Research on contribution analysis method of lubricating oil performance index

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Abstract. In the application of entropy weight method and oil performance index test, the weights of various indexes of lubricating oil in use are objectively assigned, and the correlation among multiple samples is investigated by normalization of multi-sample data of the same monitoring index, so that the weight results are more accurate and reasonable, and provide theoretical basis for oil formula optimization or life promotion.

Keywords: Contribution analysis method, index, weight.

1. Introduction

The Fuzzy and fuzzy mathematical method is an effective method to change the qualitative evaluation into quantitative evaluation, which can solve the complex problems of the fuzzy and difficult to be quantified in many fields. For example, in order to evaluate the overall performance of Lube oil formulation, Yang Hongwei et al. have successfully established the multi-objective function of lube oil formulation design and obtained the required optimal formulation by means of fuzzy and mathematical methods. Cheng Tian et al. [2] adopted entropy weight module and integrated evaluation method, standardized the original data, determined the comprehensive weight of each index, and used the model and integrated evaluation model to determine the best formula, the problem of multi-index and multi-scheme comprehensive decision-making evaluation in steam turbine oil formulation optimization is solved. [3] Considering the interaction between the functional additives and the Correlation and interaction of the performance indexes, the mould and analytic hierarchy process (AHP) method was applied in the process of multi-objective optimization of the formula of metal working fluid, the optimum formulation was obtained quickly and effectively, and the shortcomings of the traditional formulation optimization method were overcome. B. C. Based on the method of fuzzy analytic hierarchy process (AHP), the actual degradation of lubricating oil performance and its remaining service life can be evaluated accurately. In this paper, the oil in use is taken as the research object, and the decay process of oil in use is objectively evaluated by entropy weight method, and the influence weight of each index is obtained, which provides the technical support for the optimization of oil formula and the evaluation of service performance.
2. Objective weight calculation based on entropy weight method

The entropy weight method calculates the index weight according to the variation degree of each evaluation index value, the basic calculation process is as follows [5-6]:

(1) Normalization of raw data. The original data matrix of m evaluation indexes and N evaluation objects is \( A = (a_{ij})_{m \times N} \). After normalization, it can be obtained \( R = (r_{ij})_{m \times N} \). The normalized formula is:

\[
\text{POSITIVE INDICATORS: } r_{ij} = \frac{a_{ij} - \min_j \{a_{ij}\}}{\max_j \{a_{ij}\} - \min_j \{a_{ij}\}}
\]

\[
\text{NEGATIVE INDICATORS: } r_{ij} = \frac{\max_j \{a_{ij}\} - a_{ij}}{\max_j \{a_{ij}\} - \min_j \{a_{ij}\}}
\]

(2) The entropy of the index. In the judgment problem with m indexes and n objects (hereinafter referred to as \((M, N)\)), the entropy \( H_j \) of the \( J \) index is defined as:

\[
h_j = -k \sum_{i=1}^{n} (p_{ij} \ln p_{ij}) (j=1, 2, \ldots, m), p_{ij} = \frac{y_{ij}}{\sum_{i=1}^{n} y_{ij}}, k = \frac{1}{\ln n}
\]

If \( p_{ij} = 0, p_{ij} \ln p_{ij} = 0 \)

(3) Entropy weight of the index. In the \((M, N)\) judgment problem, the entropy weight \( j \) of index \( j \) is defined as:

\[
w_j = \frac{1 - h_j}{m - \Sigma_{j=1}^{m} h_j} (j=1, 2, \ldots, m)
\]

From the above definition, the basic properties of entropy weight are as follows:

(1) when the value of each object on index \( j \) is exactly the same, the entropy value reaches the maximum and the entropy weight is zero; this means that the index does not provide any useful information. On the contrary, when the value of the index \( j \) is different, the entropy value is smaller and the entropy weight is larger, which indicates that the index occupies a larger proportion and each object has obvious difference in the index, so we should pay attention to it.

(2) The greater the entropy of the index, the smaller the entropy weight, and the less important the index is 1.

3. Example solution

3.1. Raw data

| Projects                        | 0 h  | 100 h | 200 h | 300 h | 400 h | 500 h | 600 h | 700 h |
|---------------------------------|------|-------|-------|-------|-------|-------|-------|-------|
| KV (100°C)/ mm²/s               | 6.982| 6.968 | 6.977 | 6.952 | 6.977 | 6.983 | 6.929 | 6.918 |
| KV (40°C)/ mm²/s                | 44.39| 43.79 | 43.89 | 43.83 | 43.81 | 44.10 | 43.49 | 43.51 |
| Oil Sludge mg/100mL            | 1.2  | 0.8   | 1.0   | 1.3   | 1.8   | 5.8   | 8.0   | 3.4   |
| AN/mgKOH/g                     | 0.51 | 0.59  | 0.58  | 0.63  | 0.64  | 0.58  | 0.48  | 0.56  |
| RPVOT /min                     | 278  | 184   | 170   | 160   | 154   | 125   | 74    | 50    |
A brand of hydraulic oil was tested for 700h, and the changes of viscosity, sludge, acid value and rotating oxygen bomb were monitored every 100h. The test results are shown in Table 1. Trends in data are shown in Fig. 1-Fig. 2. Fig. 1 shows that the kinematic viscosity of the 700h bench has little change during operation. Fig. 2 the rotating oxygen bomb shows a decreasing trend all the time, which shows that the antioxidant is in the state of consumption, the acid value does not change obviously, the sludge tends to be stable within 400h, and then rises sharply after 400h and reaches the peak value after 600h, it is possible that the increased consumption of antioxidants, together with the use of metals as catalysts, leads to the reaction of carbon and oxygen of hydrocarbon molecules in hydraulic oil under high temperature and high pressure.

3.2. Data normalization
Because of the difference of units and orders of magnitude among different factors in the original data, it is necessary to preprocess the original data to eliminate the difference. The common methods are initial value method and mean value method. The paper uses the initial value method to normalize the data, and the results are as follows:

| Times | KV (40°C)/ mm²/s | Oil Sludge mg/100mL | AN/mgKOH/g | RPVOT /min |
|-------|------------------|---------------------|------------|------------|
| 0 h   | 1.00             | 0.15                | 0.94       | 1.00       |
| 100 h | 0.99             | 0.10                | 0.81       | 0.66       |
| 200 h | 0.99             | 0.13                | 0.83       | 0.61       |
| 300 h | 0.99             | 0.16                | 0.76       | 0.58       |
| 400 h | 1.00             | 0.23                | 0.75       | 0.55       |
| 500 h | 0.99             | 0.73                | 0.83       | 0.45       |
| 600 h | 0.98             | 1.00                | 1.00       | 0.27       |
| 700 h | 0.98             | 0.43                | 0.86       | 0.18       |
Create a normalized Matrix:

\[
Y = \begin{bmatrix}
1 & 0.15 & 0.94 & 1.00 \\
0.99 & 0.10 & 0.81 & 0.66 \\
0.99 & 0.13 & 0.83 & 0.61 \\
0.99 & 0.16 & 0.76 & 0.58 \\
1.00 & 0.23 & 0.75 & 0.55 \\
0.99 & 0.73 & 0.83 & 0.45 \\
0.98 & 1.00 & 1.00 & 0.27 \\
0.98 & 0.43 & 0.86 & 0.18
\end{bmatrix}
\]

3.3. Entropy weighting

1) Calculate the weight of the normalized index \( Y_{ij} \) under the physical and chemical performance index \( P_{ij} \):

\[
p_{ij} = \frac{y_{ij}}{\sum_{j=1}^{n} y_{ij}}
\]

2) Calculate the entropy of the physical and chemical properties \( h_j \):

\[
h_j = -k \sum_{i=1}^{n} p_{ij} \ln p_{ij}, k = \frac{1}{\ln n}
\]

3) The Coefficient of difference of physical and chemical properties was calculated \( g_j \)

\[
g_j = 1 - h_j
\]

4) The entropy weight of physical and chemical properties was obtained by normalization \( W_j \)

\[
w_j = \frac{g_j}{\sum_{j=1}^{m} g_j}
\]

The entropy weights of the four physical and chemical properties are given in Table 3, \( W = (0.00, 0.56, 0.09, 0.35) \).

Table 3. Entropy weight of each index

| Indicators | KV     | Oil Sludge | AN  | RPVOT |
|------------|--------|------------|-----|-------|
| W          | 0.00   | 0.56       | 0.09| 0.35  |

4. Conclusion

(1) Sum up, the sludge is the most important key factor in the process of using this kind of oil, and it is the key to improve the service life and optimize the formula of this kind of oil. Generally speaking, the hazards of oil sludge are: thickening of lubricating oil, accelerated wear, sediment and filter blockage, etc. It is generally recommended to control the content of oil sludge below 10mg/100mL. Thermal oxidation stability is the degree of degradation of oil antioxidant consumption, closely related to the service life of oil, acid value and oil aging after the increase of organic acid content, viscosity stability, it has the least influence on the overall performance of the lubricating oil.

(2) With the application of entropy weight method, the weight of the same monitoring index can be determined by combining several monitoring samples points, and the connection between the samples can be considered. It has important application value in the integrated evaluation of oil products.

(3) The weight is usually divided into subjective weight and objective weight. The entropy weight method is based on the summary of long-term practical experience. In order to make up for the deficiency of subjective and objective empowerment, we can combine them to determine the comprehensive weight of each evaluation index and make the comprehensive empowerment more scientific and reasonable.

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