IMPROVED SIGNAL TO NOISE RATIO OF ELECTRO-ULTRASONIC SPECTROSCOPY

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Abstract:
The paper presents signal to noise consideration of a new NDT method. Tested sample is excited by electrical and ultrasonic signals with different frequencies. On the defect new harmonic signal is created with frequency given by subtraction of exciting frequencies f_E and f_U. High sensitivity of this method follows from the fact that the signal giving information on tested sample quality has frequency different from exciting signals. The signal to noise ratio and high sensitivity for NDT analyses is based on the application of special electrical filters. The theoretical sensitivity of this method and its limitation by parasitic effects is analyzed. Therefore the new variants of circuitry are designed and used for experimental verifying. First of all the equivalent dynamic range and final sensitivity is improved using linear filters to reduce the level of exciting signals in the amplifier input and by noise in exciting electrical signal reducing. The usability of this principle and possibility of minimization of parasitic effects are confirmed by practical experiments.

INTRODUCTION

New principle of non-destructive testing of the conducting solids is presented. This electro-ultrasonic spectroscopy (EUS) method is based on effects created by motion of electric charge carriers in solids subjected to the ultrasonic wave motion. Tested sample is excited by DC or AC electrical signal and ultrasonic vibration. The main advantage of this method is the electrical signal detection on the frequency different from the frequency of exciting electrical signal. This one allows us to increase the NDT method resolution, to increase the sensitivity to small defects and to improve the signal to noise ratio. The creation of new signal with the frequency different from electrical exciting frequency can be relatively easy detected by the frequency spectral analysis [1-4].

BASIC PRINCIPLE OF PROPOSED METHOD

There are two methods of EUS: (i) DC electrical source and ultrasonic wave excitation. In this case the problem with parasitic transfer of the ultrasonic signal appears [3]. (ii) AC electrical signal with frequency f_E and ultrasonic wave with frequency f_U. In this case the classical mixing modulation principle with two harmonic components is applied [4].

EUS WITH DC ELECTRICAL SOURCE

The main idea of this method uses principle of the non-linear wave modulation spectroscopy, where the second ultrasonic signal is replaced by electrical signal and the defect testing consists in selective measuring of the parametric resistance change of the sample. This parametric resistance change is caused by the ultrasonic excitation of cracks in the electrical conducting sample.

A block diagram of the measuring set-up is shown in Fig.1. The generator with frequency f_U generates ultrasonic vibrations. The electrical signal is realized by DC voltage source V_{DC}, which generates the DC current I_{DC} through tested sample and load resistor R_L. The AC component with frequency f_U is created by ultrasonic excitation of the crack in tested sample. It is separated by coupling capacitor C_V. This signal is processed in the amplifiers and band-pass filter.

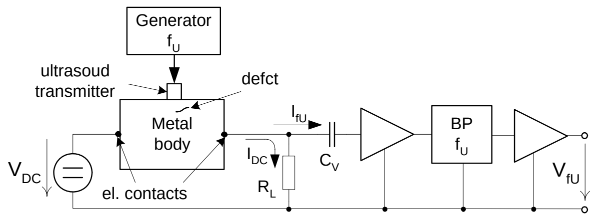

Fig. 1: Basic principle of the parametric EUS

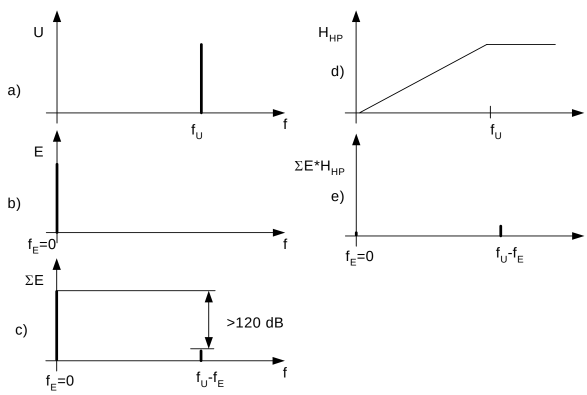

Fig. 2: Spectrums of signals a) ultrasonic signal, b) DC electrical signal, c) resultant current, d) frequency response of HP filter, d) filtered resultant signal

Fig. 2 shows the spectral view to this principle where Fig. 2a is ultrasonic and 2b is DC electrical signal. The spectrum in Fig. 2c describes the resultant circuit current with original DC component and new component with frequency f_U.

It is important that this new signal has very low value. Therefore this one cannot be processed by amplifier because the dynamic range of any amplifier is lower. Therefore the HP filter is used (Fig. 2d) and resultant signal with low dynamic range can be amplified.

Theoretical Sensitivity

It is evident that the changes of electrical resistance caused by the ultrasonic exciting are very small. Therefore it is necessary to survey the basic sensitivity of this method. We must consider that the relative change of resistance corresponds to the ratio of value of AC component and value of DC voltage on resistor R_L. Regarding to the signal processing the basic limiting factor is the background noise of the measuring set-up.

Thevenin's model of the measured signal source has internal resistance R_i which we obtain as parallel combination of resistance R_M of tested sample and load resistance R_L. The R_L value has to be higher than R_M due to the current limiting than the R_M value determines *Ri*. We can consider the value in the range 0.01 – 1 Ω. A thermal noise of this resistance is much lower than noise of any preamplifier. Therefore the preamplifier noise V_n determines the basic sensitivity. We have to consider the equivalent voltage noise, because the equivalent current noise can be omitted for low value of R_i. The noise voltage per root of frequency can be expressed as

$$V_n = V_{ne}\sqrt{B} \quad , \qquad (1)$$

Where the V_{ne} is the noise voltage per root of frequency of the preamplifier and *B* is the equivalent noise pass-band. It is evident that the resultant noise can be essentially limited by reducing of *B* value. If we consider realizable pass-band 1 kHz and voltage spectral density of low noise preamplifier V_{ne}= 1 nV/√Hz, we obtain equivalent noise voltage

$$V_n = 1.10^{-9}\sqrt{1000} = 33nV \, . \qquad (2)$$

If we consider the DC current I_{DC} = 1A then the DC voltage will be in the range 0.01 to 1 V. Therefore the minimum detectable relative value of the resistance change can be expressed as

$$\Delta R / R = 3.10^{-8} / 0.01 = 3.10^{-6} \, . \qquad (3)$$

Regarding to the high difference of noise resistance of source and preamplifier (approx. 100 – 1000), it is possible to increase the sensitivity 10 times – 100 times by use of matching transformer. By this way, we can consider maximum basic sensitivity approximately 120 to 180 dB.

The discussed measuring system has two basic advantageous. They are the simple realization of the low noise DC source of electrical signal and the simple rejecting of this DC signal before amplifying by the HP filter (R_L, C_V).

On the other hand the practical experiments show one very important disadvantage. It is the parasitic transfer of signal from the ultrasonic generator to the preamplifier (it is necessary to consider a level difference more than 120 dB). Using of magnetic and electrical shielding decreases this effect but it not rejects it successfully. Therefore we will describe the measuring set-up with AC electrical source.

PARAMETRIC EUS WITH AC ELECTRICAL SOURCE

As previous discussion shows, the use of DC electrical source brings problems with parasitic transfer of the ultrasonic signal. Therefore classical mixing modulation principle with two harmonic components will be discussed.

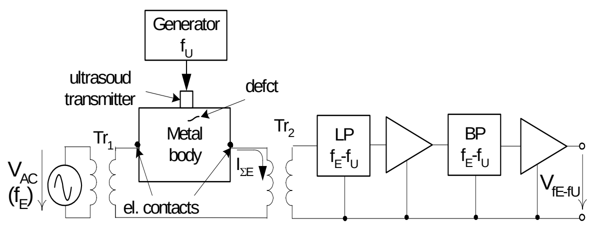

Fig. 3: Parametric electro-ultrasonic spectroscopy with AC electrical source

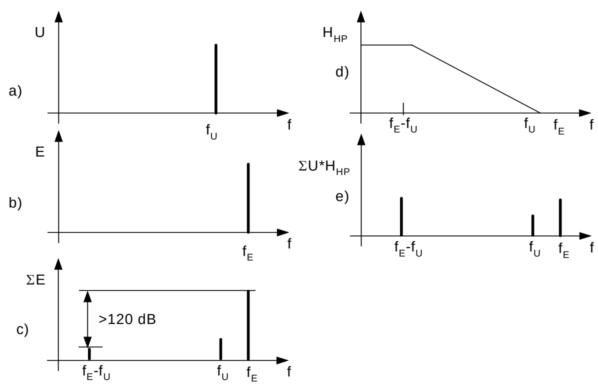

Fig. 4: Spectrums of signals with AC electrical source: a) ultrasonic signal, b) AC electrical signal, c) resultant current, d) frequency response of LP filter, e) filtered resultant signals with low dynamic range

The block diagram of this realization is shown in Fig. 3. It has more modifications in comparison with Fig. 1. First, the AC source is used. This fact enables increasing of the measuring current in sample by transformer Tr_1. By this way we can increase the

current up the 10 A. Second, the impedance matching of the signal processing input by transformer Tr_2. This transformer enables increase of measured voltage without noise rising. Third, the LC ladder LP filter is used for rejection of the exciting electrical signal with frequency f_E. This special filter has high linearity for high dynamic range and high steepness for sufficient rejection of exciting signal.
Fig. 4 shows the spectral view to this principle and it explains some problems of the dynamic range. Fig. 4a and 4b describes ultrasonic and electrical exciting signals.

Minimization of noise of the AC source

The first experiments with AC electrical source show high background noise V_{nS} in the measured pass-band near frequency f_E - f_U. This effect corresponds to the AC electrical signal generation when the signal from the oscillator is amplified by the wide-band power amplifier. Therefore the signal/noise ratio (SNR) is about 100 dB which is not sufficient for high resolution of NDT method. To eliminate this noise source the HP filter is used as is shown in Fig. 5. The HP filter for source signal transmits exciting signal with frequency f_E and attenuates low frequency noise. Corresponding change of measuring system from Fig. 3 is shown in Fig. 6. Spectrum of this filtered exciting signal is shown in Fig. 6d. It is necessary to remark that the HP filer connected to the power amplifier has to be designed for high voltage and current load of capacitors and inductors.

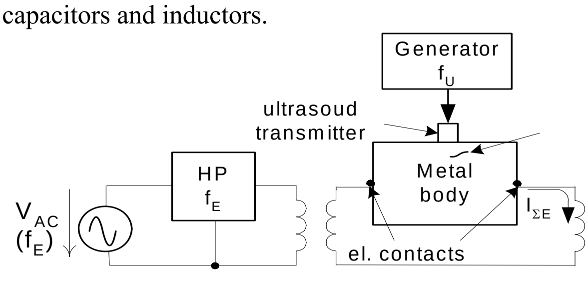

Fig. 5: Electrical exciting circuit of parametric EUS with AC electrical source (comparison with Fig. 3)

Last group of parasitic effects is connected with nonlinear contacts on tested sample. They are additional source of nonlinearity. In the case of mechanical connecting, they are also sensitive to ultrasound exciting similarly as cracks. Minimization of this effect has more possibilities as soldering, mechanical connecting with strongly molted down copper contact etc. A pulse ultrasonic exciting method makes possible the time elimination of this parasitic resultant signal. Effective way of rejecting of this parasitic ultrasonic modulation is able by four-point connection as it is shown in Fig. 7a.
This principle is well known from electrical testing of the low resistive elements as so-called 4-point connection with current and voltage contacts, where the main current flow trough the current contacts whereas the voltage contact are not loaded by current.
It is described by electrical substitution diagram in Fig. 7 b. The exciting source is expressed by source V_E with internal resistance R_L (about 1 Ω). The parasitic signal of contacts expresses the sources V_C. Their internal resistance is approximately the same as internal resistance of measured sample (about 0.001-0.1Ω).

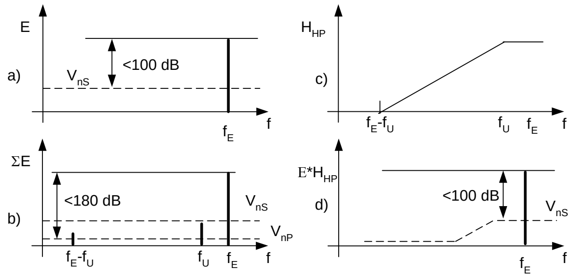

Fig. 6: Spectrums of signals and noise relations of the AC electrical source: a) source signal and noise, b) relations in tested sample, c) frequency response of AC source HP filter, d) source signal and noise after filtration

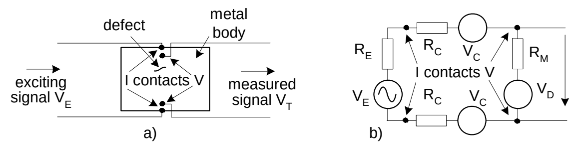

Fig. 7: Testing variant with current and voltage contacts and electrical substitution diagram: a) realization, b) electrical substitution diagram

It is very important to calculate transfer coefficients k_{VD} and k_{VC} of useful signal V_D (caused by defect) and parasitic signal of contacts V_C to measured signal V_T. The transfer coefficient k_{VD} of useful signal V_D can be expressed as voltage divider

$$k_{VD} = \frac{R_C + R_E}{R_C + R_E + R_M} \to 1 \qquad (4)$$

This value is nearly 1 because the value of $R_E >> R_M$. On the other hand, the transfer coefficient k_{VC} of parasitic signal V_C is

$$k_{VC} = \frac{R_M}{R_C + R_E + R_M} << 1. \qquad (5)$$

The rejection of parasitic signal V_C in comparison with useful signal V_D can be expressed as ratio

$$\frac{k_{VD}}{k_{VC}} = \frac{R_C + R_E}{R_M}. \qquad (6)$$

And the practical value of rejection is approximately 100-1000.
Similarly as the parasitic nonlinearity of tested object, it is necessary to discuss a parasitic nonlinearity of

whole electrical exciting circuit because it can also mix the electrical signals and transformed ultrasound signal as electrical signal. Therefore the transformers without ferromagnetic cores and linear load resistor with higher resistance have to be used.

CONCLUSION

On the defect caused non-linearity new harmonic signal is created with frequency given by intermodulation of exciting frequencies f_E and f_U. For the samples with defects higher value of intermodulation voltage is measured. The electro-ultrasonic method has higher resolution comparing to the standard testing method based on the electrical non-linearity measurements. The signal to noise ratio and high sensitivity for NDT analysis is based on the application of special electrical filters. The theoretical sensitivity of this method and its limitation by parasitic effects was analyzed. The new variants of circuitry are designed and used for experimental measuring set-up. The equivalent dynamic range and final sensitivity is improved using linear filters to reduce the level of exciting signals in the amplifier input and by the noise reduction in the exciting electrical signal.

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