Analysis of the influence of mechanical vibration control strategy on structural safety

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Abstract. The vibration of rotating machinery has always been the focus of attention in the engineering field, because it directly affects the performance, life and safety of equipment. In this paper, the influence of vibration control strategy of rotating machinery on structural safety is deeply studied, aiming at providing scientific basis for optimizing vibration control scheme. It is found that the network identification accuracy of vibration signals of rotating machinery is above 96% under different vibration conditions by the vibration control method designed in this paper, which is higher than the traditional control method. Active vibration control strategy has high accuracy and real-time, but it challenges the cost and complexity of the system. Passive vibration control strategy is excellent in specific frequency vibration suppression, but there are some limitations in multimode vibration; Semi-active vibration control strategy has both active and passive advantages and strong adaptability, but it needs complex control algorithm. These efforts will provide useful reference for the development of vibration control field of rotating machinery and the safety improvement of engineering structures.

Keywords: Mechanical vibration control, structural safety, rotating machinery.

1. Introduction

With the continuous development of industrial technology, rotating machinery plays an increasingly important role in various fields, such as wind turbines, turbines, motors and so on. However, the following vibration problems pose a severe challenge to the safety and performance of these rotating machinery [1]. Vibration may not only lead to structural fatigue and damage, but also threaten the long-term reliability and operation safety of equipment.

In order to improve the structural safety of rotating machinery, vibration control strategy has gradually become the focus of research and engineering practice. The goal of mechanical vibration control is to reduce the amplitude of the structure under vibration excitation by various means, thus reducing the risk caused by vibration [2]. However, different vibration control strategies may have different effects on the safety of structures, which makes it very important to deeply study and comprehensively evaluate the effects of these strategies.

This paper aims to deeply discuss the influence of vibration control strategy of rotating machinery on structural safety, and provide scientific guidance for engineering practice through theoretical analysis and practical case study. Through in-depth study on the influence of vibration control of rotating machinery, we are expected to contribute to the development of mechanical engineering and the improvement of structural safety.

2. Calculation of elastic force of elastic rotating shaft

Rotating machinery plays a vital role in the industrial field, including generators, wind turbines, centrifugal compressors and so on [3-4]. However, these rotating machines often face vibration problems, which may lead to equipment damage, performance degradation and even accidents. Therefore, it is very important to design effective vibration control methods to improve the stability and safety of rotating machinery.

Before designing the vibration control method of rotating machinery, it is necessary to analyze the vibration characteristics of rotating machinery in detail. Vibration may come from unbalanced mass, bearing failure, excitation force and many other aspects. Through the analysis of vibration spectrum and mode, the key vibration modes and frequencies can be identified, which provides the basis for the selection of subsequent vibration control methods. Active vibration control method is a strategy to counteract vibration by introducing active power into the system. In rotating machinery, the active controller can realize real-time vibration compensation by adjusting the rotor speed or applying excitation force [5-6]. This method requires high-precision sensors and real-time feedback system, and poses a challenge to the design and implementation of the controller. Passive vibration control method focuses on absorbing or consuming vibration energy through the special design of the structure itself. In rotating machinery, common passive control means include vibration absorber, damper and tuning mass. These passive devices can effectively reduce the vibration amplitude in a specific frequency range, but they also need to be carefully designed and adjusted according to the characteristics of rotating machinery.

Considering that there are usually multiple vibration modes in rotating machinery, it is an important task to synthesize multi-modal vibration control methods. By comprehensively applying various control methods, such as active, passive and semi-active control, different vibration modes can be covered more comprehensively and the vibration control performance of the system can be improved.

The forced vibration of rotating machinery depends on the stress of the rotor. When the stress is unbalanced, some parts of the machinery will be slightly bent and deformed, which will lead to abnormal vibration of the machinery [7]. After the vibration form and characteristics of the rotating machinery are determined, the specific position of the vibration of the rotating machinery is determined by using the unit disk rotor model, and the elastic force of the elastic shaft during the vibration of the rotating machinery is calculated.

Consider taking a short section of rotating shaft element with length dx on the elastic rotating shaft, and the bending moment M and shear force V it receives can be expressed as:

$$M = -EI\frac{d^2w}{dx^2} \tag{1}$$

$$V = -EI\frac{d^3w}{dx^3} \tag{2}$$

Where E is the elastic modulus, I is the moment of inertia of the section of the rotating shaft, and w is the deflection of the rotating shaft.

Through these two equations, the bending moment and shear force at any position on the elastic shaft can be obtained. The magnitude and direction of these forces depend on the distribution of deflection w on the rotating shaft [8].

3. Calculation of angular velocity of gear sleeve vibration

The calculation of angular velocity of gear sleeve vibration is very important for understanding the dynamic behavior and design stability of gear transmission system. The angular velocity of gear sleeve vibration is one of the key parameters to describe the vibration behavior in gear transmission system, which reflects the relative motion speed between gears, especially when there is gear meshing. The angular velocity of gear sleeve vibration is usually defined as the relative angular velocity between two adjacent gears [9]. During the rotation of a gear, the angular velocity of gear sleeve vibration describes the relative movement speed of two adjacent gears when meshing. The periodic change of angular velocity is directly related to the vibration frequency and stability of gear transmission system.

The calculation of angular velocity of gear sleeve vibration involves the geometric characteristics, rotational speed, meshing frequency and other factors of the gear, and is calculated by the following formula:

$$w_{mesh} = \pi \cdot n_1 \cdot \left(1 + \frac{1}{T}\right) \tag{3}$$

Where w_{mesh} that angular velocity of the vibration of the gear sleeve is, n_1 is the rotational speed of the gear 1, and T is the gear ratio. Based on the basic geometric relationship and kinematics principle of gear meshing, this formula provides an approximate calculation of angular velocity of gear sleeve vibration.

The vibration angular velocity of the gear sleeve is influenced by many factors, including the design parameters, rotational speed, meshing frequency and meshing angle of the gear. Especially under the conditions of high speed, high load or uneven load, the angular velocity of gear sleeve vibration may become complicated and difficult to predict. Therefore, in the design and analysis of gear transmission system, these factors must be considered comprehensively to ensure the stability and durability of the system.

4. Demodulation transformation control of rotating machinery vibration

Vibration of rotating machinery is one of the common problems in the industrial field, which not only affects the performance and life of equipment, but also may lead to equipment failure and security risks [10]. In order to effectively control and reduce the vibration of rotating machinery, demodulation and transformation control has become a highly concerned technology. Demodulation transformation control aims to achieve targeted control of vibration by extracting specific frequency components from vibration signals.

Demodulation transformation is a signal processing technology, which transforms the time domain signal into frequency domain and selectively extracts a certain frequency component. In the application of rotating machinery vibration, demodulation transformation is usually used to extract components related to rotating frequency and its harmonics from vibration signals. This enables us to locate and analyze the problems in the mechanical system more accurately, such as imbalance and bearing failure.

The combination of demodulation transformation and control strategy, that is, demodulation transformation control, can take corresponding control measures on the basis of real-time monitoring of vibration signals. For example, when the vibration signal of a specific frequency component exceeds the preset threshold, the corresponding controller can be started to adjust the system parameters to realize active vibration control. This strategy can locate and respond to vibration problems more accurately and improve the stability and reliability of the system.

Based on the principle of demodulation and transformation control, this paper controls the vibration of rotating machinery in all directions. The demodulation transformation designed in this paper controls the vibration process of rotating machinery, as shown in Figure 1.

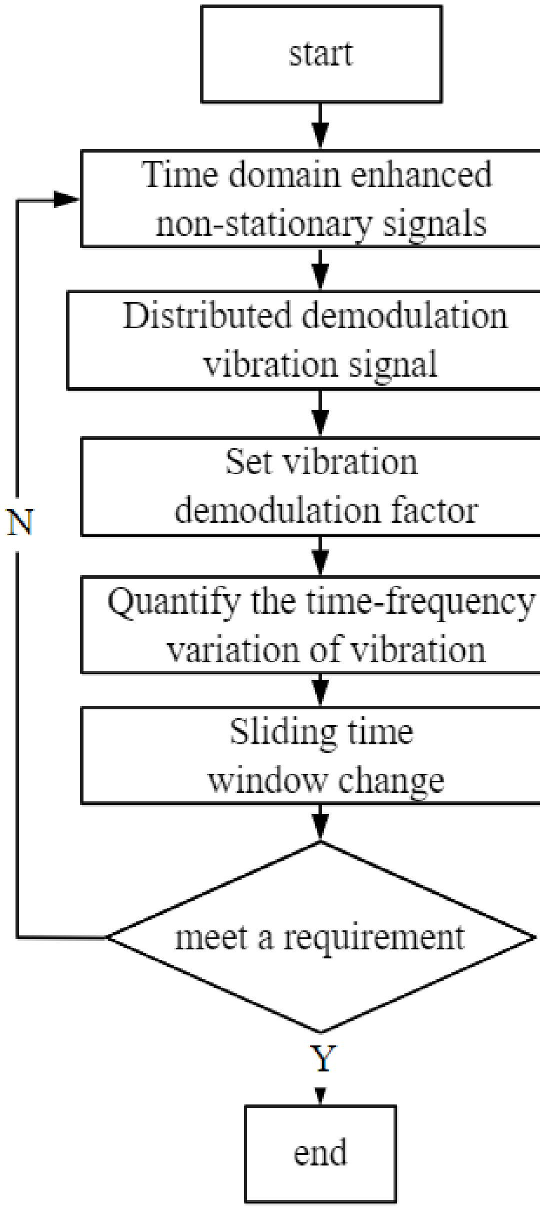

Figure 1. Demodulation transformation control vibration process of rotating machinery.

Firstly, the non-stationary signals in the vibration of rotating machinery are enhanced in time domain to improve the aggregation of vibration signals. Using the principle of step-by-step demodulation and transformation, the time-varying frequency of vibration signal is demodulated into a fixed frequency. The vibration demodulation factor of rotating machinery is set to decompose the vibration characteristic signal into single-component signals with multiple vibration characteristics, so as to improve the energy concentration of the vibration characteristic signal. By using backward demodulation, the true frequency of vibration signals of rotating machinery is continuously recovered, so that the time-frequency aggregation of signals is consistent.

Demodulation and transformation control usually requires real-time monitoring of vibration signals and adjustment of mechanical system parameters through feedback control system. This real-time control method enables the system to respond quickly when vibration problems occur, thus reducing the impact of vibration on system performance and safety.

5. Experimental analysis

In this experiment, the bearing data of rotating machinery in a laboratory are selected. The bearing data of rotating machinery contains three data sets, which are labeled as D1, D2 and D3 respectively.

The vibration data of rotating machinery under different vibration conditions are collected, including the normal state and fault state of rotating machinery. The sample data in both state categories are set to be 150.

The vibration control method of rotating machinery designed in this paper is applied to the research object. Based on the time-domain waveform change law of vibration signal in vibration control of rotating machinery, the changing trend of mechanical high-frequency attenuation signal is observed, the initial phase of mechanical vibration signal is kept unchanged, the period of vibration of rotating machinery is adjusted, and each harmonic and discrete frequency point are aliased to control the high-frequency vibration of rotating machinery together.

In order to verify the effectiveness of the vibration control method of rotating machinery designed in this paper more intuitively, the experimental method of comparative analysis is used to compare the vibration control method of rotating machinery designed in this paper with the traditional mechanical vibration control method based on improved disturbance compensation algorithm. The results are shown in Table 1.

Table 1. Comparison of identification accuracy of vibration signal network by two control methods.

data set	The proposed method/%	traditional method/%
D1	96.248	89.212
D2	97.232	90.078
D3	97.056	93.59

According to the comparison results, among the two vibration control methods of rotating machinery, the network identification accuracy of the vibration signal of rotating machinery designed in this paper is above 96% under different vibration conditions, which is higher than that of the traditional control method, indicating that the method designed in this paper has a high identification rate in the vibration control process of rotating machinery.

6. Conclusions

The vibration control method designed in this paper, under different vibration conditions, the accuracy of network identification of vibration signals of rotating machinery is above 96%, which is higher than that of traditional control methods. In practical engineering application, the selection of appropriate vibration control strategy must be based on the balance of specific structural characteristics, working environment and economic costs. In addition, the design and implementation of vibration control strategy need to comprehensively consider the multi-modal vibration characteristics of the structure to ensure the ideal effect under different working conditions. Future research should pay attention to the applicability of vibration control strategy in different types and scale structures, and combine advanced intelligent technology to optimize control algorithm and improve the adaptability and intelligence of vibration control system. Through these efforts, we are expected to provide strong support for the further development of the field of vibration control of rotating machinery and promote the safety and performance level of engineering structures.

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