MODELING OF ULTRASONIC SIGNALS IN DIAGNOSTIC DEVICES

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Introduction. The transition of hardware to digital data processing has several advantages over analog. Digital information can be stored, transmitted and reproduced at any time. Digitalization of data opens up wide possibilities for their application.

It is necessary to simulate some components of the circuit to determine their full capabilities in the design of diagnostic devices and systems. For these purposes, there are a number of software tools that allow you to virtually reproduce various processes and event development [1, 2]. On the other hand, there is no one completely universal or correct way to solve a separately set task.

The circuit transients during ultrasound diagnostics are quite situational, and not everyone can get real experimental data. Deriving a generalized technique for mathematically reproducing the process of propagation of acoustic waves in a solid medium will simplify the process of modeling receiving nodes and processing the measuring signal.

The active development of wireless data technology is opening up the new way for engineers to design mobile diagnostics. Such devices have a high level of adaptability for a variety of tasks, thereby reducing the requirements for data collection tools, since they generally do not have the task of processing them. In [3-4] the directions of wireless technology application in devices of non-destructive testing are considered.

The prerequisite for writing the article was the need to test digital signal processing algorithms when creating a mobile application for a pre-designed acoustic diagnostic device with wireless data technology [5-6].

Ultrasound signal simulation. In order to create a mathematical model of an ultrasound signal it is necessary to understand the processes and physical phenomena that occur in the wave propagation environment. The purpose of the model construction is to predict the result of the testing, reproduce the various testing situations and determine the optimal correction coefficients for real measurements.

In order for the model to be adequate, the values that will be used in the model completely replicate the real values that were taken from the experiment [6].

The signal modeling is divided into two stages: the reproduction of the excitation signal and the echo pulse signal from the flat-bottom reflector.

The first component of the model - the excitation signals are a damping harmonic oscillations. They occur due to reverberations and exponential oscillation damping on the transducer. The time during which the converter returns to equilibrium state is quite critical when performing the testing, as echo can be lost against its background. Reducing the duration of signal attenuation is achieved by damping the transducer, which increases its quality.

$$y = A \cdot \cos(2\pi f t - \varphi 1) \cdot e^{-\delta t} \quad (1)$$

where $\varphi 1$ – initial phase shift; $\delta -$ attenuation factor [$Pp/$m],

The value of the attenuation factor depends on many factors (acoustic impedance of the material, porosity, graininess, extraneous inclusions, etc.) This parameter is chosen based on the experimental values of the amplitude or pressure at two points (x_1, x_2):

$$\delta_p = \frac{1}{x_2 - x_1} \cdot \ln\left(\frac{P(x_2)}{P(x_1)}\right)\left[\frac{\text{Нп}}{\text{м}}\right] \qquad (2)$$

It is necessary to take into account the fact that the first period of the signal has full amplitude, since the converter receives energy from the power source, and the signal begins to fade only after the completion of the shock pulse formation (Fig. 1).

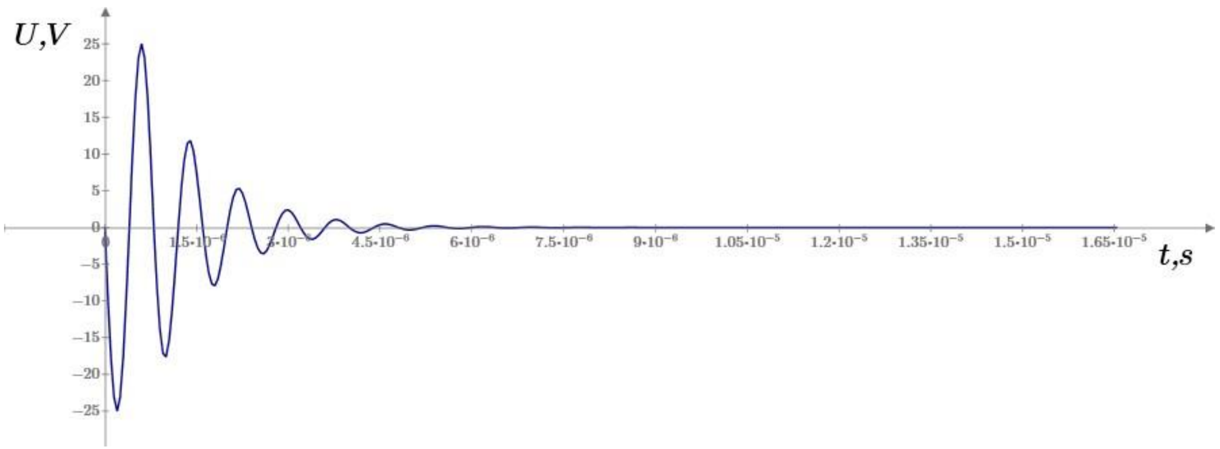

Figure 1. Model of damping harmonic oscillations

The second stage is to simulate the echo pulse. In most cases, the echo pulse is a sinusoidal signal of three periods, the frequency of the signal is equal to the frequency of the excitation pulse, but in phase the signal will be shifted by π / 2. This is due to the fact that at the boundary of two materials, the reflected signal loses half of the period. As well as the excitation pulse, the echo pulse has an attenuation factor due to energy dissipation (Fig. 2).

$$y = A \cdot k \cdot \cos\left(2\pi f t - \varphi 2 - \frac{\pi}{2}\right) \cdot e^{-(t-s)^2} \cdot e^{-\delta t} \qquad (3)$$

where: *S* - value of the displacement of the echo pulse relative to the beginning of the reference; *k* - transformation factor.

The displacement of the echo pulse simulates the depth of the flat-bottomed reflector. Transformation factor characterizes the fraction of the excitation pulse energy that has been converted into an acoustic wave. The value of the bottom factor depends on many factors (the density of the transducer to the surface, the quality of adhesion, the roughness of the surface of the object of control, etc.) so it should be set based on the results of the experiment.

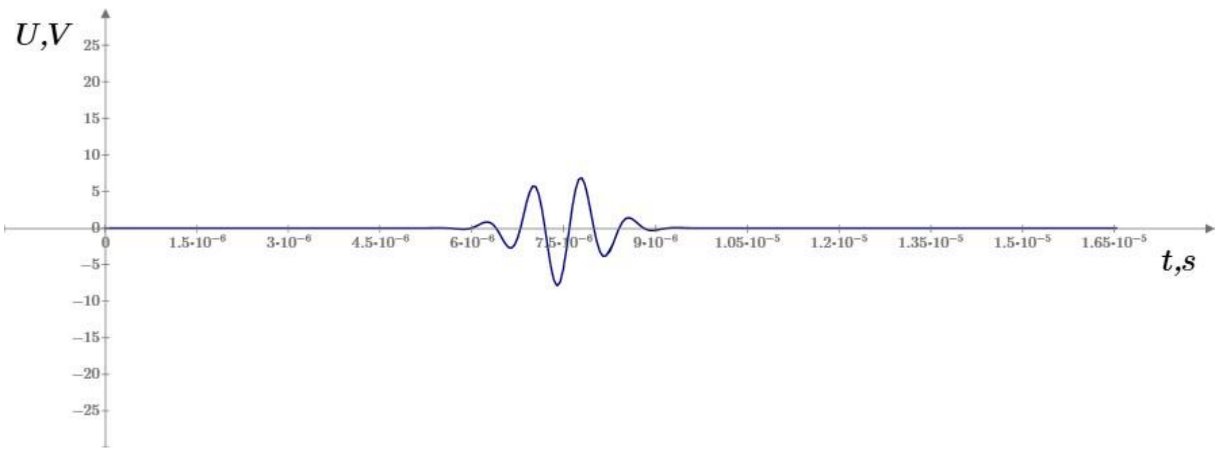

Figure 2. Model of the echo pulse

As a result of the addition of both components, we obtain an acoustic signal model in the form of an A-scan (Fig. 3). The figure shows how the coefficients of the individual components are distributed. For visual observation, the echo pulse appears three times in the image, demonstrating three different depths of flat-bottom reflector.

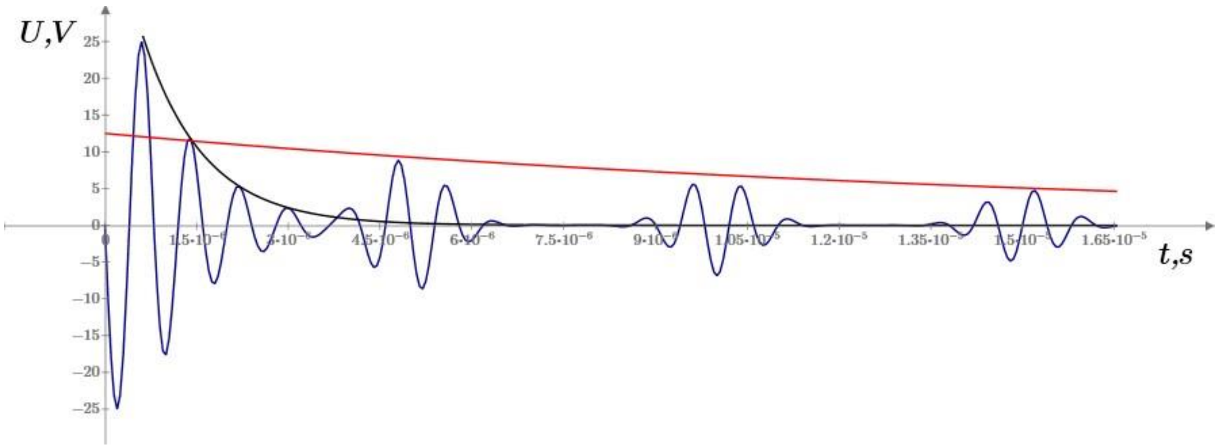

Figure 3. Signal model

The last component is the noise parameters that can be added to the basic equation to simulate the impact of various digital filtering algorithms.

Application example. Figure 4 reproduces the results obtained by scanning a 7.5 mm thick steel piezoelectric sensor with a resonant frequency of 1.25 MHz. The point coordinates for plotting were taken with the use of a 12-bit ADC with a sampling rate of 20 MHz. Noise with a maximum amplitude of 0.25 V is added to the total signal.

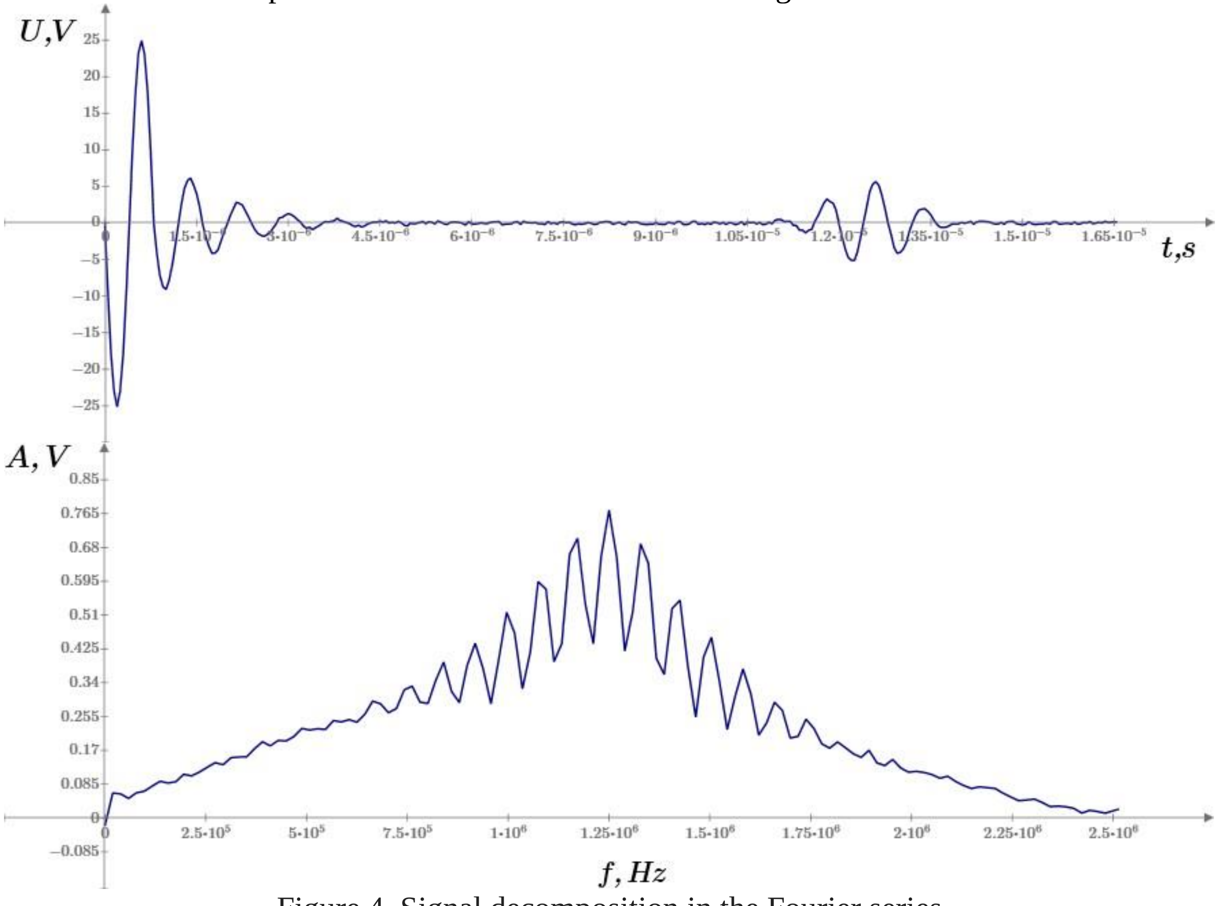

Figure 4. Signal decomposition in the Fourier series

For the proposed model, a fast Fourier transform algorithm was applied to determine the width of the signal spectrum. The graph below clearly shows how distorted the spectral picture is with respect to the main frequency of the signal.

Conclusions. The mathematical model described can be used to reproduce the results of acoustic diagnostics measurements. The simulation results will help to identify the optimal scan modes, data processing algorithms and set correction coefficients in real systems.

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