THE SIMSUNDT SOFTWARE AND VALIDATION OF THE GRAIN NOISE MODEL.

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Abstract

The main objective of the simSUNDT software is to generate synthetic data to be used within the qualification of NDT personnel. In order to substitute information retrieved from "blind" test pieces, the synthetic data not only has to be verified in terms of reflection and diffraction from the defect but it also has to be realistic to some extent. This has enforced the development of a grain noise model and the possibility to generate data that is compatible with a number of third party off-line analysis softwares.

The simSUNDT program consists of a Windows®-based preprocessor and postprocessor together with a mathematical kernel (UTDefect) dealing with the actual mathematical modeling. The software simulates the whole testing procedure with the contact probes (of arbitrary type, angle and size) acting in pulse-echo or tandem inspection situations.

In the present paper this software, with its broad variety of defect types, is briefly described.

Introduction

According to the Swedish Nuclear Power Inspectorate's requirements, in the regulations concerning structural components in nuclear installations, in-service inspection must be performed using inspection methods that have been qualified. These demands on reliability of used NDE/NDT procedures and methods have stimulated the development of simulation tools of NDT. To qualify the procedures extensive experimental work on test blocks is normally required. A thorough validated model has the ability to be an alternative and a complement to the experimental work in order to reduce the extensive cost that is associated with the previous procedures.

An infinite number of variables and possibilities have to be reduced into a limited group of statistically relevant NDT situations. The qualification of inspection systems includes the reliability to detect, locate, characterize and accurately determine the size of defects that may occur in the specific type of component. Despite the fact that the proposed qualification procedure with test pieces is very expensive it also tends to introduce a number of possible misalignments between the actual NDT situation that is to be performed and the proposed experimental simulation. Besides the problems of reconstructing the geometry and material, the fabricated defects also has to be introduced with a verified prescription of its size and NDT characteristics.

Up to this date only a couple of models have been developed that cover the whole testing procedure, i.e. they include the modeling of transmitting and receiving probes, the scattering by defects and the calibration. Chapman [1] employs geometrical theory of diffraction for some simple crack shapes and Fellinger et al [2] have developed a type of finite integration technique for a two-dimensional treatment of various types of defects. Lhémery et al [3] employs Kirchhoff's diffraction theory that enables their model to handle more complex geometries in 3D. In the literature, Gray et al [4] and Achenbach [5] presents overviews of ultrasonic NDT models.

The simSUNDT software (a modification of the SUNDT software [6]) was developed in order to generate synthetic data compatible with a number of off-line analysis softwares.

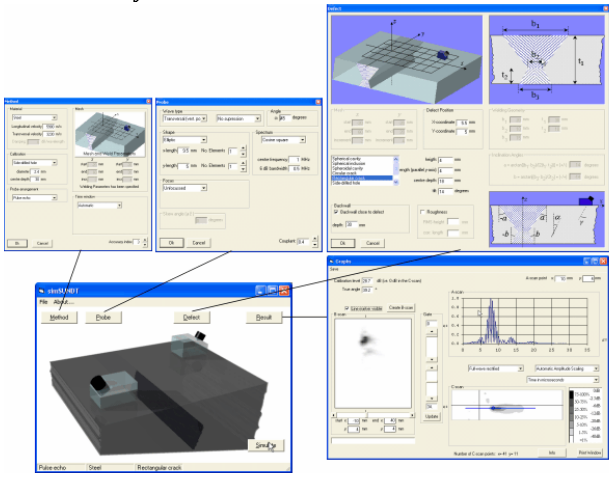

Figure 1 : The environment of the pre- and postprocessor simSUNDT.

The simSUNDT program is a Windows®-based preprocessor and postprocessor together with a mathematical kernel (UTDefect, [7-11]) dealing with the actual mathematical modeling. The UTDefect computer code has been developed at the Dept. of Mechanics at Chalmers University of Technology and has been experimentally validated and verified [8-10]. The model employs various integral transforms and integral equation techniques to model probes and the scattering by defects.

simSUNDT

The simulated test piece is at the present state restricted to be of a homogeneous and isotropic material. The model is completely three dimensional though the component is two dimensional (infinite plate with finite or infinite thickness) bounded by the scanning surface where one or two probes are scanning the object within a rectangular mesh. It is also possible to include a planar back surface, which for the strip-like crack may be tilted, but is otherwise assumed parallel to the scanning surface.

The probe is modelled by an assumed effective area beneath the probe, used as boundary conditions in a half-space elastodynamic wave propagation problem. This enables an adaptation to a variety of realistic parameters related to the probe, e.g. wave type, angle, crystal (i.e. size and shape), focus depth and contact conditions. In addition to the option of specifying the contact conditions it is also possible to suppress the ”wrong” wave component, which enhance the possibility to make an interpretation of the received signal. The receiver is modelled by applying a reciprocity argument by Auld [12]. The pair of probes can be arranged in pulse-echo (single probe), separate (fixt transmitter) or in tandem configuration (TOFD).

Based on information about the scanning mesh and the depth of the defect, the software sets the A-scan range in order to ensure a defect related signal being within the time window. If a certain part of the signal is to be gated out, the A-scan range can be specified.

In order to completely simulate the actual NDT situation, an option of calibration against a reference reflector is included in the software. The calibration procedure with a side-drilled hole is treated exactly, with the use of the cylindrical cavity, while the flat-bottom hole is approximated with an open circular crack.

Four volumetric defects are included: a spherical cavity (pore), a spherical inclusion made of an isotropic material differing from the surrounding medium (slag), a spheroid cavity (pore), and a cylindrical cavity (SDH). Three crack-like defects are included: rectangular crack (lack of fusion), circular crack (lack of fusion) and strip-like crack (fatigue crack). Both the rectangular and the strip-like crack include the possibility to model roughness on the crack surfaces. The circular crack can also be modelled as partly closed, with the degree of closure related to the crack surface conditions (roughness) and the background pressure.

The model of grain noise

A welding procedure does introduce different material properties in terms of anisotropy and grain size enlargement. In a real inspection situation, this will cause backscattered grain noise superposed to the defect signal. In order to simulate this, a rather simple model is introduced. It consists of modelling grain noise by a random distribution of elastic spherical inclusions in a welded geometry where the radii of the inclusions are calculated from a one-dimensional model of grain growth [13-15].

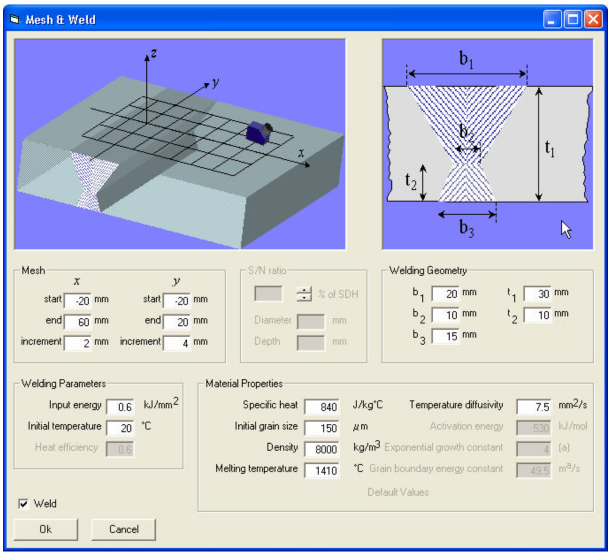

Figure 2 : Specification of the modeled weld

Based on information of the welding conditions the model calculates the extent of the weld heat-affected zone, grain size in HAZ and gives the grain size within the melted zone (see figure 3). Almost all necessary parameters can be deduced from an ordinary welding record and material properties (such as activation energy, exponential growth constant and grain boundary energy constant) are provided as choice of material. This since these parameters is often difficult to measure and hence rarely specified in the literature.

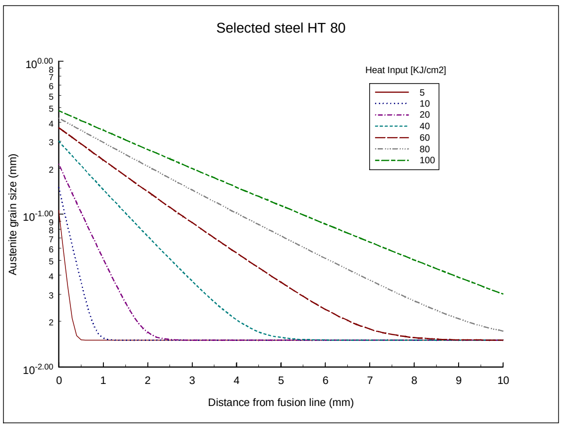

Figure 3 : Relation between heat input and grain size in HAZ for steel HT 80.

The model is based on single scattering theory, i.e. scattering between the grains are neglected. This has been verified to be a sufficient approximation for this kind of NDT application [16]. The defects are randomly distributed in a uniform manner and the number of defects should ensure that the central limit theorem is satisfied. To validate this, a control volume was investigated in order to evaluate a sufficient (volume fraction) number of defects.

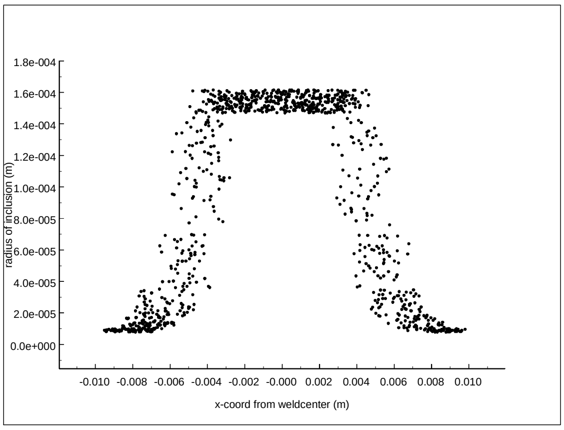

Figure 4 : One example of a distribution of grain size in the weld and HAZ as a function of the x-coordinate (figure 2).

The inclusions (diameter $0.05\mu m$) have the same density as the surrounding material but were provided with slightly deviating wave speeds ($c_i^I = \sqrt{1.2}c_i$, corresponding to 20% increase in stiffness). The volume ($20 \times 20 \times 20mm^3$) was centered 20mm below the scanning surface and a 0° (1MHz, 100% bandwidth and 10mm in diameter) longitudinal probe was used. In order to reduce computational time it is necessary to limit the extension of the grain noise model. Grains outside the heat effect zone are thus not included.

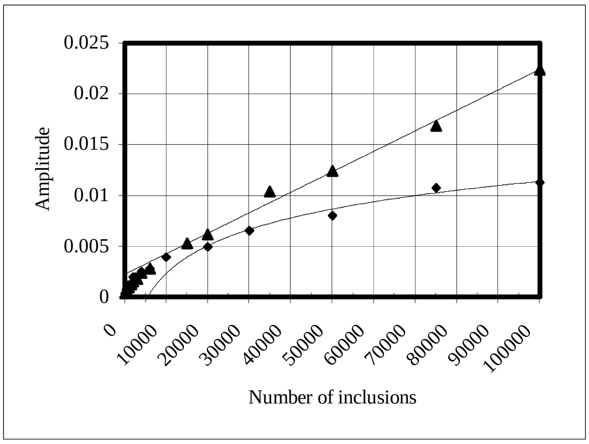

Figure 5 :.Grain noise amplitude as function of number of inclusions (the ▲ marked values are rms-values based on signals from the whole volume while ♦ marked values are from within the volume).

The number of inclusions must therefore be limited to avoid a non-physical discontinuity in the object (grains/no grains). This effect can be deduced from the results in figure 5 where the increase in signal response from the whole volume becomes almost linear with the number of defects. The tendency for the increase in signal response from within the volume instead develops into a logarithmic one.

A numerical example

In order to illustrate the effect of the grain noise model three numerical simulations of realistic NDT situations are included. In all simulations the defect is a spherical cavity with a diameter of 2mm and situated 10mm below the scanning surface (x = 5mm and y = -5mm in figure 2). This choice of defect makes the interpretation of the received signal easier since it doesn't include any diffracted contributions. The unfocused (45°) transversal probe is acting in pulse-echo mode collecting signals within the mesh found in figure 2. The same weld (weld parameters specified in figure 2) and material properties (C_L = 5900 and C_T = 3230m/s) are used in all the calculations and the amplitude of the grain noise model are not prescribed (i.e. not calibrated against a side drilled hole) in any of the simulations.

The results are visualized as A-, B- and C-scans in figure 6-8. The axes in the C-scan are predefined by the mesh in the preprocessor (the x- and y-axis are indicated with lines) and the amplitude range from 0dB down to -40dB. The maximum amplitude in the C-scan corresponds to the calibrated value visible in the upper left part of the window. In all simulations a side drilled hole was used as a reference (diameter = 2.4mm and depth = 30mm). The B-scan is defined by indicating a line in the C-scan and setting the time window with the time gate option. The current position for the presented A-scan is indicated in the C-scan by a blue circle along the B-scan line and in the B-scan by the scroll bar.

The 1MHz probe used in the simulation (in figure 5) has been changed to a 2MHz in figure 7 (the bandwidth of the probes are prescribed to 50%). The increase of frequency also gives an increase of the grain noise. This effect is expected since the wavelength is reduced. The defect is also more detectable in the C-scan found in figure 6 than the corresponding one in figure 7. The maximum signal response from the defect is reduced from 2.3dB (above reference level in figure 6) down to about 60% of the maximum value in the C-scan in figure 7. This corresponds to about 0.5dB (i.e. $\delta = \delta_{cal} + \delta_{graph}$)

below the reference level. In figure 8 a back surface has been incorporated which increase the scattering amount from the grain noise model and as can be deduced from the C-scan, it also extents its presence in the C-scan. The defect is actually no longer detectable either in the C-scan or in the A-scan.

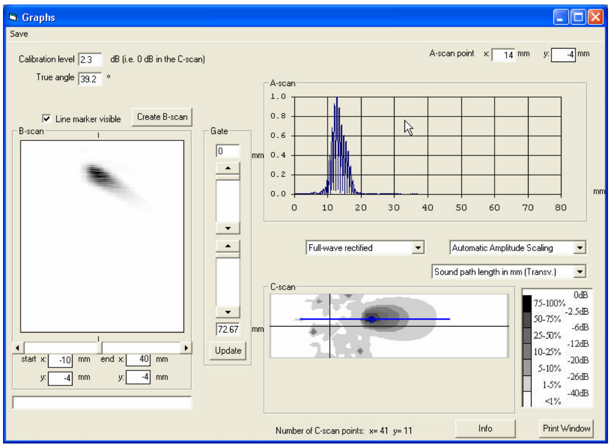

Figure 6 : Defect signal and the influence of the grain noise when a 1MHz probe is used (pulse echo).

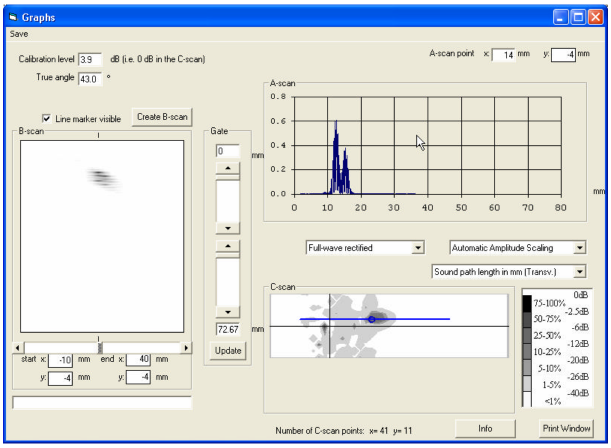

Figure 7 : Same as in figure 6 but with a 2MHz probe (pulse echo).

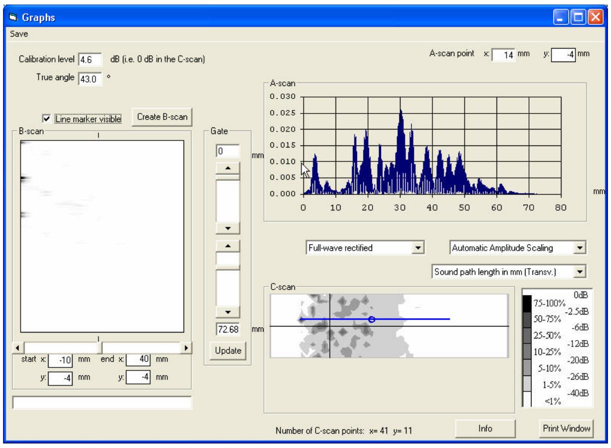

Figure 8 : Same as in figure 7 but with a back surface situated at a depth of 30mm.

References

[1] R.K. Chapman, “A System Model for the Ultrasonic Inspection of Smooth Planar Cracks”, J. Nondestr. Eval. 9, 197-211 (1990).

[2] P. Fellinger, R. Marklein, K.J. Langenberg and S. Klaholz, "Numerical Modelling of Elastic Wave Propagation and Scattering with EFIT-Elastodynamic Finite Integration Technique, Wave Motion 21, pp. 47-66, 1995.

[3] A. Lhémery, P. Calmon, I. Levær-Taïbi, R. Raillon and L. Paradis, “Modeling Tools for Ultrasonic Inspection of Welds,”, NDT & E International 33, pp. 499-513, 2000.

[4] J.N. Gray, T.A. Gray, N. Nakagawa and R.B. Thompson, in Metals Handbook 17 p. 202, ASM International, Metals Park, Ohio, 1989.

[5] J.D. Achenbach, Evaluation of Materials and Structures by Quantitative Ultrasonics, Springer, Wien, 1993.

[6] H. Wirdelius, SKI Report 00:29, Stockholm, 2000.

[7] A. Boström, and H. Wirdelius, “Ultrasonic probe modeling and nondestructive crack detection” J. Acoust. Soc. Am. 97, pp. 2836-2848, 1995.

[8] A. Boström, SKI Report 95:53, Stockholm, 1995.

[9] A. Boström and P-Å. Jansson, SKI Report 97:28, Stockholm, 1997.

[10] A.S. Eriksson, A. Boström and H. Wirdelius, SKI Report 97:1, Stockholm, 1997.

[11] P. Bövik and A. Boström, “A model of ultrasonic nondestructive testing for internal and subsurface cracks”, J. Acoust. Soc. Am. 102, pp. 2723-2733, 1997.

[12] B.A. Auld, “General electromechanical reciprocity relations applied to the calculation of elastic wave scattering coefficients”, Wave Motion 1, pp. 3-10, 1979.

[13] H. Ikawa, H. Oshige, S. Noi, H. Date and K. Uchikawa, “Relation between welding conditions and grain size in weld-heat affected zone”, Trans. of the JWS, vol 9, no. 9, 1978.

[14] H. Ikawa, S. Shin, H. Oshige, “Grain growth of commercial-purity nickel, copper and aluminium during weld thermal cycle”, Trans. of the JWS, vol 23, no. 1100, 1973.

[15] H. Ikawa, H. Oshige, S. Noi, S. Kanda, “Calculation of grain size in weld-heat affected zone using heat conduction equation”, Trans. of the JWS, vol 9, no. 1, 1978.

[16] R.B. Thompson and F.J. Margetan, “Use of elastodynamic theories in the stochastic description of the effects of microstructure on ultrasonic flaw and noise signal”, Wave Motion 36, pp. 347-365, 2001.