Type selection and design of hybrid propulsion system of ship

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Abstract: Hybrid propulsion system is a new type of dynamic form. It has the characteristic structural complexity and the diversity of operating conditions. Due to the different vessel functions, different sailing areas or different control performance requirements of the ship, types of hybrid propulsion systems are not the same. In this paper, 6000HP platform supply vessel is an example. Hybrid propulsion the system is selected by the fuzzy comprehensive evaluation method.

1. Introduction

Hybrid electric propulsion system is a new type of dynamic form. The hybrid propulsion system has been widely used in passenger ships, Marine work ship and public service and so on [1-3]. For different types of ships, the propulsion system of the host type and number, transmission mode, gear box device, the number of shaft and bearing and propeller device models and numbers are not the same.

Völker T [4] the feasibility of hybrid propulsion system for different types of ships is studied in the paper. The port tugs and ferries as the research object, team hybrid propulsion system for economic analysis.Shen Jing-kang [5] this paper analyzes the advantages and disadvantages of mechanical propulsion system, electric propulsion system and hybrid propulsion system, and introduces the configuration and type spectrum of HAVYARD 845 and A122 hybrid propulsion system. Simon Sortland [6] the configuration of the hybrid propulsion system of VS491CD three is studied, and the fuel consumption and exhaust emission of the system are compared with the traditional propulsion system. Sha Feng [7] the hybrid propulsion system is applied to the tuna fishing line, and the difference between the hybrid propulsion system and the traditional propulsion system is analyzed from the point of view of economy and reliability.

In this paper, the types and characteristics of hybrid propulsion system are studied. In this paper, the evaluation system of the hybrid propulsion system is established, and the reasonable pattern spectrum is selected based on the fuzzy comprehensive evaluation method.
2. Composition and type of hybrid propulsion system

Hybrid propulsion system is mainly composed of mechanical systems and electrical systems, as shown in figure 1 composition of hybrid propulsion system. The hybrid propulsion system has several typical operating conditions:

a) Power Take Off The main engine drives the propeller through a gearbox. A generator is connected at the gearbox that provides the electric power for the vessel auxiliary load, as shown in figure 2.

b) Boost Power Take In Diesel engine and electric motor delivers extra power through the gearbox to the propeller. Electric motor is provided by the diesel generators, as shown in figure 3.

c) Power Take Home In the process of ship navigation, diesel engine failure can't run. Propulsion power can still be provided by the electric motor, as shown in figure 4

![Figure 1. Composition of hybrid propulsion system](image1)

![Figure 2. PTO of hybrid propulsion system](image2)

![Figure 3. PTI model of hybrid propulsion system](image3)

![Figure 4. PTH model of hybrid propulsion system](image4)

After the collection and induction of the data of the domestic and international ship hybrid propulsion system type, we can get the propulsion system spectrum as shown in Table 1.

| No. | Ship name         | Power system type            | No.  | Ship name  | Power system type                          |
|-----|-------------------|-------------------------------|------|------------|---------------------------------------------|
| 1   | VS4612 AHTS      | twin machine one screw        | 8    | A122       | Twin screw diesel mechanical + PTO/PTI system |
| 2   | VS483M kII PSV   | twin machine one screw        | 9    | AX104      | Diesel-electric hybrid propulsion            |
| 3   | UT 730 WP        | Diesel-electric hybrid        | 10   | A101       | Four machine twin screw system               |
| 4   | UT 712 CD        | Diesel-electric hybrid        | 11   | Fujian 1000 tons of patrols                  | Twin machine twin screw + PTO system         |
| 5   | UT 759 ICE       | Diesel-electric hybrid        | 12   | Train ferry | Twin screw diesel                           |
3. Spectrum selection based on fuzzy comprehensive evaluation method

3.1 Establish the evaluation index system of the propulsion system spectrum

The evaluation index system needs to meet the principle of system optimization, comparability, scientific, stability, hierarchical, practicality and associability. According to the above principle, the evaluation index system of the hybrid propulsion system is established, see figure 5. Target layer: \( A = \text{(hybrid propulsion system's spectrum)} \). Factors layer: \( B_i = (B_1, B_2, B_3, B_4, B_5) \). The sub factors layer: \( C_i = (C_{11}, C_{12}, C_{21}, C_{31}, C_{32}, C_{41}, C_{42}, C_{51}) \).

![Figure 5. Evaluation index system of hybrid propulsion system based on spectrum](image)

3.2 Determine factor weight vector

In the process of hybrid propulsion system selection, evaluation index system of hybrid propulsion system gives 5 factors. The weight of various factors is not the same in the evaluation system in Table 2. Factors layer \( B_i \) relative to the target layer \( A \) of the judgment matrix can be established in Table 3.

### Table 2. Judgment matrix scale and its implication

| Scale | Meaning                                    |
|-------|--------------------------------------------|
| 1     | The two factors are of the same importance |
| 3     | The former is a little more important than the latter |
| 5     | The former is significantly more important than the latter |
| 7     | The former is more important than the latter |
| 9     | The former is more important than the latter |
| 2/4/6/8 | Intermediate value of the above judgment |

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Table 3. Factors Bij judgment matrix of the target A

| Factors | B1  | B2  | B3  | B4  | B5  |
|---------|-----|-----|-----|-----|-----|
| B1      | a11 | a12 | a13 | a14 | a15 |
| B2      | a21 | a22 | a23 | a24 | a25 |
| B3      | a31 | a32 | a33 | a34 | a35 |
| B4      | a41 | a42 | a43 | a44 | a45 |
| B5      | a51 | a52 | a53 | a54 | a55 |

By computing the judgment matrix, factor layer relative to the target layer of the weight vector \( U= (u_1, u_2, u_3, u_4, u_5) \) is obtained. Similarly according to the method described above, the sub factors layer relative to the factor layer of the weight vector \( A= (A_1, A_2, A_3, A_4, A_5) \) is obtained.

3.3 Establish the evaluation matrix of each factor

From design of ship to operation of ships, experts from different professional backgrounds give different evaluation opinion on factors and sub factors layer. According to the expert evaluation of the factors layer and sub-factors layer, evaluation set is established, \( S= (s_1, s_2, s_3, s_4, s_5, s_6) \) = (very good, good, relatively good, general, poor, very poor). The group of experts is composed of ship design experts, marine engineers, and maintenance management engineer and ship management. Using expert investigation method and probability statistics method, evaluation of sub factors layer are obtained. Because of the different factors layer has different sub factors, fuzzy evaluation matrix \( K \) of sub-factors are established. The evaluation matrix of factors layer \( M=AK \). The evaluation matrix of hybrid propulsion system \( Q=AM \).

4. Example analysis

6000HP platform supply vessel for the study, the ship in accordance with the American Classification Society (ABS) design, build and test the current specifications and rules, as shown in Table 4 and figure 6.

Table 4. 6000HP platform supply ship basic parameters

| Project         | Unit | Values |
|-----------------|------|--------|
| overall length  | m    | 79     |
| LBP             | m    | 71.4   |
| beam            | m    | 17.6   |
| depth           | m    | 7.7    |
| Maximum draft   | m    | 6.5    |
| Maximum load    | t    | 3800   |

Figure 6. The relationship between speed and power curve

In order to realize the systematic comparative analysis of spectrum of different hybrid propulsion, double sculls and four sculls main configuration of the system is given, as shown in Table 5.
Table 5. 6000HP platform supply vessel system configuration

| Name       | Double machine twin screw | Four machine twin screw |
|------------|----------------------------|-------------------------|
| Project    | Equipment details          | Main parameters         | Equipment details          | Main parameters         |
| Diesel     | Rated power                | 1720kW                  | Rated power                | 960kW                   |
|            | Rated speed                | 900r/min                | Rated speed                | 720r/min                |
| number     | 2                          | 4                       |
| Type       | MAN 8L21/31                | Type MAN 6L23/30A       |
| Generator  | Number                     | 3                       | Number                     | 3                       |
|            | Rated power                | 180kW                   | Rated power                | 180kW                   |
| Emergency  | Number                     | 1                       | Number                     | 1                       |
| PTO        | Number                     | 2                       | Number                     | 2                       |
| CPP        | Number                     | 2                       | Type                       | CPP                     |

According to the theory of 3.2 section, the relevant theory is used to construct the factor Bi to the target A judgment matrix, as shown in Table 6.

Table 6. Factor B, judgment matrix and weight vector of target A

| Factors            | Applicability B₁ | Reliability B₂ | Maintainability B₃ | Economy B₄ | Mobility B₅ | Factor weight U |
|--------------------|------------------|----------------|---------------------|------------|-------------|-----------------|
| Applicability B₁  | 1                | 1/4            | 1/3                 | 1/2        | 2           | 0.089           |
| Reliability B₂     | 4                | 1              | 4                   | 5          | 7           | 0.484           |
| Maintainability B₃ | 3                | 1/4            | 1                   | 6          | 4           | 0.260           |
| Economy B₄         | 2                | 1/5            | 1/6                 | 1          | 3           | 0.116           |
| Mobility B₅        | 1/2              | 1/7            | 1/4                 | 1/3        | 1           | 0.051           |
| Maximum eigenvalue λₘₜₜ = 5.432 | CI=0.108 | RI=1.12 | CR=0.096 | Meet the consistency check |

Where consistency index $CI = (λₘₜₜ - n) / (n - 1)$; consistency ratio $CR = CI / RI$; If $CR < 0.1$, the judgment matrix is reasonable, and the random consistency index RI is given in Table 7.

Table 7. Random consistency index

| n | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| RI| 0 | 0 | 0.58 | 0.89 | 1.12 | 1.25 | 1.32 | 1.41 | 1.45 |

In the same way, due to the influence of each factor layer, it is necessary to construct the weight distribution set, as shown in Table 8 to Table 10.

Table 8. Judgment matrix and weight vector of C₁₁ and C₁₂ relative to B₁

| Applicability | Factors | Weight C₁₁ | Size C₁₂ | Factor weight A₁ |
|---------------|---------|------------|----------|------------------|
| Weight C₁₁   | 1       | 1/3        | 0.250    |
| Size C₁₂     | 3       | 1          | 0.750    |

Table 9. Judgment matrix and weight vector of B₃₁ and C relative to B₃
Maintainability

| Factors          | MTTR C₃₁ | Dimensions C₃₂ | Factor weight A₃ |
|------------------|----------|----------------|------------------|
| MTTR C₃₁         | 1        | 4              | 0.80             |
| dimensions C₃₂   | 1/4      | 1              | 0.20             |

Table 10. Judgment matrix and weight vector of B₄₁ and B₄₂ relative to B₄

Economy

| Factors          | Total investment C₄₁ | Fuel consumption C₄₂ | Factor weight A₄ |
|------------------|----------------------|----------------------|------------------|
| Total investment | 1                    | 1                    | 0.50             |
| Fuel consumption | 1                    | 1                    | 0.50             |

Selection of ship design experts, engineers, maintenance engineers, management of ship management experts such as establishing evaluation system of expert group. According to the evaluation opinions and suggestions given by each expert, the expert comments S=(s₁, s₂, s₃, s₄, s₅)=(very good, good, relatively good, general, poor, very poor) set can be determined. The evaluation matrix of factor layer is calculated based on 3.2 section, as shown in Table 11 and Table 12.

Table 11. Evaluation matrix of sub factor layer and factor layer of twin screw propulsion system

| Twin screw propulsion system |
|------------------------------|
| Applicability factors        |
| evaluation matrix            |
| \( K_{15} = \begin{bmatrix} 0.3 & 0.5 & 0.2 & 0.0 & 0.0 \\ 0.3 & 0.3 & 0.3 & 0.1 & 0.0 \end{bmatrix} \) |
| \( M_{15} = \mathbf{A}_1 K_{15} \) |
| \( \begin{bmatrix} 0.3 \ 0.35 \ 0.275 \ 0.075 \ 0 \end{bmatrix} \) |
| Reliability factors          |
| evaluation matrix            |
| \( K_{15} = \begin{bmatrix} 0.3 & 0.4 & 0.3 & 0.0 & 0.0 \end{bmatrix} \) |
| \( M_{15} = \mathbf{A}_1 K_{15} \) |
| \( \begin{bmatrix} 0.3 \ 0.4 \ 0.3 \ 0 \ 0 \end{bmatrix} \) |
| Maintainability factors      |
| evaluation matrix            |
| \( K_{15} = \begin{bmatrix} 0.2 & 0.4 & 0.4 & 0.0 & 0.0 \\ 0.3 & 0.4 & 0.3 & 0.0 & 0.0 \end{bmatrix} \) |
| \( M_{15} = \mathbf{A}_1 K_{15} \) |
| \( \begin{bmatrix} 0.22 \ 0.4 \ 0.38 \ 0 \ 0 \end{bmatrix} \) |
| Economic factors             |
| evaluation matrix            |
| \( K_{15} = \begin{bmatrix} 0.3 & 0.4 & 0.3 & 0.0 & 0.0 \\ 0.2 & 0.3 & 0.4 & 0.1 & 0.0 \end{bmatrix} \) |
| \( M_{15} = \mathbf{A}_1 K_{15} \) |
| \( \begin{bmatrix} 0.25 \ 0.35 \ 0.35 \ 0.05 \ 0 \end{bmatrix} \) |
| Mobility factors             |
| evaluation matrix            |
| \( K_{15} = \begin{bmatrix} 0.3 & 0.4 & 0.3 & 0.0 & 0.0 \end{bmatrix} \) |
| \( M_{15} = \mathbf{A}_1 K_{15} \) |
| \( \begin{bmatrix} 0.3 \ 0.4 \ 0.3 \ 0 \ 0 \end{bmatrix} \) |

Table 12. Evaluation matrix of sub factor layer and factor layer of four machine twin screw propulsion system

| Four machine twin screw propulsion system |
|------------------------------------------|
| Applicability factors                    |
| evaluation matrix                        |
| \( K_{25} = \begin{bmatrix} 0.2 & 0.4 & 0.4 & 0.0 & 0.0 \\ 0.2 & 0.3 & 0.3 & 0.2 & 0.0 \end{bmatrix} \) |
| \( M_{25} = \mathbf{A}_1 K_{25} \) |
| \( \begin{bmatrix} 0.3 \ 0.325 \ 0.375 \ 0.15 \ 0 \end{bmatrix} \) |
| Reliability factors                      |
| evaluation matrix                        |
| \( K_{25} = \begin{bmatrix} 0.5 & 0.4 & 0.1 & 0.0 & 0.0 \end{bmatrix} \) |
| \( M_{25} = \mathbf{A}_1 K_{25} \) |
| \( \begin{bmatrix} 0.5 \ 0.4 \ 0.1 \ 0 \ 0 \end{bmatrix} \) |
| Maintainability factors                  |
| evaluation matrix                        |
| \( K_{25} = \begin{bmatrix} 0.4 & 0.4 & 0.2 & 0.0 & 0.0 \\ 0.5 & 0.4 & 0.1 & 0.0 & 0.0 \end{bmatrix} \) |
| \( M_{25} = \mathbf{A}_1 K_{25} \) |
| \( \begin{bmatrix} 0.42 \ 0.4 \ 0.18 \ 0 \ 0 \end{bmatrix} \) |
| Economic factors                         |
| evaluation matrix                        |
| \( K_{25} = \begin{bmatrix} 0.1 & 0.3 & 0.4 & 0.2 & 0.0 \\ 0.4 & 0.5 & 0.1 & 0.0 & 0.0 \end{bmatrix} \) |
| \( M_{25} = \mathbf{A}_1 K_{25} \) |
| \( \begin{bmatrix} 0.25 \ 0.4 \ 0.25 \ 0.1 \ 0 \end{bmatrix} \) |
According to the 3 section, we can get the evaluation matrix $Q_1$ and $Q_2$ of the hybrid propulsion system spectrum of twin screw propulsion system and four machine twin screw propulsion system. The experts' comments $S=(s_1, s_2, s_3, s_4, s_5)=$(very good, good, relatively good, general, poor, very poor) are graded according to the percentage, $S=(95, 80, 65, 45, 30)$. The hybrid propulsion system spectrum of twin screw propulsion system and four machine twin screw propulsion system scores in Table 13:

Table 13. Matrix and score of hybrid propulsion system

| Type                  | Spectrum evaluation matrix | Score of hybrid propulsion system |
|-----------------------|-----------------------------|-----------------------------------|
| Twin screw propulsion | $Q_1 = [0.273, 0.39, 0.324, 0.012, 0]$ | $Q_1 = 0.273 \times 95 + 0.39 \times 80 + 0.324 \times 65 + 0.012 \times 45 + 0 = 79.578$ |
| Four machine twin screw propulsion | $Q_2 = [0.413, 0.393, 0.168, 0.025, 0]$ | $Q_2 = 0.273 \times 95 + 0.39 \times 80 + 0.324 \times 65 + 0.012 \times 45 + 0 = 83.587$ |

According to the score of the hybrid propulsion system can be known, 6000HP platform supply ship selection four machine twin screw hybrid propulsion system is better than two machine twin screw hybrid propulsion system.

5. Conclusion
Five aspects of applicability, reliability, maintainability, economy and mobility to establish a hybrid propulsion system based on spectrum evaluation system. Fuzzy comprehensive evaluation method is used to comprehensively consider the weight of various factors in the system, so that the results of hybrid propulsion system type spectrum selection is more scientific and accurate.

6. Reference
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