CIVA: Simulation Software for NDT Applications

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Abstract

In today’s environment of shrinking resources, and consistent need for accurate inspections, simulation software is an effective cost cutting tool. CIVA is an advanced NDT simulation software dedicated to modeling ultrasonic (UT), radiographic (RT) and eddy current (ET) inspections without the need for physical test sample or inspection equipment. Each inspection module is comprised of simulation, imaging and analysis tools. These tools assist the user in virtually conceiving or optimizing inspection techniques and predicting their performances in realistic NDT configurations.

While the software contains three independent modules (UT, RT, ET), this paper focuses on the UT module, which has the ability to model complex phased array UT inspections for a variety of probe styles, then automatically calculate the delay laws in an exportable format. This paper will highlight the capabilities of CIVA NDT simulation software to accurately model weld inspections using phased array ultrasound.

Introduction

The National Aeronautics and Space Administration (NASA) Glenn Research Center participated in the construction of the upper stage simulator (USS) for the Ares I-X test rocket scheduled to launch later this year. The USS is comprised of hollow cylindrical sections that will be stacked and attached to each other. The USS contains critical welds that attach pieces to each other including a skin-to-flange weld.

NASA utilized CIVA NDT simulation software to help plan alternate inspections that if needed, could supplement the techniques that were specified and required for weld certification for the skin-to-flange weld. In the future, it is hoped that these modeling methods will be used to help qualify use of phased array ultrasonic test (PAUT) in place of a hand-held ultrasonic A-scan inspection while still meeting certification requirements.

Phased array inspection is quickly gaining acceptance in the NDT community and has many advantages over conventional A-scan inspections. These advantages include being able to complete a variety of scans with only one transducer and without any mechanical movement. Scan options include the ability to perform single point focusing, beam steering, direction and depth focusing, focusing at multiple points on a line, and focusing at multiple depths. These scan options provide greater flexibility to accurately inspect complex shapes and areas with physical restrictions (such as weld reinforcement) while being provided with a two-dimensional image of results. While the capabilities of PAUT are much greater than those of a single element transducer A-scan, the complexities of PAUT are also much greater. To improve understanding of the inspection process physics, including optimization of the inspection parameters, simulation and modeling are playing an ever increasing role. Simulation software such as CIVA can help to prove or disprove the feasibility for an inspection method or inspection scenario, help optimize inspections, and assist in approximating the limits of detectability all in significantly less time than could be accomplished through experimental trial and error only.

Body

Software Overview

CIVA is based on semi-analytical calculations in a user friendly graphical user interface. For complex shapes, the user can either import a drawing such as .DXF file, or draw the shape using the basic computer aided design (CAD) tools built into CIVA. With CIVA it is possible to simulate the part under inspection, view the simulated inspection results and perform additional signal processing on the results such as applying filters. Because it is based on semi-analytical calculations, computation time in CIVA is significantly quicker than with finite element analysis (FEA) modeling tools.

Each module of the software is designed to let the user simulate an inspection without the use of physical test samples or inspection equipment. For each of the three modules, UT, ET and RT, the user defines the shape, size and material of the part to be inspected as well as the parameters of the inspection equipment such as ultrasonic transducer size and frequency, eddy current probe size and frequency, and radiographic source size and energy level. For each of these modules the user defines the position of the inspection equipment in relation to part. A variety of different types of flaws can be placed in the simulated part, then the inspect results calculated and displayed. The defect response obtained from the inspection results is displayed in a similar manner to what would be seen experimentally. For UT, this means that an A-scan, B-scan or C-scan can be displayed. For ET, C-scans are displayed and for RT, radiographic images are displayed.

The UT module is the oldest and most advanced of the three modules. With this module the user can either choose from 7 pre-existing specimen shapes or create their own cylindrical or planar extrusion of a CAD created profile as shown in Figure 1. The specimen material can be chosen from a large variety of isotropic materials, anisotropic materials and composites. Materials not in the database can be easily added by defining the velocity and density of the
material. Additionally, a large variety of transducers shapes, sizes and types can be modeled including single element, dual element or phased array probes (linear, matrix and flexible arrays). Both single element and phased array probes (Fig. 2) can be modeled in either contact or immersion conditions. These probes can either be flat or focused. While water and oil are the two couplant choices already in the software, it is easy to add additional materials such as glycerin based gels. When a transducer is mounted on a wedge, the user defines the wedge dimensions, angle and wedge material. Several types of flaws are already defined in CIVA, where all the user needs to do is specify the dimensions and location. For more complex flaw modeling, it is also possible to create multifaceted and CAD contoured planar flaws. Examples of each of these flaw types can be seen in Figure 3.

Once the inspection parameters are defined, the user can calculate the defect response, or if they prefer, first model the beam profile to verify that the beam is angled and focused in the part as expected.

NASA PAUT Experimental Results

The USS of the ARES 1-X (Fig. 4) contains several critical welds including the skin-to-flange weld. To improve their inspection planning, and hopefully qualify use of PAUT in place of conventional UT for inspection of the skin to flange weld, NASA is using a combination of experimental and simulation results.

A skin-to-flange test sample was fabricated out of carbon steel. The skin and flange portions were approximately 12 mm and 25 mm thick, respectively. The skin portion was double-beveled at one end, 45° each side, and butt welded to the thicker flange section using the flux core arc welding (FCAW) method. Weld filler metal with a similar composition to that of the base steel was used. The external weld was machined flush. To simulate lack of fusion, a side-drilled hole (SDH) approximately 1.61 mm x 40 mm in length was located at one end of the part. (Fig. 5)

A General Electric (GE) Phasor XS portable ultrasonic flaw detector was used for the inspection of the test sample. The type used by NASA was a 32 crystal-element linear phased array transducer with 5 MHz flat focus and a total aperture of 16 mm x 10 mm. The element width was approximately 0.45 mm with a gap between elements of approximately 0.05 mm. Only 16 pulser-receivers were available in the instrument at one time, limiting the use to only 16 active elements out of a total of 32 elements. The use of only half the total elements resulted in an active aperture area of 8 mm x 10 mm. The transducer was attached to a Rexolite wedge. The wedge produced an incidence angle of approximately 36° and a subsequent refracted shear wave angle of approximately 54° in the steel part. Note that since a refracted angle of 54° is beyond the critical angle for longitudinal waves in steel, this study is concerned with shear wave only. As shown in Fig. 5, whether a single element or phased array transducer is used, this is a single-sided inspection of the weld. A combination of a manual hand scan and an electronic sectorial scan from 40° to 75° was performed along the exterior surface of the skin to determine the detectability of the SDH in weld interior.

Using the 5MHz transducer, ultrasonic velocity and attenuation coefficient measurements were performed on the test sample base material and also on a flat area of the weld. The shear wave velocity values for the base steel and weld steel were measured to be 0.325 cm/μsec and 0.328 cm/μsec, respectively, the difference of which is close to the measurement uncertainty for the velocity measurement method. The velocity value for the base steel was used as a setup parameter in the GE Phasor.

For the inspection of the SDH, the transducer was positioned perpendicular to the axis of the flaw. Figure 6 shows the experimental sector scan results obtained at the probe position shown in Figure 5. The large amplitude indication shown in Figure 6 at the lower right portion of the sector image is from the direct path reflection off the SDH. The maximum amplitude for this indication occurs at the 66° angle. When the probe is moved laterally away from the SDH (which is 40 mm long and extends about 2/5ths of the way across the weld) the indication from the SDH eventually disappears from sight. The Phasor display indicates that the SDH is located about 4 mm in front of the wedge and about 12.67 mm down from the surface that the probe is on. These results agreed well with actual location of the SDH in the part. The maximum amplitude from these experimental results was obtained at an angle of 66°.

NASA Validation of CIVA for PAUT

After obtaining the experimental results with the GE Phasor, NASA then used CIVA V9.1a simulation software to recreate the inspection scenario. A model of the part and transducer was created, a 1.61mm x 40 mm SDH was placed in the part at the same location and orientation as in the test sample, and a simulated 40° to 75° sectorial scan of the flaw was performed. To improve accuracy of simulation results, NASA used the velocity values obtained experimentally in place of the generic steel velocities in CIVA’s material database. From the simulation results NASA was able to determine that the maximum amplitude obtained would occur at approximately 60°. By exporting the defect response onto the model of the skin to flange test sample, it is easy to see that the maximum response occurs at the location of the SDH (see Fig 7). The ability to overlay the UT response onto a 3D model of the part is one of the advances of using CIVA. For complex geometry, it greatly assists in determining the physical cause of each response such as tip diffraction, corner echoes, direct reflection, etc.

Comparison of the simulation results (Fig. 7) to the experimental results (Fig. 6) shows a very good correlation in location and amplitude of response. The one measurable difference is that the simulation obtained the maximum
amplitude at approximately 60°, while the maximum amplitude obtained experimentally occurred at approximately 66°. There are several factors that could have caused the difference in angles including slight differences between the actual and modeled weld contour, flaw size and orientation, transducer setting (it is unknown whether the first or last 16 elements were turned off), and probe placement.

**Comparison of Flaw Configurations**

After validating the accuracy of CIVA to detect the SDH in the skin-to-flange weld, the effects of defect shape and orientation were explored. The goal was to better understand how robust the inspection would be in detecting lack of fusion. Since lack of fusion is often planar on one side, additional simulations were performed with planar defects.

Three additional simulation scenarios were created, each one containing a 1.61 mm x 40 mm planar flaw in the same location as the SDH. The flaw was oriented at 0°, 45°, and -45°. The flaw orientations can be seen in Figure 8. As seen in Figure 9, the biggest response is obtained from the reflection off the SDH. Somewhat unexpectedly however, the maximum amplitude for all three planar defects is the same. The length over which the planar flaw can be easily detected differs as shown in Figure 9. Because of the difficulty manufacturing a mid-wall planar defect, there are no experimental results to compare to the simulation results. Most likely, the curvature of the weld has affected the detectability of the planar flaws.

To determine the effects of weld contour on detectability of planar flaws the weld contour was changed from concave to flat. The flaw response from the same SDH and planar flaws was compared and evaluated. As originally expected, the maximum amplitude is obtained from the SDH, the next largest is from the planar defect oriented perpendicular to the ultrasonic beam and the smallest amplitude is from the planar defect oriented parallel to the sound beam. Based on the simulation results, demonstrated in Figure 10, the defect response from the planar flaw oriented parallel to the ultrasonic beam is indistinguishable from background noise, and therefore would go undetected unless additional scans are performed.

To further bound the detectability of lack of fusion, additional simulations at the maximum and minimum weld reinforcement could be performed. The size and location of the defects could also be varied. If the phased array transducer used was not able to easily detect these flaws, then the properties of other transducers could be modeled in an effort to determine the most effect transducer and delay laws for this inspection.

**Conclusion**

Using the UT module of CIVA simulation software, NASA was able to create a virtual part made of steel, place a side drilled hole (SDH) in the part, create a 32 element phased array transducer where only 16 elements are used at a time, place this transducer on the part, and see how the simulated defect response compares to the experimental defect response. After validating the effectiveness of CIVA, additional defects and defect angles were analyzed, as were changes in the weld contour on detectability of the flaws. CIVA allowed the user to determine how these variances in allowable parameters such as weld contour, would affect the detectability of rejectable defects (in this case lack of fusion).

**Bio**

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Ms. Schumacher holds a Bachelor of Science degree in Mechanical Engineering and a Master of Science degree in Industrial Engineering from Rutgers University. Currently she supports CIVA NDT simulation software, including training of new users. Prior to Magsoft, she was a Senior Quality Assurance Engineer for Bechtel Corporation specializing in NDT (PT, MT, UT, RT) and was qualified as a 250-1500-1 NDT Examiner in these methods. Her NDT expertise includes providing CIVA technical support, training NDT to internal and external personnel, and assisting in the NDT portion of 3rd party vendor audits. She is a co-recipient of the 2003 Bechtel Plant Machinery, Inc. General Managers Award.

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