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Recognition of Grinding Wheel Wear States Via Kullback-leibler Information Distance Method

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Abstract: According to the grinding experiment, the Kullback-Leibler information distance method is used to recognize grinding wheel wear states in the grinding process by means of the signal processing to grinding sparks. The research results show that the Kullback-Leibler information distance method can distinguish effectively the different grinding wheel wear states in grinding process both in the time domain and the frequency domain, but in the frequency domain it is more easy to realize the on-line supervision because of its less calculation, higher response rate and lower hardware requirement.

Keywords state recognition; Kullback-Leibler information distance; grinding wheel wear; grinding spark

INTRODUCTION

The state of the grinding wheel wear on-line identification is a key technique to realize the automation of grinding. The research and development of this technology is particularly important in grinding processing center, FMS and other advanced manufacturing machine tools and manufacturing system. In recent years, people proposed all kinds of methods about through the dynamic signal on-line monitoring of the grinding process to automatic recognition method of the wear of the grinding wheel, such as online monitoring of the grinding force, grinding chatter, grinding noise, the surface roughness of the workpiece, the grinding process of acoustic emission, etc., continuing to find simple and practical, accurate and reliable new method for identification of a grinding wheel wear states.

The author in literature [1] proposed a new method using grinding spark signal to on-line identify grinding wheel wear conditions, and analyzed the feasibility of the theoretical analysis and experimental research. On this basis, this paper further discusses the application of the information distance method in this field, and obtained some valuable research results.

TEST METHODS AND TEST RESULTS

Experimental System and Method

The grinding experiments work on M1432 ordinary cylindrical grinder. Grinding method chooses Cylindrical Plunge type, specimen is chosen for bearing ring (material is quenching bearing steel GCr15), grinding wheel is GB46ZR2SP 400 x50 x 203, wheel speed n_s = 1670 r/min, the workpiece speed n_W = 112 r/min, and the grinding fluid uses emulsion.

Figure 1 shows the test system and data acquisition & processing block diagram. Install the self-made infrared sensor probe on the tangent of the grinding wheel and workpiece interface, which is located at the points of contact side about 30mm (analysis and the experimental results showed that: this position of grinding spark signal is stable. [1]). the grinding spark signal measured by infrared sensor is then amplified by infrared tester and transformed into the magnetic tape recorder and displayed on the oscilloscope. For comparison, the grinding vibration and acoustic signals are all measured. After A/D conversion, various signals are transport into the computer for analyzing and processing.

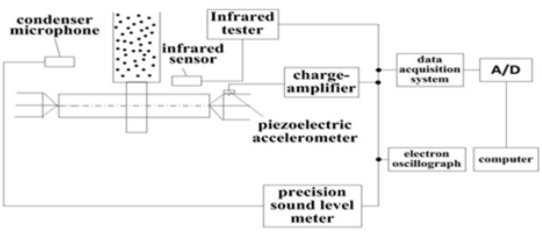

Figure 1. test system and data acquisition and processing block diagram

In the preliminary test, he grinding wheel dull standard is determined through various phenomena in grinding, such as grinding sound variation, oscillations, etc. In the formal stage, the wheel restart to grinding until blunting and after a period of time it stopped. In order to reduce the influence of random factors, the experiment repeated many times.

The Test Results of a Preliminary Analysis

Preliminary analysis of the different stages of grinding spark signal show that : the mean, variance, kurtosis coefficient, probability density function, power spectrum and other statistical characteristics of the signal can all used to distinguish the different grinding wheel wear states in a way. Among them the signal variance and power spectrum are more sensitive. Analysis results showed that due to the randomness and complexity, the change of the characteristic signal changes with volatility. Therefore, it is necessary to find a characteristic parameter with more sensitive, and can quantitatively describe the difference between different grinding spark signals so as to increase the recognition accuracy of grinding wheel wear states.

TIME-DOMAIN DISTANCE METHOD AND THE RESULT OF RECOGNITION

The Basic Principle of Time Domain Information Distance Method

Suppose there are two discrete random signal {Xr} and {Xt}, all kinds of information distance function can be used to distinguish between {Xr} and {Xt} [2]. The KL information distance function is widely applied in this field (referred to as KL distance). KL distance in time domain is calculated as follows [2]: Firstly two AR model of stochastic signal in the time domain are set up, respectively. Its general form is

$$x_k = a_1 x_{k-1} + \cdots + a_i x_{k-i} + \cdots + a_n x_{k-n} + e_k$$
$$e_k \sim NID(0, \sigma_e^2) \tag{1}$$

where n is the model order, a_i is the estimated parameters of the model , e_k is the residual error of the model, σ_e^2 is the model of residual variance.

According to the information theory, the AR model's residual variance can be used to construct the KL distance which reflects the differences degree of two random signals. The function is

$$I(\mathrm{r,t}) = \ln\left[\frac{\sigma_R^2}{\sigma_T^2}\right] + \frac{\sigma_{RT}^2}{\sigma_T^2} - 1 \tag{2}$$

where σ_R^2 is the estimates of the model residual variance of the reference signal {Xr}, σ_T^2 is the estimates of the model residual variance of the detecting signal {Xt}, σ_{RT}^2 is the residual variance of the detecting signal {Xt} obtained by AR model established by reference signal {Xr}

In the grinding process, grinding spark signal reflecting the wear of the grinding wheel changes as a short-time stationary random signal. According to the general rule of grinding wheel wear, at the beginning of the grinding, the dressing grinding wheel wear is minimum, which can be chosen as the reference signal {Xr}. With the increase of grinding time and grinding wheel wear quantity increasing, grinding spark signal at different times can be chosen as detecting signal {Xt}. Calculated the KL distance values of different time, which can reflect the state of grinding wheel wear in different stages of grinding.

The Identification of the State of the Grinding Wheel Wears in Time Domain

Figure 2 shows the changes of grinding spark's KL distance for different grinding stage. We can see that with the increase of grinding time, KL distance is gradually increased. In the normal wear stage, KL distance changes with low volatility, which means the grinding performance of the wheel changes little. In the sharp wear stage, KL distance increases obviously, which means that there is an obvious difference between the grinding performances. The KL distance values grow vigorous at boundaries of the wear stages, showing that it has strong recognition ability.

The above experiment results show that in time domain the KL distance can clearly distinguish the different state of grinding wheel wear. In order to get the KL distance, you need to establish multiple AR models. The calculation is large, and it has a high request for monitoring system hardware.

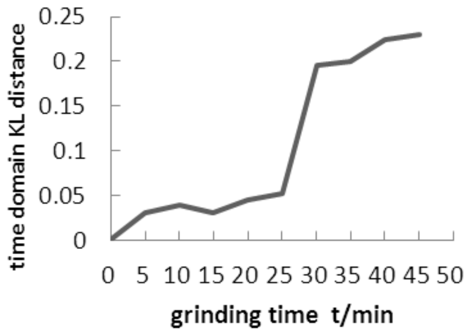

Figure 2. time domain KL distance the change curve along with grinding time

FREQUENCY DOMAIN INFORMATION DISTANCE METHOD AND THE RESULT OF RECOGNITION

The Basic Principle of Frequency Domain Information Distance Method

Due to the time domain information distance method calculating workload is large, it is not suitable for on-line monitoring. Reduce the amount of calculation is the key to shorten the time of random signal's modeling in time domain. Therefore, we adopt frequency domain information distance method to solve this problem.

Frequency domain information distance method is to use the random signal's nonparametric model, power spectrum instead of AR model in time domain, which constructed the frequency domain KL distance so as to reflect the difference degree of two random signals.

Suppose the power spectrum of reference signal {Xr} is Ssi, the power spectrum of detecting signal {Xt) is Sti, (i= 1, 2, ⋯ , N). According to the information theory, the frequency domain KL distance functions is [2,4]

$$I(\mathrm{s},\mathrm{t}) = \frac{1}{2N}\sum_{i=1}^{N}(\log\frac{S_{si}}{S_{ti}} + \frac{S_{ti}}{S_{si}}) - 1 \qquad (3)$$

Frequency domain information of KL distance function, also known as spectrum distance function, can fully reflect the differences between two random signal power spectrums. Obviously, in an ideal condition (the power spectrum of the detecting signal and the reference signal are equal) the spectrum distance should be zero. The greater the difference between two signal power spectrums, the spectrum distance value is larger.

In the spectrum distance calculation, with the power spectrum instead of the AR model in time domain, and the power spectrum can be quickly obtained by fast Fourier transform method, it can greatly reduce the workload of KL distance calculation in frequency domain. It can save operation time and improve the response speed, and reduce the demand for hardware. It is good for the realization of online monitoring.

The Identification of the State of the Grinding Wheel Wears in Frequency Domain

Figure 3 shows the changes of the grinding spark signal spectrum distance in different grinding stage. We can see that the KL distance change rule of frequency domain and time domain are very similar. With the increase of grinding time, spectrum distance value gradually increased. In the normal wear stage, spectrum distance changes with low volatility. In the sharp wear stage, spectrum distance value increase obviously. The test results show that the frequency domain information of KL distance can also clearly distinguish different grinding wheel wear states.

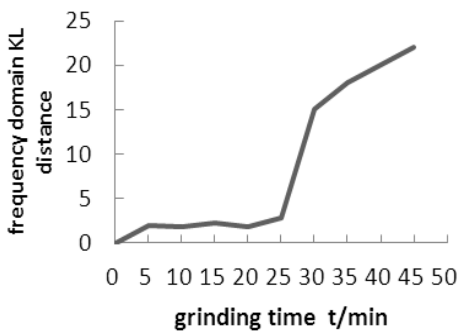

Figure 3. frequency domain KL distance the change curve along with grinding time

CONCLUSION

(1) the time domain and frequency domain information distance method can both effectively distinguish the grinding wheel wear state with grinding spark signal. It provides a new quantitative method for on-line identification of the grinding wheel wear state.

(2) the frequency domain information distance method has a lower calculation, faster response and lower requirements for hardware equipment. It is more suitable for online monitoring.

(3) the determination of threshold method in the identification process needs certain prior knowledge. It has some difficulties in practical, and may have further study about self-learning method to determine the threshold.

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