Evaluation Method of Rolling Bearing Quality (Part Ⅰ: Theory)

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Abstract. The influencing factor analysis of rolling bearing quality is an unknown probability distribution and correlation of complex research problems. It is not comprehensive to solve this type of problems only based on the classical statistics. In this paper, the nonlinear relationship between influencing factors and rolling bearing quality was analyzed using the grey system theory, and the linear relationship was analyzed by further combining classical statistical theory. The effect of influencing factors on the bearing quality was comprehensively considered. Finally, a regression model was established to determine the main factors affecting bearing quality, providing an effective solution and basic idea for the assessment of rolling bearing quality.

Introduction

Rolling bearing is an important basis for various machinery products. Its quality plays an irreplaceable role for the normal operation of machinery and equipment. Therefore, it is particularly important to make an evaluation of bearing quality.

In the research of rolling bearing quality, V. Barzdaitis made an evaluation on the deep groove ball bearing quality [1]. P. F. Morris proposed a bearing steel quality assessment method [2]. K.S. Jiang proposed a new method for the diagnosis of bearing quality defect [3]. X.T. Xia proposed the new fuzzy forecasting technique to solve the dynamic performance prediction problems of rolling bearings under conditions of small sample size and unknown probability distribution [4]. X.T. Xia and Y.T. Shang put forward the fuzzy comprehensive evaluation method for evaluating bearing quality, and established the comprehensive evaluation model of bearing quality based on fuzzy theory and mathematical statistics [5, 6].

Bearing performance, such as vibration or bearing life, etc, is an important evaluation index of bearing quality [7].Traditional methods conduct research based on the classical statistical theory combined with a small amount of experimental data. However, the research of bearing quality is affected by many factors, and traditional research methods have limitations in many aspects. This kind of problems is typical small sample size problems, in which the feature information of research object is incomplete, the variation tendency is unknown, and the test samples and experimental data are severely poor. Poor information theory can effectively solve this problem [8, 9]. In this paper, the gray system theory of gray correlation degree [10] and the relative correlation degree combining the linear regression model of classical statistical theory are used. This method effectively pick out the main factors affecting the rolling bearing quality, provides a new theoretical basis to control and solve the quality problem of the rolling bearing and has very important practical application value.

Influencing Factors Analysis

Gray Correlation Degree. The grey relational analysis is mainly used to evaluate the degree of correlation between the similarity degree and distance of the geometric shape of each data sequence.

Assuming that the original data sequence of bearing vibration acceleration, X_0, is the mother sequence, and the data sequence for each individual influencing factor, X_i, as subsequence, which are given as

$$X_0 = \left(x_0(1), x_0(2), ..., x_0(k), ..., x_0(n)\right) \tag{1}$$

and

$$X_i = \left(x_i(1), x_i(2), ..., x_i(k), ..., x_i(n)\right), i = 1,2,..., \tag{2}$$

Through preprocessing X_0 and X_i, new data sequences

$$X_0^0 = \left(x_0^0(1), x_0^0(2), ..., x_0^0(k), ..., x_0^0(n)\right) \tag{3}$$

and

$$X_i^0 = \left(x_i^0(1), x_i^0(2), ..., x_i^0(k), ..., x_i^0(n)\right), i = 1,2,..., \tag{4}$$

are obtained, where in

$$x_0^0(k) = x_0(k)D \tag{5}$$

and

$$x_i^0(k) = x_i(k)D \tag{6}$$

D is the initialization operator.

Define the absolute difference as

$$\Delta_{0i} = \left|x_0^0(k) - x_i^0(k)\right| \tag{7}$$

the minimum absolute difference as

$$\Delta_{\min} = \min_i \min_k \left|x_0^0(k) - x_i^0(k)\right| \tag{8}$$

and the maximum absolute difference as

$$\Delta_{\max} = \max_i \max_k \left|x_0^0(k) - x_i^0(k)\right| \tag{9}$$

The correlation coefficient of X_0 and X_i is

$$\xi_{0i}(k) = \frac{\Delta_{\min} + \Delta_{\max}\xi}{\Delta_{0i} + \Delta_{\max}\xi} \tag{10}$$

The gray correlation degree of X_0 and X_i is

$$\gamma_{0i} = \gamma(X_0^0, X_i^0) = \frac{1}{n}\sum_{k=1}^{n}\xi_{0i}(k) \tag{11}$$

In the formula, ξ is the resolution ratio, $\xi \in (0,1]$, usually take $\xi \le 0.5$; the larger ξ, the higher the resolution; the smaller ξ, the lower the resolution.

Relative Correlation Degree. Set the original data sequence of X_0 and X_i as

$$X_0 = (x_0(1), x_0(2), ..., x_0(k), ..., x_0(n)) \tag{12}$$

$$X_i = (x_i(1), x_i(2), ..., x_i(k), ..., x_i(n)), i = 1,2,..., \tag{13}$$

Where, k is the data number, $k = 1,2,...,n$.

Through an initialization process, the sequence of X_0 and X_i is changed to be

$$X_0' = \frac{X_0}{X_0(1)} = \left(x_0'(1), x_0'(2), \cdots, x_0'(k), \cdots, x_0'(n)\right) \tag{14}$$

$$X_i' = \frac{X_i}{X_i(1)} = \left(x_i'(1), x_i'(2), \cdots, x_i'(k), \cdots, x_i'(n)\right) \tag{15}$$

Through further zero point processing, the original data sequence is changed into.

$$X_0^0 = (x_0^0(1), x_0^0(2), ..., x_0^0(k), ..., x_0^0(n)) \tag{16}$$

$$X_i^0 = (x_i^0(1), x_i^0(2),..., x_i^0(k),..., x_i^0(n)), i = 1,2,..., \tag{17}$$

Wherein

$$x_0^0(k) = x_0^{'}(k) - x_0^{'}(1) \tag{18}$$

$$x_i^0(k) = x_i^{'}(k) - x_i^{'}(1) \tag{19}$$

The relative correlation degree of X_0 and X_i is defined as

$$e_{0i} = \frac{1+|s_0|+|s_i|}{1+|s_0|+|s_i|+|s_0 - s_i|} \tag{20}$$

Wherein

$$|s_0| = \left|\sum_{k=2}^{n-1} x_0^0(k) + 0.5x_0^0(n)\right| \tag{21}$$

$$|s_i| = \left|\sum_{k=2}^{n-1} x_i^0(k) + 0.5x_i^0(n)\right| \tag{22}$$

$$|s_0 - s_i| = \left|\sum_{k=2}^{n-1}\left(x_0^0(k) - x_i^0(k)\right) + 0.5\left(x_0^0(n) - x_i^0(n)\right)\right| \tag{23}$$

Grey relational degree and relative correlation degree are used to study the correlation degree between different research data. The correlation sequence, consisting of gray correlation degree and relative relation degree, are paid attention to instead of their specific value. Through sorting the correlation degree to obtain correlation sequence, the influence degree of each factor on the bearing vibration acceleration value can be determined. Through qualitative fusion of obtained correlation sequence, the nonlinear main influencing factors can be chosen out.

One Element Linear Analysis. One element linear regression analysis is carried out for all the obtained experimental data. The analysis consists of several processes: establishes linear regression equations between the vibration acceleration value, Y, and each influence factor, X ;test the linear correlation among each linear regression equation; calculate the correlation coefficient r for each equation, and determine its relevance. The correlation coefficient, r_0, can be known from the correlation coefficient threshold table when α and n are determined. When $|r| \geq r_0$, it is linear related, otherwise unrelated.

The main factors affecting the bearing quality were obtained by combinations of the influence factors linearly related to the vibration acceleration, which are picked out from calculation, and the nonlinear correlation factors chosen out before.

Establish Regression Model

Through the above analysis, the main factors influencing the bearing vibration were picked out, and the new sequence, X, was obtained,

$$X = \left(X_1,..., X_i\right) \tag{24}$$

Wherein, i is the number of the main influence factor.

Multiple linear regression equation is established and optimized. According to the 6σ value guideline, the maximum value of the standard deviation is 1, and the error is 6dB during the study process of bearing quality control. If the error is too large when the standard deviation is more than 1, even if the significance level of the regression equation meets the requirements, its significant meaning in engineering application still cannot be verified.

The effect parameters are chosen out and the regression model were optimized using the Optimum experimental data modeling and optimization of computer systems. Optimization process principle is that to excluded one variable from the polynomial, re-establish a polynomial regression equation, carry out *F*-test for all new polynomial, and determine their significance and standard deviation, effective regression equations are obtained and the main factors affecting the bearing quality are thus chosen out.

Summary

In this paper, a new method to analyze experimental data of rolling bearing quality was proposed based on the combination of the gray system theory and the classical theory of statistics. An evaluation model was reasonably established using the grey correlation degree, relative correlation degree, one linear regression analysis and linear regression model theory. A new theoretical basis was proposed and helps to accurately pick out the influencing factors, which are linearly or nonlinearly related to the rolling bearing quality. The results can also be referenced to data analysis of other types of parts quality, and has great engineering significance.

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