fire accidents account for about 11% of ship accidents, and engine room fires account for more than 75% of the total number of ship fires[1,2]. Ship engine room fire has the characteristics of heavy load, rapid spread, high difficulty in detection and rescue, large loss and casualties, etc. It is an important factor affecting the safety of ships and personnel, and has attracted more and more attention from management and researchers[2].

The statistics of ship engine room fire accidents from 1960s to 1970s show that 26 of 53 fire accidents occurred in engine room area. The statistics of ship fire accidents not caused by war in the British Royal Navy from 1969 to the following 15 years show that among 116 fire accidents, there were 53 accidents of engine room fire[3].

According to the statistics of The Australian Transport Safety Bureau (ATSB), from 2005 to 2010, there were 546 ship accidents in Australian waters, including 69 ship fire and explosion accidents, accounting for about 12.6%, and the frequency of occurrence is relatively stable every year[4].

According to the statistics of The Japan Transport Safety Agency (JTSB), in the five years from 2017 to 2021, the JTSB counted 3,635 ship accidents of various types, including 136 ship fire and explosion accidents, accounting for about 3.7 percent.

In the Yangtze River, engine room fires account for more than 50% of ship fires, and ship fire accidents occur frequently.

From 2005 to 2020, a total of 29 fire accidents occurred in Zhoushan waters, including 22 minor accidents and 7 ordinary accidents. Six people died or missing. In terms of time, there were 11 fires in the hot season from July to September, accounting for about 38% of the total. The proportion of fire accidents in engine room is relatively high, which accounts for about 55% of the total number of fire accidents on average.

In 2016, the 96th session of the IMO Maritime Safety Committee adopted a proposal by the China Maritime Safety Administration on “improving seafarers' training and education through effective use of lessons learned from accidents”. According to the proposal, the IMO Sub-committee on implementation (responsible for maritime investigation) and the Sub-Committee on Human element, Training and Watchkeeping (responsible for seafarers' training and education) will establish a systematic coordination mechanism for their work. The Sub-Committee on Human element, Training and Watchkeeping will make effective use of the lessons learned

from the accident summarized by the Sub-Committee on implementation to improve the training and education system for seafarers with a view to avoiding the recurrence of similar accidents.

Marine Engineering College of Dalian Maritime University offers the course“ Marine Engineering Case Analysis” and has set up a teaching and research team for the course. The team has been committed to the teaching and research of marine engineering case analysis. It has taught the course of Marine Engineering Case Analysis for many undergraduates, and officially published a textbook of Marine Engineering Case Analysis. In the process of collecting and studying marine engineering cases for many years, the author found that the ship engine room fire accidents occurred frequently, resulting in relatively large property and casualty losses. Therefore, the author has been focusing on collecting and sorting out the cases of ship engine room fire, and has carried out in-depth research on these cases, in order to summarize the causes of ship engine room fire accidents and other influencing factors, and discuss the prevention measures to prevent the occurrence of ship engine room fire accidents.

This paper studies a total of 100 actual accident cases of ship engine room fire, all of which are from official data, most of which are from accident case investigation reports of MAIB, ATSB, JTSB, Hong Kong Marine Department and China Maritime Safety Administration, and a small number of accident case data are from scientific papers. Therefore, the research data of this paper is reliable and the research conclusion has certain reference value.

2. Case study of ship engine room fire accident

2.1 Cause analysis of engine room fire

Based on the analysis of 100 actual cases of engine room fire, the causes of engine room fire can be summarized into six categories: ① Fuel leakage contact with high temperature surface; (2) Mechanical failure; ③ Operation error; (4) Electrical failure; ⑤ Illegal hot work; ⑥ Improper accumulation of inflammables.

2.1.1 Fuel leakage contact with high temperature surface

There were 46 fires accidents in engine room caused by fuel leakage contacting with high temperature surface, including 19 main engine leakage fires, 13 auxiliary engine leakage fires, 7 thermal oil boiler leakage fires, 6 hydraulic oil leakage fires and 1 oil tank leakage fire. Fuel leakage is mainly in the form of pressure spatter and dripping, of which pressure spatter is the majority, a total of 32 cases. Fuel leakage mainly comes from engine room fuel oil, lubricating oil, hydraulic oil. The main causes of fuel leakage can be divided into pipeline failure, connector failure, seal failure and pressure control valve failure. The forms and causes of various fuel leakage are shown in Table 1. High temperature surface is the ignition source of leaking fuel, mainly refers to the exposed high temperature surface of diesel engine exhaust pipe and turbocharger.

Table 1 Fuel leakage form and cause statistics

Leakage form	Pipeline failure			Seal failure			Connector failure			Pressure control valve failure	
Reason	Wear through	Welding failure	Crack	Shaft seal failure	Gasket failure	Seal ring failure	Thread connector or compression fitting failure	Flange failure	Bolt failure	Pressure regulating v/v failure	Safety v/v failure
Times	3	2	11	2	2	1	9	9	4	2	1

A total of 16 engine room fires were caused by pipeline failure, mainly in the form of wear through, welding failure, crack, etc. Wear through refers to the perforation caused by vibration wear of the components in contact with the pipeline. There are 3 cases in total. Welding failure refers to the welding damage caused by poor welding quality, there are 2 cases in total. The main causes of pipeline cracks include corrosion, high pressure, fatigue, material defects, etc., with a total of 11 cases.

Seal failure refers to the failure of the shaft seal, gasket or sealing ring in the power line system, which caused a

total of 5 engine room fires.

Connector failure includes three main forms: thread connector or compression fitting failure, flange failure and bolt failure. This kind of failure resulted in 22 fires in engine room, including 9 failures of thread connector or compression fitting failure, 9 failures of flange and 4 failures of bolt. Thread connector or compression fitting failure mainly show failure of such joints connecting instruments and meters, while bolt failure only shows loosening and fracture of bolts.

Pressure control valves in pipelines mainly include back pressure valves, pressure regulating valves, safety valves, etc. High pressure caused by pressure control valve failure will cause damage to pipeline connectors or seals, and may also cause pipeline rupture, resulting in 3 engine room fire accidents in total.

2.1.2 Mechanical failure causing engine room fire

A total of 13 engine room fires were caused by mechanical failures. In this paper, the mechanical failures causing engine room fire mainly include crankcase or turbocharger explosion, cylinder gas leakage, boiler dry burning, generator coil short circuit, oil pump bearing high temperature and so on. There were 4 engine room fires caused by crankcase explosion, involving two types of equipment: diesel engine and air compressor, including 3 diesel engine crankcase explosion fires and 1 air conditioning compressor crankcase explosion fires. The main causes of diesel engine crankcase explosion are the fracture of moving parts (piston, connecting rod and connecting rod bolt) and bearing overheat. The fracture of moving parts will break the crankcase, resulting in oil and gas leakage, and the oil and gas will be ignited by the energy generated by fierce collision. Overheating of bearings will cause excessive oil and gas concentration in the crankcase, and the oil and gas will ignite on the high-temperature bearing surface, resulting in explosion. The reason of the air conditioning compressor crankcase explosion is that the air enters the crankcase (the low-voltage relay fails), and the cylinder block temperature rising, causing the oil and gas explosion in the crankcase. There were two fire accidents caused by cylinder gas leakage, which were caused by fitting bolt breakage of starting valve and cylinder head gasket failure. Dry burning of boiler caused 2 fire accidents in engine room, and 1 oil fired auxiliary boiler and 1 exhaust gas boiler respectively. High temperature of bearing of oil pump caused 2 fires. Bearing high temperature led to damage of mechanical shaft seal, fuel leakage occurred and ignited by hot bearing. Other causes caused 1 engine room fire each. See Table 2 for details of fire caused by mechanical failure.

Table 2 Statistics of engine room fire caused by mechanical equipment failure

Failure form	Crankcase explosion		Cylinder gas leakage		Boiler fire		Pump fire	T/C explosion	Generator fire	Main engine surface fire
Reason	Diesel engine moving parts fracture or bearing overheat	Air enters a/c compressor crankcase	Start v/v fitting bolt breakage	Cylinder head gasket failure	Short of water and the combustion protection control failure	Soot fire due to water shortage of e.g.b.	Shaft seal damage due to high temperature of bearing	Scavenge box fire	Generator coil short circuit due to overspeed caused by governor failure	Surface oil stain ignited by high temperature of oil mist detector
Times	3	1	1	1	1	1	2	1	1	1

2.1.3 Operation error causing engine room fire

Among the 100 engine room fires, 22 were caused by operational errors. The reasons of engine room fire caused by operational error include: ① Fuel oil tank overflows caused by oil transferring and fuel oil contacts with ignition source, a total of 4 cases; ② Improper maintenance of boiler burners resulted in furnace flareback and explosion, a total of 6 cases; (3) Fuel leaks and contacts with ignition source caused by operation error during disassembly and assembly, a total of 6 cases; ④ Illegal installation of non marine equipment causing overload fires, a total of 2 cases; (5) Electrical failure in detection resulting in explosion of power distribution board, 1 case in total; ⑥ Improper filling refrigerant (air) causing 2 explosions in total; ⑦ Combustible gas generated from boiler chemical cleaning encounters ignition source, 1 case in total. The specific situation of fire

caused by operation error is shown in Table 3.

Table 3 Statistics of engine room fire caused by operation error

Error form	Fuel tank overflow	Improper boiler maintenance	Incorrect disassembly and assembly	Illegal equipment installation		Electrical detection error	Improper filling refrigerant (air)		Boiler cleaning operation error
Reason	Transferring operation error, oil overflow contacts hot surface	Fuel leakage due to improper burner maintenance causing furnace explosion	Fuel leakage contacts hot surface due to incorrect disassembly and assembly	Illegal installation of non marine generator, resulting in overload and fire	Illegal installation of sampling valve leads to fuel leakage and fire on the hot surface	Short circuit caused by checking main switch voltage, resulting in explosion of distribution board	Air conditioning compressor explosion due to incorrect oxygen filling into system	Air compressor explosion caused by high pressure gas of respirator cylinder during charging	Hydrogen produced by boiler chemical cleaning explodes when encountering hot lamp
times	4	6	6	1	1	1	1	1	1

2.1.4 Electrical failure causing engine room fire

A total of 9 engine room fires were caused by electrical failure. The reasons include: (1) The control failure of electric heater ignited fuel gas, a total of 2 cases; ② Electrical components short circuit ignites combustibles, a total of 5 cases; ③ Electrical components overload ignites combustibles, a total of 2 cases. See Table 4 for details of fire caused by electrical failure.

Table 4 statistics of engine room fire caused by electrical failure

Failure form	Fuel-air mixture explosion	Short circuit fire			Switchboard fire	Switchboard explosion
Reason	Failure of electric heater of fuel oil settling tank	Short circuit of generator battery ignites combustibles due to corrosion and wear	Short circuit of oil separator control box ignites oil stain below	Engine room cable aging short circuit ignites combustibles	Mechanical failure of generator circuit breaker causes ignition of distribution board	The dielectric vapor is ejected from capacitor, ignited and forms an arc flash between 11000V busbars
Times	2	2	1	2	1	1

2.1.5 Ignition of combustibles by illegal hot work

In 100 engine room fire accidents, 8 fires were caused by illegal hot work. The causes include: ① Hot work ignites fuel-air mixture, a total of 3 cases; ② Hot work ignites the surrounding solid or liquid combustibles, a total of 5 cases. See Table 5 for details of fire caused by illegal hot work.

Table 5 Statistics of engine room fire caused by illegal thermal work

Failure form	Hot work detonates fuel-air mixture		Hot work ignites surrounding solid-liquid combustibles					
Reason	The welding tongs contact the oil tank top, and the electric arc generated in oil tank detonates fuel-air mixture	Cargo oil tank explosion caused by welding of steam fire extinguishing pipeline in engine room	Fuel-air mixture explosion in engine room caused by electric welding operation when oil tank door is opened	Cutting the engine room floor plate with a cutting torch ignites oily bilge	When repairing leaking fuel pipe, the spark generated by the angle grinder ignites the oil mist at the leaking point	Sparks from gas cutting ignite the plastic cloth covered on the main engine	Hot work ignites the foam plastic interlayer under the hot work area	The molten metal when welding the rail base ignites the cable insulation
Times	1	1	1	1	1	1	1	1

2.1.6 Improper storage of flammables

Improper accumulation of inflammables caused 2 fires in the engine room. One was caused by falling of canned inflammables from a high place, and the other was caused by spontaneous combustion of oiled cotton waste stored in the workshop.

The proportion of engine room fire caused by various causes is shown in Table 6.

Table 6 Percentage of engine room fire caused by various reasons

Reason	Fuel leakage contacts hot surfaces	Mechanical failure	Operation error	Electrical failure	Illegal hot work	Improper accumulation of inflammables
Times	46%	13%	22%	9%	8%	2%

Fig. 1 shows the fishbone diagram of engine room fire cause based on causality analysis.

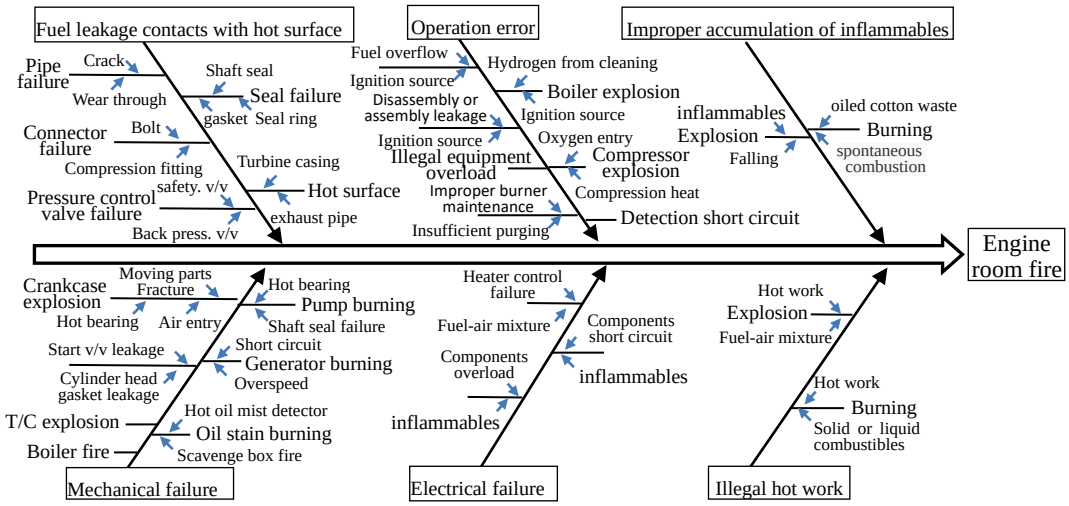

Fig. 1 Fishbone diagram of engine room fire causes

Fishbone diagram, also known as cause and effect Diagram or Ishikawa diagram, is a common method to explore the causes of problems. It is simple, practical, in-depth and intuitive. The fishbone diagram of engine room fire causes clearly presents the levels and causal relationship of fire occurrence, which is convenient for the study of the problem.

2.2 Time analysis of engine room fire

The fire occurrence in engine room during 24 hours a day is shown in Table 7.

Table 7 Engine room fire conditions during 24 hours a day

Period	0-2	2-4	4-6	6-8	8-10	8-12	12-14	14-16	16-18	18-20	20-22	22-24
Times	6	7	6	2	13	14	11	20	7	4	6	4

Table 7 shows statistics every two hours. If the event happens at 16:00, the period 16-18 is counted. It can be seen that the engine room fire occurred a total of 58 times between 8 a.m. and 16 p.m., which may be related to the working hours in this period, during which the operating equipment in the engine room increased and the operation was more frequent. Also, according to ASTB statistics, most ship accidents occur between 8 a.m. and 11 a.m. After this time, the number occurrences are fairly constant during afternoon and drop off to a low point around 9 p.m. There was a slight rise in occurrences between 1 a.m. and 7 a.m. The statistical data in this paper are basically consistent with those of ASTB.

2.3 Ship movement analysis during engine room fire

Ship movement can be divided into four types: maneuvering navigation, constant speed navigation, anchoring and berthing. The running condition and manual operation of mechanical and electrical equipment will vary with ship movements. Therefore, ship movement has a certain influence on the occurrence of engine room fire. Table 8 shows the statistics of the number of engine room fires in different ship movement. In this table, the engineering ship in working condition is regarded as a maneuvering navigation. It can be seen that most engine room fire accidents occur when the ship is in constant speed navigation, which may be related to the long time the ship is in this movement. Because the ship has been in maneuvering and anchoring for a relatively short time, the number of engine room fires is relatively small.

Table 8 Ship movement during engine room fire

Ship movement	Maneuvering navigation	Constant speed navigation	Anchoring	Berthing
Times	7	65	8	20

2.4 Analysis of fire extinguishing measures in ship engine room

In case of engine room fire, the fire extinguishing measures taken mainly include using portable fire extinguishers, releasing gas or foam fire extinguishing system, activating water mist fire extinguishing system, spraying fire water, onshore assistance in fire extinguishing, etc. See Table 9 for the fire extinguishing measures taken in the statistical cases.

Table 9 Fire extinguishing measures during engine room fire

Measures	Using portable fire extinguishers	Releasing gas or foam	Activating water mist	Spraying fire water	Onshore assistance
Times	18	56	6	12	12

A total of 56 engine room fires used gas or foam fire extinguishing systems, of which 5 failed to release. The release failure included non release or partial release, mainly due to improper operation, insufficient pressure of control cylinder, control pipeline leakage, etc. In addition, there were 4 cases where the engine room was not effectively closed, resulting in the effect of gas or foam fire suppression affected.

The utilization rate of gas or foam fire extinguishing in engine room fire is 56%, the success rate of its release was 91%, and the success rate of extinguishing was 84%. In a total of 18 cases portable fire extinguishers were used, of which 4 were successfully extinguished, with a success rate of 22%. Of the 6 activated water mist fires, 3 fires were put out successfully, with a success rate of 50%. Among the 6 water mist activated fires, 3 were successfully extinguished, with a success rate of 50%.

Fire water in engine room fire is mainly used for boundary cooling and internal fire extinguishing of boiler. It has been proved that gas or foam is not effective for boiler internal fire. Spraying fire water can effectively extinguish boiler internal fire.

However, if fire water is used to extinguish the fire inside the exhaust gas boiler, attention should be paid to the impact of excessive water on the main engine. It is only when the ship is in port or in coastal waters that it is possible to get help from shore to put out fires. In most cases, it is up to the crew to deal with the fire themselves.

2.5 Engine room fire damage and casualty analysis

Because of heavy load, rapid spread and difficult to put out, engine room fire often causes huge property loss and casualties. In China, fires are classified according to the number of casualties and property losses. For example, general fires are those that cause less than 3 deaths, less than 10 serious injuries, or direct losses of less than 10 million yuan. Among the engine room fires counted in this paper, 1 fire is particularly serious (ship foundering), 4 are major fires, and the rest are general fires. Table 10 shows the statistics of engine room fire losses and casualties.

Table 10 Damage and injuries from engine room fires

Losses or casualties	Minor loss	Foundering	Cause casualties	Number of injured	Number of deaths	Number of boiler related injuries / deaths
Number of cases / persons	7 cases	1 case	32 cases	64 persons	27 persons	23 injuries /7 deaths

The minor loss in this paper refers to that the engine room fire did not cause the functional damage of electromechanical equipment or casualties, only 7 times, indicating that the engine room fire has a high probability of damage to electromechanical equipment and personal safety.

In 32 fires that caused casualties, the total number of casualties was 91, with an average of about 2 injuries and

1 death per fire. The number of casualties caused by ship boilers is the highest, mainly caused by boiler fire and explosion.

3. Preventive measures of ship engine room fire

1. Carefully find and timely eliminate fuel leakage in daily management

According to the statistics of this paper, fuel leakage caused by the failure of pipelines, seals, connectors and pressure control valves accounted for 46% of engine room fires.

According to the statistics in this paper, 46% of the engine room fires are caused by fuel leakage due to the failure of pipelines, seals, connectors and pressure control valves. In addition, the engine room fire caused by leakage due to incorrect disassembly and assembly operation accounted for 6%. Therefore, the engine room fire caused by actual fuel leakage accounts for 52%.

In the daily management of the engine room, great attention should be paid to the problem of fuel leakage, carefully find all forms of fuel leakage, once found, take immediate measures to eliminate the leakage source. In routine disassembly and installation operations that may involve fuel leakage, care should be taken not to cause fuel leakage, especially in disassembly operations close to ignition sources.

2. Wrap and cover exposed hot surfaces in time

Diesel engine exhaust pipe, supercharger, steam pipe, boiler shell, etc. are all high-temperature surfaces. If leaked fuel splashes or drips onto such high-temperature surfaces, it is likely to cause engine room fire.. SOLAS Convention for high temperature surface protection requirements include: (1) Surfaces with temperature above 220℃ which may be impinged as a result of a fuel system failure shall be properly insulated; ② Precautions shall be taken to prevent any oil that may escape under pressure from any pump, filter or heater from coming into contact with heated surfaces.

Special attention should be paid not to damage the heat insulation material wrapped on the high temperature surface during routine maintenance of mechanical equipment, and the missing heat insulation material should be made up immediately. Managers should be aware that even if the surface is not originally hot, it will become hot under certain circumstances. For example, overheating of the bearing will turn the bearing shell into a high-temperature surface, and overheating of the bearing will often damage the shaft seal, resulting in fuel leakage. If the leaked fuel contacts the high-temperature surface of the bearing housing, it will cause a fire. Managers should also be aware that even if the thermal insulation of hot surfaces is intact, if the leaked fuel penetrates into the gap of the thermal insulation material, it will also cause a fire. Therefore, the most fundamental measure of engine room fire prevention is to eliminate fuel leakage.

3. Standard operations should be performed in routine maintenance and management

The main causes of engine room fire caused by mechanical equipment faults include crankcase explosion, turbocharger explosion, cylinder gas leakage, boiler dry burning, generator coil short circuit, bearing high temperature, etc. Special attention should be paid to prevent similar faults in daily maintenance and management. The maintenance and management of electrical equipment should pay attention to prevent the control failure of electric heater, short circuit and overload of electrical components. During the maintenance of boiler burners, special attention should be paid not to cause fuel oil leakage into the furnace. In the event of successive ignition failures, adequate air purge must be performed when reigniting. Open the furnace door with extreme caution after a failed ignition, as oxygen can cause the boiler flareback and explode. Hot work must be carried out in accordance with the operation specifications, and is prohibited in the presence of possible oil, gas and other combustible materials.

4. Establish and implement rules and regulations on ship fire prevention

Rules and regulations on ship fire prevention include open fire operation system, fire drill system, regular inspection system on fire fighting equipment, crew training system, engine room inspection system, etc. The ship shall establish a engine room fire prevention leading group with the chief engineer in charge, supervise and inspect whether the fire safety system of each post in the engine department is implemented, analyze the causes of the problems found and formulate preventive measures.

5. Carry out regular fire safety inspection

Ship engine room fire safety inspection is not only the inspection of fire equipment, fire prevention structure, but also should focus on the inspection of engine room fire prevention. The most fundamental measures to prevent engine room fire include: (1) Eliminate fuel leakage; (2) Prevent mechanical and electrical equipment from fire failure; ③ Standard operation in daily management and maintenance. Practice has proved that daily fire safety inspection can effectively avoid the occurrence of fire.

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Author's Biography

Zhang Xingbiao, born in 1972, received his B.E degree in Marine Engineering College of Dalian Maritime University（DMU） in 1995. After graduation, he worked as a seaman and successively served as the third engineer, the second engineer and the first engineer. In 2004, he obtained a master's degree in engineering from DMU and later taught at the University. In 2005, he obtained the first-class chief engineer certificate, and in 2008 was engaged as an associate professor, he obtained the senior chief engineer certificate in 2021.

He had about 12 years of seagoing experience, had worked on more than ten ships, six types of ships, and more than 50 months as chief engineer.

He had edited two undergraduate textbooks, compiled a book "Marine Engineering Case Analysis", and participated in the compilation of 10 textbooks, with a total of more than 1.1 million words.

He has published nearly 10 papers in various domestic journals and participated in 6 scientific research projects.