

## Fault Detection in the Two-for-One Twister

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**Abstract:** The two-for-one (TFO) twister is precision machinery that twists fibers rapidly under constant tension. Since the quality of the twisted yarn is directly deteriorated by faults of the twister, such as the distortion of the spinning axis, bearing abrasion, and tension irregularity, it is important to detect faults of the TFO twister at an early stage. In this research, a new algorithm is proposed to detect faults of the TFO twister and their causes, by measuring the vibrations of the TFO twister and obtaining frequency components with a FFT algorithm. The TFO twister with faults showed increased vibrations and each fault generated vibrations at different frequencies. By analyzing changes of characteristics of vibrations, we can determine faulty twisters. The proposed fault detection algorithm can be implemented cheaply with a signal processor chip. It can be used to find when to repair a faulty TFO twister without much loss of yarn on-line.

**Keywords:** Fast Fourier transform, fault detection, two-for-one twister, vibrations.

### 1. INTRODUCTION

Yarn-twisting is the process that increases the cohesive force of textiles by twisting fibers, thus protecting them from the tension generated at the time of weaving and knitting. The two-for-one (TFO) twister, as shown in Fig. 1, is a device used most frequently for yarn-twisting. A fiber wound off from the fixed bobbin passes through the tension control unit and a guide of the spindle in the air. The fiber is twisted once per one rotation of the spindle. The fiber passed through the guide is wound into a roll, and it is twisted once again at this time. Since the fiber is twisted twice per one rotation of the spindle, it is called a TFO twister. The TFO twister has several advantages such as high productivity, continuous processing and low energy consumption.

Many efforts to improve the TFO twister have been made. They include spindle designs [1,2], detection of faults in twisted textiles [3-5], analyses of the dynamic characteristics of the TFO twister, and the

physical properties of the twisted yarn [4]. Du and Hearle [1,2] established a numerical single disc model for the mechanics of friction twisting such as yarn paths, tension, and torque generation over the disc surface. It was applied also to a multi-disc spindle system. Ribolzi *et al.* [3] provided an automatic system which can detect faults in textiles by observing the diffraction spectrum on the textile surface. Hong *et al.* [4] established a mechanism that analyzes yarn quality by using laser sensor that samples the diameter signal of yarn. Wavelet analysis and fast Fourier transformation (FFT) were applied to extract fault characteristics. Sette and Boullart [5] suggested an approach for quality assessment and fault detection by using two types of neural networks of the Kohonen map and the back propagation network.

Since the TFO twister is precision machinery that rotates rapidly to twist fibers under constant tension, it is difficult to detect faults of the running TFO twister. Therefore, most TFO twisters are repaired after the twisted yarn is degraded by a faulty TFO twister. If faults of the TFO twister can be detected and corrected at an early stage before the twisted yarn is degraded seriously, the productivity of the twisting process can be improved. Research for the detection and distinction of faults in the TFO twister, however, has not been reported yet, while the fault detection systems of other rotating machinery [6,7] have been available.

Since the TFO twister rotates rapidly, its vibrations may have inherent frequency characteristics. The vibration characteristics of the twister with faults will be changed. In this research, the vibration signals of the twister were measured with a vibration sensor attached to the spindle bolster, and their frequency

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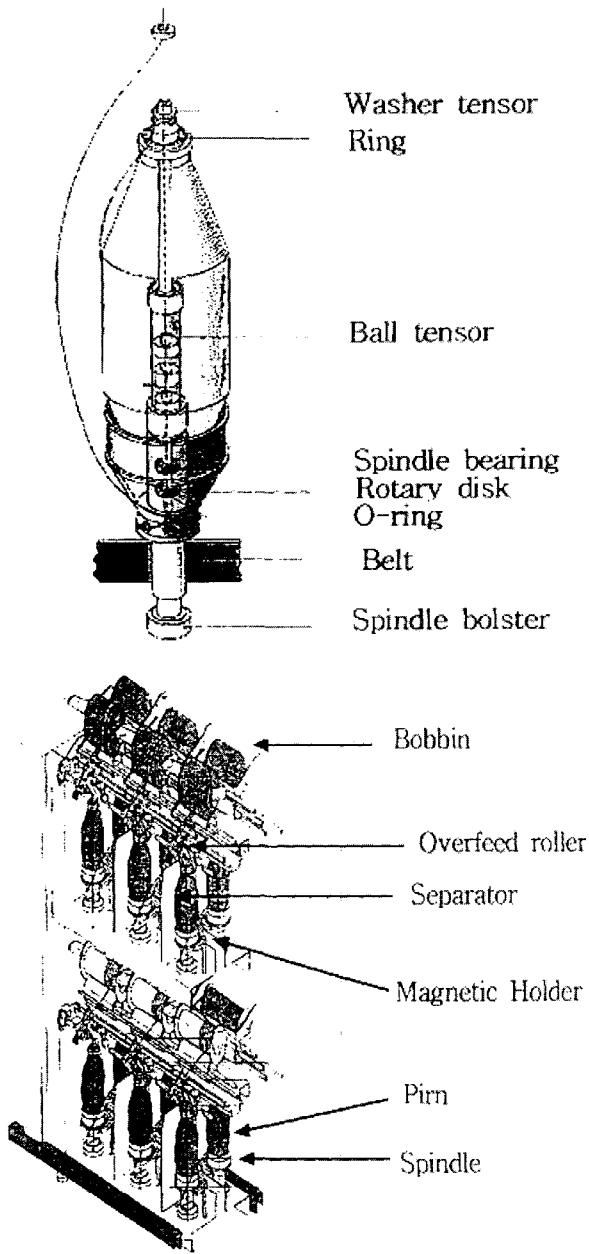


Fig. 1. The two-for-one (TFO) twister.

components were obtained by using the FFT algorithm. From the changes of the frequency components, faults of the twister are detected. In order to show possibilities of detecting faults and their causes, experiments have been performed for the TFO twister with a distorted spinning axis and/or abraded bearings.

**2. FAST FOURIER TRANSFORM**

The Fourier transform is an efficient computational tool that extracts information about frequency components of an arbitrary signal and is used in many industrial fields. For the discrete signals, the Fourier transform becomes DFT(discrete Fourier transform),

which is described as follows [8];

$$H(f_n) = \sum_{k=0}^{N-1} h_k e^{j2\pi kn/N},$$

$$f_n = \frac{n}{NT}, \text{ for } n = -\frac{N}{2}, -\frac{N-1}{2}, \dots, \frac{N-1}{2}, \frac{N}{2}, \tag{1}$$

where  $T$ ,  $N$ , and  $h_k$  denote the sampling interval, the total number of sampled signals, and the  $k$ 'th measured signal, respectively. As shown in (1), many calculations may be required to compute the DFT of measured discrete signals. Cooley and Turkey developed a new numerical algorithm that reduces the number of computations needed in the DFT analysis [8]. This algorithm is called the Fast Fourier Transform (FFT). Now, many FFT algorithms and signal processor chips that implements FFT algorithms on-line are available.

**3. FAULT DETECTION SYSTEM**

**3.1. Vibration measuring system**

The schematic diagram of the vibration measuring system is shown in Fig. 2. The vibration measuring system consists of a vibration sensor, a signal conditioner, an A/D converter module (Lab-made with the ADuC182 chip, Analog Device) and a personal computer. Since the TFO twister rotates at a speed of about 12,000RPM, we looked for a fast vibration sensor with high sensitivity and high resolution. Therefore, we chose an accelerometer (Model: 14103, B&W Sensing Technology), which has the sensitivity of 100mV/g, the resolution of 0.002m/s<sup>2</sup> and the measurement frequency range between 0.5Hz~4kHz, as the vibration sensor. The vibration sensor was attached to the spindle bolster of the TFO twister. The vibration signal measured by the vibration sensor is transmitted to the signal conditioner manufactured by B&W Sensing Technology. The signal conditioner converts the vibration signal to a voltage signal with a range of ±5V. The voltage signal is converted to a digital signal through an A/D converter module. In order to measure high frequency signals above 200 Hz, we used the programmable ADuC812 chip manu-

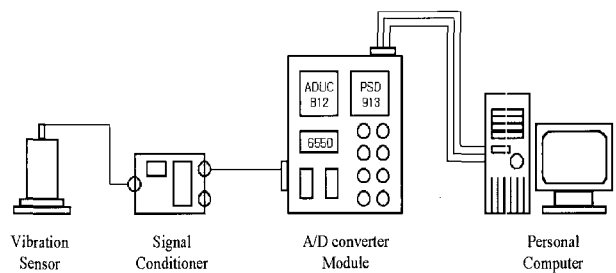


Fig. 2. Schematic diagram of the vibration measuring system.

factured by Analog Device as the main micro processing unit for the A/D converter module, which contains a 12-bit ADC (analog to digital converter) with a maximum conversion speed of 200 kHz. Since the ADuC812 chip has an input voltage range of 0V~2.5V which is different from the output voltage range of the signal conditioner, the voltage signal from the signal conditioner must be adjusted to meet the input range of the ADuC812 chip. As an example, if the voltage signal from the signal conditioner is not sufficient, the signal should be amplified with appropriate gains, to enhance the resolution of the signal. Conditioning circuits for low voltage signals were also included in the A/D converter module. The resulting digital signal is linear to the vibration signal and it has a range between 0~4095. To analyze the vibration signal (which will be discussed later) using the FFT algorithm, the digital signal should be transmitted to the personal computer. Due to the high resolution and high conversion speed of the digital signal, however, it is hard to directly transmit to the personal computer on a continuing basis. Therefore, the data for a given time interval into the memory of the A/D converter module are first stored and then are transmitted to the personal computer by using the serial communication of RS422.

### 3.2. Fault detection of the TFO twister

Due to the rapid rotation of the TFO twister, its vibrations may have inherent frequency characteristics. Faults of the twister, such as a distortion of the spinning axis, bearing abrasions and the tension irregularity, will change its frequency characteristics. If these changes can be detected before the quality of twisted yarn is seriously degraded and the exact time to repair can be recognized, we can save fibers considerably. This can be achieved by using the vibration measuring system and the FFT algorithm as previously mentioned.

In addition, we can identify the causes of faults. There are various kinds of faults that influence the vibrations of the TFO twister. Each fault will generate oscillations at different frequencies. For example, frequency components of the vibrations of the TFO twister with distorted spinning axis will be different from those of the twister with abraded bearings. Through experiments, a table of frequency pattern changes for each fault can be made. When a fault happens, the fault can be determined by looking for the table. The overall fault detection procedure for the TFO twister can be summarized as follows:

- (1) The vibration signal is obtained from the vibration measuring system and experiments.
- (2) Applying the FFT algorithm, the frequency pattern of the measured vibration signal is obtained.
- (3) Comparing the obtained frequency pattern with the prepared table of frequency pattern changes,

the fault of the twister with its cause can be determined.

## 4. EXPERIMENTAL RESULTS AND DISCUSSION

The TFO twister that rotates at a speed of about 12,000RPM was experimented. The vibrations of a normal twister as well as twisters with a distorted spinning axis and abraded bearings were measured. Vibration signals are sampled with sampling rate of 4,800Hz. In one experiment,  $2^{14}$  samples (about 3.3 seconds) were obtained. To obtain information about the frequency components of vibration signals, the measured signals were analyzed by using the FFT algorithm. For a distortion of the spinning axis, an experiment was performed on two kinds of twisters. One is the case of a slight distortion that is difficult to recognize, and the other is a serious distortion that was found out at a periodic inspection. To simplify the analysis, the FFT algorithm was directly applied to the digital signal, which is linear to the vibration (acceleration) signal, without any other preprocessing of data. Since a component at frequency zero is not meaningful, we made this value zero. The resulting frequency components of the digital signal are in proportion to those of the vibration signals, except for frequency zero. If all of data are used in the frequency analysis, significant time and effort may be required. To reduce the number of computations, it is needed to reduce the number of samples to be analyzed. This can be achieved by reducing the measuring time.

### 4.1. Frequency analysis for a normal twister

The vibration signal for a normal twister is shown in Fig. 3. It is hard to determine special features from this noisy measured signal. Fig. 4 shows the frequency components of a normal TFO twister obtained from the whole data ( $2^{14}$  samples). From the results of the two kinds of twister, we can find out common results where a very high peak is shown at

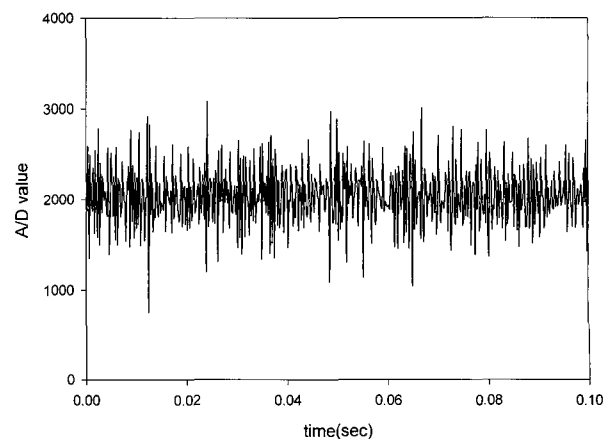


Fig. 3. Vibration signal of a normal TFO twister.

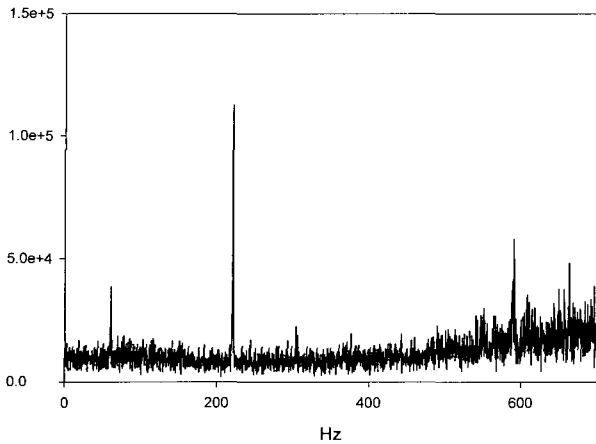
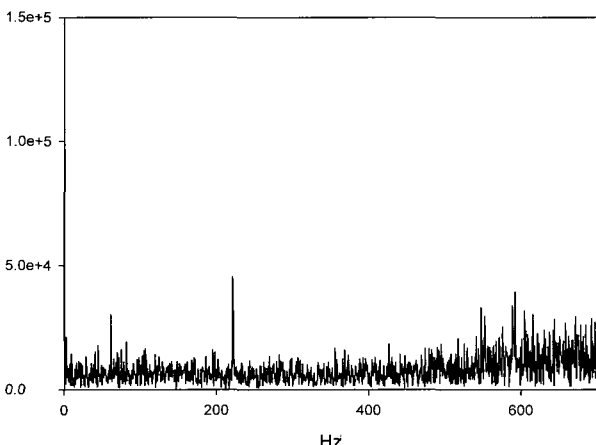
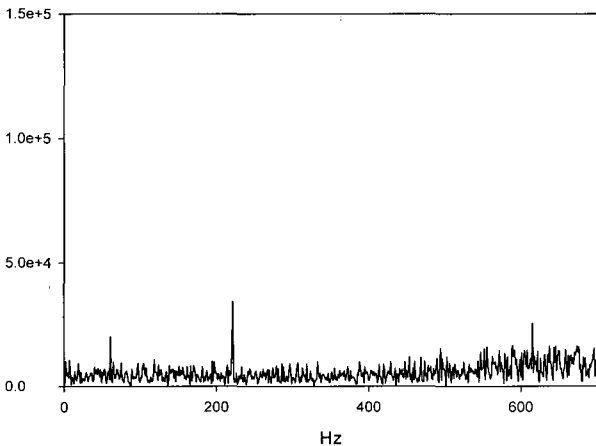


Fig. 4. Frequency components for a normal TFO twister.



(a)  $2^{13}$  samples.



(b)  $2^{12}$  samples.

Fig. 5. Frequency components for a normal TFO twister with reduced numbers of samples.

about 220Hz. It is a normal rotational vibration of about 12,000 RPM of the TFO twister. A different oscillation is shown at about 60Hz, which is due to the AC power noise. Frequency components due to measurement noises are also shown in a high

frequency range.

Fig. 5 shows the frequency components of a normal twister which are for the  $2^{13}$  and  $2^{12}$  samples. High peaks are shown also at 220Hz and 60Hz. The height of peak, however, is decreased as the number of samples to be analyzed is reduced. It is concluded that the oscillation of a normal twister has characteristic frequencies of 220Hz and 60Hz.

4.2. Frequency analysis for a twister with a distorted spinning axis

Figs. 6 and 7 show the results of frequency analyses for the twister with slightly and seriously distorted spinning axes, respectively. First, consider the results from slight distortion of spinning axis as shown in Fig. 6. Peaks are shown at characteristic frequencies of 220Hz and 60Hz, which are the same as those for a normal twister. The heights of these peaks are higher than those of a normal twister because the oscillations due to the distortion of the spinning axis are increased. A peak appears also around 670Hz by the influence of the distortion of spinning axis.

Next, consider the results of the frequency analyses for the seriously distorted spinning axis, as shown in Fig. 7. Peaks are shown at characteristic frequencies of 220Hz, 60Hz and 670Hz as in a twister with slightly distorted spinning axis, but their heights increase higher. In addition, unlike the twister with a slightly distorted spinning axis, there are peaks at various frequencies.

From these experiments, we can extract the following facts for the twisters with distorted spinning axes:

- (1) When the spinning axis begins to become distorted, the heights of peaks grow.
- (2) As a result from the distortion of the spinning axis, a peak appears around 670Hz.
- (3) If the spinning axis is distorted seriously, peaks appear at various frequencies including 670Hz.

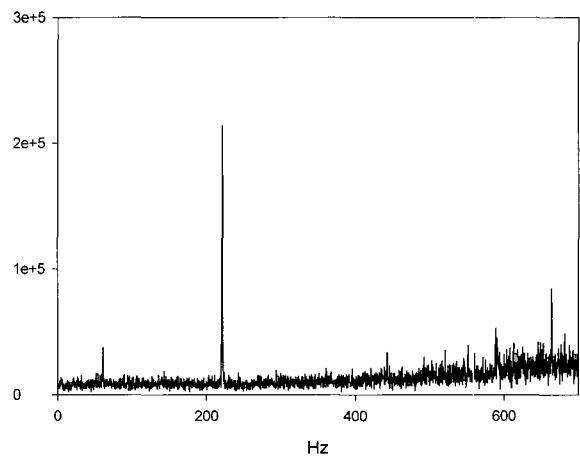


Fig. 6. Frequency components for a TFO twister with a slightly distorted spinning axis.

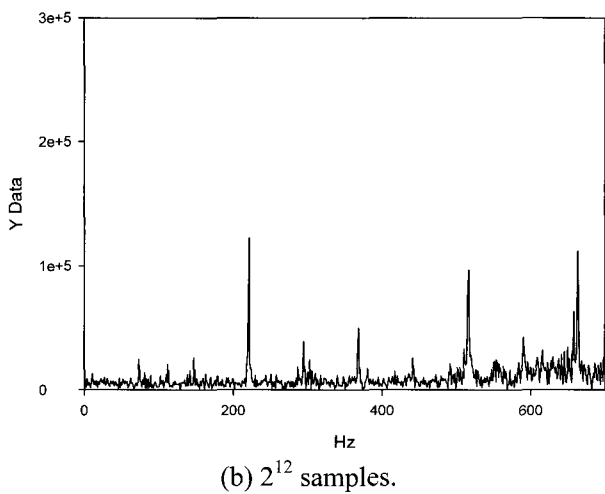
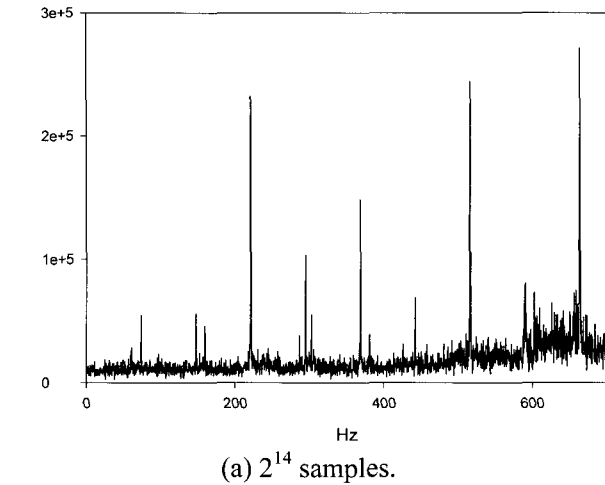


Fig. 7. Frequency components for the TFO twister with seriously distorted spinning axis.

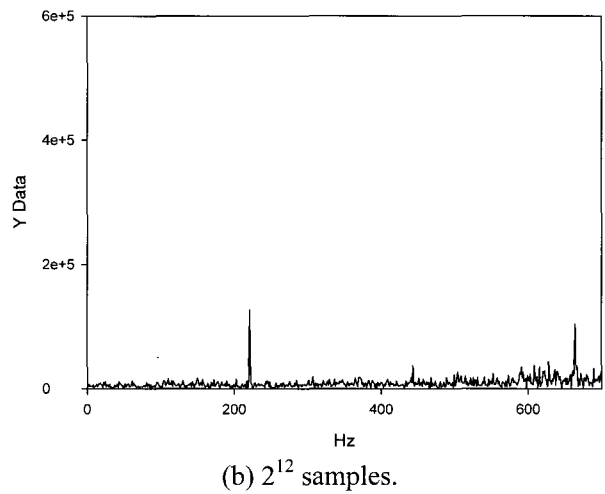
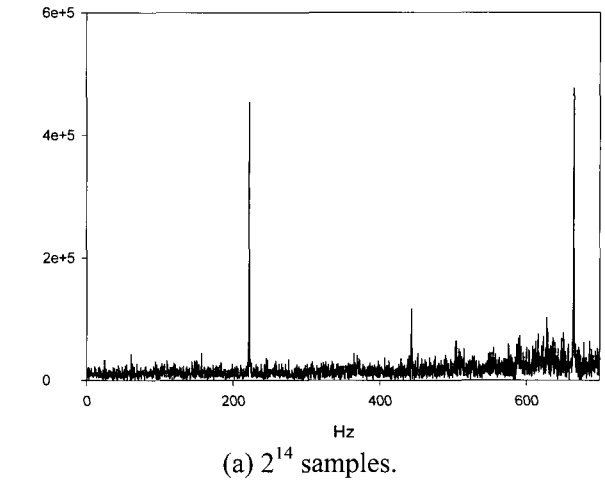


Fig. 8. Frequency components for two TFO twisters with abraded bearings.

#### 4.3. Frequency analysis for a twister with abraded bearings

Results of the frequency analysis for a twister with abraded bearings are shown in Fig. 8. A peak is shown at the characteristic frequency of 670Hz as in the twister with the distorted spinning axis. Peaks are shown at the frequencies of 220Hz and 60Hz as in a normal twister. Their heights are higher than those of a normal twister (about 5 times). In addition to these peaks, a peak appears around 450Hz, although its height is small. This peak can be used to discriminate the causes of faults between a distorted spinning axis and abraded bearings.

### 5. CONCLUSIONS

In this research, a simple method to detect faults of TFO twisters at an early stage has been proposed. A vibration signal is measured using a vibration sensor attached to the spindle bolster of the TFO twister and its frequency components are extracted by using the FFT algorithm. From the pattern of frequency

components, we can detect faults of the TFO twister. By applying this analysis to a real TFO twister in the field, we obtained the following conclusions. Normal twisters generate oscillations at their characteristic frequencies. As twisters begin to become abnormal, the vibrations increase. Different types of faults generate oscillations at different characteristic frequencies. The characteristic frequencies of the twister in this experimental research are shown in Table 1. By comparing the frequency components of the measured vibration signals with those in Table 1, we can determine whether the twister is faulty and the source of fault.

Table 1. Characteristic frequencies of the two-for-one twister.

	Characteristic frequencies
Normal twister	220Hz and 60Hz
Distortion of spinning axis	670Hz
Abrasion of bearings	450Hz

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