Research on Intelligent Matching Technology of Marine Electric Propulsion System Based on Fuzzy Multiple Decision Making

XiaomiChen and ChunxueHao*
Qingdao Haixi Electric Co., Ltd, Qingdao, Shandong, 266555, China
*Corresponding author’s e-mail: eforpaper@163.com

Abstract. Based on matching process of ship electric propulsion system and the fuzzy multiple decision technology, an intelligent matching method of ship electric propulsion system is proposed with the establishment method of factor set, decision set and fuzzy linear transformation in line with the ship electric propulsion system. The decision result from this method is found to be dependent on the maximum membership principle or the score system. By an example, the fuzzy multiple decision-making method is simple in calculation, in line with actual situation and also provides a guidance in the design of ship electric propulsion system. Further related methods and directions are discussed in the end.

1. Introduction
With the rapid development of power electronic technology, AC speed regulation theory and computer control technology, marine electric propulsion system (MEPS) has made breakthroughs in mobility, reliability, operational efficiency, propulsion power and other aspects, and its application scope is constantly expanding. In addition to icebreakers, dredgers, ferries and other engineering ships, MEPS is also widely used in oil tankers, cruise ships and container ships of all sizes such as bulk carriers, and these demonstrated its broad market prospect[1].

From the macro point of view, the MEPS is an important part of the ship power system, and its operation reliability determines the reliability of the ship power system, even the reliability of the ship operation; from the micro point of view, the MEPS is a complex system composed of propulsion transformer, propulsion converter, propulsion motor and related protection and control circuits system, if case one of them has a short board, it may lead to performance degradation of the whole system. Therefore, in order to ensure the reliability of ship electric propulsion system and meet the required economic and technical indicators, it is imperative to have a fitting design on ship electric propulsion system to ensure smooth and coordinated operation in all components of the equipment.

At present, the research on matching design technology has been done in some aspects. In [2], the matching technology of ship engine and propeller in ship pod electric propulsion system was studied, and the matching design software was developed; in [3], the intelligent matching technology between cylinder liner and piston of marine diesel engine based on genetic algorithm was studied. In this paper, a design method of intelligent matching system for marine electric propulsion system is proposed based on fuzzy theory, which aims to optimize the comprehensive design of MEPS.
2. Intelligent matching and fuzzy multiple decision making
The matching process of MEPS is the process of selecting the best scheme according to the technical index of each equipment in the system, including the comprehensive analysis of the power, efficiency, stability, requirements and impact on the external system, which is also a decision-making process. Therefore, some decision-making methods can be applied to the matching process of MEPS. At the same time, there are many qualitative indicators and expert's heuristic experience described by natural language in the matching process of MEPS. In order to apply this kind of fuzzy information, one method is to quantify the qualitative index and expert experience, the other is to adopt fuzzy multiple decision-making [4-6].

Fuzzy multiple decision-making (FMDM) is an effective decision-making method to make comprehensive evaluation of things affected by many factors. FMDM can directly apply fuzzy information to decision-making, and select an optimal scheme from the matching scheme according to the principles provided in the fuzzy information.

Let \( U = \{u_1, u_2, \ldots, u_n\} \) be the set of \( n \) factors or Indies and \( V = \{v_1, v_2, \ldots, v_m\} \) the set of \( m \) decision-makings. The number and name of their elements can be determined subjectively by people according to the actual needs of the problem. Different factors have different positions, functions and weights, so the decision-making is different. Any decision-making of \( V \) are not absolutely positive or negative, so fuzzy multiple decision is a fuzzy subset of \( V \) [7]:

\[
B = \{b_1, b_2, \ldots, b_m\} \in \Gamma(V)
\]  

(1)

Where \( b_j \) (\( j = 1, 2, \ldots, m \)) reflects the position of the \( j \)-th decision-making in multiple decision-making \( v_j \), (e.g. membership of fuzzy set \( B \), \( B(v_j) = b_j \)), \( \Gamma(V) \) is the fuzzy set of subsets of \( V \). Multiple decision-making set \( B \) depends on the weight of each factor \( A = \{a_1, a_2, \ldots, a_n\} \in \Gamma(U) \) which is a fuzzy subset of \( U \) and \( \sum_{i=1}^{n} a_i = 1 \), and \( a_i \) represents the weight of the first factor. Therefore, once the weight \( A \) is given a multivariate decision \( B \) can be accordingly obtained.

Therefore, it is necessary to establish a fuzzy transformation from \( U \) to \( V \). If each factor \( u_j \) is separately evaluated as \( f(u_j) \), the fuzzy mapping \( f \) from \( U \) to \( V \) can be seen [8]:

\[
f : U \rightarrow \Gamma(V)
\]

(2)

\[
u_j \mapsto f(u_j) \in \Gamma(V)
\]

(3)

After the fuzzy linear transformation \( T_f \) is obtained for a specific weight \( A \), the multiple decision-making can be obtained by applying the fuzzy composition operation:

\[
B = A \circ T_f
\]

(4)

The basic process of FMDM is as follows:

Figure 1. Basic process of multiple decision making.

3. Research on Intelligent Matching Technology of electric propulsion system

3.1. Index set
MEPS are an important part of the ship's power system, which converts electrical energy into mechanical energy to drive the propeller to rotate. Therefore, it’s most important indicators are rated speed, rated power, maximum torque and other performance indicators. At the same time, it requires
for external power system, lubricating oil system, cooling system and installation conditions etc. as well as external generated harmonic, electromagnetic and vibration. In addition, safety, maintainability, energy saving, automation, price and other indicators will also have an impact on the design of MEPS. Therefore, the index set is determined as follows:

$$U = \{u_1, u_2, u_3, u_4, u_5, u_6, u_7, u_8\}$$

Where $u_1$ represents performance, $u_2$ represents external requirements, $u_3$ represents external influence, $u_4$ represents safety, $u_5$ represents maintainability, $u_6$ represents energy saving, $u_7$ represents automation and $u_8$ represents price.

3.2. Decision making set
Let the decision making set be

$$V = \{v_1, v_2, v_3, v_4\}$$

Where $v_1$ means excellent, $v_2$ means good, $v_3$ means medium, and $v_4$ means poor.

3.3. Fuzzy linear transformation
For a ship's electric propulsion system design scheme, several professionals and customers can be asked to express their opinions on the performance of the scheme. If 50% of the people think it is excellent, 30% of the people think it is good, 10% of the people think it is medium and 10% of the people think it is poor, then we can get the following results:

$$\left(\begin{array}{cccc}
1 & 1 & 1 & 11 \\
12 & 13 & 14 & 0.5 \\
15 & 16 & 17 & 0.3 \\
18 & 19 & 20 & 0.1 \\
21 & 22 & 23 & 24 & 0.1
\end{array}\right)$$

According to formula (4) the fuzzy multiple decisions is obtained as follows:

$$B_1 = A_1 \odot T_f = (b_{11}, b_{12}, b_{13}, b_{14})$$

$$B_2 = A_2 \odot T_f = (b_{21}, b_{22}, b_{23}, b_{24})$$

Where the composition is the fuzzy matrix product, e.g. $b_{11} = \bigcup_{i=1}^{8} a_{i1} \cap u_{i1}$, here $\bigcup = \max$, $\cap = \min$.

For the final result, the scheme can be determined as excellent, good, medium and poor according to the principle of maximum membership, or the results can be calculated as 1-point system or 100 point system after normalization.

To sum up, the basic process of intelligent matching of marine electric propulsion system based on fuzzy multiple decision is as follows:
4. Example

There are two kinds of electric propulsion system design schemes for a certain ship, and the main equipment parameters are shown in the table below.

| Device       | Main Parameter                                   | Scheme 1                                      | Scheme 2                                      |
|--------------|--------------------------------------------------|-----------------------------------------------|-----------------------------------------------|
| Propulsion   | Rated capacity: 1600KVA                         | Rated capacity: 1500KVA                      |                                               |
| Transformer  | Transformation ratio: 690V / 720V               | Transformation ratio: 690V / 720V             |                                               |
|              | Impedance voltage: 6%                          | Impedance voltage: 6%                        |                                               |
|              | Efficiency: 98%                                 | Efficiency: 98%                              |                                               |
|              | Cooling mode: air cooling                       | Coolig mode: air cooling                      |                                               |
|              | Insulation method: epoxy resin casting          | Insulation method: epoxy resin casting        |                                               |
|              | Size: 1200 × 600 × 800 (mm)                     | Size: 1000 × 600 × 800 (mm)                  |                                               |
|              | Weight: 1.5T                                    | Weight: 1 t                                   |                                               |
| Propulsion   | Input rated voltage: AC690V                     | Input rated voltage: AC690V                  |                                               |
| Converter    | Output rated voltage: AC630v                    | Output rated voltage: AC630v                 |                                               |
|              | Output rated current: 1600A                     | Rated output current: 1250A                  |                                               |
|              | Three phase load asymmetry: 5%                  | Three phase load asymmetry: 5%               |                                               |
|              | Efficiency: 96%                                 | Efficiency: 94%                              |                                               |
|              | Cooling mode: water cooling                     | Cooling mode: water cooling                   |                                               |
|              | Size: 3200 × 800 × 2200 (mm)                    | Size: 2800 × 800 × 2000 (mm)                 |                                               |
|              | Weight: 4T                                      | Weight: 3T                                    |                                               |
| Propulsion   | Rated power: 1200kW                             | Rated power: 1200kW                           |                                               |
| Motor        | Rated voltage: AC690V                           | Rated voltage: AC690V                         |                                               |
|              | Efficiency: 95%                                 | Efficiency: 95%                              |                                               |
|              | Power factor: 0.85                              | Power factor: 0.85                           |                                               |
|              | Cooling method: water                           | Cooling method: water                         |                                               |
|              | Size: 2300 × 1600 × 1800 (mm)                   | Size: 2300 × 1600 × 1800 (mm)                |                                               |
|              | Weight: 5.8t                                    | Weight: 5.8t                                  |                                               |
| Control      | Console: Yes                                    | Console: Yes                                  |                                               |
| System       | Energy management system: Yes                   | Energy management system: Yes                 |                                               |
|              | Fault diagnosis system: Yes                      | Fault diagnosis system: None                  |                                               |
|              | High degree of automation                       | Degree of automation: medium                  |                                               |
|              | Reliability: high                               | Reliability: medium                           |                                               |

For the above two fuzzy solutions, please express your opinions:
The ship owner a has the requirements of excellent performance, high safety and high degree of automation for the marine electric propulsion system. Other factors can be properly considered, and the weight of each factor can be taken as follows:

\[
A_a = (0.25, 0.05, 0.05, 0.25, 0.05, 0.05, 0.25, 0.05)
\]

The calculation of fuzzy multiple decision is as follows:

\[
B_{a1} = A_a \odot T_{f1} = (0.25, 0.2, 0.1, 0.1)
\]

\[
B_{a2} = A_a \odot T_{f2} = (0.1, 0.2, 0.25, 0.2)
\]

According to the principle of maximum subordination, scheme one is superior than scheme two.

The results were normalized as follows:

\[
B_{a1}' = \left( 0.25, 0.2, 0.1, 0.1 \right)
\]

\[
B_{a2}' = \left( 0.13, 0.26, 0.35, 0.26 \right)
\]

In the percentile system, the excellent is 100, the good is 75, the medium is 50, and the difference is 25:

\[
SCORE_{a1} = B_{a1}' \times \begin{pmatrix} 100 & 75 & 50 & 25 \end{pmatrix}^T = 73.75
\]

\[
SCORE_{a2} = B_{a2}' \times \begin{pmatrix} 100 & 75 & 50 & 25 \end{pmatrix}^T = 56.5
\]

It can be seen that for ship a, scheme 1 should be selected.

If there is a ship-owner B, its requirements for the ship's electric propulsion system are low installation conditions and low price. Other factors can be properly considered, and then the weight of each factor can be taken as follows:

\[
A_b = (0.05, 0.35, 0.05, 0.05, 0.05, 0.05, 0.05, 0.35)
\]

Fuzzy multiple decision making is as follows:

\[
B_{b1} = A_b \odot T_{f1} = (0.1, 0.2, 0.3, 0.35)
\]

\[
B_{b2} = A_b \odot T_{f2} = (0.3, 0.35, 0.2, 0.1)
\]

According to the principle of maximum subordination, scheme one is poor and scheme two is good.

The results of percentage system calculation are given by:

\[
SCORE_{b1} = 52.5
\]

\[
SCORE_{b2} = 72.25
\]

It can be seen that for ship B, scheme 2 should be selected.
5. Conclusion
The intelligent matching method of marine electric propulsion system (MEPS) based on fuzzy multiple decision-making is proposed in this paper. According to the different requirements of MEPS, the optimal scheme can be obtained from the alternatives. The calculation is simple; the result is intuitive and has certain practical value. Of course, the method proposed in this paper can be improved by fine-tuning of the following factors: first, the fuzzy linear transformation matrix depends on the subjective judgment of professionals and customers with a certain degree of subjectivity. Similarly, the selection of factor weight is also subjective. How to establish objective, reasonable and practical fuzzy linear transformation matrix and weight matrix is an important question. Although there are relevant methods, it needs further research. Secondly, the intelligent matching proposed in this paper is the process of selecting the best scheme among the alternatives, which is a lower level matching. A better or higher level matching should be based on the requirements of marine electric propulsion system, meet the main parameters of various equipment, or optimize the marine electric propulsion system in the selection database to form a higher level of intelligent matching.

References
[1] BAO Y., SHI W.F. (2011) Research on Operation Simulation of Ship Electric Propulsion System. Navigation of China, 5: 34–38.
[2] QIN Y.Z. (2015) The Research of Ship-marine-propeller Matching to Podded Electric Propulsion System Ship. JiMei University, Xiamen.
[3] ZHANG H., ZHOU L.P., TANG W.K., and ZHANG S.G., (2016) Research on the Intelligent Optimal Matching System of Marine Diesel Engine Piston and Cylinder Liner. Journal of Jiangsu University of Science and Technology (Natural Science Edition), 2: 559-564.
[4] XIE J.L., and LIU C.P. (2017) Fuzzy Mathematics Method and Application. Huazhong University of science and technology press, Wuhan.
[5] ZHANG C.H., and LI H.B. (2001) Application of Fuzzy Decision in Lighting Control of Cities. Automatic of Electric Power System, 4: 49–52.
[6] LIU H.W. (2005) Vague Set Methods of Multicriteria Fuzzy Decision Making. System Engineering-Theory and Practice, 5: 102–109.
[7] WANG F.Y., MO H., ZHAO L., and LI R.M. (2018) Type 2 Fuzzy Sets and Logic. Tsinghua university press, Beijing.
[8] LIANG S.T., LIU W.D., and MENG D.D. (2018) The Research on the Parameter Tuning Method of an Analytic Type Fuzzy Integral Hybrid Controller. Proceedings of ICMCCE2018, 50-55.