Ray Tracing Software for the Layout of Ultrasonic Weld Seam Inspection

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Abstract
A fast ray trace based simulation software has been developed in order to determine the best layout for the ultrasonic weld seam inspection of large diameter line pipes prior to the production process. An interactive graphical user interface allows the user to adjust the relevant settings. The resulting sound propagation in the pipe wall is directly visualized in a negligible computational time. The program comprises a model to take into account the influence of the ultrasonic sound anisotropy. For the validation of the simulation results, comparisons with semi-analytical calculations were carried out.

Keywords: ultrasonic weld seam inspection, welding, sound velocity anisotropy

1. Introduction

Longitudinal welded large diameter line pipes are a frequently used means of oil and gas transmission. For the security of persons and environment a safe operation has to be guaranteed by the most stringent quality requirements. Thus the quality control of the pipes, especially those of the weld seam, plays an important role in the production chain. Besides other testing methods like filmless radiography, EUROPIPE, as one of the leading manufacturers of large diameter line pipes, provides ultrasonic examinations of the pipe welds before and after expansion using an automated ultrasonic test unit (see Figure 1).

Figure 1: Automatic weld seam ultrasonic inspection in the E-cycle
The weld is tested in the 12-o’clock-position and the ultrasound is coupled by means of the water jet technique. The test unit travels along the stationary pipe in order to avoid problems due to the pipe movement. The probes are arranged in different planes and guided along the weld individually. For the detection of longitudinal defects 6 x 2 probes are used. They are placed in pairs, oriented in opposite directions symmetrically to the weld. The test probes can be operated in a pulse-echo-mode or as pairs in the tandem mode.

Figure 2 shows a sample setup for the detection of longitudinal defects in a pulse-echo-mode.

A transducer introduces a refracted shear wave into the pipe segment. The incident angles of the acoustic waves and the skip distances are determined by the relevant testing requirements. Since defects have to be detected and localized not only in the weld itself, but also in the heat affected zone and the adjacent base metal with practically constant testing sensitivity and reliability, a careful setting and a proper adjustment must be assured. For the layout of a testing configuration in dependence on the pipe and weld seam geometry a software tool has been developed. This software is based on a ray tracing method for the calculation of ultrasonic wave paths. While it is known that rays cannot model diffraction effects, they are a well-established and useful construct to provide fast, intuitive and reasonable correct results.

2. Software features

The software provides a ray based layout of the ultrasonic weld seam inspection for longitudinal defects (see Figure 3). The following setup is taken into account: The probe produces a longitudinal wave in a water couplant, which encounters the interface to the test specimen and experiences a mode conversion into shear waves. For the detection of longitudinal defects only the SV-wave shall be considered here, which is refracted into the pipe obeying Snell’s law. Afterwards the wave impinges on the inner surface and is reflected without mode conversion. The software describes this wave propagation in the pipe by a beam, confined by two rays, representing the 6dB field contour in the far field limit [1].

In order to model the process most accurate within the limits of the ray picture, the program provides an interactive display for quite a number of features. After setting the pipe dimensions (like diameter and wall thickness) and defining the weld properties, a
schematic picture of the pipe segment is drawn. The user can specify the width and frequency of the transducer. Automatically the 6dB field contour is calculated. The user can also adjust the angle of incidence, dependent on the water path temperature, and the location of the transducer in such a way that the final inspection volume is well adapted to the detection of defects, as can be directly controlled by the visualization in the program. The gate settings of the automated ultrasonic inspection system can be taken into account and will be indicated in the drawing. This allows a confirmation of the specifications for review and acceptance prior to the start of production as demanded by customers. Furthermore the software can take into account sound velocity anisotropy effects, which occur in thermomechanically (TM) rolled plates. This feature shall be described in more detail in the following.

Figure 3: Interactive user interface of the ray tracing software

2.1 Sound velocity anisotropy

The TM-plates, which are used as the base material for large diameter line pipes exhibit a pronounced texture, resulting from the rolling process. As a consequence, the elastic properties of the material are anisotropic, leading to an anisotropy in the ultrasonic velocities, respectively. The differences can be in the order of magnitude of 10%. This anisotropy of the ultrasonic velocity will also influence the sound velocity for an incidence angle of the SV-wave. Due to Snell’s law, small changes in the sound velocity may result in large changes in the final angle of incidence. Figure 4 shows that this behaviour is mostly relevant for flat incidence angles, which are typically used for longitudinal defect detection.
For a basic understanding of the sound velocity anisotropy an analytical model for wave propagation in TM-plates has been set up. The theoretical model comprises different aspects of physics and mathematics, namely mathematical possibilities to describe texture, classic elasticity theory, analytical models for ultrasonic wave propagation in isotropic and anisotropic materials [2,3,4]. As a result, the angular dependence of the sound velocity of a metal with cubic crystal symmetry and orthorhombic sample symmetry can be described by four sound velocities. For a comparison with experimental values, different materials have been investigated with regard to their angular dependence of the sound velocity in the longitudinal defect direction. The results confirm the good accordance between theoretical predictions and experimental values and show a clear dependence on the texture of the TM-rolled plates. However, for flat incidence angles (like used for longitudinal defect detection) the experimental data exhibit only a small material dependence and the absolute values are close to the standard values.

In general it can be concluded that the angular dependence of the sound velocity and its consequences for the ultrasonic weld inspection cannot be neglected. This need is being addressed through embedding the model for the calculation of the sound velocity anisotropy into the ray tracing software.

3. Validation by semi-analytical simulation

While the ray tracing software comprises a lot of features to make the model of the UT inspection more realistic, it cannot take into account diffraction effects. In order to check if the ray model provides reasonable correct assessments, it has been compared to calculations by a semi-analytical simulation. The results for the case of a setup with a pipe diameter of 1220 mm, a wall thickness of 34.6 mm, an incidence angle of 60° and a probe center distance of 130 mm are shown in Figure 5. The upper figure denotes the final inspection volume as calculated by the ray tracing method, the lower one exhibits the corresponding representation calculated by a semi-analytical approach, which considers also diffraction effects. Despite from the fact that due to attenuation the waves

![Figure 4: Dependence of incidence angle on sound velocity](image)
in Figure 5 b) propagate only up to the first skip distance, it is clearly visible that the results are well consistent.

4. Summary & Conclusions

It has been shown that the presented ray tracing software is a fast means of the optimized weld seam inspection layout. The interactive GUI allows the user to specify the relevant test settings and visualizes the resulting inspection volume. For the calculation of the incident angle the influence of the ultrasonic sound velocity anisotropy is taken into account. Despite the simplifications of the ray model, the results are qualitatively in good accordance to calculations by a semi-analytical approach.

References