

UMASIS, AN ANALYSIS AND VISUALIZATION TOOL FOR DEVELOPING AND OPTIMIZING ULTRASONIC INSPECTION TECHNIQUES

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Abstract

Simulation tools are more and more used during the development and optimization of ultrasonic inspection techniques. Their advantages are clear; They provide additional insight in the performance of an inspection technique at lower cost compared to a purely experimental approach. Furthermore, they overcome practical limitations like availability of transducers and test blocks during the design of new techniques. There are already a number of modeling tools available; most of them use ray-tracing or semi-analytical Kirchhoff integral methods for fast calculations. They solve approximations of the full elastic wave equation and therefore do not take into account all wave phenomena. These algorithms also limit the visualization possibilities; essentially they provide a simulated A-scan.

UMASIS is a software tool that takes a different approach. It uses the power of wave equation based forward modeling to calculate the full elastic wave field. All wave phenomena, like mode conversion, are automatically taken into account. Furthermore, the calculation of the wave field allows advanced visualization possibilities, like full wave field visualization and decomposition in P- and S-waves.

Several cases show that UMASIS can successfully be used to optimize inspection configurations or even complete ultrasonic inspection tools. The combination between comprehensive forward modeling and advanced visualization capabilities turns-out to be a powerful tool to understand the underlying complex physics, without the need of in-depth understanding of the modeling algorithm.

1. Introduction

New inspection procedures are traditionally developed using experiments on test pieces with artificial defects. The increased availability of computer resources however makes the use of simulations a better option for developing and improving the inspection procedures. Advanced numerical algorithms, such as Finite Difference (FD) or Finite Element (FE) methods, can calculate the full ultrasonic wave field inside the object under inspection. These schemes allow not only an accurate prediction of ultrasonic responses, but are also able to visualize the wave field. This simulation approach has two major advantages over the more traditional approach.

- Generally, the only output of experiments is the electrical signal from the transducer. Information about the wavefield inside the object remains hidden. Simulation tools can reveal this wavefield, which leads to an improved insight in the propagation and behavior of ultrasonic waves during inspection.
- Simulations are very easy to set-up in comparison to lab experiments and allow easy variation of the various parameters of the inspection technique and properties of the inspection object. Furthermore, you are no longer limited by the availability of hardware and test blocks. It reduces the experimental work to a single validation step.

This way simulation tools strongly speed up (and reduce cost of) the R&D phase of ultrasonic inspection technique. The additional insight improves the reliability, in terms of reduced false call rate and increased POD.

If one wants to make full use of these advantages, the modeling software should fulfill several requirements. The software must be easy to use and must require only knowledge of ultrasonic NDT instead of an in-depth understanding of numerical modeling. Also, by comparing and evaluating the results of multiple configurations it must be easy to gain a fast and thorough insight in the performance of an inspection technique. If the software fulfils these requirements, simulation tools can aid the industry developing innovative solutions for inspection problems.

UMASIS is a commercially available software tool that models and visualizes the two-dimensional propagation of ultrasonic waves through an arbitrary object using finite difference calculations. By means of a dedicated FD scheme [1,2], the full elastic wave equation inside the model can be calculated and therefore all wave phenomena are taken into account. However, no extensive computer resources are required by performing the calculations on an external computer cluster. UMASIS communicates with this cluster of an internet connection.

This approach is schematically depicted in Figure 1. UMASIS is build up from three blocks (see Figure 1). The first block is a graphical user interface (GUI) where the user can draw an arbitrary geometry, including a source and receivers. This geometry is exported from the GUI and send to the second block which contains the finite difference algorithms. Here the propagation of ultrasonic waves is calculated. For the calculations this software program communicates over the internet with an external computer cluster. When the calculations are ready the results are imported into the third block, which is another GUI that visualizes the results and allows basic analysis. For extensive analysis the results can be exported to MatLab. The drawing and visualization block are integrated into a single software program. The main advantages of using this platform is its simplicity: the user is only concerned with the drawing of the models and analysis of the results. No knowledge about the numerical algorithms is required.

The use and advantages of numerical modeling will be further demonstrated on three cases.

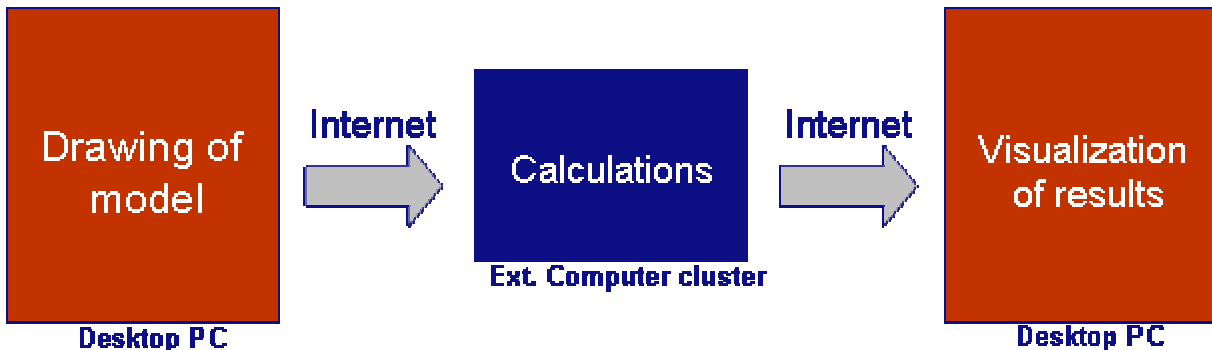


Figure 1. Schematic depiction of the concept of UMASIS.

2. Determination of POD-curves of TOFD inspection

UMASIS is intensively used in the POD generator project^[3]. One goal of this project is to asses the effectiveness of TOFD inspections under various circumstances using a numerical modeling approach. This is done by determining the POD for various inspection parameters and circumstances. To obtain reliable POD's the output of the simulations has to be as realistic as possible. Therefore UMASIS is used in this case for two reasons:

- 1) Because the full elastic wave equation is solved, all wave phenomena are taken into account. This is essential if one wants to generate realistic output.
- 2) It allows easy variation of the object of inspection and inspection parameters. This way effects that influence the inspection such as surface roughness, grain scattering, misalignment, and weld properties can be easily implemented.

Figure 2 shows the geometry of a circumferential weld between two pipe segments inspected using a TOFD setup. In the top left and right of the model a source and receiver transducers are positioned. In the right of the screen the parameters of the source can be seen. Ray-paths can be seen near the index points of both transducers, which help with the alignment of the transducers.

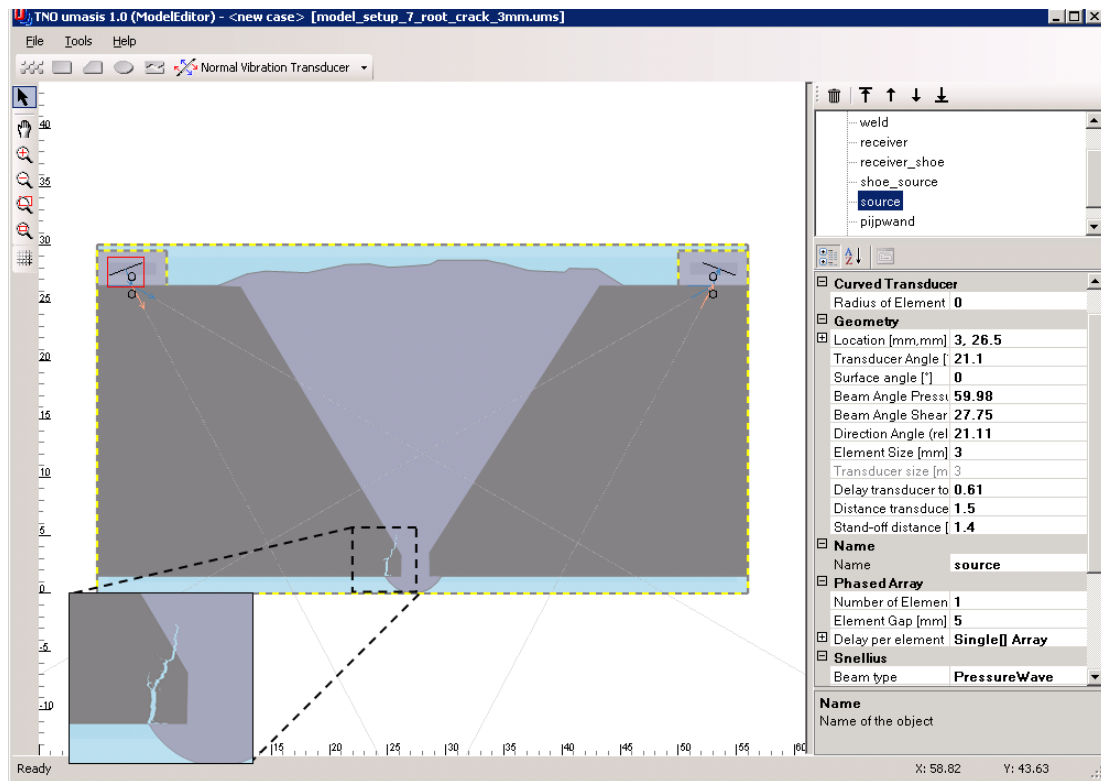


Figure 2. Drawing screen of UMASIS. Inside the model grid the inspection geometry of TOFD simulation is drawn. The inset shows a zoom of a crack present in the root of the weld.

Goal of the POD project is to generate realistic POD's based on simulations. The following details are added to the simulations to make the output more realistic:

- As can be seen in Figure 2 a realistic V-weld is inserted into the object. The weld is obtained by tracing a photograph of a real weld.
- Near the root of the weld a small crack is visible (see the inset for a more detailed zoom). Being able to model realistic defects is an important advantage of the numerical approach in comparison to the experimental approach. The response of a synthetic defect can be much different than the response of a realistic defect. Notches or side drilled holes are 'perfect' defects, while realistic defects can have branches, different orientations, or varying thickness. More realistic, but still artificial defects can be inserted into a test object, but because this is often an uncontrolled process, the exact properties of the defect are unknown and can only be obtained by destructive analysis. UMASIS allows the insertion of realistic defect by importing images into the model.
- The top and bottom of the pipe wall are not smooth, but have a rough surface (note that this is not visible in Figure 2). The amount of surface roughness is a parameter of the model.
- The weld contains grains, which can greatly influence the outcome of an inspection by the addition of noise to a B-Scan. This so called grain scattering is added by applying small wave speed variations to the material inside the weld.

- Another important influencing factor during inspection is probe movement during scanning. This is added to the simulations by slightly shifting the probes at every position. The amount of variation is a parameter of the model.

The model of Figure 2 is exported from UMASIS and sent the computer cluster by using an internet connection. The TOFD simulations in the POD project are evaluated with an isotropic 2D finite difference scheme^[1,2]. This scheme is based on the full elastic wave equation and therefore takes all wave phenomena into account. To gain a thorough insight in the influence of the various parameters on the inspection, the results are analyzed by importing the output of the simulations into UMASIS.

Figure 3 shows the typical output of the numerical simulation of a TOFD inspection. In the centre of the window a snapshot of the wavefield inside the object is presented. In the left image several wave fronts are visible, denoted by different colors. In this case the blue color denotes compression waves and the red color denotes shear waves. The right image of Figure 3 shows again a snap shot of the same wave field, this time a few microseconds later. In this image red and blue indicate the phase of the wave. Using the two images different wave phenomena important for TOFD inspections are investigated.

- The mode converted echoes are an important aspect of TOFD inspection. The left screen clearly shows the mode conversion at the back wall.
- When the wave fronts hit the defect diffraction occurs at the tip of the crack. The travel time of this diffraction relative to the travel time of the head wave is used to size the defect.
- Phase flip of the mode converted wave is clearly visible in the right image. This allows an investigation of the phase of the wave fronts.

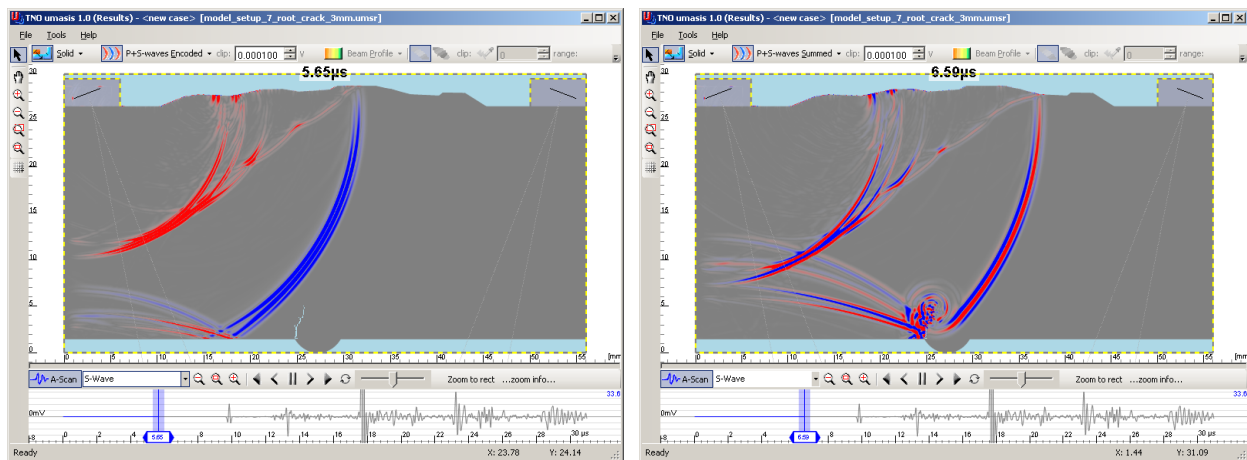


Figure 3. Two snap shots of the wavefield inside the TOFD geometry during inspection. In the left image the red and blue colors are used to denote wave mode. In the right image red and blue are used to indicate the phase of the wave.

Another advantage of the numerical modeling is explained in Figure 4. It shows a zoom of the wavefield around the receiver wedge just before the head wave is recorded (see the blue line in the bottom of the image). By combining the A-scan and the wave field, the echo in the bottom of the screen is connected to the wave front in the visualization screen. By subsequently following the wave front back in time the origin of the wave front can be determined. This feature is used to explain the different echoes in the A-scan, which can be quite complicated in the case of TOFD inspections.

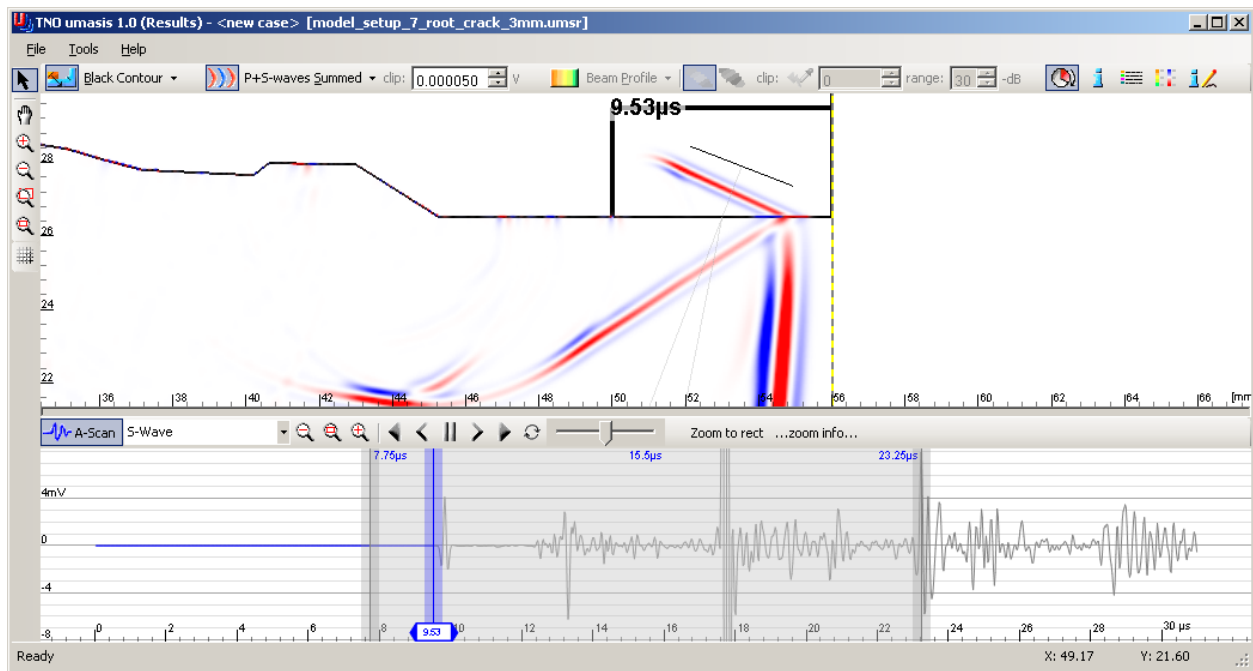


Figure 4. Zoom of the wave field around the receiver wedge just before a wave front hits the receiver crystal. In the bottom the recorded A-scan is visible. The blue indicator corresponds to the simulation time of the snap shot.

3. Phased array

To demonstrate in which way the simulations can assist during the development of ultrasonic inspection techniques without being limited by the availability of hardware, a theoretical inspection with a phased array is simulated. On top of a piece of steel a linear phased array is placed. By giving each element of the array a specific time delay, the beam can be steered in any direction in the object of inspection. UMASIS allows one to determine the basic design parameters of phased arrays.

The top left image of Figure 5 shows the model of this theoretical setup. On top of the steel test piece (gray) a wedge (yellow) with the linear phased array is placed. The beam is steered at different heights inside the test piece. The next images show the beam profile when the beam is steered at the bottom, 50% height and 25% height of the steel piece. On top of the beam profile the wave front of the shear waves is visible. It clearly shows the focusing effect.

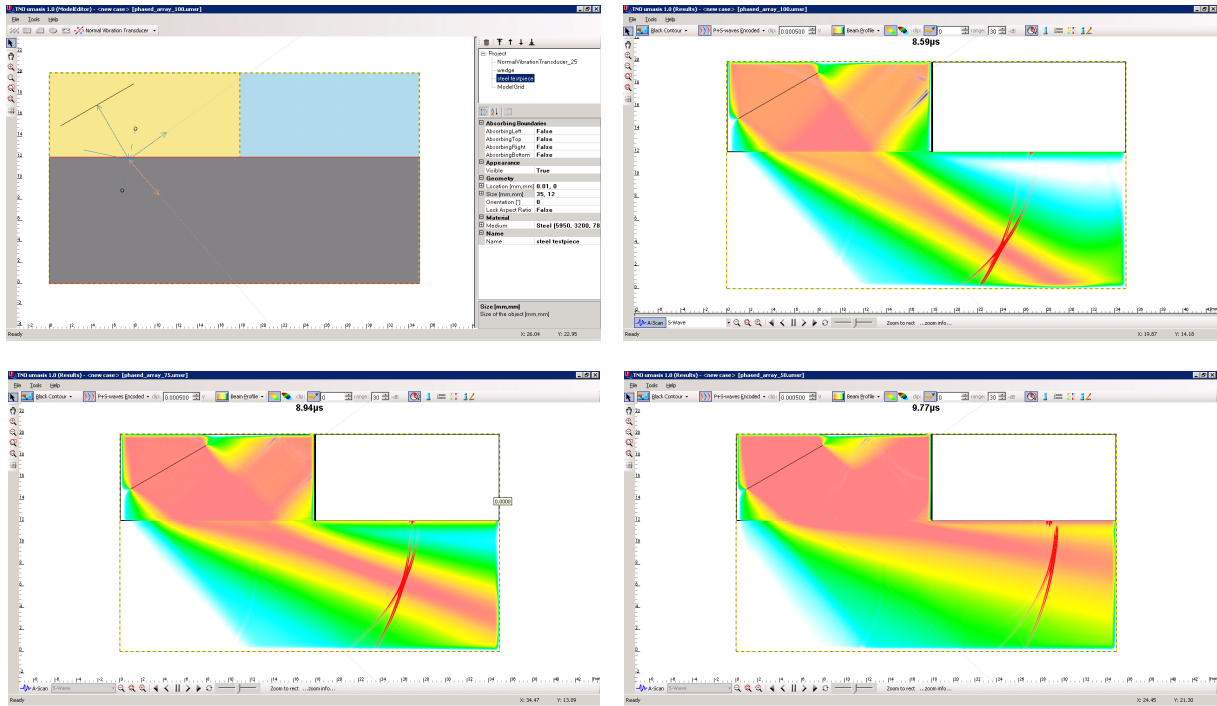


Figure 5. Demonstration of a theoretical phased array setup. The top left image shows the geometry drawn in UMASIS, consisting of a steel test piece with a linear array on top of it. The other images shows beam profiles when the beam is steered at 100%, 50% and 25% of the height of the steel testpiece.

Using the one-way beam profile the quality of the focal spot can be determined, which in turn determines the response from possible defects. This way the phased array can be designed (in terms of number of elements, element size and gap between elements) for optimal detectability of defects.

5. Conclusions & future

In this paper we showed the capabilities of UMASIS and its advantages during the development and optimization of ultrasonic inspection techniques. Working with UMASIS requires only knowledge of ultrasonic NDT and no understanding of the numerical algorithms. Advanced simulations can be setup in less than an hour by an inexperienced user. By removing the need for large local computer resources, the computationally heavy intensive finite difference simulations can be performed on any desktop computer. This way anyone can use the full power of finite difference simulations, which automatically take all wave phenomena into account. The advanced visualization capabilities of UMASIS reveal the wave fronts during inspection, which can greatly improve the insight into the performance of an inspection technique.

The advantages of using numerical modeling were demonstrated on three cases:

- The determination of the POD of TOFD inspection. Here the accuracy and ability to easily implement all kinds of influencing factors to a model was very important.
- Design of phased arrays. When designing phased array simulations can aid in determining basic design parameters.

We continue with the development of UMASIS. Algorithms which can operate in 3D and therefore allow the simulation of guided waves are already available. In the same way UMASIS can make use of algorithms that take anisotropy or visco-elastic damping into account.

References

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