Uncertainty Evaluation of Bearing Performance Based on Gray Bootstrap Method

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Abstract: The models describe the basic characteristics of rolling bearing vibration, the behavior of bearing friction torque and the basic characteristics of rolling bearing noise respectively, by developing four evaluating, i.e. the estimated interval, the estimated true value and the uncertainty.

1. Introduction

The vibration characteristics of rolling bearings have great influence on the dynamic characteristics, working life and reliability of aerospace propulsion system [1-4]. The simulation system of aerospace propulsion system implemented by the NASA of the United States involves the vibration characteristics of rolling bearings [1-2]. Many researches have also devoted to the subtle analysis of the mechanism, influencing factors and control methods of bearing vibration. Many advances have been made [3- 7]. In order to grasp the basic characteristics of bearing vibration in general, the current researches involve the comprehensive problems of dynamic measurement and evaluation [7-10]. Because the bearing manufacturing and assembly system is a dynamic stochastic process with uncertain probability distribution and many unknown and unknown systematic errors, the bearing vibration produces many unpredictable complex changes [4-6, 9-11 ], To the difficulty of dynamic assessment and control.

Friction torque is one of the most important indexes to evaluate the flexibility of high-speed aerospace bearings. It can describe the friction and lubrication of high-speed bearings in work [12-13]. In order to ensure the good operation of the spacecraft, the change state of the bearing friction torque must be monitored and evaluated online. Since the change of the bearing friction torque is uncertain, it is a random process. In particular, the bearing friction torque distribution of unknown probability, and there are a variety of system error interference, accurate assessment of the system must be dynamically separated error. It is difficult to solve with statistical theory.

The noise of the rolling bearing has a significant influence on the working performance and working environment of the host machine. In fully automatic production mode, the bearing manufacturing and assembly system is a dynamic stochastic process with uncertain probability distribution and many known and unknown trend items. It belongs to the system of uncertain information with scarcity of information, which causes many bearing noise unpredictable and complex changes [14, 15], and will make dynamic assessment more difficult.
At present, the grey prediction model GM (1, 1) [15] and the Bootstrap method [16, 17] are popular methods to evaluate uncertain systems with unknown probability distribution of scarcity information. Bootstrap can simulate the unknown distribution, but when there are few data, the evaluation error can be infinite. On the contrary, GM (1, 1) has good forecasting function to make up for this defect. However, the model has special requirements on the original data and can not effectively evaluate the uncertainty because of the strong attenuation of random error. Therefore, this paper synthesizes the advantages of GM (1, 1) and bootstrap, proposes a gray bootstrap dynamic assessment method GBM (1,1) (grey bootstrap method).

2. Experiments

2.1. Dynamic evaluation of bearing vibration

Experimental Rolling bearing type is H7008C, motor speed 4950 r / min, the applied radial load of 13.2 KN. Test time and bearing vibration information automatically accumulated by the computer control system shows the bearing vibration sampling frequency of 5kHz, the unit is ms^-2.

A number of data N=100 from original data series x are sampled. Let m=4, B=500 and P=70%, calculated by the grey bootstrap model, the mean uncertainty \( U_{\text{mean}} \) is 0.2448 ms^-2, the estimated true value \( X_0 \), uncertainty \( U \) and the estimated interval \([X_L, X_U]\) are as shown in Figure 1.
According to Fig.1a, the estimated interval \([X_L, X_U]\) envelopes the random fluctuation path of \(X\) from the outside closely, this shows that GBM (1, 1) describes the transient state of bearing vibration perfectly. And the reliability of the estimated results can usually be up to 100% at the given confidence level.

According to Fig.1b, the estimated true value \(X_0\) describes the trend of \(X\) dynamically. On the whole, \(X\) rises first and then declines and then rises is reflected by \(X_0\) basically.

According to Fig.1c, the uncertainty \(U\) reflects the variation domain of \(X\), the bigger the random fluctuation of \(X\) is, the bigger the uncertainty \(U\) is. On the contrary, the smaller the uncertainty \(U\) is, the smaller the random fluctuation of \(X\) is.

2.2. Dynamic evaluation of bearing noise

Noise of tapered roller bearings is investigated to test the grey bootstrap model. A number of data \(N=109\) from original data series \(x\) are sampled. Let \(m=4, B=500\) and \(P=70\%\), calculated by the grey bootstrap model, the mean uncertainty \(U_{\text{mean}}\) is 8.47338dB, the and the estimated true value \(X_0\), uncertainty \(U\) and the estimated interval \([X_L, X_U]\) are shown in Figure 2.

![Dynamic evaluation of bearing noise](image)

Figure 2 Dynamic evaluation of bearing noise.

According to Figure 2a, when \(t<11\), there is lower noise process \(X\). In this process, the value of \(X\) increases and the fluctuation of \(X\) decreases when \(t\) increases, namely \(X_0\) is increasing and \(U\) is decreasing; when \(t>10\), there is a stationary noise process \(X\), namely \([X_L, X_U]\), \(X_0\) and \(U\) stay on a
plateau; and when \( t>80 \), there is an increasing and fluctuating noise process \( X \), namely \( [X_L, X_U] \) is extending, \( X_0 \) is steady and \( U \) is increasing. This process of noise change can be perfectly traced with \([X_L, X_U]\), \( X_0 \) and \( U \), shown in Figure 2a-c.

In this experiment, probability distribution and trend of random function on noise of tapered roller bearings are unknown, however, the GBM(1, 1) can effectively evaluate the transient uncertainty \( U \) and the estimated true value \( X_0 \) at the given hour \( t \). Therefore, without any prior information, the GBM (1, 1) can exactly describe unknown trends and unknown distributions of a time series in practical engineering with poor information. It is noteworthy that, as it can be seen from Figure 2a, the estimated interval \([X_L, X_U]\) using the GBM (1, 1) includes all data of the original data series \( X \) exactly, and that the reliability of the estimated result at the \( P=70\% \) confidence level is up to \( P_\text{a}=100\% \).

2.3. Dynamic evaluation of bearing friction torque

Bearing friction torque measurement is obtained indirectly by the acquisition of the relevant components of the electrical signal output. Experimental bearing type is 86738 motor speed 5.54 r / min.

Let \( m=3, B=500 \) and \( P=70\% \), calculated by the grey bootstrap model, the mean uncertainty \( U_{\text{mean}} \) is 0.24455V, the estimated true value \( X_0 \), uncertainty \( U \) and the estimated interval \([X_L, X_U]\) are shown in Figure 3.

![Figure 3 Dynamic evaluation of bearing friction torque.](image-url)
According to Figure 3a, the estimated interval \([X_i, X_i]\) envelopes the random fluctuation path of X from the outside closely, this shows that GBM (1,1) describes the transient state of bearing vibration perfectly. And the reliability of the estimated results can usually be up to 100% at the given confidence level.

According to Figure 3b, on the whole, \(X_n\) rises first and then declines and then rises and then decline. This is consistent with the law of X.

According to Figure 3c, there is no clear trend in the uncertainty U over time. But the uncertainty U can reflect random error.

3. Conclusions

As we all know, the vibration, the noise and the friction torque are the important performance of the rolling bearing. In this paper, the GBM (1,1) is used to evaluate the uncertainty of these three performance.

There are two main characteristics of the GBM (1,1). On one hand, trends can be separated from complex data series in the process of dynamic measurement when there is no any prior information about trends. On the other hand, the dynamic uncertainty can be evaluated without any prior information about probability distribution of random variables.

Furthermore the reliability of the estimated results can usually be up to 100% at the given confidence level.

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References