Use of Sectorial Scanning for Anisotropic Weld Inspection

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Abstract. Ultrasonic phased array technology is now often applied for weld inspection. Principles and applications to isotropic materials are now well known and quite frequent. However for anisotropic materials, the difficulty is to know and to take into account the ultrasonic waves velocities depending on the angle of propagation. If these variations can be determined theoretically from elastic constants, it is difficult to dispose and to determine them.

The application of a linear electronic scanning does not matter since the angle of propagation and therefore velocity are constant. On the contrary, the use of a sectorial electronic scanning is more difficult for anisotropic materials since the angle of propagation is not constant: one different velocity for each angle of propagation.

In this paper, a solution is proposed to apply a sectorial scanning for weld inspection in spite of material anisotropy. This solution is based on the use of a standard ultrasonic phased array device and specific sectorial scanning based on the anisotropic material properties. Results show major improvements of performances in detection and localization.

Introduction

Ultrasonic inspection of anisotropic materials is always difficult. Several applications are concerned with these materials: energy, petrochemistry… Conventional ultrasound is already applied to inspect such materials. For example, to decrease the effect of anisotropy in a weld joint, a transmitter generating a longitudinal wave in the material and a separated receiver are used (TRL transducers). When using conventional probes, anisotropy is corrected according to the angle of propagation by calibrating the velocity for each angle.

Some recent applications appeared using phased array transducers, based on the same principles. This technology improves resolution and gives images of the test part. However, in standard phased array devices, the material is only defined with one velocity (for the considered wave).

When base metal has anisotropic properties, a wave that propagates at an angle has its own velocity. This velocity changes with angle and vibration mode. Thus it is only possible to apply a linear scanning.
Some rare efficient devices can take into account the material anisotropy and then can apply sectorial scanning considering the variation of velocity according to the angle of propagation. These devices are based on theoretical principles and need the definition of the tensor of elastic constants of the material.

Ultrasound wave velocity can be calculated for isotropic materials and does not depend on the angle of propagation. On the contrary, ultrasound wave velocity has to be calculated for all the angles of propagation and in every direction for anisotropic materials. The difficulty remains that the tensor of elastic constants is always unknown. The determination of the constants is very hard or taken from bibliography.

For a weld inspection, we have succeeded in applying a sectorial scanning using a standard phased array device, considering the anisotropy of the base metal in order to image the test part. In this paper we will show the effect of anisotropy on a sectorial scanning with standard setup. Then we will describe the solution that can be applied to simplify this problematic and the results obtained in a weld.

1 Effect of the anisotropy on a standard S-scan

Delay laws are computed by taking into account the characteristics of the array (pitch), the wedge (position of the elements, angle of incidence, velocity) and the material of the part (velocity). When the probe and the wedge are correctly defined, delay laws are usually well computed, and calibration only corrects small gaps.

The part that has to be tested here is a pipe made of an anisotropic material with an internal transverse notch. In spite of what is commonly done in bibliography, we use here shear waves.

The velocity calibration is made using the two notches with a linear scanning. The angle of refraction is constant and velocity is constant whatever the shot. This calibrated velocity is then applied for the linear scanning and for a sectorial scanning while material is considered as isotropic.

The probe is moved above the internal notch and the following acquisition shows the maximum of amplitude obtained with the two setups at each position.

![Fig. 1. Effect of anisotropy: comparison between linear and sectorial scannings](image)

For the linear scanning, Fig. 1 always shows the echo at the same depth for all the sequences of the setup. A calibration of the wedge delay will be necessary in order to adjust the position in depth of these echoes all deeper than the current position of the notch.

However, for the sectorial scanning, we notice that the echo of the notch is going deeper when the angle increases. Unfortunately, in most of devices, it is impossible to
define several different velocities for one material, always considered as isotropic. Then a solution is proposed to correct this.

2 Inspected component and experimental setup

2.1 Specimen

The part that is proposed to be inspected is a pipe made of an anisotropic material with a weld. The potential heterogeneity of the weld is not taken into account in this paper.

The previous reference reflectors described in clause 1 will be used first to define the material characteristics and setup the inspection.

2.2 Inspection setup

In order to correctly cover the weld joint, two sectorial scannings are to be defined. Moreover, it seems necessary to reduce the last angles of refraction due to the difficulty to propagate for high angles as it can be seen on S-scan of Fig. 1.

The two sectorial scannings can be geometrically specified: angles of refraction, active apertures… Here again, as much as possible we want to use shear wave for this inspection.

This geometrical consideration allowed to specify the two sequences to setup:

- 1\textsuperscript{st} sequence: inspection of the top of the weld with sectorial scanning from 40° to 60° and point of incidence at about 20 mm from the axis of the weld.
- 2\textsuperscript{nd} sequence: inspection of the bottom of the weld with sectorial scanning from 50° to 65° and point of incidence at about 12 mm from the axis of the weld.

The aim of the following of the study is thus to determine the velocity of shear wave in this material in order to setup these two sectorial scannings.
3 Simple consideration of the material anisotropy

3.1 Velocity according to angle

The velocity for each angle must be known to compute the correct delay laws in order to generate the real expected refracted waves. These velocities could be theoretically determined using the slowness curves computed from the elastic constants. In bibliography, these slowness curves for anisotropic materials illustrate the existence of one longitudinal refracted wave, and two refracted quasi-shear waves. Unfortunately, as said in introduction, the elastic constants are unknown, and thus the slowness curves.

Here both angle and velocity are unknown. The S-scan obtained in Fig. 1 seems to show a single shear wave. We then can hope that it is possible to only consider the angular sector we would need. It is necessary to estimate the angle first and to calculate the velocity. We defined a methodology based on Snell-Descartes law to calculate the velocities according to the refracted angles.

A sectorial scanning is applied in a perfectly known isotropic material and then identically applied on the anisotropic material to be characterized. The use of reference reflectors allows to determine the angles of refraction in both isotropic and anisotropic materials. Snell-Descartes law finally gives the velocities in the anisotropic material.

This methodology allowed to obtain the following Fig. 4 showing the variation of velocity of a shear wave in the anisotropic material according to the angle of refraction.

![Fig. 4. Variation of velocity of shear wave according to angle of refraction](image)

This variation shows a difference of velocity of more than 300 m/s between the first and last angles. This curve can now be used to compute the delay laws of the sectorial scannings angle by angle with the actual velocities. These laws were all computed using Ultravision software.

3.2 Results on reference part

The sectorial scanning defined previously is applied on the reference part. The probe is moved above the two internal and external notches and the following acquisition shows the maximum of amplitude obtained with this setup at each position.
For both internal and external notches, the maximum of amplitude of echoes for each position is always located respectively at inside and outside walls. This setup seems to take correctly into account the variation of velocity due to the anisotropy of material.

Before evaluating this configuration for weld inspection, a calibration in sensitivity is applied in order to obtain the same amplitude of echoes whatever the depth of the reflector.

4 Application of sectorial scanning for weld inspection

4.1 Reference reflectors in a weld

The previous results have shown the possibility to simply and locally take into account the anisotropy of the material. We propose to validate this configuration on a mock-up containing a weld and different reference reflectors.

The inspection will be realised using two probes located on either side of the weld. Height reflectors are symmetrically placed in different sections of the mock-up as shown below:

- Four notches: at inside and outside walls, two centred on the axis and two along the chamfer.
- Four oblong holes: in the thickness, two centred on the axis and two along the chamfer.

The sectorial scannings defined in section 2.2 and set in section 3 are now applied on this mock-up.

4.2 Results obtained on the mock-up

Two sectorial scannings were defined to inspect either the top of the weld or the bottom of the weld. They are applied on either side of the weld.

We first show on Fig. 7 the results obtained on the four notches.
Fig. 7. Application of the configuration on the notches of the mock-up:
   a. external notches on the chamfer;
   b. external notch on the weld axis;
   c. internal notch on the weld axis.

The figure below now shows the results obtained on the oblong holes in the thickness of the mock-up.

Fig. 8. Application of the configuration on the oblong holes of the mock-up:
   a. holes on the chamfer;
   b. holes on the weld axis.

Fig. 7 and Fig. 8 show very good results in terms of detection and location of the notches and oblong holes, whatever the position of the reflector on the chamfer or in the weld joint. Errors on localisation in depth and distance from the weld axis are generally less than 1 mm. Results obtained on one side and on the other side of the weld are consistent.

Such results are very encouraging to apply this configuration on plant to inspect welds after manufacturing process.
If the potential heterogeneity of the weld joint does not seem to damage the quality of detection and localisation of reflectors, amplitude of echoes strongly decreases for reflectors located at outside wall and more inside the weld joint.

Thus, in order to improve the probability of detection especially for defects that could be located inside the weld joint, these results allowed us to determine a gain correction according to the position of the reflector either on the chamfer or inside the weld joint, and either at inside or outside wall.

**Conclusion**

In this paper, we tried to simplify the problematic of the anisotropy of a material that complicates or prevents the inspection. For example, we showed the impossibility to apply a sectorial scanning when using basically tools of phased array devices. Conversely, the use of efficient devices taking into account some rarely available data of the material like the tensor of elastic constants is not easily possible in industry.

Nevertheless, for our case of application, we succeeded in determining the variation of velocity of the anisotropic base metal of a pipe according to the angle of propagation of a shear wave. Two sectorial scannings were defined and setup.

The application of this setup with TOPAZ, allowing sectorial scanning with different velocities, gave very good results in terms of detection and localisation of reflectors both on the chamfer and inside the weld.