Research on Fault Diagnosis of Fin Stabilizer System Based on Optimum Searching Strategy*

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Abstract - As the composition, working principle and failure data recorded in the process of actual operation, in the non-retractable valve controlled anti-rolling fin system are in-depth analyzed. FTA method is used to set up the fault tree model, and the model is analyzed to determine the failure modes and the main reasons of the fin system. In allusion to the shortage of fault tree analysis method that path searching is not clear enough in actual fault search, the optimum search strategy based on the multi-objective decision in fault diagnosis of fin system is put forward, the path of locating failure cause is realized to be simple, steps of fault diagnosis are optimized, so that the efficiency of diagnosis is improved further.

Index Terms - Fin stabilizer, Fault tree analysis, Optimum search strategy, Searching costs.

I . Introduction

Along with the development of the economy, and the progress of maritime career, higher requirements are put forward during the voyage of ship, such as operability, comfort and security [1]. Controllable anti-rolling fin system is the main stable installation equipped with ship, it has been regarded as necessities of the ship as ship's seaworthiness guaranteed. But as a result of that fin is integrated organization composed of machine, electricity and hydraulic, and its structure and technology is complex and parts related to each other closely [2]. As the system goes to fault, failure types and causes are complex. The users which only operate simply can hardly find out the failure cause, even the technicians may take a long time to find out fault reason. How to optimize the fault search strategy, short the time of fault locating and improve the efficiency of diagnosis is always a topic people studied on.

II. Fault tree analysis of fin stabilizer

A. Brief introduction of FTA

Fault tree analysis (FTA) is a commonly used fault diagnosis method in practical engineering [3]. The possible factors (including hardware, software, environment, etc.) which cause system failure are listed clearly by this method, and the factors are in the form of logic diagram. According to the built fault tree, basic faults can be distinguished, the fault reason can be determined and the occurrence rates can be calculated.

B. Principle of hydromantic control part of fin

In this paper, non-retractable valve controlled fin is analyzed as a simple, and its working principle is: at startup, pressure regulating electromagnetic relief valve is powered, motor starts with no-load, power on the valve is cut off after 2s, and pressure buildup, at this moment the zero/roll fin valve is off power, hydraulic oil from the variable pump of constant pressure is pulled into reset hydro-cylinder to reset zero, unlocking valve is powered to be unlocked after 2s delayed, the zero/roll fin valve is powered after 3s delayed from unlocked, reset pressure unloading, fin transfer circuit connected, and fin enter working state after 1s. At stop time, disconnect/reduction wave signal off, zero/roll fin valve is off power delayed 1s, and hydraulic oil is pulled into the reset oil cylinder to reset to zero, at the same time, unlocking valve is off power to be locked, the motor is stopped as locking in place. The schematic diagram of valve controlled hydraulic system is shown as following:

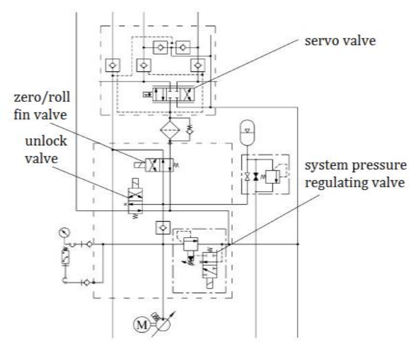

Fig. 1 hydraulic schematic diagram of non-retractable valve controlled fin

C. Fault tree of fin stabilizer system

According to the general establishing steps of the fault tree, the fault of fin stabilizer is taken as the top event, and the direct reasons “the system cannot start ", "fin stabilizer can't stabilize" and "halt of the fin “are taken as the second level. The reason "system can't start" has two branches: "power supply" and "power not supply ". Furthermore, system failure under the "power supply" reason is caused by class components fault, such as electric control system, electro-hydraulic servo system. Fault of components can be found step by step, such as servo valves, potentiometer, overflow valve, amplifier and so on. Finally, the entire bottom event (possible reason) of the fault tree can be found. The simplified fault tree of the fin stabilizer is shown in figure 2.

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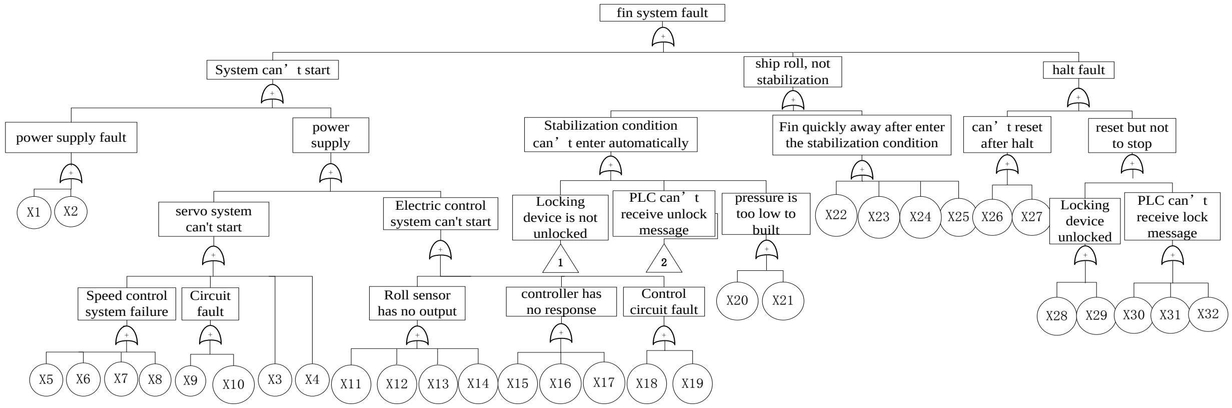

Fig 2 simplified fault tree of the fin stabilizer

III. Optimum searching strategy

1) For complex systems, the traversal search according to fault tree analysis always causes low efficiency. So it is necessary to find an optimal search sequence, under the premise of consideration the probability, the search cost and other factors by applying to intelligent diagnosis system, for improving the efficiency of equipment diagnosis [6]. Minimum cut sets are set to be $X_1, X_2, ..., X_n$, the probability of each bottom event when the system failure occurs are $P_1, P_2, ..., P_n$, and the corresponding search cost are $C_1, C_2, ..., C_n$, including time and money cost by searching. The values of heuristic information of corresponding searching path are $I_1, I_2, ..., I_n$, which mean influence level induced by the success searching.

2) Assume in the searching for the cause of system failure, there are "n" search schemes and "m" event attributes (probability, cost and so on) affect search scheme need to be considered. Search scheme set is denoted by $X = X_1, X_2, ..., X_n$, attribute value of search scheme is denoted by $Y = y_1, y_2, ..., y_m$. The search decision matrix A is expressed as:

$$A = \begin{bmatrix} X_1 \\ X_2 \\ ... \\ X_n \end{bmatrix} \begin{bmatrix} y_{11} & y_{12} & ... & y_{1m} \\ y_{21} & y_{22} & ... & y_{2m} \\ ... & ... & ... & ... \\ y_{n1} & y_{n2} & ... & y_{nm} \end{bmatrix} \quad (1)$$

In order to facilitate comparison, the attribute values are unified conversed in [0, 1]. The normalized matrix Z_{ij} is written as follows.

$$Z_{ij} = Y_{ij} \div \sqrt{\sum_{i=1}^{n} y_{ij}^2} \, (i = 1, ..., n; j = 1, ...m) \quad (2)$$

3) In multi-objective decision, in order to ensure all search scheme attributes are taken into account, "least square method" is used to calculate the weighted values of each attribute which reflect the relative materiality of the attribute. Weighted value the larger, import of the attribute greater.

The relative important degree of the attribute "i" to "j" is denoted by b_{ij}, and in numerical it's approximately equal to W_i / W_j. The comparison results of "m" attributes are expressed in matrix B.

$$B = \begin{bmatrix} b_{11} & b_{12} & ... & b_{1m} \\ b_{21} & b_{22} & ... & b_{2m} \\ ... & ... & ... & ... \\ b_{m1} & b_{n2} & ... & b_{mm} \end{bmatrix} \approx \begin{bmatrix} W_1/W_1 & W_1/W_2 & ... & W_1/W_m \\ W_2/W_1 & W_2/W_2 & ... & W_2/W_m \\ ... & ... & ... & ... \\ W_m/W_1 & W_m/W_2 & ... & W_m/W_m \end{bmatrix} \quad (3)$$

Choose a group of weight values $\{W_1, W_2, ..., W_m\}$, to make sure the quadratic sum of the error $b_{ij}W_j - W_i$ is the minimum.

$$Z = \min\{\sum_{i=1}^{m}\sum_{j=1}^{n}(b_{ij}W_j - W_i)^2\} \quad (4)$$

The weight value $\{W_1, W_2, ..., W_m\}$ is constrained by:

$$\sum_{i=1}^{m} W_i = 1 (W_i > 0) \quad (5)$$

According to equation (2) and equation (5), standardized searching decision matrix S is calculated by the following equation:

$$S_{ij} = W_i Z_{ij} \, (i = 1, ..., n; j = 1, ...m) \quad (6)$$

4) The ordering method (TOPSIS) for approaching ideal solution is adopted to determine the best ideal solution and the worst of the negative ideal solution of attribute values, which mean the optimal searching scheme S^+ and the worst scheme S^-.

$$\begin{aligned} S^+ &= \{S_1^+, S_2^+, ..., S_n^+\} \\ &= \{(\max_i S_{ij} \mid j \in J) \mid (\min_i S_{ij} \mid j \in J') | i=1,2,...,n\} \end{aligned} \quad (7)$$

$$\begin{aligned} S^- &= \{S_1^-, S_2^-, ..., S_n^-\} \\ &= \{(\min_i S_{ij} \mid j \in J) \mid (\max_i S_{ij} \mid j \in J') | i=1,2,...,n\} \end{aligned} \quad (8)$$

In the equation (8), J is the benefit property set and J' is the cost property set.

The ideal solution and the negative ideal solution are assumed values and cannot be found in the schemes. The solution which is closest to the ideal solution and away from the negative ideal solution is the real solution.

The distances of each solution to the ideal solution are:

$$D_i^+ = \sqrt{\sum_{j=1}^{m}(S_{ij} - S_i^+)^2} \quad (i=1,2,...,n) \tag{9}$$

The distances of each solution to the negative ideal solution are:

$$D_i^- = \sqrt{\sum_{j=1}^{m}(S_{ij} - S_i^-)^2} \quad (i=1,2,...,n) \tag{10}$$

The relative close degree E_i is used to measure the distances of the two sizes, and the large value is needed to be search and detect.

$$E_i = D_i^- / (D_i^- + D_i^+), 0 \le E_i \le 1 \tag{11}$$

IV. Solving fault diagnosis of fin system using optimal search scheme

The flow chart of the optimal searching method based on fault tree analysis of the fin stabilizer is shown in Fig3.

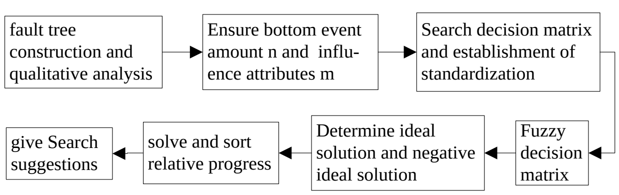

Fig 3 flow chart of the optimal fault searching method of fin

The fault tree of fin stabilizer system is shown in Fig.2, $X_1, X_2, ..., X_{32}$ stands for reasons of the system failure. I for information value search, C for searching cost and P for probability of occurrence, and the rank is shown in Table1. In the table, I =1 represents the information value is the largest. C =1 represents the search cost is the lowest, and P =1 represents the probability of occurrence is the biggest.

The search decision matrix according to this table is:

$$A = \begin{bmatrix} X_1 \\ X_2 \\ ... \\ X_{32} \end{bmatrix} \begin{bmatrix} 25 & 29 & 26 \\ 13 & 26 & 25 \\ ... & ... & ... \\ 16 & 28 & 23 \end{bmatrix} \tag{12}$$

Matrix Z is got by normative approaching equation (12)

$$Z = \begin{bmatrix} X_1 \\ X_2 \\ ... \\ X_{32} \end{bmatrix} \begin{bmatrix} 0.300 & 0.288 & 0.307 \\ 0.156 & 0.258 & 0.295 \\ ... & ... & ... \\ 0.192 & 0.278 & 0.271 \end{bmatrix} \tag{13}$$

Table 1 the main impact factor of the failure reasons of the retractable fin stabilizer

No.	Fault cause	Rank of I	Rank of C	Rank of P	No.	Fault cause	Rank of I	Rank of C	Rank of P
X1	power switch isn't open	25	29	26	X17	DYCJ fault	17	14	22
X2	switchboard fault	13	26	25	X18	switch fault of master	26	19	16
X3	Fin mechanical arrangeme	4	1	5	X19	spill fault of master carton	8	20	15
X4	ancillary circuit fault	19	13	9	X20	Set point of pressure regulating spill value changes or spill valve damage	6	2	2
X5	main oil-way fault	12	9	6	X21	air in oil line	6	6	4
X6	servo oil-way failure	23	10	7	X22	pump discharge pressure too small	2	5	2
X7	hydraulic pump fault	1	7	3	X23	servo valve fault	18	3	1
X8	motor fault	3	8	11	X24	potentiometer fault	22	4	3
X9	SDCJ fault	11	11	10	X25	relevance circuit break	21	7	4
X10	SDJ4 fault	5	12	8	X26	line break	21	27	21
X11	without 380V	20	22	12	X27	reset valve fault	15	24	22
X12	blown fuse	24	21	13	X28	locking device	2	23	18
X13	intermediate-frequency circuit	5	17	13	X29	zero drift	15	29	24
X14	amplifier module fault	10	18	14	X30	micro switch drift	7	26	19
X15	gyroscope fault	9	16	17	X31	micro switch break	7	25	20

According to the characteristics of the fin stabilizer system and the actual diagnosis data of fault, the judgment matrix B is obtained as equation (14), based on comparison the weight of the information heuristic value, searching costs and the occurrence probability of fault.

$$B = \begin{bmatrix} 1 & 1/3 & 1/2 \\ 3 & 1 & 3 \\ 2 & 1/3 & 1 \end{bmatrix} \tag{14}$$

Due to the method of least square of weighted value, the LaGrange function $L(W, \lambda)$ is built:

$$L(W,\lambda) = \sum_{i=1}^{3}\sum_{j=1}^{3}(W_i - C_{ij}W_j)^2 + 2\lambda(\sum_{i=1}^{3}W_i - 1) \tag{15}$$

Set $\partial L / \partial W_l = 0$, then, $KW + \lambda e = 0$ (16)

Among equation (16),

$$K = \begin{bmatrix} \sum_{i=1}^{m} B_{i1}^2 + m - 2 & -(B_{12}+B_{21}) & \dots & -(B_{1m}+B_{m1}) \\ -(B_{21}+B_{12}) & \sum_{i=1}^{m} B_{i2}^2 + m - 2 & \dots & -(B_{2m}+B_{m2}) \\ \dots & \dots & \dots & \dots \\ -(B_{m1}+B_{1m}) & -(B_{m2}+B_{2m}) & \dots & \sum_{i=1}^{m} B_{im}^2 + m - 2 \end{bmatrix} \quad (17)$$

$$W = [W_1, W_2, ..., W_m]^T \quad (18)$$

$$e = [1, 1, ..., 1]^T \quad (19)$$

$$m = 3 \quad (20)$$

Weight vector W is calculated:

$W = [0.3322, 0.2733, 0.3945]^T$

Then standard searching decision matrix S after weighted is written as:

$$S = \begin{bmatrix} 0.0997 & 0.0788 & 0.1211 \\ 0.0518 & 0.0706 & 0.1165 \\ \dots & \dots & \dots \\ 0.0638 & 0.0761 & 0.1072 \end{bmatrix}$$

Ideal solution $S^+ = \{0.0040, 0.0027, 0.0093\}$

Negative ideal solution $S^- = \{0.1036, 0.0788, 0.1211\}$

The distance to the ideal solution of each solution

$D_i^+ = \{0.1657, 0.1356, ..., 0.1361\}$

The distance to the negative ideal solution

$D_i^- = \{0.0039, 0.0526, ..., 0.0423\}$

The relative close degree of each solution to the ideal solution

E_i ={0.0232,0.2796,0.8919,0.5257,0.6986,0.5233,0.9030,0.7334,0.6377,0.7432,0.4052,0.3540,0.6105,0.5262,0.5004,0.4382,0.3266,0.2951,0.5202,0.8856,0.8478,0.9328,0.6724,0.6028,0.5949,0.1833,0.2831,0.5207,0.2432,0.4362,0.4278,0.2370}

According to value of E_i, order of searching scheme is determined. The scheme with the largest E_i should be search, detect and diagnose first. According to the above calculation search scheme, the rank of searching scheme is sorting for $X_{22}, X_7, X_3, X_{20}, X_{21}, X_{10}, X_8, X_5, X_{23}, X_9, X_{13}, X_{24}, X_{25}, X_{14}, X_4, X_6, X_{28},$ $X_{19}, X_{15}, X_{16}, X_{30}, X_{31}, X_{11}, X_{12}, X_{17}, X_{18}, X_{27}, X_2, X_{29}, X_{32}, X_{26}, X_1$, the result is shown in Fig.4

Fig.4 rank orders of searching scheme

If successfully searched, the diagnosis would be stopped. Otherwise, update the established fault decision matrix of fin stabilizer and the searching cost after test, in order to consider the previous results and the present detection result together, and then searching for a new solution until diagnosis is successful.

V . Conclusion

In this paper, on the basis of in-depth analysis of anti-rolling fin system, the fault tree model is established based on fault tree analysis method, and the main failure modes of anti-rolling fin system are found. Multi-objective optimization decision theory is applied, and multi-IF (impact factors) including fault probability, search costs and illuminating value provided by the searching are comprehensive considered, the most likely path to reach the problem solving is selected in the state space, and the optimal search strategy is determined. As the path of fault reason searching be simplified, the fault of anti-rolling fin system is quickly located, and the efficiency of diagnosis is improved, and it has use for reference for rapid fault location strategy of other complex systems.

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