Communication Equipment Residual Life Prediction Method Based on Multi-environmental Time Similarity Theory

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Abstract. In order to reduce the high costs of Communication Equipment operation and maintenance management, a novel residual life prediction method for Communication Equipment based on multi-environmental time similarity (METS) theory was proposed to make scientific and reasonable cost maintenance strategy of Communication Equipment. This method has introduced a reference Communication Equipment which has similar operational environment and type of the object Communication Equipment to obtain similarity coefficient (running hours and start/stop cycles) of the reference unit life evaluation parameters under actual operation conditions and benchmark operation conditions by using experience operational data. Based on the METS theory, the object unit factored running hours and start/stop cycles under benchmark operative conditions were obtained through calculating its actual running hours and start/stop cycles under actual operational conditions. And then the object unit residual life was predicted by comparing with maximum maintenance interval. Finally, a factory Communication Equipment HGP component residual life prediction is provided as the example to verify the scientific validity and feasibility of the prediction method.

Keywords: communication equipment, theory of similarity, multi-environmental time similarity (METS) theory, residual life prediction.

1. Introduction

The key to develop Communication Equipment maintenance strategy is to accurately predict the remaining life of the important parts. At present, the life prediction of Communication Equipment is generally carried out by artificial statistics[1][2]. This method is not only time-consuming and accuracy is not high, it can only get approximately prediction of the remaining life and cannot meet the requirements of highly automated operation of power systems. Therefore, a highly automated life prediction method for Communication Equipment is urgently needed. The common methods for the life prediction of large equipment are: the method based on failure physics, state extrapolation, statistical
regression and similarity[3-5]. The method based on failure physics can obtain a more accurate prediction[6][7]. However, in order to establish a complete failure physical model, it is necessary to stop and check the equipment, which is not permitted for production; The method based on state extrapolation predicts the distribution of equipment’s remaining life by comparing the further development of the running state with the failure threshold (or the failure surface)[8][9], so it needs a certain failure threshold. The method based on statistical regression predicts remaining life through the expectation of the distribution of failure probability which is obtained by predicting the further development of equipment’s running state. However, it needs a large number of historical data of similar devices to get the function of the failure probability of the equipment[10][11]; The method based on similarity is gradually rising in recent years. It predicts the remaining life of equipment which is in service by predicting the same equipment’s remaining life of weighted average at a certain time. Compared with the previous three methods, the fourth method is simpler and more effective because there is no need to model and predict the recession signal itself, and is a simple and effective method for predicting the of the device itself[12]. But this method doesn’t consider the influence of environment, time and other factors on the life prediction.

Based on the discussion above, This paper proposes a new method of life prediction for Communication Equipment based on METS. Based on METS theory, the equivalent running time in benchmark running condition and the times of starting and stopping of object set are obtained by calculating the actual running time and the times in the actual running conditions, then remaining life of the object set is predicted.

2. Prediction method of communication equipment

2.1. Communication equipment life prediction model

part of high temperature should be first and hen other parts in the maintenance of Communication Equipment. Based on their research and practical experience, the technical personnel selects the three representative parts combustion system, hot channel and the rotor as the benchmark of maintenance life, and determines other parts’ maintenance life by referring to the reference values of the above parts.

![Figure 1. Principle of prediction model of remaining life.](image)
The principle of prediction model of remaining life for Communication Equipment based on METS theory is shown in Fig. 1. The reference set (R) and object set (O) are chosen as the reference object and study object for discussing METS theory and the actual running condition of the object set and benchmark running condition of reference set are similar. The benchmark running condition (B) is the basic load running condition of natural gas as fuel, no water injection or steam and continuous normal start without tripping. The actual running condition (A) is completely opposite, it’s the variable load running condition of various fuels (natural gas, light oil, heavy oil etc.) as fuel, water injection or steam and urgent quick start with tripping. We solve the similarity factors of life evaluation parameters (running time, times of starting and stopping) of the reference set in benchmark running condition and actual running condition by using the experimental study in benchmark running condition and experience running data in actual running condition. Based on the equality of the similarity factor of object set and reference set in the two running conditions, we can predict the object set’s remaining life in benchmark running condition by calculating its actual running time and starting times in actual running condition.

2.2. Determining the similarity factor of reference set

The maintenance of the Communication Equipment is in the order of high temperature parts first and then the other parts, and its checking is in the order of combustion parts first, then the hot passage part and last the rotor part. The hot passage part is taken as an example for giving the similarity factor of life evaluation parameters of reference set. The running time and the times of starting and stopping the combustion system and rotor system parts are similar to the hot channel parts.

The main factors that affect the service life of heat passage parts of the Communication Equipment are fuel type, water injection or steam ratio, change of starting cycle power, tripping power, starting mode and so on. According to the test data in actual running condition and experience running data in benchmark running condition of the thermal channel parts of reference set provided by the Communication Equipment manufacturer, the similarity factor of life evaluation parameters (running time and the times of starting and stopping) of the thermal channel parts of reference set in this two conditions can be obtained, shown as the formula (1) and (2).

The similarity factor of running time of the thermal channel parts of reference set:

\[
\lambda_{HI}^{R}(\alpha_1, \alpha_2, \alpha_3, \alpha_4, t_n) = \frac{y_{HI}^{RB}(t_n)}{y_{HI}^{RA}(t_n)} = (K + MI) \cdot (\alpha_1 + 1.5\alpha_2 + A_4\alpha_3 + 6\alpha_4)
\]  

(1)

In the formula: \(M\) and \(K\) are the injection factors of water and steam, they are determined by the humidity control mode, steam injection rate, and the material of the third and second nozzles. From Table 1: \(I\) is the percentage of water/steam injection volume and inlet air flow; \(\alpha_1, \alpha_2, \alpha_3\) are annual basic load running time(h) of burning natural gas, light oil and heavy oil respectively; \(A_4\) is the severe factor of heavy oil; \(\alpha_4\) is the annual peak running time (h).

**Table 1. Injection factors of water and steam.**

| M  | K  | Control mode | Water/steam injection rate | N2/N3 Material  |
|----|----|--------------|----------------------------|-----------------|
| 0  | 1.0| dry          | <2.2%                      | GTD–222/FSX414  |
| 0  | 1.0| dry          | >2.2%                      | GTD–222         |
| 0.18 | 0.6| dry          | >2.2%                      | FSX414          |
| 0.18 | 1.0| wet          | >0%                        | GTD–222         |
| 0.55 | 1.0| wet          | >0%                        | FSX414          |

The similarity factor of times of starting and stopping of the thermal channel parts of reference set:
In the formula: $\alpha_1$, $\alpha_2$, $\alpha_3$, $\alpha_4$, $\alpha_5$, $\alpha_6$ are annual part load, basic load, peak load, urgent start, fast lifting load starting times and annual tripping times respectively; $\alpha_{i_1}$ is the severe factor of tripping; $n$ is the number of tripping type.

3. Program implementation of maintenance predicting

Condition-based maintenance decision system for Communication Equipment (CMB system) is composed of two parts: (1) real-time online prediction program of the Communication Equipment service life running on the computing server side; (2) displaying results and information system management B/S program. running on the WEB server side.

The data of the real time running state of the Communication Equipment parts is transmitted to the distributed control system DCS through the sensor, and then to the real time database by the interface machine connected with the system.

On the computing server side, the real-time running parameters of the Communication Equipment are read by the program from the real time database and then running state description is formed through calculation, analysis, judgment. Calculate the service life of Communication Equipment related parts in actual operating condition, convert it into equivalent service life in benchmark running condition, then compare it with the maximum service life in benchmark running condition, and finally predict the remaining life and store the predicting results in the SQL database table.

The condition-based maintenance decision system based on B/S architecture model of internet/intranet structure uses the browser as a unified user interface and does modular design based on object-oriented method. The WEB terminal program can be divided into 3 parts, which are condition-based maintenance decision module, maintenance spare parts information management module and the system information management module. Condition-based maintenance decision module reads real time remaining life data of Communication Equipment related parts in SQL database, calculates and decides the specific condition-based maintenance time of related parts by choosing different condition-based maintenance decision models and then displays the remaining life prediction and maintenance decision results of each part on the web page. Maintenance spare parts information management module makes reasonable maintenance plan for Communication Equipment related parts according to the result of condition-based maintenance decision and at the same time does a good job in the replacement of spare parts and plan management. System information management module is in charge of website information release. Each module’s division and design follows the principle of high cohesion and low coupling. They respectively do developing and testing independently. When the system runs, the main module calls each sub module each sub module completes a relatively independent function, so the system has good transplantation and extension.

4. Calculation analysis of remaining life

The running data of Communication Equipment heat passage parts of a power plant is taken as the example. The program reads running data of Communication Equipment’s test points of ignition signal since the inspection and maintenance of hot channel last time, and then the actual running time and starting times of object set in the actual running conditions is calculated according to the calculation process of real life and historical life, as shown in Table 2.

| Natural gas running | Light oil running | Heavy oil running | Peak load running |
|--------------------|------------------|------------------|------------------|
| 1 3216.3           | 2 358.6          | 0                | 135.6            |
According to formula (1) and Table 2, the equivalent running time in benchmark running condition of object set of hot channel component can be calculated, as shown in formula (3): the percentage of water/steam injection volume to inlet air flow I is 2.4%; the material of the third and second nozzles is FSX–414; the set is in running under dry control and the values of K and M are respectively 0.6 and 0.18 at this time.

\[ y_{H}^{O}(t_{n}) = y_{H}^{O,A}(t_{n})\alpha_{2}^{O}(\alpha_{1},\alpha_{2},\alpha_{3},\alpha_{4}, t_{n}) = (K + MI)(\alpha_{1} + 1.5\alpha_{2} + A_{f}\alpha_{3} + 6\alpha_{4}) = 18 \text{ 129.97 h} \]  (3)

Take the statistical results of Table 3 and Table 4 into formula(2),we can calculate the equivalent starting and stopping times of in benchmark running condition of object set of hot channel component, as shown in formula(4).

Table 3. Calculation results of actual starting times.

|          | Partial load | Basic load | Peaking load | Urgent starting | Fast increasing loading |
|----------|--------------|------------|--------------|-----------------|------------------------|
|          | 232 times    | 262 times  | 8 times      | 3 times         | 4 times                |

Table 4. Calculation results of tripping times.

| Project   | Partial load | Basic load | Peaking load |
|-----------|--------------|------------|--------------|
| Tripping times | 6 times | 17 times | 3 times |
| Tripping factor | 6.5 | 8 | 10 |

\[ y_{S}^{O}(t_{n}) = y_{S}^{O,A}(t_{n})\alpha_{2}^{O}(\alpha_{1},\alpha_{2},\ldots,\alpha_{6}, t_{n}) = 0.5\alpha_{1} + \alpha_{2} + 1.3\alpha_{3} + 20\alpha_{4} + 2\alpha_{5} + \sum_{i=1}^{n}\alpha_{6}(\alpha_{f} - 1) = 635.4 \]  (4)

As shown in Table 4, the set should try to avoid tripping especially in peaking load condition. At this time, the life loss of Communication Equipment heat passage part of one tripping is 10 times of normal shutdown.

5. Conclusions

This paper proposes a new method of life prediction for Communication Equipment based on METS. The new method introduces the same type set that has similar running environment with object set as the reference and solves its similarity factor (running time and the times of starting and stopping) of life evaluation parameters between the conditions actual running and benchmark running. Based on METS theory, the equivalent running time and starting times in benchmark running condition object set are obtained by calculating the actual running time and the times in actual running condition, then compare the calculating results with the maximum maintenance interval and the remaining life of the object set can be predicted. Finally, a factory Communication Equipment HGP component residual life prediction is provided as the example to verify the scientific validity and feasibility of the prediction method.

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Reference

[1] Mao Dan, Zhu Yue-shan. An Analysis of the M701F Communication Equipment Maintenance Conception [J]. Communication Equipment Technology, 2010(3):53-57.
[2] Gong Wen-qiang, Wang Qin-gren. Strategies optimization of Communication Equipment overhaul based on EOH analysis [J]. Electric Power, 2011, 44(8):40-42.
[3] Jardine A, Lin D M, Banjevic D. A Review on Machinery Diagnostics and Prognostics Implementing Condition-Based Maintenance[J]. Mechanical Systems and Signal Processing, 2006, 20(7):1483-1510.
[4] Heng A, Zhang S, Tan A, et al. Rotating Machinery Prognostics: State of The Art, Challenges and Opportunities [J]. Mechanical Systems and Signal Processing, 2009, 23(3):724-739.

[5] Meng Guang, You Ming-yi. Review on condition-based equipment residual life prediction and preventive maintenance scheduling [J]. Journal of Vibration and Shock, 2011(8):1-11.

[6] Chookah M, Nuhi M, Modarres M. A Probabilistic Physics-of-Failure Model for Prognostic Health Management of Structures Subject To Pitting and Corrosion- Fatigue[J]. Reliability Engineering & System Safety, 2011, 96(12):1601-1610.

[7] Xu D, Huang J E, Zhu Q, et al. Residual Fatigue Life Prediction of Ball Bearings Based on Paris Law and Rms[J]. Chinese Journal of Mechanical Engineering, 2012, 25(2):320-327.

[8] Gao Shuang, Dong Lei1, Gao Yang, et al. Mid-long Term Wind Speed Prediction Based on Rough Set Theory [J]. Proceedings of the CSEE, 2012(1):32-37.

[9] ChenN Ning, Sha Qian, Tang Yi, et al. A Combination Method for Wind Power Predication Based on Cross Entropy Theory [J]. Proceedings of the CSEE, 2012(4):29-32.

[10] Elliott R J, Siu T K. An Hmm Approach for Optimal Investment of An Insurer[J]. International Journal of Robust and Nonlinear Control, 2012, 22(7):778-807.

[11] Hassan M R, Nath B, Kirley M, et al. A Hybrid of Multiobjective Evolutionary Algorithm and Hmm-Fuzzy Model for Time Series Prediction[J]. Neuro- Computing, 2012, 81(4):1-11.

[12] Wang T, Yu J, Siegel D, et al. A Similarity-Based Prognostics Approach for Remaining Useful Life Estimation of Engineered Systems: 2008 International Conference on Prognostics and Health Management, Phm 2008, Denver, United States, 2008[C]/IEEE, 2008:53-58.