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Separation of Signals Acquired with EMAT in Dual Coil Configuration

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Abstract

In this paper, the proposal of electromagnetic acoustic transducer (EMAT) in dual coil configuration with consequent application of signal de-noising algorithm is presented in detail. Dual EMAT contains two operated coils in a single housing. Both coils transmit and receive the ultrasonic signal. Based on the proposed coil configuration, two signals characterizing material structure at the same place are received and consequently evaluated. This configuration makes the flaw detection process more accurate and the noise level can be efficiently suppressed using advanced signal processing algorithms. In this study, we also investigate the proposal of signal processing algorithm used for signal and noise separation. The proposed algorithm based on independent component analysis (ICA) uses the statistical information to separate useful signal as fault echo from the undesirable echoes that are caused by the scattering from grains contained in materials. Using our proposed algorithm it is possible to recognize the fault echo that is hidden under the noise level from backscattering noise. The performance of both, proposed EMAT in dual coil configuration and algorithm is compared on simulated and acquired EMAT signals.

Keywords: EMAT transducer, Signal separation, Noise reduction.

1. Introduction

Electromagnetic acoustic transducers [1], [2] are emerging as a mainstream Non-Destructive Evaluation (NDE) technique. Electromagnetic acoustic transducer (EMAT) is commonly used for the non-contact generation and detection of ultrasonic signals in metals for some time. EMAT consist of a coil and a magnetic field, applied to a conducting substrate. The transmitter coil is conventionally driven with a shock current pulse. The characteristics of electromagnetic acoustic transducers as an ultrasonic source depend on the direction of the applied magnetic field and eddy current density induced at a conducting surface. The presence of a Lorenz force on the substrate causes an elastic wave to propagate into the volume of the material, or along the surface. EMAT detection works via an inverse process, where motion of the surface induces an electromagnetic field into the coil. EMAT offers several distinct advantages over traditional piezoelectric transducers for many inspection applications requiring novel solutions. These advantages include: operation without a coupling fluid, non-contact operation, high temperature operation, and the ability to utilize shear horizontal (SH) waves. EMATs are also ideally suited to launching and receiving Rayleigh waves, Lamb waves, and shear horizontal (SH) plate waves. The primary disadvantage of EMATs when compared to piezoelectric transducers is poor transduction efficiency. One of the most useful EMAT applications is flaw detection in metallic materials. In this case, the efficiency is very important factor. The received EMAT signal contains back-wall echo, fault echo and reflections of ultrasonic waves from structure of the tested material. These reverberations are commonly called as backscattering noise (coherent noise). Another source of noise can be caused by influence of electronic circuitry and this noise is called electronic noise (incoherent noise). Both backscattering and electronic noise have to be considered as a part of received EMAT signal. In the case of coarse grained structure of materials the noise can sometimes totally mask the echoes from flaw and must be suppressed.

Many methods for noise reduction have been proposed. This paper describes a novel electromagnetic acoustic transducer in dual coil configuration [3]. The present EMAT commonly contains one coil where the signal is corrupted with relatively higher noise level. Based on this feature we proposed and created the dual coil configuration where the sensitivity is much higher. In this dual coil configuration, other signal processing methods in terms of noise reduction can be used. This paper also addresses using of blind source separation algorithm for noise suppression. [4], [5]. Algorithm is evaluated and performed on both artificial and real measured signals.

The paper is organized as follows: In the second section the principal and construction of dual EMAT transducer is clearly described. The next section presents the basic theory of blind source separation algorithm. The third section of this paper is focused on theoretical experiments, where the signal separation method is evaluated in terms of signal-to-noise ratio enhancement on simulated EMAT signals. The signal was simulated based on the real parameters (frequency response) of our designed EMAT transducer. The fifth section describes our designed EMAT system and the data acquisition of EMAT signals with consequent de-noising on raw signals. In this study, the transducer with the central frequency of 4 MHz was used. For the measurement of EMAT signals calibration gauge was proposed.

2. Dual EMAT construction

Although the contactless feature is one of the main advantages of EMATs, there are many additional benefits such as the very flat frequency response of the two-coil system, the ability to accommodate wide temperature fluctuations, the ease of generating either longitudinal or shear wave modes or both, as well as the capability of generating and detecting surface waves. The standard EMAT transducer contains one coil as a source of magnetic field and one excitation coil.

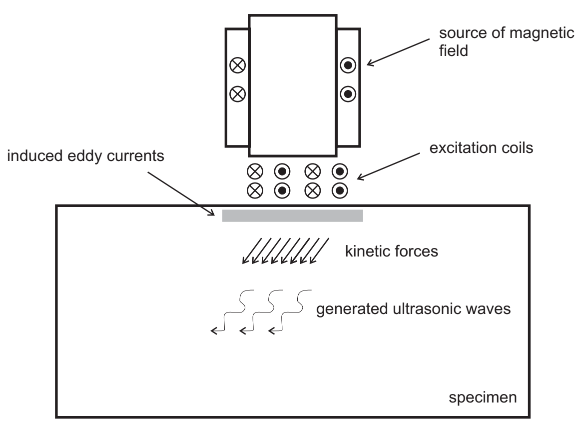

Fig. 1. Principal of ultrasonic wave generation using dual EMAT configuration

In dual EMAT configuration (see fig.1), the transducer contains two coils as sources of magnetic field and two excitation coils. These coils are closest above each other. In this extension, with this transducer two signals are received. These signals consider the same material structure due to the similar ultrasonic wave propagation. Based on these signal with similar statistical properties, the advanced signal separation methods based on independent component analysis can be used.

2. Blind signal separation

Blind signal separation (BSS) consists in recovering unobserved signals or sources from several observed mixtures. The simplest BSS model assumes the existence of *n* independent signals $s_1(t),...,s_n(t)$ and the observation of as many mixtures $x_1(t),...,x_n(t)$, these mixtures being linear and instantaneous. This is compactly represented by mixing equation

$$\mathrm{x}(t) = A\mathrm{s}(t), \tag{1}$$

Where $\mathrm{s}(t) = [s_1(t),...,s_n(t)]^T$ is an $n \times 1$ column vector collecting the source signals, vector $\mathbf{x}(t)$ similarly collects the *n* observed signals and the square mixing matrix contains the mixture coefficients. The BSS problem consists in recovering the source vector $\mathbf{s}(t)$ using only the observed data $\mathbf{x}(t)$, the assumption of independence between the entries of the input vector $\mathbf{s}(t)$ and possibly some a priori information about the probability distribution of the inputs. It can be formulated as the computation of an $n \times n$ separating matrix B whose output $\mathbf{y}(t)$

$$\mathbf{y}(t) = B\mathbf{x}(t) \tag{2}$$

is an estimate of the vector $\mathbf{s}(t)$ of the source signals. The basic BSS model can be extended in several directions considering for instance more sensors than sources, noisy observations, complex signals and mixtures. The solving of equation (2) depends on the selected algorithm. Many algorithms have been published with different results. One of the most popular algorithms is called FastICA (Fast Independent Component Analysis), it is described in detail in [12], [13]. Before the FastICA algorithm can be used, it is very important to characterize the model for the ultrasonic signal separation. The main question is to propose the sources signals $\mathbf{s}(t)$.

3 Theoretical results

3a Noise analysis

First of all, the noise analysis of measured EMAT signals has to be performed. The noise analysis involves the amplitude and frequency analysis is represented by histogram and power spectral density. The EMAT signal measured on the calibration gauge K1 were used for this analysis. The set of 1000 signals were acquired using ultrasonic STARMANS DIO2000 system. The representative signal can be seen in fig. 2.

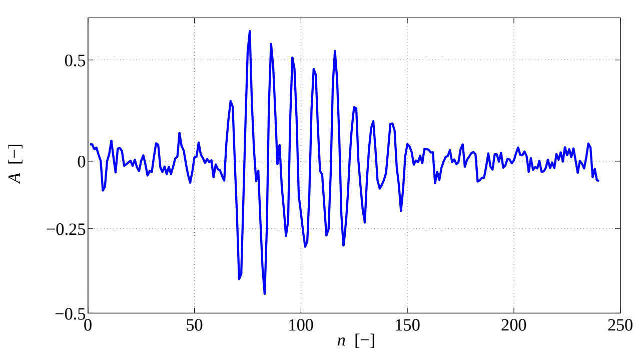

Fig. 2. Acquired EMAT signal on calibration gauge K1

The acquired EMAT signal with EMAT in dual coil configuration was used for the amplitude and frequency analysis. The amplitude analysis is represented by histogram (see fig.3a). The frequency analysis of acquired EMAT signals is represented by power spectral density (see fig. 3b.)

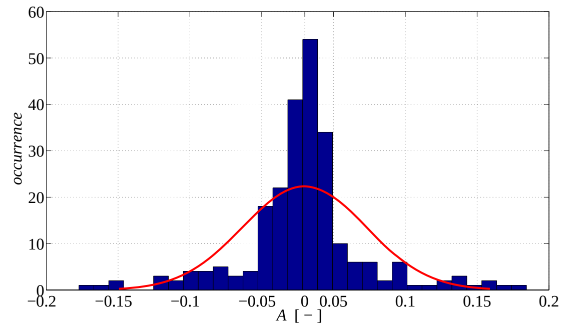

Fig. 3a Amplitude analysis

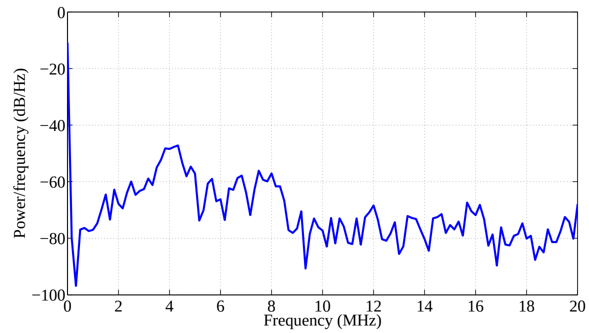

Fig. 3b Frequency analysis

From fig. 3a and fig. 3b can be seen that noise has the amplitude distribution similar to Gaussian distribution. From the power spectral density can be seen that noise can be considered as white noise. In case of noise, two sources of noise have to be considered. The first of noise arises from scattering of ultrasonic signals from grains. Another source of noise is caused by electronic circuitry influence.

3b EMAT signal simulation

For the evaluation of proposed de-noising methods we created the set of simulated EMAT signals. These signals were created based on known central frequency and frequency bandwidth of created electromagnetic acoustic transducer. The example of frequency response of EMAT burst together with simulated signal is in Fig. 4. (left). To the simulated signal we also add the fault echo corresponding to the circle flaw. Noise with Gaussian distribution was added within *SNR* = 1 – 60 dB. The simulated signal with fault echo, back-wall echo and noise with *SNR* = 15 dB is in Fig. 4. (right).

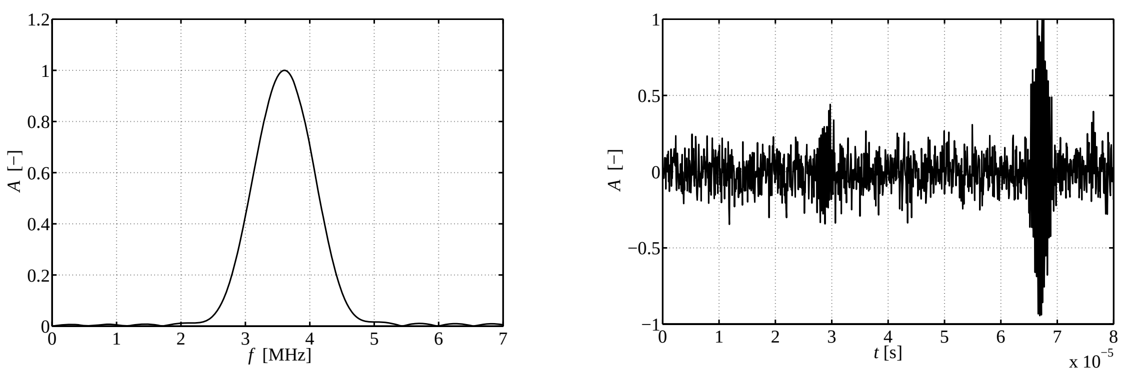

Fig. 4. Frequency response (left) and simulated EMAT signal (right)

These signals were used for the evaluation of blind source separation method. The main task was to efficiently suppress the noise.

3c De-noising of simulated EMAT signals

For the evaluation, the set of 1000 signals each containing two signals (theoretically acquired) were considered as an input to the blind source separation method. The difference of these signals was only the standard deviation of noise level. Both signals have to considered the same material structure and electronic noise. Based on these considerations, the BSS method was used for the de-noising of simulated EMAT signals.

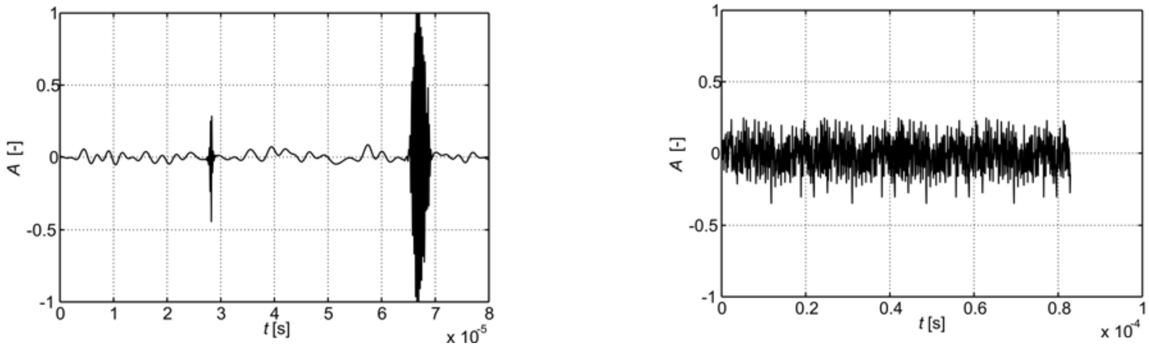

Fig.5. a) Separated signal, b) separated noise

As can be seen in fig.5. the signals were separated. The noise level was succesfully separated from acquired signal and in the case of fault echo detection, it can be detected easily (see fig.5.b).

4 Experimental results

4a Experimental setup

Full EMAT acquisition system was designed by the Starmans electronics Ltd. company using the electromagnetic acoustic transducer with central frequency of 3.6 MHz. The system consists of a pulsar for generating of high frequency peaks, system for measurement of EMAT signals, EMAT preamplifier and system for the precise positioning of EMAT transducers. The transducer was moved along the material and the data were sent to the personal computer via USB interface. The system can be described in Fig. 6.

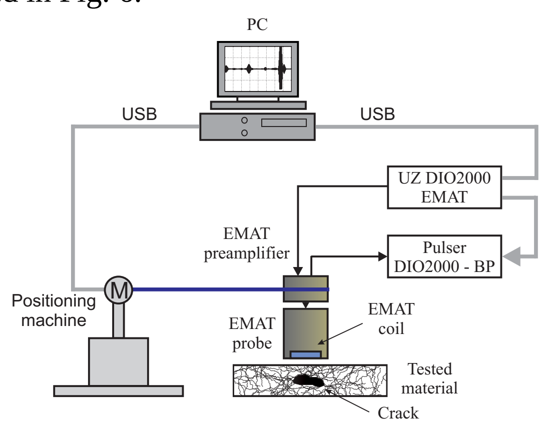

Fig.6. Full EMAT acquisition system

For the measurement of EMAT signals a gauge with different flaws sizes. All flaws are circle shaped and size is within 0.7 – 10 mm.

4b De-noising of acquired EMAT signals

Method used in this paper for the noise suppression is the blind source separation used on EMAT signal and noise separation in configuration as is described in fig. 1. Based on this configuration the EMAT signals were acquired. We obtained two EMAT signals that can be described using the following equations:

$$x_1(t) = a_{1s}s_{1s}(t) + a_{1n}n_{1e}(t)$$
$$x_2(t) = a_{2s}s_{2s}(t) + a_{2n}n_{2e}(t) , \qquad (3)$$

where $s_{1s}(t)$ and $s_{2s}(t)$ is the source signal acquired with dual EMAT transducer and $n_e(t)$ is the electronic noise. As the sources signals in this configuration we can considered all the reflections from the material structure (backscattering noise, fault echo and back-wall echo). If the basic presumptions of equation (3) should be valid the sources $s_{1s}(t) = s_{2s}(t)$ and noise $n_{1e}(t) = n_{2e}(t)$. In this consideration the presumptions are only theoretical.. Clearly mentioned, the ultrasonic waves propagated through the material structure generated by coil no.1 have similar reflections as the ultrasonic waves propagated from coil no.2. It means that both sources are similar and it is clear that $s_{1s}(t) = s_{2s}(t)$. The same situation is with the noise $n_e(t)$.

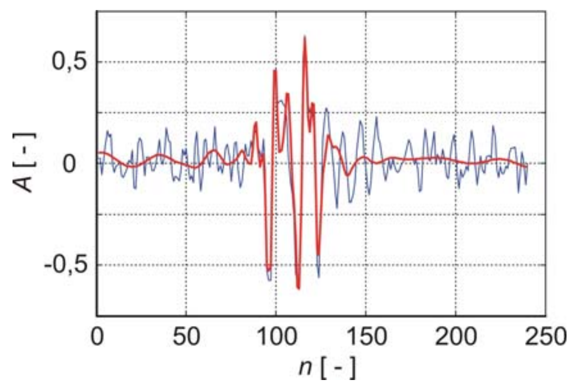

Fig. 7 Application of BSS method for noise suppression

In case there is the same housing for the EMAT transducer, also the coil and cable is similar and only one EMAT system is using for the processing of acquired signals, the blind source separation method can be used.
From the mentioned simple overview, the method blind source separation can be used for de-noisind of EMAT signals. The application of blind source separation using FastICA algorithm can be seen in fig. 7. As can be seen from fig.7, the noise was efficiently suppressed and back-wall echo is without changes. In addition, the method was used for the de-noising of signals measured on calibration gauge with different drilled flaws *D* within 0.3 – 5.2 mm. The acquired signal was measured and consequently de-noising algorithm based BSS method was used. The filtered signals were evaluated using standard deviation *STD* of samples corresponding to noise.

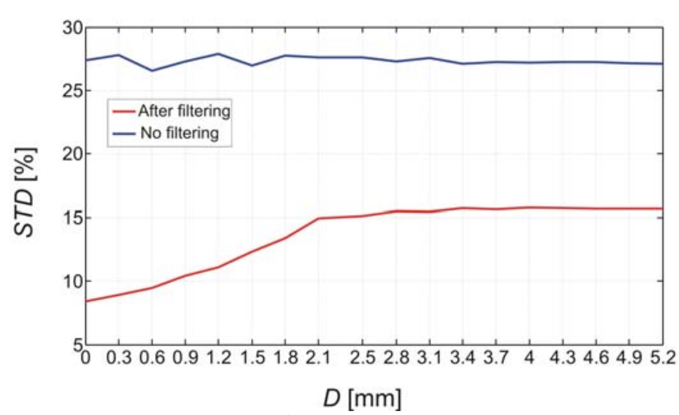

Fig. 8. Evaluation of BSS method on EMAT signals

As can be seen from fig. 8. the standard deviation values are for different flaw sizes lower. It means that noise was succesfully suppressed.

Conclusion

The novel electromagnetic acoustic transducer in dual coil configuration was presented in this paper. This dual EMAT transducer offers better sensitivity in terms of fault echo representation. Using measured signals, the advanced digital signal-processing method based blind source separation was used for efficient noise reduction. The performance of this method have been assessed both through a number of numerical tests on simulated EMAT signals. The methods have shown valid alternative for filtering of EMAT signals with relatively higher noise level. The application of presented blind signal separation method is an initial research only and in the future it will be looked into detail.

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