# Rotor Experiment Platform Smooth Acceleration and Deceleration Rubbing Experiment Analysis

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**Abstract.** Through simulating Rubbing fault occurrences of rotors on a rotor experiment platform, based on fast Fourier transformation (FFT) and Hilbert-Huang transformation (HHT), we achieved frequency characteristics and time-frequency characteristics of the fault-signals, issued under different conditions, and compared both analysis results. By using the HHT based time-frequency analyzing method, particularities of Rubbing faults can be more accurately reflected compared to the conventional frequency spectrum method, and serve much better the purpose of predicting and analyzing such kinds of faults.

**Keywords:** Rotating machinery; Rubbing faults; Hilbert-Huang transformation; Time-frequency analysis

## 1. Introduction

Rotor Stator Rub is one of the common faults of large rotating machinery, such as turbine generator, pumps, etc. generally occurs in the site of a small gap between the rotor and the stationary parts. In engineering practice, variety of reasons can cause Rubbing, such as imbalance, misalignment, relative motion between the rotor and stator, etc[1]. Due to that Rubbing can cause a series of adverse consequences for rotor system, and even lead to serious machine damage accident. Therefore, exploring the vibration characteristics of rotor Rubbing, especially early Rubbing characteristics, and detecting these features, so that we can avoid Rubbing fault and secondary faults, this has important practical significance [2].

When the rotating Machinery occurs Rubbing fault, due the impact and friction of Rubbing process changes damping, stiffness, elastic force of the rotor, showing non-linear, therefore vibration signals are non-stationary[3]. Generally, higher harmonic components in spectrum are treated as Rub diagnostic features. Research has also pointed out, 1P/X and 1P/X component of Rubbing fault can be used as a basis for early diagnosis. Since the Fourier transform is a decomposing method for steady signal, for fault analysis such as Rubbing, will inevitably conceal non-stationary of signals, therefore, in recent years, non-stationary signal processing method has been widely used in the extraction Rubs and made certain results[4]. Hilbert-Huang transform (HHT) is a time-frequency analysis method developed in recent years for non-stationary signal. This method has been widely used in geophysics, electrical, mechanical and other fields, and achieved certain results. In Rubbing, gear failure, crack diagnosis. The authors conduct Rubbing experiments in laboratory, through the HHT processing for fault signal, analysis its time-instantaneous frequency distribution. So expected to a better understanding for the important rotor fault, but also can provide a basis for accurate diagnosis of faults [5].

## 2. HHT Method

HHT is consist of EMD and Hilbert transform. For the initial input data, the steps of EMD are summarized as follows:

1. Identify the extrema.
2. Generate the upper envelope line u (t) and lower envelope line v(t) from the max point and the min point by cubic spline curve.
3. Compute the average of the upper envelope line and lower envelope line m(t) = [u (t) + v(t)]/2.
4. Compute the difference h(t) between x(t) and m(t).
5. Repeat steps 1 – 4 until satisfy IMF conditions.
6. Still repeat front steps,until separate all IMF.And we get:

$$x(t) = \sum_{i=1}^{n} c_i(t) + r_n(t)$$

where n is the number of IMFs.

Hilbert transform every IMF, make $x_i(t) = c_i(t)$

$$y_i(t) = \frac{1}{\pi} P \int_{-\infty}^{+\infty} \frac{x(\tau)}{t-\tau} d\tau$$

P is Cauchy principal component.

Structure analytic signal $z_i(t) = x_i(t) + iy_i(t) = a_i e^{i\theta_i(t)}$

Among them

$$a_i(t) = \sqrt{x_i(t)^2 + y_i(t)^2}$$

$$\theta_i(t) = \arctan(y_i(t) / x_i(t))$$

Define Instantaneous frequency as

$$\omega_i(t) = \frac{d\theta}{dt}$$

Ignore residual components

$$x(t) = \mathrm{Re} \sum_{i=1}^{n} a_i(t) e^{j\theta_i(t)} = \mathrm{Re} \sum_{i=1}^{n} a_i(t) d^{\int \omega_i(t) dt}$$

Frequency $\omega_i(t)$ and amplitude $a_i(t)$ are related to time. That can form a three dimensional spectrum called Hilbert Amplitude spectrum.

Go a step further, we can define the marginal spectrum:

$$h(\omega) = \int_{-\infty}^{+\infty} H(\omega, t) dt$$

Above EMD and the corresponding Hilbert spectrum analysis method called Hilbert-Huang transformation (HHT) [6].

## 3. Experimental Programs

### 3.1. Experimental Device.

We installed a pair of the eddy current sensor on both sides of the rotor experiment platform Circular disk. The left side of disk is the motor drive, and the Rubbing location on the right side.

### 3.2. Channel Settings.

CH1 Channel: the eddy current sensor on the left side of disk (measure X direction displacement).
CH2 Channel: the eddy current sensor on the left side of disk (measure Y direction displacement).
CH3 Channel: the eddy current sensor on the right side of disk (measure X direction displacement).
CH4 Channel: the eddy current sensor on the right side of disk (measure Y direction displacement).
CH5 Channel: Key phasor pulse, one pulse per revolution.
TACH1 Channel: Speed measurement channel.

### 3.3. Sampling Frequency

In order to simulate the real vibration when mechanical failure happens, the sampling frequency is set 5120 Hz. then the analysis frequency is set 2000 Hz.

### 3.4. Experiment Process

In this experiment, 5 set of experiments were done, sampling data was saved to 5 documents. The specific information is as follows:

1) Normal: Normal circumstances; speed up-keep-speed down process, the maximum speed is 3000 r/min; the sampling points: 618496.

2) Rubbing test 1: Rubbing of speed up and speed down process, maximum speed is 3000 r/min; the sampling points: 618496.

3) Rubbing test 2: Rubbing of Speed up and speed down process, maximum speed is 3300 r/min; the sampling points: 618496.

4) Rubbing test 3: Rubbing of constant speed, speed is 3300 r/min; the sampling points: 155648.

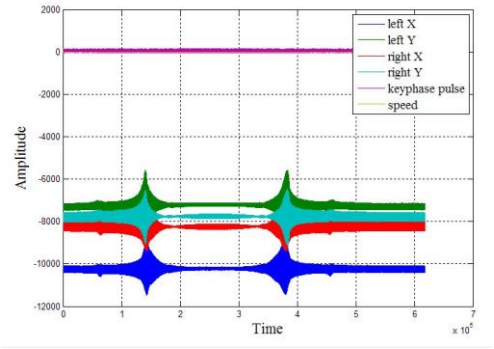
5) Rubbing test 4: Rubbing of constant speed, speed is 1490 r/min; the sampling points: 155648.

## 4. Results Analysis

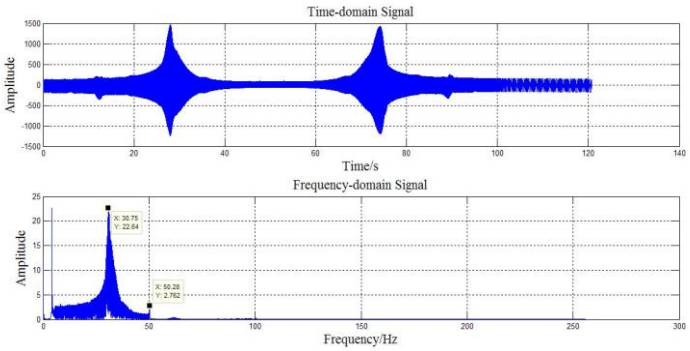
There are many different types of faults during operation in rotating machinery, such as unbalanced, the initial bending, stiffness asymmetric, misalignment, oil whip, seal instability, etc, Rubbing is just one symptom. Many factors affect Rubbing, mainly boils down to two factors: One is the geometric factor. For example, due to the small gap between the static and dynamic parts, temperature changes and other causes of friction movement components. Another factor is due to the imbalance, misalignment, oil whip and other reasons make excessive vibration caused friction. In addition, shaft parts loose, external stimulus is too large will cause friction movement components too. When Rubbing occurs, it increases the vibration of rotating machinery, even cause serious damage to the entire machinery. In this paper, we selected three different signals to compare. They are: normal signal, lifting speed Rubbing signals and uniform Rubbing signal.

### 4.1. Normal Speed up-keep-speed down Process

By HHT analysis method, we research CH1 channel signal of normal condition. The results are as follows:

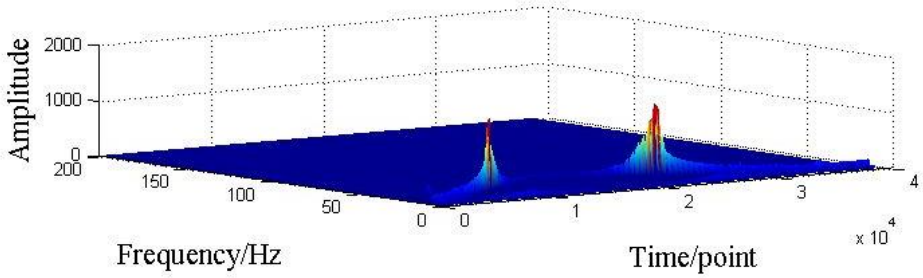



(a) Signals of all channels

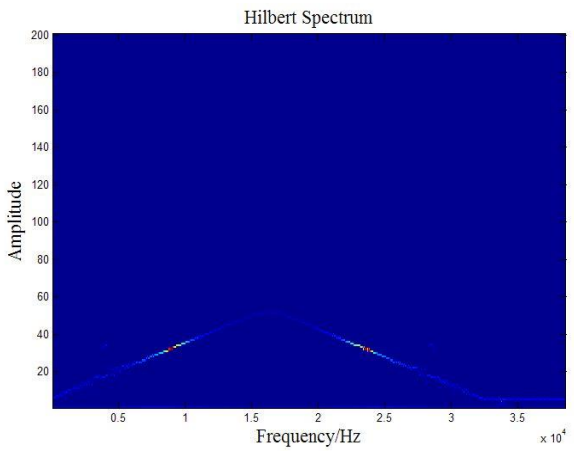


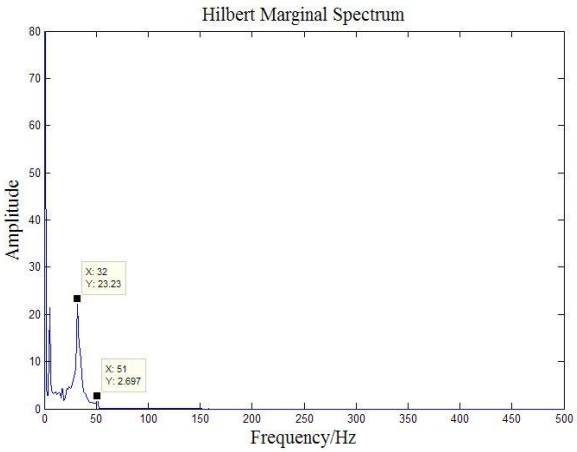

(b) Time-domain and frequency-domain signal

Hilbert 3D Plot




(c) Hilbert 3D plot



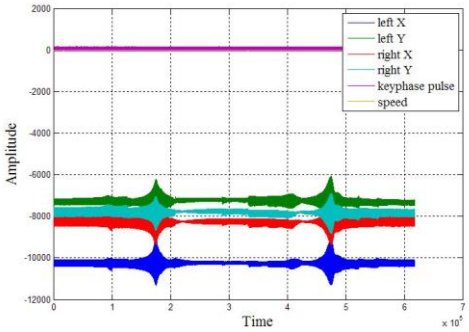



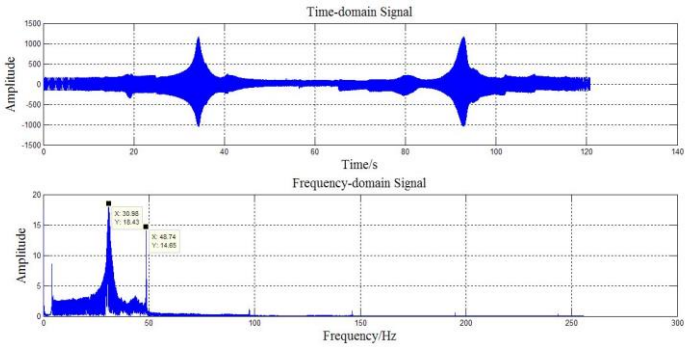

(d) Hilbert spectrum (e) Hilbert marginal spectrum

Fig.1 Analysis results of normal acceleration and deceleration signals

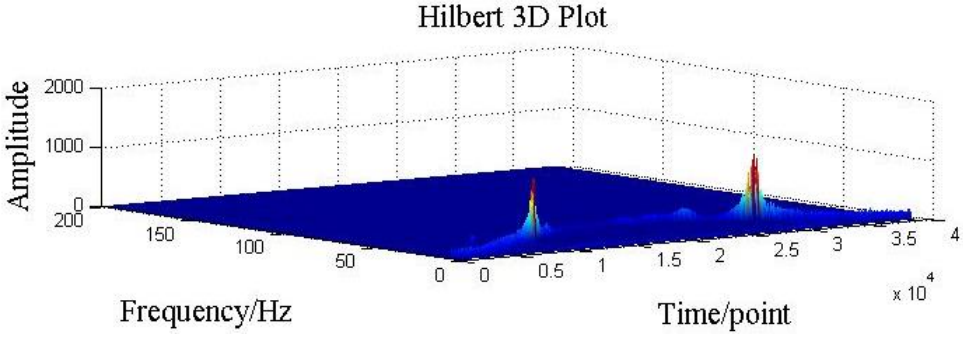
### 4.2. Rubbing of Speed up-keep-speed down Process

By HHT analysis method, we research CH1 channel signal of Rubbing test 1 condition. The results are as follows:

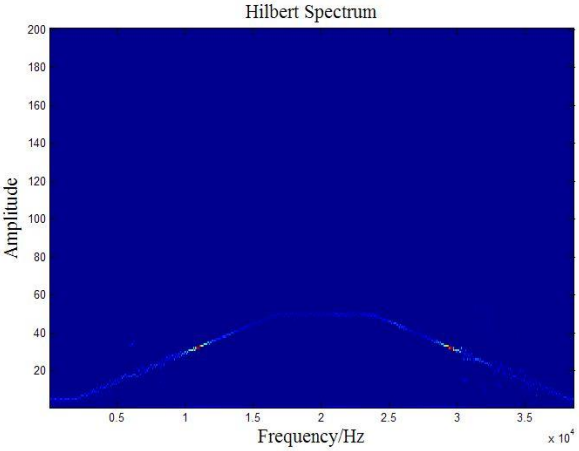


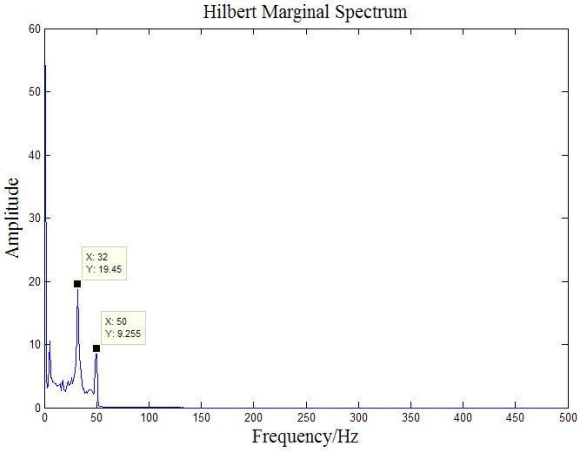




(a) Signals of all channels (b) Time-domain and frequency-domain signal




(c) Hilbert 3D plot




(d) Hilbert spectrum (e) Hilbert marginal spectrum

Fig.2. Analysis results of acceleration and deceleration Rubbing signals

Research the above charts, we can draw the following conclusions:

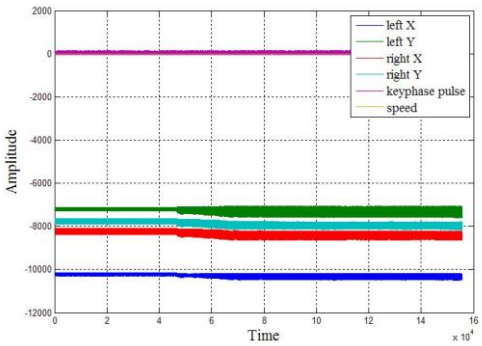
1. At first, we can find the different feature compare to the normal signal. It appears that twice, thrice and four times frequency doubling in the process of speed up and speed down due to Rubbing fault. But the low amplitude indicate the energy is low too.

2. In Hilbert spectrum, we observed that instantaneous frequency wave clearly between point 10000 and point 20000 in the process of speed up because of Rubbing and impacting. The whole process of speed up and speed down has fluctuate of frequency, that is a linear frequency modulation process, but we can't see it very clearly on the time-domain waveform.

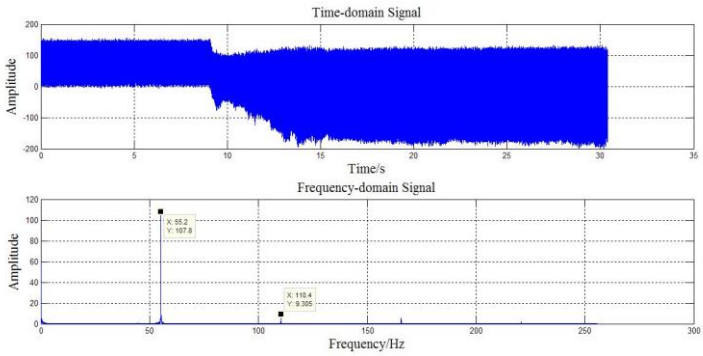
3. In the marginal spectrum, the highest amplitude is on the natural frequency due to the maximum energy. In other area, instantaneous amplitude of frequency are similar, because energy distribution is substantially uniform.

**4.3. Rubbing of Constant Speed Process**

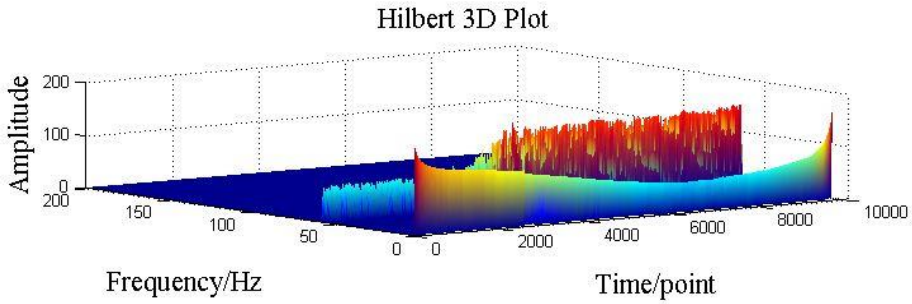
By HHT analysis method, we research CH1 channel signal of Rubbing test 3 condition. The results are as follows:



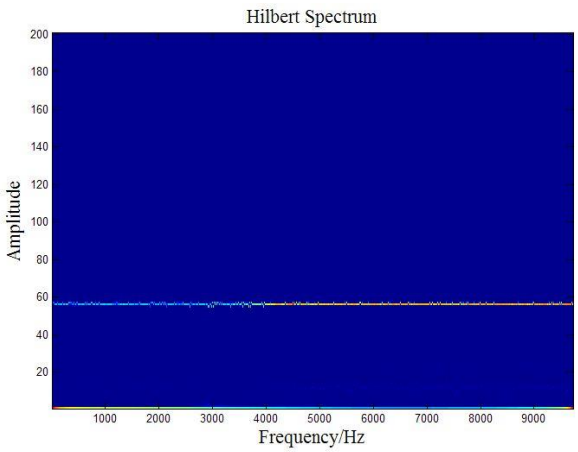

(a) Signals of all channels



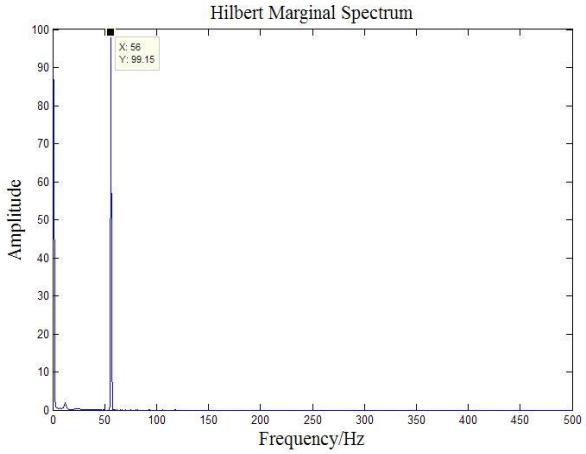

(b) Time-domain and frequency-domain signal




(c) Hilbert 3D plot




(d) Hilbert spectrum




(e) Hilbert marginal spectrum

Fig.3 Analysis results of constant speed Rubbing signals

Research the above charts, we can draw the following conclusions:

1. Through compare to the two time-domain waveform In different speed,when the rotor rotate at 3000r/min,Rubbing probably begins at 9th second.In a longitudinal direction,vibration amplitude is reduced, but the amplitude in the opposite direction is significantly increased.Combined with

instantaneous frequency hopping in the Hilbert spectrum,express Rubbing impact plays the major role.Because of high speed, friction didn't make speed down so obvious.However, when the rotor rotate at 1490r / min,we can see the amplitude has a significant clipping on the time-domain waveform,it should be weakened because of the friction on speed.

2. Two speed multiplier component have emerged on the amplitude spectrum, which is a characteristic of rotor Rubbing.

## 5. Conclusion

Through the rotor experimental simulation under different Rubbing fault, compared the analysis results of FFT and HHT in different conditions, the following conclusions can be drawn:

1. Rubbing fault occurrences of rotors can be manifested as mutation and the regularity fluctuation of instantaneous frequency along base frequency. The intensity of mutation and the regularity fluctuation related to the strength of Rubbing. That reflect the process of Rubbing and impacting.

2. It can be more accuracy reflect the feature of Rubbing fault occurrences if we use HHT method.so we can diagnose the Rubbing fault occurrences in early phase.

We must point that: the conclusion of this paper is under the experiment of the single disk flexible rotor experiment platform. Because of the complexity of field equipment, The Rubbing fault occurrences of rotors on large rotating machinery should conduct a further research.

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