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The Quantitative Study on Failure Factors of Marine Electric Motor Based on Analytic Hierarchy Process

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ABSTRACT

In order to facilitate the ship managers to manage and maintain the ship electric motor, this paper analyses the relevant factors of the ship electric motor failure, makes a quantitative analysis of the ship electric motor failure factors by using the analytic hierarchy process (AHP), obtains the proportion and weight of each failure factor in the ship electric motor failure, and puts forward targeted suggestions. From the results, the main factors leading to the failure of ship electric motor are water ingress, dampness and overload, which is in line with the reality. This shows that analytic hierarchy process (AHP) can effectively solve the problem of difficult quantitative analysis of fault factors in ship equipment management.

Keywords: *The Failure of Marine Electric Motor, Quantitative Research, Analytic Hierarchy Process*

1. INTRODUCTION

The main function of marine motors is to convert electric energy into mechanical energy and to drive various mechanical equipment on the ship. According to statistics, more than 200 large and small asynchronous motors are required to maintain the normal operation of a 10000-ton ship. They play an important role in different "posts" of the ship, such as lubricating oil pump, seawater cooling pump, fresh water cooling pump, fuel supply pump, air compressor There are more than 30 driving motors for oil separator and other equipment. Therefore, the normal operation of ship electric motor directly determines whether the equipment driven by it can work normally, which poses a threat to the safety of ship navigation. According to the operation characteristics and technical performance of the motor, how to find the motor failure in time, take effective maintenance methods, formulate corresponding maintenance measures and improve the fault handling speed is of great significance to ensure the safe and reliable operation of the ship's electrical system and prolong the service life of the ship's electrical equipment.

2. THE FAULT CHARACTERISTICS OF SHIP ELECTRIC MOTORS

At present, the marine motor is mainly three-phase asynchronous motor, which is an enhanced version of the corresponding land motor. The land motor is specially treated in the process according to the working environmental conditions of the ship, and the insulation material is required to be resistant to damp heat, mold and salt fog. ship electric motors are mainly distributed in the ship engine room. The ship engine room is a place with high temperature, high humidity, poor ventilation, strong vibration and serious oil and water splash. Its working environment is relatively poor. If the motor operates continuously in this environment for a long time, its overall service performance and technical working conditions will gradually decline and fail, resulting in failure, it has seriously affected the safe operation of the ship and the daily life of the crew.

A certain fault phenomenon of the motor may be caused by several failure factors, and a certain failure factor can usually lead to several fault phenomena. For experienced electricians, they can quickly find the fault causes and eliminate them, and pay special attention to these failure factors in daily maintenance, but for inexperienced new electricians, it may not be able to deal with these situations, causing hidden dangers to the safety of the ship. In view of this, this paper introduces the analytic hierarchy process into the fault analysis of marine motor and makes a quantitative analysis on the failure factors of motor. The results show that the quantitative evaluation result of analytic hierarchy process is more scientific and reasonable than managing motor based on work experience.

3. THE BASIC OVERVIEW OF ANALYTIC HIERARCHY PROCESS

Analytic hierarchy process (AHP) is a hierarchical weight decision analysis method proposed by American operations research scientist sati in the 1970s. The analytic hierarchy process first processes the complex decision-making problem into structured graphics, decomposes it into multiple evaluation indexes, then divides each evaluation index into several evaluation schemes, and then determines the proportion of each evaluation index or evaluation scheme by pairwise comparison according to the judgment of professionals.

The quantitative evaluation using analytic hierarchy process generally includes the following steps:
(1) Establish a hierarchical structure diagram that can describe the independent internal elements of the analyzed system;
(2) According to the structure diagram and referring to the established principles, the evaluation matrix is determined by pairwise comparison;
(3) Solve the judgment matrix, obtain the characteristic root and consistency index of the matrix, and check the consistency;
(4) Calculate the weight value of each element.

4. THE QUANTITATIVE ANALYSIS OF FAILURE FACTORS OF MARINE MOTOR

4.1 Determine the hierarchical structure and elements of each layer

Firstly, this paper takes the failure of marine motor as the general goal of analysis and evaluation;
Secondly, through the collection of relevant data and the investigation of the chief engineer and electrical engineer who have worked on the ship for a long time, it is found that the failures of the ship's motor mainly include: poor insulation of the ship's motor winding to the ground, overheating or even smoking of the motor during operation, large motor vibration during operation, no rotation and buzzing of the motor after power on There are four fault phenomena of abnormal operating current value of motor. We take the above four fault phenomena as the elements of intermediate criterion layer. Based on the analysis of the above fault phenomena, the possible factors of each fault phenomenon are obtained as the elements of the index layer, and the quantitative analysis of the failure factors of ship electric motor is obtained. The element codes of each layer are shown in Table 1.

Table 1 The element code of each layer

Target	Fault phenomenon		The Cause of failure	
A ship electric motor failure	B1	Poor insulation of marine motor winding	C1	Damp or water immersion of motor winding
			C2	The motor winding insulation layer is aged due to long-term overload
			C3	The insulation layer of motor winding is damaged due to mechanical collision
			C4	The insulation layer is damaged due to process problems during maintenance
	B2	The motor overheats or even smokes during operation	C5	Bearing damage
			C6	Motor voltage too high
			C7	Motor voltage too low
			C8	Motor phase loss
			C9	Motor cooling fan damaged
			C10	High working environment temperature or serious motor fouling or poor heat dissipation
			C11	Serious motor overload
	B3	The motor vibrates greatly during operation	C5	Bearing damage
			C12	Poor rotor dynamic balance
			C13	Bending of motor intermediate shaft
			C14	Loose or deformed rotor core
			C15	The coupling or pulley center is not corrected
			C16	Loose anchor bolts of motor
	B4	The motor does not rotate when energized and has a buzzing sound	C5	Bearing damage
			C7	Motor voltage too low
			C8	Motor phase loss
			C11	Serious motor overload
			C17	Open circuit of motor stator and rotor
			C18	Motor rotor stuck

Thus, the hierarchical model of quantitative research on ship electric motor failure factors can be obtained, as shown in Figure 1.

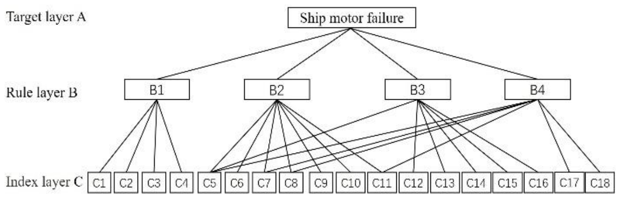

Figure 1 The hierarchical structure of quantitative research on failure factors of marine motor

4.2 Construction of judgment matrix and consistency verification

In the hierarchical structure diagram of quantitative research on ship electric motor failure factors in Figure 1, the importance of each evaluation or index element of criterion layer and index layer is a qualitative concept, which cannot be effectively evaluated quantitatively in analytic hierarchy process. Therefore, we need to compare the above related factors, give them appropriate scale values, realize the measurement value of the importance of each element, and then form a judgment matrix to transform the qualitative evaluation into quantitative evaluation. According to the general practice, we divide the relative importance between any two elements into 9 scales, mark the two evaluation elements as Xi and XJ respectively, and define $a_{ij}=\frac{x_i}{x_j}$. The value range is 1, 3, 5, 7 and 9, and the reciprocal is 1, 1 / 3, 1 / 5, 1 / 7 and 1 / 9. The specific meaning is shown in Table 2.

Table 2 The relative scale values of judgment matrix elements

Value（a*ij*）	Meaning
1	X*i* and X*j* are equally important
3	X*i* is slightly more important than X*j*
5	X*i* is more important than X*j*
7	X*i* is very important compared with X*j*
9	X*i* is absolutely important compared with X*j*
2,4,6,8	The intermediate value of the above two adjacent assignment scales
1,1/3,1/5,1/7,1/9	a*ji*=1/a*ij*

According to the hierarchical structure model of quantitative research on the motor failure factors of the target ship, through consulting the data, questionnaires and interviews with senior chief engineer and electrical engineer, sort according to the importance of relevant influencing factors, input the AHP calculation software, and obtain the judgment matrix of criterion layer (B1 ~ B4) and index layer (C1-C18), as shown in Table 3 to table 7.

Table 3 The judgment matrix of criterion layer

1.Motor failure; Consistency ratio: 0.0654; Weight of "motor failure": 1.0000; λmax:4.1747

Motor failure	B2	B1	B3	B4	W*i*
B2	1	0.3333	3	7	0.2676
B1	3	1	5	9	0.5577
B3	0.3333	0.2	1	5	0.133
B4	0.1429	0.1111	0.2	1	0.0417

Table 4 The judgment matrix and weight value of index layer (C5 ~ C11) relative to B2

2.B2 Consistency ratio:0.0828; Weight of "motor failure":0.2676; λmax:7.6755

B2	C5	C6	C7	C8	C9	C10	C11	Wi
C5	1	3	3	6	5	0.33	0.25	0.14
C6	0.33	1	0.33	5	3	0.17	0.11	0.06
C7	0.33	3	1	5	4	0.25	0.2	0.10
C8	0.17	0.2	0.2	1	0.33	0.14	0.11	0.02
C9	0.2	0.33	0.25	3	1	0.14	0.14	0.04
C10	3	6	4	7	7	1	0.33	0.24
C11	4	9	5	9	7	3	1	0.4

Table 5 The judgment matrix and weight value of index layer (C1 ~ C4) relative to B1

3.B1 Consistency ratio:0.0931;Weight of "motor failure":0.5577; λmax:4.2487

B1	C1	C2	C3	C4	Wi
C1	1	5	7	9	0.617
C2	0.2	1	5	7	0.256
C3	0.14	0.2	1	2	0.078
C4	0.11	0.14	0.5	1	0.048

Table 6 The judgment matrix and weight value of index layer (C5 、C12~ C15) relative to B3

4. B3 Consistency ratio:0.0718; Weight of "motor failure":0.1330; λmax:6.4526

B3	C5	C12	C13	C14	C15	C16	Wi
C5	1	6	4	5	0.33	3	0.247
C12	0.17	1	0.25	0.33	0.125	0.2	0.032
C13	0.25	4	1	3	0.2	0.33	0.094
C14	0.2	3	0.33	1	0.17	0.25	0.056
C15	3	8	5	6	1	4	0.419
C16	0.33	5	3	4	0.25	1	0.152

Table 7 The judgment matrix and weight value of index layer (C5、C7、C8、C11、C17、C18) relative to B4

5.B4 Consistency ratio:0.0767; Weight of "motor failure":0.0417; λmax:6.4829

B4	C17	C18	C5	C7	C8	C11	Wi
C17	1	0.17	0.25	0.33	0.2	0.14	0.033
C18	6	1	4	5	3	0.33	0.248
C5	4	0.25	1	3	0.33	0.2	0.094
C7	3	0.2	0.33	1	0.25	0.17	0.057
C8	5	0.33	3	4	1	0.25	0.153
C11	7	3	5	6	4	1	0.415

In order to ensure the accuracy of calculation, consistency inspection is required. Table 8 shows the random consistency index values RI of matrices of order 1 ~ 10.

Table 8 The random consistency index value（RI）of matrix of order 1 ~ 10

N	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

In the table, n represents the order of the judgment matrix and RI represents the consistency proportion.

For the criterion layer judgment matrix, the order of the matrix is n = 4, and its RI = 0.0654 ＜ 0.90;

For the judgment matrix of index layer (C5 ~ C11) relative to B2, the matrix order is n = 7, and its RI = 0.0828 ＜ 1.32;

For the judgment matrix of the index layer (C1 ~ C4) relative to B1, the order of the matrix is n = 4, and its RI = 0.0931 ＜ 0.90;

For the judgment matrix of index layer (C5, C12 ~ C15) relative to B3, the matrix order n = 5, and its RI = 0.0718 ＜ 1.12;

For the judgment matrix of the index layer (C5, C7, C8, C11, C17, C18) relative to B4, the order of the matrix is n = 6, and its RI = 0.0767 < 1.24;
It can be seen from the above that each judgment matrix has satisfactory consistency indicators, and it can be concluded that the data is valid.
Further, the weight value and histogram of various factors in the index layer for ship electric motor failure can be obtained, as shown in Table 9 and Figure 2.

Table 9 The quantification of failure factors of marine motor

Hierarchical structure C	B1	B2	B3	B4	Total weight value
	0.5577	0.2676	0.133	0.0417	
C1	0.6171	0	0	0	0.3442
C2	0.2585	0	0	0	0.1442
C3	0.0773	0	0	0	0.0431
C4	0.0472	0	0	0	0.0263
C5	0	0.1419	0.2466	0.0944	0.0747
C6	0	0.0627	0	0	0.0168
C7	0	0.0958	0	0.0567	0.028
C8	0	0.0231	0	0.1535	0.0126
C9	0	0.0386	0	0	0.0103
C10	0	0.2418	0	0	0.0647
C11	0	0.396	0	0.4145	0.1232
C12	0	0	0.0316	0	0.0042
C13	0	0	0.0936	0	0.0125
C14	0	0	0.0561	0	0.0075
C15	0	0	0.4197	0	0.0558
C16	0	0	0.1524	0	0.0203
C17	0	0	0	0.0331	0.0014
C18	0	0	0	0.2478	0.0103

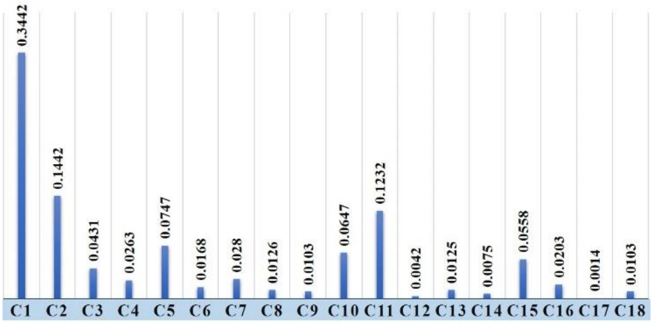

Figure 2 The quantitative weight table of ship electric motor failure factors

5. CONCLUSION

It can be seen from table 9 and Figure 2 that among the factors of ship electric motor failure, the weight value of C1 (damp or water immersion of motor winding) accounts for the largest proportion, which is 0.3442; The second is C2 (winding insulation aging caused by long-term overload of motor), and the weight value is 0.1442; Third, the weight value of C11 (motor overload) is 0.1232. From the analysis, C2 and C11 belong to the same kind of fault factor, that is, the overload phenomenon of motor. The first three types of fault factors account for more than 60% of ship electric motor failure. In addition, C5 (bearing damage) also accounts for a considerable proportion of ship electric motor failure factors.
In this regard, the duty engineer and Electrical Engineer shall pay special attention to the waterproof and moisture-proof management of the ship's motor, timely identify the potential overload of the motor, and try to avoid the overload work of the motor. In addition, in the management of ship spare parts, attention shall be paid to the timely inspection and greasing of the bearing

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