Methods to Predict the Rest Life of Gear System

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Abstract. Under the development of large-scale, complicated and automatic rotating machinery, people’s requirements for efficiency, safety and reliability are increasing daily. It has an important impact on prolonging equipment life, improving equipment utilization rate, increasing equipment safety, shortening maintenance time and reducing maintenance cost based on condition monitoring, identification and diagnosis of rotating machinery at the initial stage of fault. Taking the gear transmission system as the research object, this paper collects and enumerates the methods of gear system life prediction, and proposes a combined mathematical model of WD-GM (1,1) to predict the degeneration trend and failure time of gears. The prediction accuracy can reach 95%.

1. Introduction

Gear transmission system is a kind of rotating machinery system. During the working process of its fault diagnosis, the research work on fault mechanism should be carried out, so that the maintenance staff can analyze the fault characteristics more deeply [1]. The detection of the rotational state of the gear transmission system and the fault work are carried out on the basis of diagnostic equipment and fault mechanism. It is necessary to study the mechanism and do a good job in the theory of mechanical vibration, material failure, kinematics and tribology. What’s more, it is also important for mathematical models under different parameters on the basis of the mechanism. The numerical analysis method in the fault mechanism is also very common. The cause of the fault and the symptom of the fault are deeply analyzed, and the life prediction work is applied to the actual production. The methods of obtaining information and the basic methods of diagnosis are divided into many diagnostic technologies: vibration detection technology, oil analysis technology, etc., which play a very important role in practical work.

2. Present research situation and dynamic analysis of development

At present, the life prediction methods of gear transmission system at home and abroad are more traditional, which mainly stay in studying a single signal of a certain mechanical link, such as vibration signal or acoustic emission signal in mechanical devices. The judgment principle of this traditional method is to diagnose the fault of a single signal in a mechanical device according to its physical characteristics. Traditional methods have certain limitations, especially in signal acquisition, which is easily disturbed by the external environment. In addition, operators often make mistakes in diagnosis due to subjective factors due to poor perception of early single signal faults. In other current methods, the physical feature diagnosis of simultaneous sampling of multiple signals in the same domain, the same frequency domain and the same spatial state except for a single signal will be carried out by improving the above method, but this improved method still has the disadvantage of low
prediction accuracy [2]. Therefore, the thinking is further broadened, the correct rate of life prediction of gear transmission system is improved, and the application of mechanical devices in various fields is becoming more and more stable.

3. Methods of the gear transmission system life prediction

3.1 Life prediction about vibration analysis

In the life prediction of gear transmission system, the research method of vibration analysis was adopted earlier. At present, the focus of this kind of research is mainly reflected in several aspects such as fault mechanism analysis, feature parameter extraction, intelligent fault diagnosis, signal noise reduction and processing, etc. In the research of extracting parameters, it has experienced a gradual transition from the early direct and simple measurement of vibration parameters in each time domain to the analysis of vibration frequency domain. The change of this method is due to the development of signal processing technology, especially the progress of effective methods represented by FFT. At the beginning of the study, Bridal and JamesI.Taylor used the minimum variance cepstrum method to diagnose the minor faults of bearings. On the basis of realizing the order tracking technology, the vibration signals of mechanical devices are collected, and this technology can still analyze and obtain more accurate fault diagnosis data of gear system even if the speed changes little [3-4]. In recent 10 years, with the continuous enrichment of modern signal analysis methods such as Hilbert-Huang transform, wavelet analysis, empirical mode decomposition, time-frequency analysis and other means, the accuracy of signal analysis results applied to gear system faults has been significantly improved. At the same time, the envelope spectrum demodulation technology used to extract the characteristic harmonics of gearbox under off-design conditions has also been well applied in the life prediction system.

3.2 Life prediction about oil analysis

Another technology is oil analysis technology. The working principle of this technology is to obtain the relevant information state of the mechanical power transmission system by detecting the performance state of gear lubricating oil and analyzing the abrasive particles carried by it, so as to realize the evaluation and prediction of gear system faults. In the fusion of oil and vibration information, the life of the gear box is predicted mainly by analyzing whether the information of vibration and abrasive particles is overloaded. In the meantime, the relationship between the causes of various faults can be analyzed. In other similar studies, the relationship between peak value and mean value changes of vibration signals in high frequency period and friction parameters is analyzed aiming at the relationship between vibration and wear signals of mechanical bearings. Domestic researchers combine vibration analysis method and oil analysis with D-S evidence theory to study the life of gear system. The wear of gear system is analyzed by establishing a mathematical model, and the scientific nature of the mathematical model is verified. Although the physical properties of trace metal powder particles contained in lubricating oil can be used to detect the wear condition of gear system, it is difficult to extract the wear particles of gear system immediately by this method. If off-line analysis is carried out, it would affect the continuous operation of gear system. The use of oil analysis requires the precision of the instrument to reach strict standards, and the process of taking samples is complicated. Through the monitoring of rolling bearings, a variety of composite information such as grease temperature and vibration signals can form a multi-signal monitoring system of gear system. The test results fully verify the deficiency of using lubricating oil state to reflect gear system faults. When there is a slight fault in the early gear system, the grease temperature does not change significantly, but when there is a large-scale serious fault, the grease temperature increases obviously [5-6].

4. The simulation of gear life prediction based on WD-GM (1,1)

Gear failure data is from Air Defense and Anti-missile Weapon Launching System Fault Diagnosis
Lab in Air Force Engineering University. After calculating the real CV value of this type of gear in the whole cycle, 1000 datas are determined according to 7:3 about the training set and data test set, so the first 700 CV values are selected for training. The training set is decomposed by wavelet to make CV more stable, which is convenient to improve the prediction accuracy.

Wavelet decomposition can be realized by wavelet toolbox in MATLAB. The original wind speed series is decomposed into one approximate component (a6) and six detail components (d1-d6) by using the wavelet base of db6 type. Next, the model is used to predict the TEST set of a6 and d1-d6, and the predicted value of CV at that time can be obtained by summing the seven predicted data.

4.1. **WD-GM (1,1) prediction model**

The combination model structure is as shown in the figure below.

4.2. **The simulation results of WD-GM (1,1)**

Wavelet decomposition result of combined model is shown in figure 2.
After summing $a_1$, $d_1$-$d_6$, the gear life prediction curve at 701-1000 time can be obtained, as shown in fig. 3. Table 1 shows the predicted MAPE value, RMSE value and prediction accuracy of WD-GM (1, 1) model, and table 2 shows the comparison between predicted failure time and actual failure time.

Fig. 2 WD decomposed results of the original gear value

Fig. 3 WD-GM (1,1) prediction result
Calculating formula for failure moment:
\[ s = (x|_{GV=0.05} - n_p) \]

In which, \( x|_{GV=0.05} \) is the x-axis coordinate when GV is 0.05 (it means the moment of failure).

### Table 1 Performance indicators of WD-GM (1,1)

| Indicators (AVG) | WD-GM (1,1) |
|------------------|-------------|
| MAPE (%)         | 4.931       |
| RMSE             | 0.038       |
| P                | 0.951       |

### Table 2 Predicted failure moment

| Real result/min | Predicted result/min |
|-----------------|----------------------|
| 955             | 963                  |

5. Conclusion

By combing and enumerating the traditional methods, integrated methods and intelligent methods of gear system life prediction, this paper collects the development trend and application prospect of gear system fault diagnosis at home and abroad in recent years, and summarizes the advantages and disadvantages of various method systems. Therefore, it is beneficial to integrate the advantages of detection technologies under different systems, which effectively improves the accuracy of life prediction of gear systems and maximizing safety benefits. In Chapter 3, the simulation tool MATLAB and the combined model method are used to predict the gear life, and good results are obtained, with an accuracy of 95%. The comprehensive combing of the research on life prediction methods of gear system is conducive to its attention and technical improvement in a larger field, which is also convenient for scholars and research institutions at home and abroad for future studying.

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References

[1] Guo R, Zhao Z Q, Jia X L, et al. External gear pump life prediction based on ANFIS study [J]. Journal of instruments and meters, 2020, 41(01): 223 -232.
[2] Shi H, Zeng J C. Considering gear real-time residual life prediction of mutation state detection [J]. Journal of vibration and shock, 2017,36(21): 173-184.
[3] Liu J. Based on the analysis of vibration signal of rotating machinery fault diagnosis method research [D]. Huazhong university of science and technology, 2018.
[4] B. Ali, Jaouher, C. Morello, et al. Accurate bearing remaining useful life prediction based on Weibull distribution and artificial neural network[J]. Mechanical Systems & Signal Processing,2016,56/57:150-172.
[5] B. Aldenhoff, H. Hochreither, J. Springer. Entwurf und Bauausführung der Stabbogenbrücke über den Main bei Sulzbach[J]. Stahlbau,2001,70(6).
[6] Stone G, Miemczyk J, Howard M, et al. ESTABLISHING BUILD TO ORDER IN THE EUROPEAN AUTOMOTIVE SECTOR[J]. IFAC Proceedings Volumes,2006,39(3).