

Simulation of 28 Element Ultrasound Transducer for Non-Destructive Evaluation (NDE) Applications



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Abstract: Quantitative ultrasound based Non-Destructive Evaluation (NDE) is one of the leading test procedures used in testing of finished products in manufacturing industry. It can detect surface as well as subsurface flaws accurately. It is also employed in medical diagnostic for various purposes. The main objective of this paper is to simulate 28 element ultrasound transducer pair for through transmission testing procedure. The simulation is done using k-Wave toolbox (open source toolbox) and MATLAB. The simulation results show that the received signal strength and resolution is far more improved over single and dual element transducer probes available in the market. The simulation of wave propagation through three layered aluminum material is also shown in the results. Based on results, it can be concluded that 28 element transducer pair are the optimum solution for NDE evaluation challenges with reference to cost, size, and design complexity.

Keywords: Non-Destructive Evaluation (NDE), Quantitative Ultrasound Wave, k-Wave, Material Density, Wave Propagation, Simulation Environment, Time of Flight (TOF).

I. INTRODUCTION

Quantitative Ultrasound (QUS) based Non-Destructive Evaluation (NDE) technique is popular and useful in testing manufactured products in industry. QUS is an ultrasound wave with a frequency more than 20 KHz. Ultrasound waves with low frequency range can propagate through different materials based on their physical properties. material under acts as a waveguide and allows waves to propagate through it. The propagation of ultrasound waves through the material causes scattering and attenuation of the waves proportional. Many parameters can be estimated based on attenuation and backscatter of the transmitted ultrasound wave. The use of ultrasound-based technique is huge, and it has potential to replace ionized radiation-based methods like X- Ray based testing. The cost involved in the establishment of infrastructure and size of X-ray based test instruments is very high as compared to ultrasound-based test instruments. In addition to this, ultrasound-based test instruments are portable and less complex in design. The testing is performed with the help of two different techniques namely: Pulse-Echo and Through Transmission. However, Pulse-Echo method is more popular as it requires less space and hardware.

The Through Transmission method requires access of both sides of material which is not possible in all situations. The high frequency ultrasound wave in the range of 20 KHz to 200 KHz is used in NDE testing procedure.[1]

The NDE process involves transmission of ultrasound signal into the material under test. The transmitted wave reflects from surface and various other layers of the material and the suitable conclusion can be drawn based on signal processing algorithms. The ultrasound transducer plays vital role in this process. Many surface and subsurface flaws can be detected very easily with ultrasound probe of required dimensions and accuracy. Initially single element ultrasound transducer was used in the testing process but now due to dual element or multi-element transducer is also used in many NDE machines. There are many ultrasound-based NDE machines available in the market. However, it is observed that most of the machines are using maximum dual element transducer for testing purpose. But it is also observed that by increasing the number of elements and related parameters the measurements can be made more accurate and precise. [2]

The multi-element transducers are often used in biomedical imaging applications with high frequency ultrasound waves for diagnosis and imagination of various body tissues. These transducers can provide real time images of heart, womb, gall bladder etc. and help to diagnose the disease in human body. The similar results can be obtained in NDE testing of manufactured products like metal blocks or metal pipes etc. The similar phase array-based transducers are used in inspection products from nuclear industry or from the defense industry [3]. The ultrasound parameters like speed of sound (SOS) and received signal strength are used to compute the necessary information from the echo signal received by the transducer. The subtle flaws can be located by using phase angle of the echo signal. The ultrasound probe consist of transducer and related assembly is communicating the echo signal to the processing mechanism for display and communication purpose. Among all these elements the role of transducer is very important. The size, shape, and number of elements in the transducer can improve the quality of signal and will in turn improve the accuracy of NDE equipment. The standard beamforming techniques can be used to create the B-mode ultrasound scan image on the instrument display. The A-scan and B- scan are correlated with each other and often B-mode image can be created by advance processing algorithms and multi-pass adaptive techniques. Due to many number of reasons, the design of ultrasound transducer is very important.

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Despite continual efforts from the researchers in the field of NDE, there is a huge scope to work in transducer design. This paper shows simulation of 28 element ultrasound array transducer for NDE application. The ultrasound transducer design is implemented and simulated in the MATLAB with the help of k-wave toolbox.

The k-Wave is an open source toolbox designed to simulate acoustic wave propagation, photoacoustic image reconstruction and transducer design and simulation etc. The toolbox uses k-space pseudospectral method of simulation of ultrasound waves. [4] k-Wave is fast and easy to implement option for transducer design simulation as compared to other state of art simulation platform.

This paper is organized as follows. The section II describes proposed methodology, simulation environment and parameter selection for transducer simulation. The section III described experimental results and discussion and finally conclusion is drawn in section IV based on results presented in section III.

II. PROPOSED METHODOLOGY

The main objective of this work is to simulate 28 element ultrasound transducer pair using k-Wave. A pair of ultrasound transducers is designed for through transmission methodology of NDE. The designed transducers will be excited with sample input signal of frequency 200 KHz. The sample 3-layer aluminum material is constructed in k-Wave environment. The wave propagation through the material is tested for various material density values. The following figure shows simulation strategy in k-Wave.

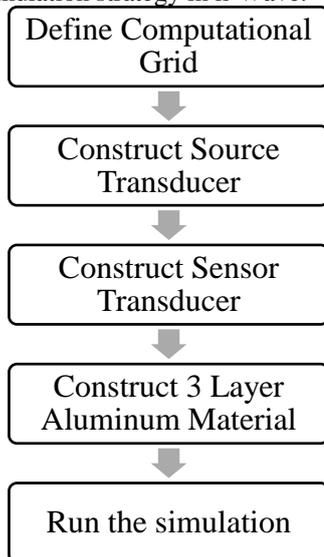


Fig 1. Simulation Strategy in k-wave

A. Defining Computational Grid

The k-pseudo spectral simulation method requires reference computational grid for simulation. This is analogous to a structured mesh containing identical rectangular elements. The grid size used for proposed simulation is 110 X 110 [11 mm X 11 mm]. The following figure shows simulation grid in k-Wave.

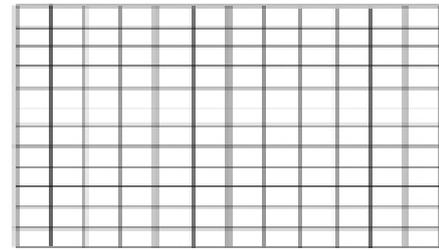


Fig 2. Computational Grid

B. Constructing Source and Sensor Transducer

The source and sensor transducer are identical in design. It is rectangular 28 element array transducer with piezoelectric material. The transducer construction parameters are mentioned in following table. The k-Wave supports both 2D and 3D design and simulation modes. The source and sensor transducer pair are designed in 3D for simulation. The figure 3 and 4 shows source and sensor transducer.

Table 1 SPEED OF QUS THROUGH DIFFERENT MEDIUM

Sr. No	Parameters	Value
1	No of Elements	28
2	Element Length	30 Grid
3	Element Width	1 Grid
4	Element Spacing	0.1 Grid
5	Transducer Radius	Inf
6	Active Elements	All
7	Focus Distance	0.5 mm
8	Steering Angle	Nil
9	Transmit Apodization	Rectangular
10	Receive Apodization	Rectangular

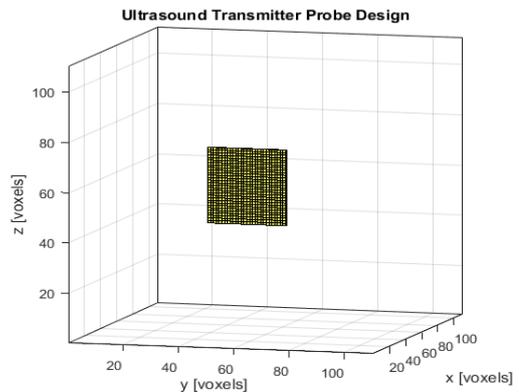


Fig 3. Source Transducer

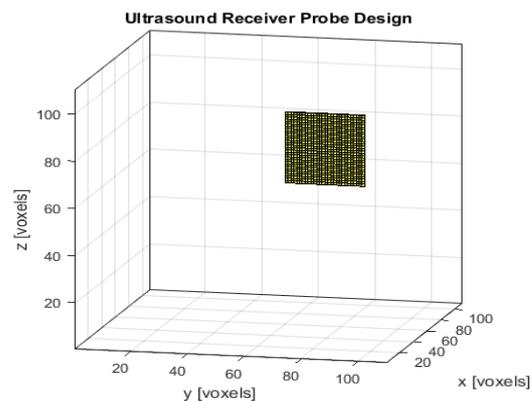


Fig 4. Sensor Transducer

C. Constructing 3 Layer Aluminum Material

The 3-layer simulation medium is constructed using the k-Wave medium property setup for simulation. The various parameters of aluminum layers are set as mentioned in table II. The ultrasound signal is passed through the material and recorded at the sensor transducer.

Table 2 Parameters of Aluminum Material for Simulation [5]

Sr. No	Medium Parameters	Value
1	Layer 1 Density	2700 Kg/Cube Meter
2	Layer 1 Width	30 Grids
3	Layer 1 Speed	6420 M/ Sec
4	Layer 2 Density	1800 Kg/Cube Meter
5	Layer 2 Width	30 Grids
6	Layer 2 Speed	3880 M/ Sec
7	Layer 3 Density	2300 Kg/Cube Meter
8	Layer 3 Width	30 Grids
9	Layer 3 Speed	5120 M/ Sec

D. Running the Simulation

The k-Wave supports 2D and 3D simulation of ultrasound wave propagation. The 2D and 3D simulation gives similar results except 2D or 3D output signal. The 2D simulation is preferred as 3D simulation requires huge time and high-performance computing hardware. The simulation can be further reduced by reducing number grids and transducer size of proposed system. The GPU based systems can be used to perform 3D simulation.

III. RESULTS AND DISCUSSION

The ultrasound transducer design and simulation of wave propagation is performed for 110 X 110 size grid. The k-Wave version 1.3 is used for the simulation. The inbuilt function kspaceFirstOrder2D is used for 2D simulation. The parameters like received signal amplitude and time of flight (TOF) can be used to find the suitable conclusion. The following figure shows the 3-layer medium used for simulation.

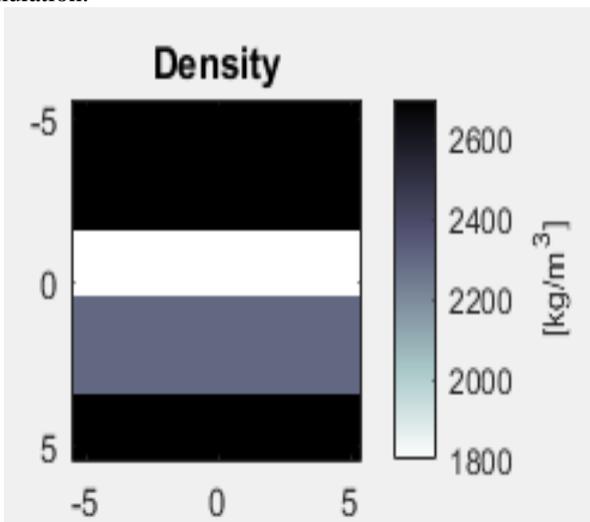


Fig 5. 3-Layered Aluminum Medium

It is observed that the signal propagating through the medium attenuates as it penetrates the medium. The propagating signal in the medium is affected by the medium properties. There are 3 layers with different medium density. The propagating signal reflects at every boundary of every layer. This weakens the signal further and caused very less signal at receiving transducer. The following figure shows the propagating ultrasound field in the medium.

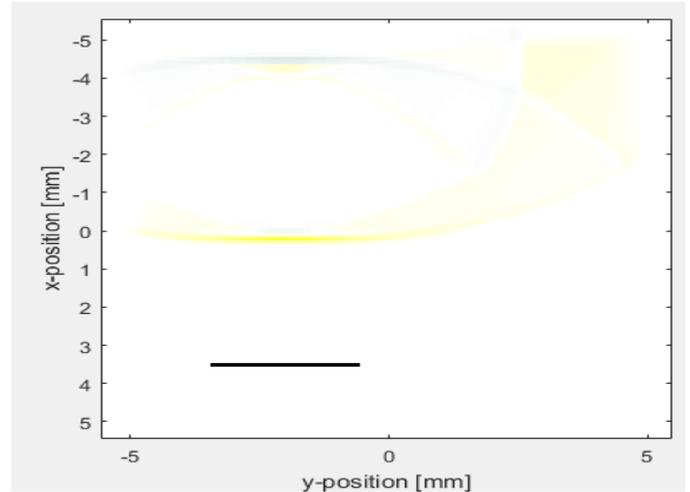


Fig 6. Propagating Ultrasound Signal through Medium

The propagating signal is affected at every layer boundary and one component reflects toward source transducer and another component moves forward in the medium. This component reaches to the receiving transducer and creates impact on transducer. It is observed that the recorded signal at receiving end is affected by all layers and its effect is visible in the signal. There are three different components visible in the signal for every layer crossing. Following figure shows the received signal at sensor transducer.

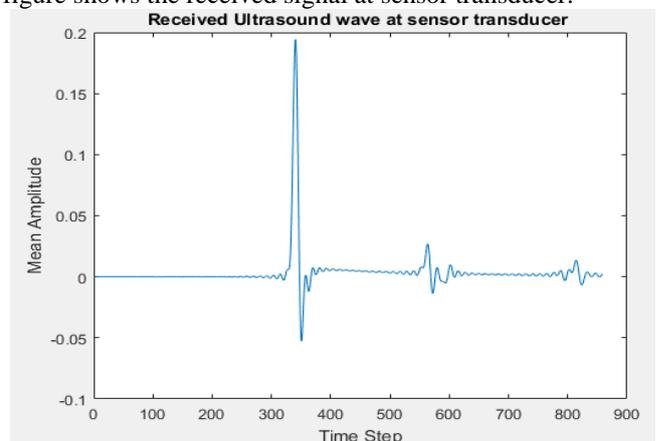


Fig 7. Received Signal

The parameters like received signal strength and time of flight can be computed by using the signal shown above. It is also observed that change increasing the number of elements in sensor and source transducer increases strength of output signal also gives improved resolution. However, increasing the number of elements in the transducer increase cost, size, and design complexity hence number of transducer elements is tradeoff between these parameters. The following table indicates change in received signal strength with respect to change in number of elements in transducer pair.

Table 3 Received Signal Strength for Number of Elements

Sr. No	Number of Elements	Received Signal Strength (mV)
1	20	180
2	28	200
3	50	230
4	75	250
5	100	270



IV. CONCLUSION

There is significant amount of research is going on in the field of ultrasound transducer design, but it is observed that there is still scope to work on transducer design parameters. It is observed that 28 element transducer gives considerable output signal for further processing. By using appropriate amplifier in further stages required information can be extracted. The transducer output can be improved by increased by increasing the number of elements, but it leads to additional cost and size. Hence 28 element transducer pair can be considered as ideal transducer for non-destructive evaluation of metallic products. The accuracy of information can be improved further by changing the shape of transducer from rectangular to other shape. The transmit and receive apodization can also help in increasing the accuracy based on material under the test. For flaw detection in material the steering angle can be changed from zero to required value.

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