Beam Control System for Ultrasound Scanning Device

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Abstract. The problems of FPGA based beam control system for ultrasound scanning system is considered. As a result of enhancement of algorithm of linear phased array focusing method for increasing efficiency of phased array elements is proposed. The application of the method for the real ultrasound scanning system is also considered.

1. Introduction
Ultrasound scanning systems (USS) is one of the most effective modern nondestructive testing tools which allow to carry out reliable detection and accurate localization of the defects. Such systems can be configured to obtain narrow linear or focused beam which can be moved in some region to scan the object under test.

Currently the most effective USS are based on ultrasound phased arrays (PA) which usually consist of piezoelectric crystal elements placed in the polymer insulating matrix [1,2]. The main feature of phased array ultrasonic technology is the computer-controlled excitation of individual elements in multielement probe. The excitation of the elements allows generating an ultrasound focused beam the parameters of which such as angle, focal distance, and focal spot size can be modified in wide ranges. The beam parameters are controlled by the delays (phases) and amplitudes of each element in PA.

The delays distribution over the PA elements corresponding to the required beam parameters is specified by a certain focal law. The focal law for probes which is in direct contact with the test piece and intended to generate longitudinal waves has a parabolic shape [3]. Then the large scanning angle is used some elements of PA becomes not active that leads to decreasing efficiency of USS. To eliminate this problem the original algorithm has been proposed. This algorithm provides correction of focal law to activate all array elements and increase efficiency of USS. To implement this algorithm the special FPGA controlled USS has been developed.

2. Improved algorithm of linear phased array focusing
Convenient algorithm for ultrasound beam focusing uses the focal law of parabolic shape which is rotated in polar system of coordinates [4] (Figure 1). The general expression for this shape has the following form:

\[ Ax^2 + By^2 + Cxy + Dx + Ey + F = 0 , \]  

\[ y = v \tau , \]
\[ A = \sin^2 \theta / 2f, \]  
where \( \tau \) is time delay, \( \nu \) is the sound velocity in the medium, \( f \) is the focal length, \( N \) is the number of elements, \( p \) is the size of the single element, \( \theta \) is an angle in the polar coordinate system.

For large values of the scanning angle the boundary elements of array are not involved since they are leaving the parabola field. Thus in Figure 1 the right element is not involved due to turning. For the most efficient use of PA the displacement of parabola in direction of focal axis is proposed. For this purpose the focal law is changed. The focal distance is also should be adjusted so that the focal point (Figure 2) remains unchanged. It allows to activate all elements of PA. To keep the focal point in the predetermined position the condition of constant radius vector should be fulfill (Figure 2):

\[ |r| = \text{const}. \]  

The adjusted focal length could be determined from the equation:

\[ f_i^2 - \left| f_i - \frac{p^2(N-1)^2 \cos(\theta)^2}{8} - \sin(\theta) \frac{p(N-1)}{2} f_i \right| = 0. \]
Figure 2. Correction of one-dimensional phased array focal law: $\tau$ - delay, $N$ - elements number, $\theta$ - rotation angle, $F$ - focus point, $r$ - radius vector, 1 - non-deployed parabola, 2 - parabola rotated by the angle $\theta$, 3 - adjusted deployed parabola.

In equation (1) the coefficient $F$ (8) is changed after this correction:

$$F = \frac{p^2 (N-1)^2}{8 f + \sin(\theta) p(N-1)} / 2.$$  \hfill (11)

This corrected focal law allows to increase efficiency of the PA.

3. FPGA based ultrasound scanning system

One of the most important, expensive and technically complex element of ultrasound scanning system is digital control unit. The main purposes of this system are beam forming and primary experimental data processing. Though the digital control system was developed to control ultrasound scanning system described in [5] it can be adapted to a wide range of the similar type systems.

The ultrasound scanning system [5] comprises the transmitting and receiving parts. The transmitting part consists of a transmit beamformer (LM96570 [6] of National Semiconductors Corporation) generating exciting pulses with individually controlled delays and transmit pulser (LM96550 [7] of National Semiconductors Corporation) forming the amplitudes of the pulses and the ultrasound transducer converting the electrical pulses into the ultrasound waves with the required parameters. The receiving part consists of the following main parts: the transmit/receive switches (TX810 [8] of Texas Instruments) preventing passing the large exciting pulses to the input of high sensitivity elements, the time variable gain amplifier, low pass filter and analog-to-digital converter (ADC) realizing using a single IC AFE5851 [9] of Texas Instruments. This ultrasound scanning system is controlled by the special dedicated digital system based on FPGA IC.

The digital control system should meet the following requirements:
1. Beam forming control for 32 channel ultrasound transmitter, specifically it should control delays and amplitudes of exciting pulses for each transmitting element;
2. Ultrasound waves transmitting triggering;
3. High speed ADC configuring and triggering;
4. Receiving sampled signal from ADC;
5. Preprocessing of the obtained experimental data.

Analysis of the requirements shows that the strongest limitations is caused by receiving data from 32 channels of high speed ADC. Indeed if the ADC with sampling frequency of 32MHz (for each
channel) and resolution of 12 bit then taking into account that number of channel is equal to 32, the data rate of 12GS/s is required. Implementation of so high data rate of receiving signals with the requirements of real time referencing is extremely difficult operation. Currently the most efficient way to implement this operation is usage of Field Programming Gate Array (FPGA) based devices since they have well-developed efficient parallel architecture. It has been used Virtex-5 FPGA [10] of Xilinix Corporation. To implement high rate data receiving from the multichannel ADC the LVDS interface has been used.

Besides FPGA the digital control system also comprises: clock oscillator, power supply, ROM for FPGA configuration file storing and RAM for pulse forming and data processing assistance, interfaces for connection with the abovementioned components of the transmitting and receiving parts, and with computers and others FPGAs.

The block diagram of the digital control system is presented in Figure 3.

![Block diagram of the digital control system](image)

**Figure 3.** Block diagram of the digital control system.

During operation FPGA generates a control signals for transmitting and receiving parts. FPGA defines focal law and the ultrasound beam parameters. Specifically FPGA implements the proposed above improved algorithm of linear phased array focusing which allows to increase efficiency of the ultrasound phased array. After implementing of the proposed algorithm FPGA configures the beamformer and the pulser to obtain the required ultrasound waves. Then FPGA generates signal to start measurement and receives the signals from ADC.

The developed system is adapted to operate under control of a computer. The special software provides the following possibilities: 1) Control of the ultrasound scanning system by operator; 2) Graphical representation of the actual hardware configuration and results of measurements; 3) Transmitting control information to FPGA; 4) Receiving measurement results (experimental data); 5) Ultrasound scanning device technical state monitoring.

4. Conclusions
The FPGA based beam control system for ultrasound scanning system is developed. The work is performed according to the Russian Government Program of Competitive Growth of Kazan Federal University. It was shown that the correct selection of the pulses delays controlling beam parameters can increase efficiency of the ultrasound transceiver. The algorithm of linear phased array focusing and method of increasing efficiency of phased array elements are proposed and implementation of the
proposed method for real ultrasound scanning system is considered. It has been shown that this method can be used for a wide range of ultrasound nondestructive testing equipment based on an ultrasound phased arrays.

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