OPPOSITE PHASED TRANSDUCER — NOVEL TYPE OF TRANSDUCER

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ABSTRACT. Defect sizing is an important task giving input to fracture mechanics evaluation. The exact evaluation of sound field is the key factor to analyse precisely defects in materials. Sizing accuracy is affected by the size of the sound field. There are several methods available for sizing: SAFT, Acoustic Holography, Tip diffraction, Amplitude drop. In SAFT and acoustic holography applications the sound field is calculated according to the back propagation of sound waves from an object (defect, flaw). The echoes are calculated according to their origin. In tip diffraction technique the external sides of defect are determined based on direct echoes coming from the crack tips. Amplitude drop technique is affected by the sound field size to defect size ratio. Opposite phased transducer is based on sound field determination in design phase. The sound field is calculated using an ultrasonic modelling software and the sound field is very narrow also for a long sound path distance. This feature is used when sizing by using opposite phased transducer.

INTRODUCTION

One of the main targets of using focusing in ultrasonic testing is to improve the accuracy of determination of co-ordinates, size and shape of different defects in the testing objects. As a rule, the accuracy improvement is associated with the use of ultrasonic transducers having optimal acoustic characteristics.

Focusing radiators have been most extensively explored by now, and are widely used for the establishment of acoustic fields with predetermined geometry, for example, for acoustic energy concentration in the required direction. In a number of practical applications, multi-element transducers based on the regulation of amplitudes and phases of exciting signals in certain elements are used. Such approach allows to test main characteristics of the directivity (polar) pattern. However, these acoustic systems are complex, expensive, and require the availability of non-standard additional devices.

MODELLING OF OPPOSITE PHASED TRANSDUCER

The Basic Idea

The analysis of a wide range of ultrasonic radiators has resulted in the study of the acoustic field with the “reverse focusing”, that can be established by means of changing to the opposite of the phase value belonging to one of the exciting signals from two symmetrically arranged ultrasonic sources. The acoustic axis of the considered opposite
phased radiator has a narrow “zero region” – a region, where acoustic pressure is in the zero vicinity (see Figure 1). Thus, whereas there is a narrow axial beam of relatively high amplitude in the focusing systems, in the opposite phased radiator there is a narrow axial gap of the acoustic pressure amplitude. These characteristics encouraged an application of the opposite phased radiator in order to improve the accuracy of determination of coordinates, and size and shape of different defects.

**Computer Simulation of Acoustic Fields of the Opposite Phased Radiator**

For theoretic reasoning of the opposite phased radiator application, acoustic fields calculations with the help of Modification of the Numerical Finite Difference Method (MFDM) developed specifically for ultrasonic applications [1] were made. An unquestionable flexibility of most part of numerical methods – *their capability to interpret whole classes of wave tasks in a uniform manner* – also served as a basis for the MFDM usage.

For simulation of acoustic fields of a normal (direct beam) opposite phased radiator it is enough to use a two-dimensional (2D) scalar wave model of ultrasonic propagation:

\[
\nabla^2 p - \frac{1}{c^2} \frac{\partial^2 p}{\partial t^2} = \Phi
\]

where \( p \) - pressure, \( \Phi \) - external action, \( c \) - ultrasonic velocity, and \( t \) - time. As initial data, a rectified opposite phased distribution of an amplitude of ultrasonic oscillations under the radiator plates that takes place in real transducers was used, and a pulse radiation pattern was taken into account.

This model and an MFDM numerical algorithm were successfully implemented in the CAD “IMPULSE” [2], with the help of which a study of properties of acoustic fields of a normal opposite phased radiator was conducted.

Figure 2 shows the radiation field (the field of maximal modular values of the sonic pressure of the finite-difference grid during whole simulation time) simulation results for two cases:
- two symmetrical radiator plates are located immediately adjacent to each other in one plane (Case A);
- two symmetrical radiator plates are located at an angle of 7 degrees to each other (Case B)
It is seen from the figures that in both cases we have a comparatively narrow zero region. In the second case, the maximums of the sonic pressure amplitude of each opposite phased half of the radiation field are subtended towards the radiator’s axis. If we place a receiving plate between two radiator plates, in reflection from the plane, that is perpendicular to the radiator’s geometric axis, an electric signal on the receiving plate $A_{rec}$ will be close to zero as a result of cancellation effect of the received opposite phased pulses. Its $A_{rec}$ value will become different from zero, when symmetry of the radiation field, or symmetry of acoustic properties, or geometry of the medium of ultrasonic waves propagation with respect to the radiator’s axis is broken.

This property of an opposite phased radiation of ultrasonic waves was used as the basis for the application of an opposite phased transducer and an appropriate method of nondestructive testing for the improvement of accuracy of co-ordinates determination and defect size assessment. In case of scanning with an opposite phased transducer along the object’s surface, in the event of the availability of plane defects on it, the following wave processes are observed. When the transducer is moved along the surface of the testing object 4 (see Fig. 3), one of the radiator plates happens to be the first plate that is close to the defect (Position I): for example, Radiator 1 and the ultrasonic pulse, that is radiated by it, is reflected from Defect 5, and a pulse from Radiator 2 goes inside the object. In this case an amplitude of the received signal is growing as a result of the increase of the defect area from which an ultrasonic pulse is reflected. An increase continues until the second ultrasonic pulse starts reflecting from the defect. This transition corresponds to the transducer position, when the defect edge is located in the centre of the zero region of the radiation field (Position II).

Then after reflecting from Defect 5 the second ultrasonic pulse gets onto Receiver 3 simultaneously with the first pulse. Since these pulses are radiated in an opposite phase, they start attenuating each other, while they are being received simultaneously. As the transducer is moving over the defect, an impact of the second reflected pulse is increasing. As a result, the total amplitude $A_{rec}$, received by the Receiver 3 is reduced during transition from Position II to Position III. Thus, a maximum of the received signal $A_{rec}$ is achieved at the moment when the defect edge is on the transducer’s acoustic axis, that is ultrasonic pulses of one of the radiators are reflected from the defect, and pulses from the second radiator are going inside the testing object. In case of moving away from the defect similar processes are observed, but in reverse order. As a result, the defect beginning and end correspond to the position of the opposite phased transducer, when a maximal amplitude of the received signal is registered.
FIGURE 3. An illustration of wave processes taking place during scanning with an opposite phased transducer (1), radiators (2), receiver (3), testing object (4), defect (5).

It is important to note that the closer the radiators are to each other, the steeper are the fronts in the vicinity of the zero region of the radiation field. If the radiators are located at the distance from the transducer’s acoustic axis, that is comparable with their dimensions, the required front steepness can be achieved by placing the radiators at a small angle to the transducer’s acoustic axis (see Figure 2, Case B). All this is more likely to result in the recording of a maximal value of $A_{rec}$, and accordingly will allow to determine the coordinates of the defect edges more accurately.

THE EQUIPMENT USED FOR EXPERIMENTAL WORK

SAFT-equipment is based on a CPS-software which permits the acquisition, analysis and reporting of ultrasonic inspection data, figure 4a. Ultrasonic data can be acquired by using semiautomatic or automatic testing equipment.

The equipment uses a 2d-saft algorithm or pseudo 3d-saft view, which is actually a combination of pictures of 2d-saft reconstruction, not a genuine 3d-saft reconstruction. The software includes also saft-module for curved surface.

The dynamic range of the equipment is 100dB, it is a 1-channel system, the usable frequency range is from 0.5 MHz to 20 MHz. The maximum sampling frequency is 160 MHz. The range of measurement is about 2.5 m for longitudinal waves in ferritic steel.

The equipment contains a PCUS11-ultrasonic card which controls the data acquisition. Also an external ultrasonic equipment can be used with this equipment. The system is easily adapted to different manipulators. The system has been used together with a linear wire-based co-ordinate equipment (semi-automated inspection), with different types of pipe scanners and also with a scanning device used for the inspection of the outer surface of reactor pressure vessel.
The SUMIAD-system can provide 1/4/8/16 ultrasonic channels options, figure 4b. The ultrasonic pulser and receivers are based on a modular multi-channel ultrasonic flaw detector (pulser and receivers independent), which is programmed and calibrated individually and in different ways depending on the particular inspection procedure. The ultrasonic part is fully controlled from the DAS. It can be operated locally or remote controlled (up to 150 meters). The main characteristics are:

- The maximum PRF (pulse repetition frequency) is 10 KHz.
- The ultrasonic part provides logarithmic rectifier (with dynamic range higher than 80 dB) and linear amplifier
- The programmable parameters of ultrasonic instrument are:
  * Pulse voltage
  * Damping
  * Pulse width
  * Pre-amplifier gain/attenuation
  * Pre-amplification mode (pitch/catch, pulse/echo)
  * Main logarithmic amplification. Switched gain/attenuation
  * Fine logarithmic control. Gain/attenuation
  * RF filters central frequency/width
  * Fine tuning of filters central frequency
  * Rectification (linear/logarithmic)
  * Post-rectification ('video') filtering (full linear option)

MEASUREMENTS

Here are shown some applications where opposite phased transducer, figure 5, has been used to measure some simple reflectors. The main goal of these measurements was to prove that the opposite phased transducer behaves as modelled and shown in Figures 1 - 3. Three notches of depths 2 mm, 4 mm and 6 mm are shown in Figure 6. In the figure the minimum value of the amplitude is seen in the middle of the indication. This is showing the real position of the defect. This means that in case of crack this can be localised very accurately compared e.g. to normal 0° L probe. It can be used also for defect sizing but the frequency must be suitable for the defect size in concern.

The opposite phased transducer has also its limitations. In case of an area containing several cracks, the measured sound field can be used to define the borders of the cracked area as can be seen in Figures 7 and 8. In Figure 7 is shown the raw data which is giving as much information as SAFT-reconstructed image in Figure 8. This indicates as shown theoretically that the sound field is narrow and very little can be achieved in the reconstruction for sizing purposes.
FIGURE 5. Opposite phased transducer with a SAFT measurement arrangement for onsite application.

FIGURE 6. Nozzles measured with an opposite phased transducer.
It is seen in Figure 9 that the measured amplitude of the opposite phased transducer is following the modelled behaviour. From the notch lying along the surface only the end of the notch is seen. This feature can be used for sizing interface defects (laminations). Both in the case of a single defect and multidefects the minimum amplitude is seen in the middle of the defect. For single defects this method is an easy way to size the defect.
DISCUSSION AND CONCLUSIONS

This paper introduces a new type of transducer, the sound field properties of which can be used for detection and especially for sizing of defects. For a single defect this method is easy to apply for sizing purposes. In the case of several defects the transducer frequency must be high enough to improve the detection and separation capability of small defects. The frequency used in these measurements was 2 MHz, which can't be applied for detection of tip signal of a small crack. The opposite phased transducer can be used e.g. for detection of laminations and other interface defects. The sound field is very narrow and only slowly opening even in the case of long sound path distances. The behaviour of opposite phased transducer has been modelled with a software using numerical finite difference method (MFDM) and the behaviour is shown in practise by some simple tests.

REFERENCES