Research on feature extraction of steam turbine shafting vibration signal

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Abstract—Vibration signal feature extraction is the primary problem of steam turbine condition monitoring and fault diagnosis. This paper focused on the analysis and recognition of vibration signal feature extraction, carried out model innovation on the basis of the existing status, and studied new modeling and solution methods. The vibration fault signals of typical steam turbine shafting were described respectively, and the time-frequency characteristics were studied by wavelet analysis.

1. Introduction

Steam turbine generator set is the key production equipment of power plant. Due to the complexity of its equipment structure and the particularity of its operation environment, its operation status is directly related to the production safety and economic benefits of enterprises [1]. Therefore, fault diagnosis and early warning of steam turbine generator unit are important safety guarantee means. Among them, the monitoring and diagnosis of bearing bush vibration signal of steam turbine generator unit is the top priority. It reflects the important feature information of the working state of rotating machinery. Effectively extracting this feature is of great value to fault diagnosis.

Vibration signal analysis and processing methods mainly include time domain, frequency domain and time-frequency domain. Time domain analysis is the earliest fault signal method, which mainly includes dimensional parameters such as peak value, mean value and variance, dimensionless parameters such as kurtosis and pulse factor and probability distribution characteristics. With the development of integral transformation in the field of mathematics, frequency domain analysis has been widely used in the field of engineering. Spectrum analysis, power spectrum analysis, resonance demodulation and inverse frequency analysis are also emerging. Among them, wavelet analysis is a new signal analysis method, which inherits the idea of using the simple harmonic function of Fourier analysis as the basis function to approximate any signal [2].

2. The vibration characteristics

In order to improve the steam work efficiency, the general steam turbine rotor is designed as a flexible rotor running at high speed. The flexible rotor would pass through the critical speed in the process of startup and shutdown, which would produce strong vibration. The incidence of several typical faults accounts for more than 90% of the total, including mass imbalance, misalignment, dynamic and static rubbing, bearing looseness, oil film oscillation and so on.
2.1. Mass unbalance
Rotor unbalance fault is the most common vibration fault type of steam turbine generator unit. The characteristic time domain waveform of unbalanced fault vibration signal is an approximate sine wave, and its axis trajectory is a stable ellipse, which is dominated by power frequency and contains some harmonic components [3]. When the speed is constant, its vibration amplitude is usually stable. The spectrum of unbalance fault is shown in Figure 1.

![Fig. 1 Spectrum of mass imbalance](image)

2.2. Misalignment
Misalignment is also a common fault type of steam turbine generator unit. When the misalignment deviation is too large, the rotor movement may cause bearing wear, shaft bending, dynamic and static rubbing and other faults, resulting in serious consequences. The rotor misalignment changes the support load of the bearing, changes the oil film pressure, reduces the load, and may cause oil film instability. Bearing misalignment will not cause vibration, which mainly affects the load distribution and other operating conditions of the bearing. The misalignment fault of shafting is more complex, which can be divided into parallel misalignment, angular misalignment and comprehensive misalignment. The spectrum of misalignment fault is shown in Figure 2.
2.3. Dynamic and static touch the ground

Dynamic and static rubbing is the process of contact and friction between rotating parts and stationary parts. The characteristic time-domain waveform of dynamic and static impact wear vibration signal is distorted and the phenomenon of "top cutting" appears. The frequency spectrum of fault vibration signal is rich. In addition to power frequency, there are also frequency components such as double frequency, triple frequency and fractional double frequency. Dynamic and static rubbing is one of the common faults in unit startup and operation. This fault usually causes severe vibration of the rotor, and even bending of the rotating shaft, resulting in shafting accidents. According to the impact direction, it can be divided into axial impact, radial impact and combined impact. The frequency spectrum of dynamic and static impact is shown in Figure 3.
2.4. Bearing loose
If there is too much clearance or looseness in the mechanical equipment, a small imbalance can also lead to large vibration. If the bearing is loose due to insufficient tightening force[4], the oil film characteristics of the bearing will deteriorate, which may lead to bearing instability. In addition, bearing looseness will reduce the dynamic rigidity of the support system and lead to the decrease of the critical speed of the shafting. These will affect the vibration characteristics of rotor and bearing. In the case of looseness, in addition to the basic vibration of rotation, high-frequency components, such as double frequency and triple frequency, and fractional components such as 1/2 double frequency and 2/3 double frequency, will also occur. The frequency spectrum of bearing looseness is shown in Figure 4.

![Figure 4: Spectrum of bearing looseness](image)

3. Signal analysis
Using reasonable signal processing technology to extract effective fault features from vibration signals is the key to equipment fault diagnosis. Vibration signal feature extraction includes time domain analysis, frequency domain analysis, time-frequency analysis, wavelet analysis, mode decomposition and so on.

3.1. Time domain analysis of vibration signal
As the most basic analysis method, the time-domain statistical analysis method of vibration signal includes indexes: mean value, variance, effective value, peak to peak value, single peak value, etc. Intuitively analyse the vibration of the rotor. Assuming that the period of signal x (T) is t, the calculation of each time domain index is [5]:

The mean $E[x(t)]$ is expressed as:

$$u_z = E[x(t)] = \lim_{T \to \infty} \frac{1}{T} \int_0^T x(t)dt$$

Expression in discrete case:

$$\hat{u}_z = \frac{1}{N} \sum_{i=1}^{N} x(t_i)$$
The mean square value \( E[x^2(t)] \) represents the average energy in the fluctuation of the signal:

\[
 u_x^2 = E\left[x^2(t)\right] = \lim_{T \to \infty} \frac{1}{T} \int_0^T x^2(t) \, dt
\]  
(3)

Expression in discrete case:

\[
 \hat{u}_x^2 = \frac{1}{N} \sum_{i=1}^{N} x^2(t_i)
\]  
(4)

The variance of the signal describes the fluctuation of the vibration signal deviating from its mean value and reflects the dynamic component of the signal. Its mathematical expression is:

\[
 \sigma_x^2 = E\left[(x(t) - E[x(t)])^2\right] = \lim_{T \to \infty} \frac{1}{T} \int_0^T \left[x(t) - u_x\right]^2 \, dt
\]  
(5)

Expression in discrete case:

\[
 \hat{\sigma}_x^2 = \frac{1}{N} \sum_{i=1}^{N} \left[x(t_i) - \hat{u}_x\right]^2
\]  
(6)

The square of the variance is called the standard deviation and is expressed in S:

\[
 S = \sqrt{\lim_{T \to \infty} \frac{1}{T} \int_0^T \left[x(t) - u_x\right]^2 \, dt}
\]  
(7)

Expression in discrete case:

\[
 \hat{S}_x = \sqrt{\frac{1}{N} \sum_{i=1}^{N} \left[x(t_i) - \hat{u}_x\right]^2}
\]  
(8)

3.2. Frequency domain analysis of vibration signals

The frequency characteristic of signal is the most common realization form of vibration signal. The frequency domain analysis could directly reflect each frequency component of vibration. The basic theory of frequency domain analysis is Fourier transform. For any signal with period T, the spectrum of time domain signal is to decompose the signal into signals with different frequencies. Assuming that the period of signal \( x(t) \) is T, the calculation of each frequency domain index is:

\[
 x(t) = x(t \pm nT)
\]  
(9)

Expressed as equally spaced spectral components:

\[
 X(f) = \frac{1}{T} \int_{-\frac{\pi}{T}}^{\frac{\pi}{T}} x(t)e^{-2\pi jft} \, dt
\]  
(10)

Then the time signal is obtained by inverse transformation:

\[
 x(t) = \sum_{-\infty}^{\infty} X(f)e^{2\pi jft} \, dt
\]  
(11)

3.3. Time-frequency analysis of vibration signal

The time-frequency analysis method of vibration signal is the most advanced method in vibration signal analysis at present. The representative is the wavelet analysis method proposed by French scientist J.Morlet. Empirical mode decomposition (EMD) is a signal analysis method proposed by Chinese American Huang E and others in 1998. It decomposes the signal according to the time scale characteristics of the data itself without setting any basis function in advance. At this point, its self-
adaptability is better than the harmonic basis function, wavelet basis function and Fourier decomposition based on a priori. It has obvious advantages in dealing with non-stationary and nonlinear signals, and the signal of rotating machinery fault diagnosis is precisely this kind of signal, so it has been widely used in this field.

EEMD is an improvement of EMD method. It solves the problem of mode aliasing by adding white noise. Many scholars at home and abroad have proposed the combined model of EEMD and different entropy to extract the characteristics of mechanical equipment vibration signals. EEMD has better adaptability than EMD method.

4. Conclusion
This paper mainly analyzed the characteristic signals of mass imbalance, misalignment, dynamic and static rubbing, bearing looseness, oil film oscillation and so on. The feature extraction methods of time domain, frequency domain and time-frequency domain were used to extract the feature of steam turbine vibration fault. The time domain analysis method could intuitively analyze the vibration of the rotor, and the calculation was simple. The frequency characteristic of signal was the most common realization form of vibration signal. The frequency domain analysis could directly reflect each frequency component of vibration. The basic theory of frequency domain analysis is Fourier transform. With the development of computer and the application of fast Fourier transform algorithm, the frequency domain analysis of vibration signal is more convenient.

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