

NDE by means of frequency sweep excitation and spectrogram method

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This paper presents a strategy and a system configuration for eddy current testing, which can improve measurement quality and reduce the total time of tests for crack detection. A frequency sweep excitation and spectrogram method (FSES) is proposed. An experimental system is developed for arbitrary single-frequency excitation by using phase-locked loop (PLL) frequency synthesizer. The experimental results shows very high signal to noise ratios and also make it easier to carry out non-destructive evaluations.

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1. Introduction

For an estimation of crack size, excitation frequency components play important roles. Authors had already reported about "Multi-Frequency Excitation and Spectrogram (MFES) Method". By exciting with the waveform containing plural harmonic components, this method can illustrate characteristic relationship between the frequency responses and the crack sizes. So far, we had confirmed that crack sizes and shapes had given significant influences on the frequency responses from the results of MFES measurements. Thus, MFES method had given a lot of good results for crack characterization [1][2]. In the MFES method, an excitation waveform is synthesized from plural selected frequency components. Since the eddy current path inside a testing specimen depends on the excitation frequency, this method can bring forth the characteristic relationship between frequency and crack size or shape.

On the other hand, the MFES method has some problems. Two of them are worth pointing out here. First, there is the difficulty caused by discrete Fourier transform (DFT) or FFT analysis. Second, there is the one due to the superposition of frequency components.

To eliminate these setbacks, we propose the "Frequency Sweep Excitation and Spectrogram Method" [5]. It utilizes only single frequency component, in other words, a specimen is excited by sinusoidal waveform. However, by employing a PLL synthesizer to generate system clock, the exciting frequency can be chosen arbitrarily, and the sampling number N is always constant. This configuration makes signal processing easier and available to operate in real time.

2. Frequency sweep excitation and spectrogram method

As described above, MFES method has two difficulties.

The first difficulty of MFES is that the frequency components usable for the excitation waveform are limited, due to discrete Fourier transform (DFT) analysis. Theoretically, frequency components can be selected arbitrarily for an exciting waveform; however, DFT can only analyze the harmonic components of the primary frequency. For example, when the primary frequency is set to 50Hz, the usable frequency components are limited to 100, 150, 200, 250Hz, and so forth. In this case, we cannot choose arbitrary frequency components such as 60, 70 or 80Hz. Especially eddy current testing of a magnetic specimen requires detailed analysis within the lower frequency range. In order to increase the frequency resolution, a lower frequency (such as 10 or 20Hz) can be chosen as the primary frequency, of course; however, this leads to an increase of the sampling number N , while also extending the FFT analyzing time tremendously.

The second difficulty we would like to point out is that the MFES method requires an A/D converter that satisfies both specifications, that is, high speed and high resolution. The sampling resolution of each frequency component decreases when many components are superposed. When an excitation waveform is synthesized from 16 components with the same amplitude, it means that 4-bit resolution is reduced for each component. If a 12-bit A/D converter is used, the resolution of each component is less than 8-bit. In order to extract a small defect signal, 8-bit resolution is not enough.

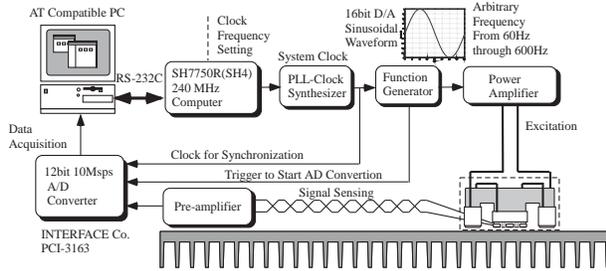


Fig. 1. Block diagram of Frequency Sweep Excitation and Spectrogram Method

Fig. 1 shows the structure of the developed block scheme of whole system. In order to generate an arbitrary frequency, a phase-locked loop (PLL) system clock generator is employed. This PLL generates a clock frequency from 1MHz up to 10MHz. The upper limit, 10MHz, is determined from the maximum sampling rate of the 12-bit A/D converter, PCI-3163.

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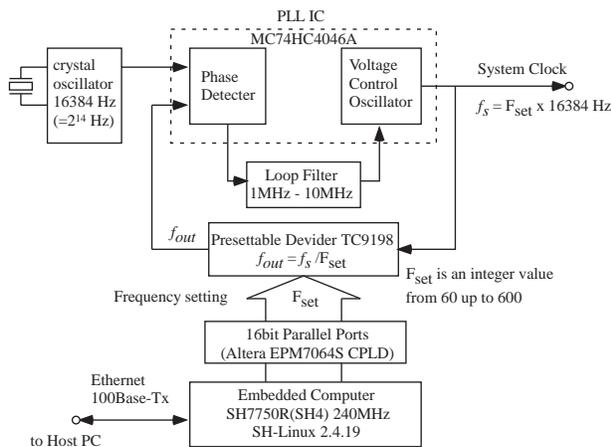


Fig. 2. Constructions of Phase Locked Loop (PLL).

Sinusoidal waveform data (16-bit resolution) are written into two fast EPROMs (27C256-7) at within 16384 (14-bit) points per period as shown in Fig. 3. The digital data of the waveform are converted into an analog sinusoidal voltage through a 16-bit D/A converter, LT-1668. Finally we can obtain the waveform of the single-frequency component $f = F_{set}$.

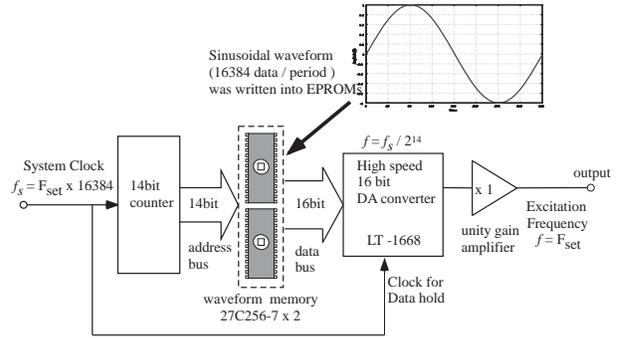


Fig. 3. Constructions of the functions generator.

3. Nondestructive evaluations with FSSES

Fig. 4 shows the test specimen used in the experiments. A specimen is made of stainless steel SUS-304, and has artificial defect of 5 mm length, 10 mm width and 2 mm depth (40%).

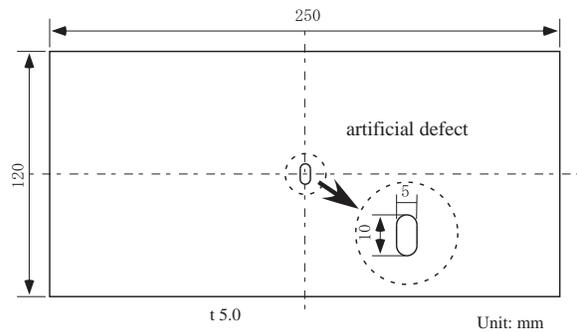


Fig. 4. SUS-304 specimen with artificial defect (depth 2 mm, 40%).

Fig. 5 shows the constructions of a transducer. It is made of TDK PC40EE30-Z ferrite core. Two excitation coils (0.3mmf UEW wire, 50Turns) are wound around the outer yoke legs, and two search coils (0.05mmf UEW wire, 10Turns) are wound at the bottom of a central yoke leg, search coil A and search coil B as shown in fig. 5.

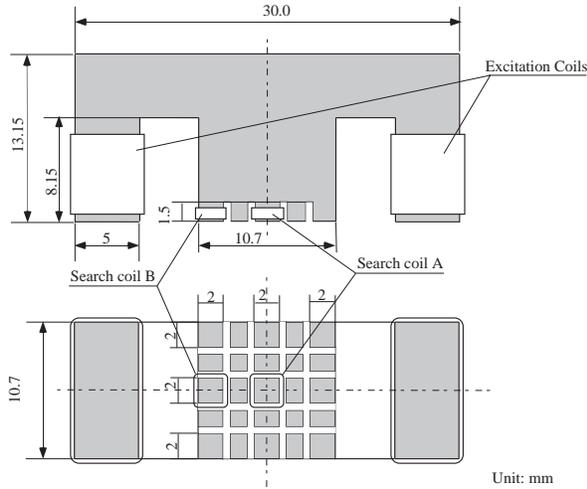


Fig. 5. Constructions of transducer.

In order to evaluate the validity of FSES, comparisons between FSES and MFES were done within same frequency excitation condition. Fig. 6 show two spectrogram of surface side defect signal picked up by search coil A. Fig. 6 (a) is a result by MFES, and 6(b) by FSES. Tendencies are quite similar in both results. FSES leads much larger signal levels. Fig. 7 are results picked up by search coil B, also they are quite similar.

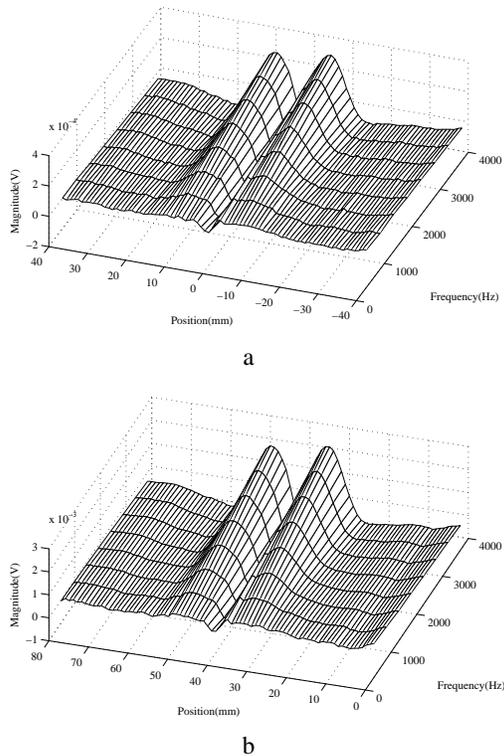


Fig. 6. Spectrogram of 40% surface side defect (Search coil A), (a) MFES, (b) FSES

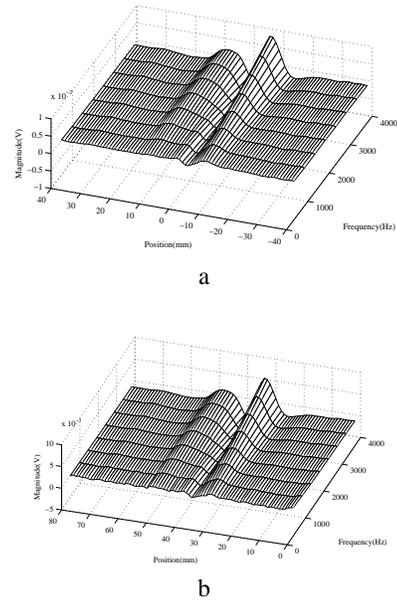


Fig. 7. Spectrogram of 40% surface side defect (Search coil B), (a) MFES, (b) FSES.

Fig. 8 show results of opposite side defect signal picked up by search coil A. Due to opposite side defect, signals become smaller than above two results. FSES results seem to more smooth characteristics because of its high signal to noise ratio. Fig. 9 show results of opposite side defect signal picked up by search coil B. They also show good agreements.

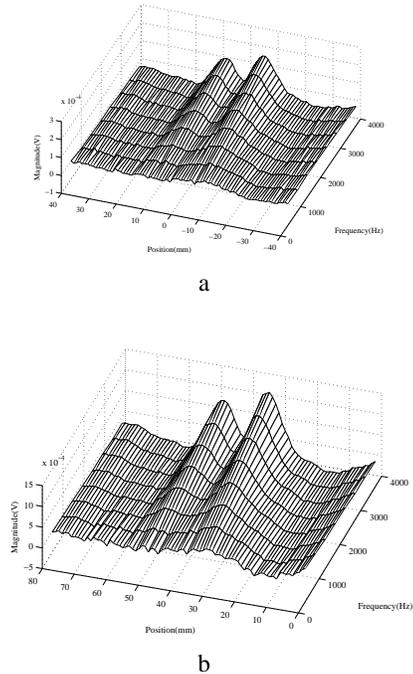


Fig. 8. Spectrogram of 40% opposite side defect (Search coil A), (a) MFES, (b) FSES,

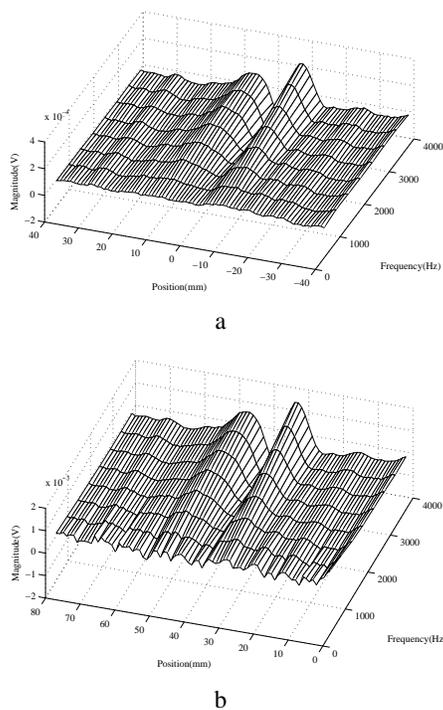


Fig. 9. Spectrogram of 40% opposite side defect (Search coil B), (a) MFES, (b) FSES.

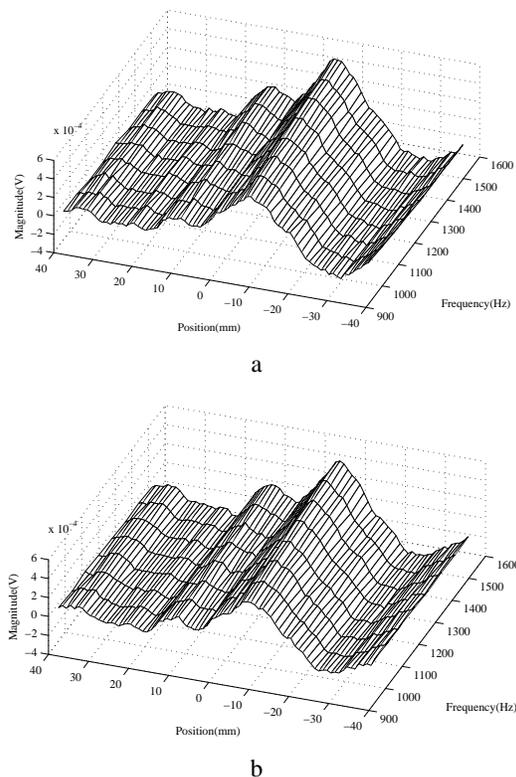


Fig. 10. (a) Focused FSES Spectrogram of 40% opposite side defect (Search coil A), (b) FSES results show good reproducibility.

Fig. 10 show reproducibility of spectrograms of opposite side defect (search coil A). Two results are measured by FSES in lower frequency. Excitation frequencies are set to from 480 through 1600 Hz every 160 Hz. Therefore, results indicate more detail behaviour compared to Figs. 8. Two results of Figures 10 (a) and (b) are almost same. It can be said FSES can provide excellent reproducibility.

4. Conclusions

In this paper, we proposed a “Frequency Sweep Excitation and Spectrogram Method”. An experimental system for non-destructive testing is developed. This system can perform in arbitrary frequency excitation which was impossible for conventional MFES. Experimental results show the validity of this method.

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