Study on Condition Monitoring and Evaluation of Auxiliary Engine of Steam Turbine Based on Matter-element Theory

WANG Bo, ZHAO Yu-zhu

Steam Turbine and Gas Turbine Technical Department, Huadian Electric Power Research Institute, Hangzhou 310030,
Zhejiang Province, China
* Corresponding author: WANG Bo 458612891@qq.com

Abstract. As an important equipment in thermal production process of thermal power unit, auxiliary equipment of steam turbine, such as feed-water pump, whether it can operate safely and economically is very important for normal operation of thermal power plant. Considering that the auxiliary machine on the side of the steam turbine of a power plant has the characteristics of high failure rate, a state monitoring and evaluation method based on the matter-element theory is proposed. Based on the establishment of the monitoring index and evaluation model of the auxiliary engine on the side of the steam turbine, the correlation degree between the main operating parameters of the auxiliary engine and the monitoring model is determined. According to the value of correlation degree, the operating condition of auxiliary machine is judged to be excellent, good, qualified or malfunction. Finally, a 300MW steam feed pump is taken as an example to prove that this method has certain engineering application value.

1. Introduction

Feed-water pump is one of the important auxiliary machines of large thermal power plant and steam turbine unit of nuclear power plant. As the boundary point between the low pressure system and the high pressure system of the heat engine part of the power station, it must have corresponding subsystems such as lubrication, cooling and sealing. Due to the particularity of working environment and the complexity of equipment, the failure rate of feed water pump is very high. Therefore, it is necessary to evaluate its running condition, determine its health level, evaluate its running risk, and provide corresponding basis for the maintenance decision. The grey theory is applied by LI Jian-lan and HUANG Shu-hong to make quantitative evaluation on several operating states of feed-water pumps of a 300MW unit by calculating the grey correlation degree [1]. However, this approach requires the equipment operation parameters dimensionless processing, large amount of calculation and because the dimensionless model has certain subjectivity, so is likely to make the evaluation results and the actual operation condition. We proposed a matter element model to judge the running state of feed water pump in order to make the evaluation more objective.

Extension theory was founded in 1983 by CAI Wen, a Chinese scholar, to solve the problem of subjective and objective contradictions. Based on the matter element theory and the extension set theory, we can study the influence of quantity and quality on the described problems at the same time. So as to fully understand the system characteristics, the extension matter-element evaluation method is often used to deal with the contradiction problems of multiple parameters and large mixing degree [2-
3. It has been widely used in many fields [4-5]. Is proposed in this paper based on the matter-element model of feed water pump running state evaluation method, set up the matter-element model of feed water pump running state level, feed water pump running state by computing the rank between the extension of correlation degree, and then evaluate its running state.

2. The matter-element
The matter-element contains three basic elements in extension theory. Assuming the name of object R is N, the characteristics are C, the magnitudes of C are P, the basic element or matter-element to describe the object is $R = (N, C, P)$. Assuming the object is a multidimensional matter-element whose feature vector is $C = [c_1, c_2, \ldots, c_n]$, and corresponding value $P = [p_1, p_2, \ldots, p_n]$ is a numerical matrix, the expression of matter-element is:

$$ R = (N, C, P) = \begin{bmatrix} N & c_1 & p_1 \\ & c_2 & p_2 \\ & \vdots & \vdots \\ & c_n & p_n \end{bmatrix} $$

(1)

Assuming any element $u$ in the domain $U$ is corresponding to a real number $K(u) \in (-\infty, +\infty)$, then $A = \{ (u, y) | u \in U, Y = K(u) \in (-\infty, +\infty) \}$ is a extension set in the domain $U$. $Y = K(u)$ is the correlation function of $A$, $K(u)$ is the correlation degree of the extension set $A$. Assuming $x \in (-\infty, +\infty)$ is any point, $X_0 = [a, b]$ and $X = [c, d]$ are any ranges in the real domain, $X_0 \subseteq X$, and they are with no common endpoints, then the dependent correlation function is:

$$ k(x) = \frac{\rho(x, X_0)}{D(x, X_0, X)} $$

$$ \rho(x, X_0) = \left| x - \frac{a + b}{2} \right| - \frac{b - a}{2} $$

$$ D(x, X_0, X) = \begin{cases} \rho(x, X_0) - \rho(x, X), x \in X_0 \\ -1, x \in X \end{cases} $$

(2)

The correlation function can calculate the correlation extent between point $x$ and interval $X_0$. If $k(x) > 0$, then it means the extent that point $x$ belongs to $X_0$, if $k(x) < 0$, then it does not mean the extent that point $x$ belongs to $X_0$, and the value of k( x) higher, the likelihood greater.

3. Operating condition evaluation index and the grade of auxiliary engine of steam turbine
Referring to the operation rules of a 300MW unit in China and the classification criteria for the operation status of feed pump in literature [1], This paper divides the running state of the feed pump into four grades: excellent, good, qualified and fault. The evaluation index and corresponding parameter range are shown in table 1.

| The evaluation index | Permissible range | evaluation grade |
|----------------------|------------------|------------------|
| Vibration amplitude of feed-pump /μm | 0—50 | 0—15 | 15—30 | 30—40 | 40—50 |
| Bearing temperature of feed pump $T_1$ /℃ | 60—70 | 60—62 | 62—65 | 65—67 | 67—70 |
| The temperature at the outlet of the cooler | 35—46 | 35—38 | 38—40 | 40—42 | 42—46 |
The evaluation index | Permissible range | evaluation grade |
|-----------------|-----------------|-----------------|
| T2/℃ Sealing water temperature | 55—75 | 55—60 | 60—65 | 65—70 | 70—75 |
| Lubricating oil pressure P/MPa | 0.1—0.24 | 0.2—0.24 | 0.16—0.2 | 0.13—0.16 | 0.1—0.13 |

4. The matter element model of operation state evaluation of feed pump was established
The matter element model of running state of feed water pump can be described by the following n-dimensional matter element:

\[
R = (N, C, V) = \begin{bmatrix}
N & c_1 & v_1 \\
& \vdots & \vdots \\
& c_n & v_n
\end{bmatrix}
\]  

Where, R is the feed pump operating state matter element; N is the operating status level; C is the performance evaluation index; V is the value of operation condition evaluation index of feed pump.

4.1 The classical region for determining the operation status of feed pump
According to extension theory and matter-element model theory, combined with the numerical interval of each index in each grade in table 1, the classical domain of the operation status of feed water pump was established, as shown below: good, or

\[
R_1 = \begin{bmatrix}
\text{excellent} & A \langle 0.15 \rangle \\
T_1 & \langle 60, 62 \rangle \\
T_2 & \langle 35, 38 \rangle \\
T_3 & \langle 55, 60 \rangle \\
P & \langle 0.2, 0.24 \rangle
\end{bmatrix}
\]  

\[
R_2 = \begin{bmatrix}
\text{good} & A \langle 15, 30 \rangle \\
T_1 & \langle 62, 65 \rangle \\
T_2 & \langle 38, 40 \rangle \\
T_3 & \langle 60, 65 \rangle \\
P & \langle 0.16, 0.20 \rangle
\end{bmatrix}
\]  

\[
R_3 = \begin{bmatrix}
\text{qualified} & A \langle 30, 40 \rangle \\
T_1 & \langle 65, 67 \rangle \\
T_2 & \langle 40, 42 \rangle \\
T_3 & \langle 65, 70 \rangle \\
P & \langle 0.13, 0.16 \rangle
\end{bmatrix}
\]
4.2 Characteristic Elements of Operation State of Feed Water Pump

In matter-element theory, the concepts of "segmental domain" and "qualitative function" are established [2]. They describe the dialectic rule of objective things from quantitative change to qualitative change. The section domain reflects the number value interval corresponding to a certain feature of the research object. When the mathematical description value of the object in a certain state is within the range of the domain, its properties remain stable. Conversely, when the change of this value exceeds the node domain, it will cause the change of "quality" of this property [2-3]. According to the extension matter-element theory \( X_0 = \langle a, b \rangle \), \( X = \langle c, d \rangle \), \( X_0 \in X \), and there's no common endpoint, combined with the numerical interval from excellent to failure of each evaluation index in Table 1. In short, the allowable range of each evaluation index, the section area where the running state of the feed pump can be established, i.e., the feature element is:

\[
R_x = \begin{bmatrix}
X & A & \langle 0.10, 0.13 \rangle \\
T_1 & \langle 67, 70 \rangle \\
T_2 & \langle 42, 46 \rangle \\
T_3 & \langle 70, 75 \rangle \\
P & \langle 0.10, 0.13 \rangle 
\end{bmatrix}
\]

4.3 The Calculation of Correlation Function Value and Correlation Degree

Extension correlation function can be expressed as:

\[
K_y(p_y) = \begin{cases}
-\frac{\rho(p_y, P_j)}{\rho(p_y, P_j)} & P_j \in P_y \\
\frac{\rho(p_y, P_j)}{\rho(p_y, P_j)} - \frac{\rho(p_y, P_j)}{\rho(p_y, P_j)} & P_j \notin P_y
\end{cases}
\]

(5)

Where \( \rho(p_y, P_j) \) is the distance between matter-element to be evaluated and every classic field, \( \rho(p_y, P_j) \) is the distance between matter-element to be evaluated and section field, \( P_j = \frac{1}{2} |a_j - a_j| \), \( i = 1, 2, 3, 4 \); \( j = 1, 2, 3, 4 \); is the size of each classical field, the correlation degree of the matter-element to be evaluated is:

\[
\lambda_i = \sum_{j=1}^{4} W_{ij} K_y(p_y), i = 1, 2, 3
\]

(6)

\( W_{ij} \) is the weight of the evaluation indicators listed in Table 1, considering the importance of the listed 5 evaluation indicators for the safety and economic operation of feed-water pump and combined with relevant studies in literature [1], the weight vector is given as:

\[
[W_{i1}, W_{i2}, \cdots, W_{i5}] = [0.35, 0.25, 0.10, 0.10, 0.2]
\]

In order to keep the correlation degree of all state indicators in the range of [-1, 1], so as to facilitate state evaluation, normalization processing should be carried out according to the following formula:

\[
\lambda^*_i = \frac{2\lambda_i - \lambda_{\min} - \lambda_{\max}}{\lambda_{\max} - \lambda_{\min}}, i = 1, 2, 3
\]

(7)
Where, \( \lambda_{\text{max}} = \max_{i \in \{1, 2, 3\}} \{\lambda_i\} \) and \( \lambda_{\text{min}} = \min_{i \in \{1, 2, 3\}} \{\lambda_i\} \).

4.4 The Evaluation Principles

The advantages and disadvantages of the running state of the feed pump can be judged by the following formula according to the maximization principle:

\[
\text{IF} \ (\lambda \ast_k = 1) \text{THEN} \ (S_0 = S_k)
\]

If \( \lambda \ast_k = 1 \), then judge the running state level as \( S_k \). The probability of other state grades can be determined according to the relative value of their correlation degree. The greater the relative value of correlation degree, the greater the probability of approaching this state.

5. Application Analysis

In literature [1], four sets of data of feed pump operation of a subcritical 300MW unit are presented. Two of the groups were selected as evaluation objects. In order to verify the validity and accuracy of the extension matter-element method, one group is selected as the rated parameter and the other is the non-rated parameter detected in operation. If the feed water pump operates under rated parameters, the evaluation result obtained under the condition of accurate model should be "excellent" or "good". The two groups of data are: \( Y_{01} = \{20, 65, 40, 68, 52\} \) and \( Y_{02} = \{52, 68, 40, 65, 20\} \), Wherein, \( Y_{01} \) is rated operation data of feed pump. Their corresponding current entity elements are:

\[
R_{01} = \begin{bmatrix}
X_{01} & A & 20 \\
 & T_1 & 65 \\
 & T_2 & 40 \\
 & T_3 & 65 \\
 & P & 0.18
\end{bmatrix} \quad R_{02} = \begin{bmatrix}
X_{02} & A & 52 \\
 & T_1 & 68 \\
 & T_2 & 40 \\
 & T_3 & 65 \\
 & P & 0.22
\end{bmatrix}
\]

According to equations (3) and (4), the value of correlation function and correlation degree are calculated in combination with the weight of evaluation index given above. Finally, relative correlation degree is calculated according to equation (5), and the result can be obtained: For data \( Y_{01} \), \( \lambda \ast_1 = [-0.449, -1, -0.411, -1] \). The four values in this vector correspond to "excellent", "good", "qualified" and "failure" respectively.

According to the maximization principle of equation (6), the operating state of the feed pump can be judged as \( S_0 = S_2 = \text{"good"} \). It is an objective fact that the operation of thermal equipment under rated parameters corresponds to "good" working condition. For \( Y_{02} \), \( \lambda \ast_2 = [-0.972, -0.547, 0.231, 1] \), determine the operating state of the feed pump according to the maximization principle, \( S_0 = S_2 = \text{"failure"} \). The results are consistent with those obtained by grey mathematical model in the literature [1]. Through the case analysis of the above two data sets, the validity, accuracy and engineering application value of the extension matter-element model in evaluating the running state of the feed pump or fault identification are fully verified.

6. Conclusions

It can be effectively dealt with diverse characteristics of feed water pump running state parameters and quantitatively evaluated running state and fault identification of feed water pump based on the matter-element model and the extension evaluation method.

The extension matter-element model established does not require a large number of state evaluation samples, and the evaluation results are intuitive; The model has simple algorithm and short computation time. It is an efficient method to evaluate the status of power station equipment.
It is feasible and accurate to apply the extension matter-element method to the status evaluation, fault diagnosis and maintenance decision-making of thermal equipment and systems of power stations, and its engineering application value is high.

References
[1] LI Jian-lan, HUANG Shu-hong. A grey model for evaluation of operation state of auxiliary power station[J]. Power engineering, 2007, 27(6): 915-917.
[2] CAI Wen. Matter-element model and application[M]. Beijing: science and technology literature publishing house, 1994.
[3] WU Meng-shi, XIA Hong-shan, ZHENG Yan-qin. Airport service quality evaluation based on multilevel matter-element model[J]. Aerospace computing technology, 2013, 43(4):68-71.
[4] REN Jin-zhou, ZHOU Rong-yi, ZHONG An. Safety evaluation model of dangerous chemicals storage based on matter element analysis I[J]. Mineral Engineering Research, 2016, 31(6): 77-80.
[5] LI Shao-hua, WANG Lei, ZHANG Wang. Fuzzy matter element model based running state evaluation for medium-speed coal pulverizers[J]. Thermal Power Generation, 2013, 42(4):20-24.