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순간주파수를 이용한 모터고장진단

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Motor Fault Monitoring using Instantaneous Frequency

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Abstract - Instantaneous frequency(IF) has important physical meaning for nonstationary signal. Motor current is well known that to be a nonstationary signal whose properties vary with respect to the time-varying normal operating conditions of the motor, particularly with load. Time-frequency methods can overcome the shortcomings of the traditional spectral analysis techniques, nonstationary signal analysis approaches have been introduced. We examine the concept of IF as a potential candidate for condition monitoring of motors.

1. Introduction

Traditional time-domain and spectral analysis for current based monitoring of motor condition such as Fourier transform have several shortcomings. The Fourier transform is unable to provide any information about the time dependency of the frequency content of nonstationary signals.

Motor current is well known that to be a nonstationary signal whose properties vary with respect to the time-varying normal operating conditions of the motor, particularly with load. Time-frequency methods can cure the shortcomings of the traditional spectral analysis techniques, nonstationary signal analysis approaches have been introduced.

The nonstationary signals whose frequency content changes with time are encountered commonly in many research areas such as radar and sonar analysis, signal detection and parameter estimation, image processing, and fault diagnosis etc. The important feature of nonstationary signal is that they have time-varying spectrum. The frequency at a particular time is described by the concept of IF. IF is used to know when frequency components exist and how change with time. IF characterized important physical parameters of the signals.

In this paper, we examine the potential of motor condition monitoring by analyzing nonstationary motor current via IF. The paper is organized as follows. The concept IF is described in Section 2.1. The Wigner-Ville distribution as representative time-frequency distribution is represented in Section 2.2. The experimental result is shown in Section 3. Conclusions are given in Section 4.

2. 1 Instantaneous frequency

As a generalization of the definition of frequency, IF is defined as the rate of change of the phase angle at time t of the analytic version of the signal [1]. Given a real signal $s(t)$, the analytic signal $z(t)$ is a complex signal having the actual signal as the real part and the Hilbert transform of the signal as the imaginary component;

$$z(t)=s(t)+jH[s(t)]=a(t)e^{j\Phi(t)} \quad (1)$$

where the amplitude $a(t)$ and the phase $\Phi(t)$ are clearly given by:

$$a(t)=\sqrt{(s(t))^2+(H[s(t)])^2} \quad (2)$$

and

$$\Phi(t)=\tan^{-1}\left(\frac{H[s(t)]}{s(t)}\right) \quad (3)$$

and the Hilbert transform is given by the principal value of the integral in (4).

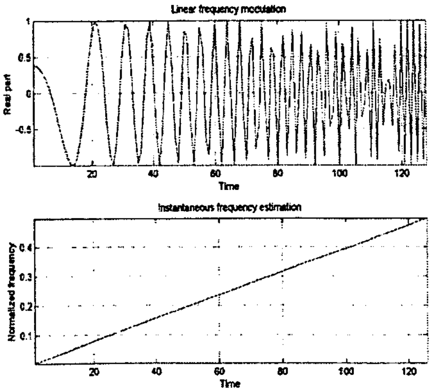

Figure 1. Linear frequency modulation and corresponding estimation of the instantaneous frequency

$$H[s(t)]=\frac{1}{\pi}\int_{\infty}^{\infty}\frac{s(t)}{t-\tau}dt \quad (4)$$

The instantaneous frequency is, by definition in (5).

$$f_i(t)=\frac{1}{2\pi}\frac{d\Phi(t)}{dt} \qquad (5)$$

One can easily confirm from the previous definitions that the IF of a harmonic function is constant and coincides with the frequency of the function. One can gain intuitive appreciation for the concept of IF by examining a chirp signal. A linear chirp is defined as $y(t)=\cos(at)t$ from where the interpretation of a frequency varying linearly with time is evident[2]. A plot of a linear chirp and its instantaneous frequency computed from (5) are shown in Fig. 1. As one can see, the IF definition captures the time variation of the frequency accurately. Note that when the chirp is represented in the Fourier domain the result contains a large number of components with different frequencies and the simple nature of the signal is lost.

2. 2 Wigner-Ville Distribution

A time-frequency distribution which is particularly interesting is the Wigner-Ville distribution defined as[3]:

$$W_x(t,\nu)=\int_{-\infty}^{\infty}x(t+\frac{\tau}{2})x^*(t-\frac{\tau}{2})e^{-j2\pi\nu\tau}d\tau \qquad (6)$$

or equivalently as

$$W_x(t,\nu)=\int_{-\infty}^{\infty}X(\nu+\frac{\xi}{2})X^*(\nu-\frac{\xi}{2})e^{-j2\pi\xi t}d\xi \qquad (7)$$

In particularly, the Wigner-Ville distribution is always real-valued, it preserves time and frequency shifts and satisfies the marginal properties. Wigner-Ville distribution is another estimator for the instantaneous frequency as the first moment of the distribution with respect to frequency.

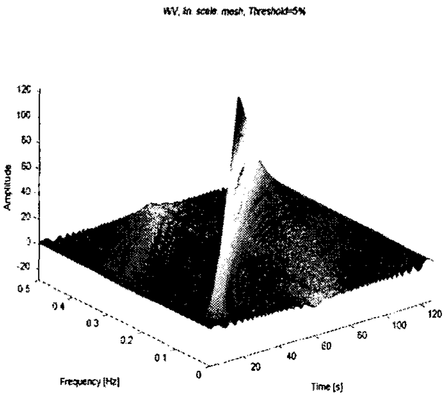

Figure 2. Wigner-Ville distribution of the liner chirp signal

An interpretation of this expression can be found in terms of probability density. Equation (6) is the Fourier transform of an acceptable form of characteristic function for the distribution of the energy. Cohen developed a generalized formulation for the distribution of energy in time and in frequency and defined the instantaneous frequency to be the average of the frequencies that exist in the time-frequency plane at a given time. A comprehensive discussion on the various proposed formulations may be found in Boashash.

3. Experimental Results

The implementation of motor driving system is shown in Fig. 3. The motors used in this system are model HSX0804211 with 2.2KW. One has in good conditions and the other has with fault in the winding insulation. The same inverters, Fuji electric FRN3.7c1s-2J, are used in the systems. The load rate can be controlled by changing DC voltage.

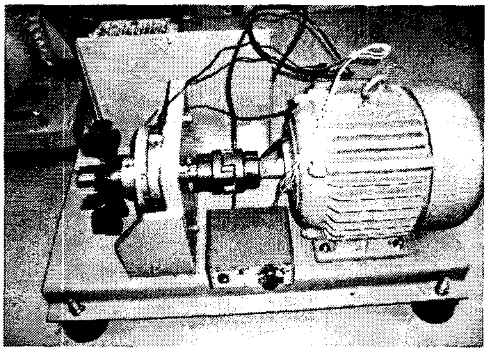

Figure 3. Motor driving system

For verification, we diagnosis in advance the condition of the motors used in this experiment by using KS-1000 shown in Fig. 4 which is a commercial motor diagnosis system.
It can diagnosis motor condition by analyzing harmonics and current unbalance rate while the motor is on the operation. The harmonics and current unbalance rate can be obtained by harmonic and current probe respectively.

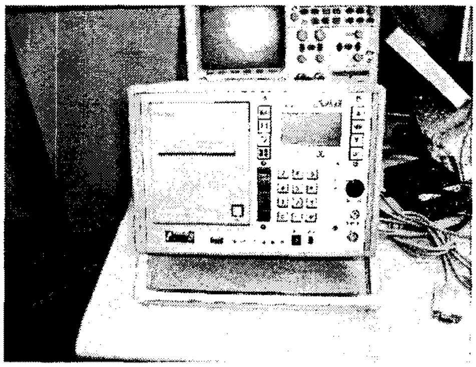

Figure 4. KS-1000 motor diagnosis system

Table 1. Result for diagnosis of winding insulation using KS 1000

	Motor with fault	Motor in good condition
Diagnosis result for winding insulation	0.519 (B2)	0.152 (A)

The KS-1000 can diagnosis not only electrical component such as winding insulation but also mechanical parts such as bearing and housing in the motor driving system.

The result for monitoring condition of electrical parts of the two motors used in this experiment is represented in Table 1.

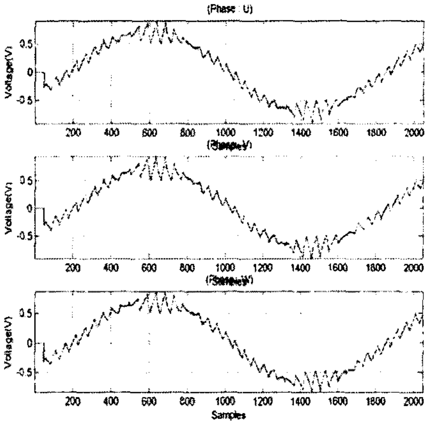

Figure 5. Current signals for good condition motor

The KS-1000 shows two kinds of diagnosis result at the same time. It gives both quantitative and qualitative results. According to table 1 condition of the motor with fault in winding insulation is "B2". It means that condition of the winding insulation of the motor will be severe defect in six month.

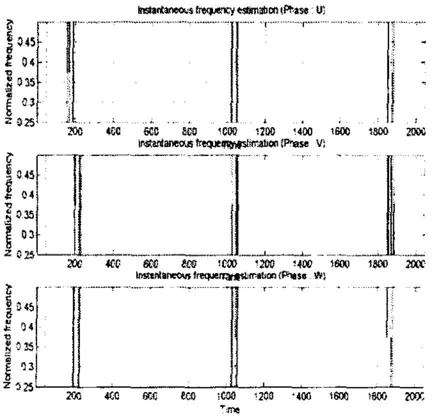

Figure 6. Estimation of the instantaneous frequency of current signals for good condition motor

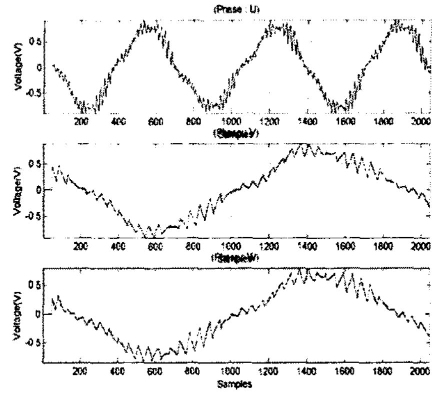

Figure 7. Current signals for motor with winding insulation fault

The current waves for each phase are obtained by current meter while the motors are on operation at 60 ㎐, and it is recorded by oscilloscope with rate of 200M/sec sampling frequency. We acquire three current signals per each phase and analyze the signals using IF. Fig. 5 shows current signal for motor in good condition, and its corresponding IF is shown in Fig. 6. The result for motor with fault is shown in Fig. 7 and Fig. 8.

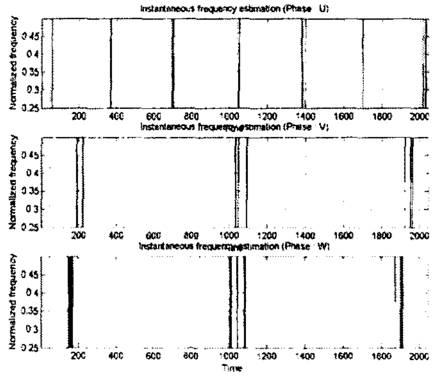

Figure 8. Estimation of the instantaneous frequency of current signals for motor with winding insulation fault

4. Conclusions

In this paper, we have presented an approach for current based motor fault monitoring via IF. IF gives an accurate information for nonstationary signal. It provides suitable tools for current based motor fault monitoring. The relationship between quantitative representation of fault and IF needs to be explored in further research.

[References]

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