CHARACTERIZATION OF NOISE IN AUSTENITIC STAINLESS STEEL

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INTRODUCTION

When ultrasonically inspecting austenitic stainless steel, the objectives can be viewed as a requirement to locate, size, and classify anomalies within the austenitic stainless steel material. Most ultrasonic inspections are carried out using "A-scope techniques." These techniques work well when used by a diligent and experienced operator. With the advent of two major subsystems: (1) a high-speed data-acquisition and imaging system, and (2) an automatic remotely controlled robotic scanning system. The limitations and character of such inspection becomes more system dependent, which can be readily demonstrated. Today's ultrasonic equipment can be used without an immersion tank and without manual assistance to reliably couple ultrasound to the part under inspection. The use of automatic scanners and associated techniques permits data to be acquired with highly repeatable results.

The purpose of this paper is to identify various significant sources of error that occur during the inspection of austenitic stainless steel, and to define how these sources of error influence the location and classification of targets. Those sources of ultrasonic subsystem error in target location include grain scattering and attenuation errors in beam position, target characteristics, transducer beam-position errors, encoder errors, anomalistic intermediate surfaces, the presence of multiple targets and transducer sidelobes. Target location error will result because of electronic noise, which is easily removed by averaging.

Target classification is also a major concern. A target will be treated in this paper as a signal-pattern recognition problem and location problem. The classification will be limited by the uniqueness of the target and the ultrasonic subsystem errors. The target characteristics used are those predicted by the fracture mechanics models.

This work was carried out using the EPRI/Amdata scanning and data-acquisition imaging system, known as the IntraSpect imaging system, together with the AMAPS scanner. The search units used for these efforts include a conventional hardshoe transducer and a booted search unit. This system is shown in Figure 1.

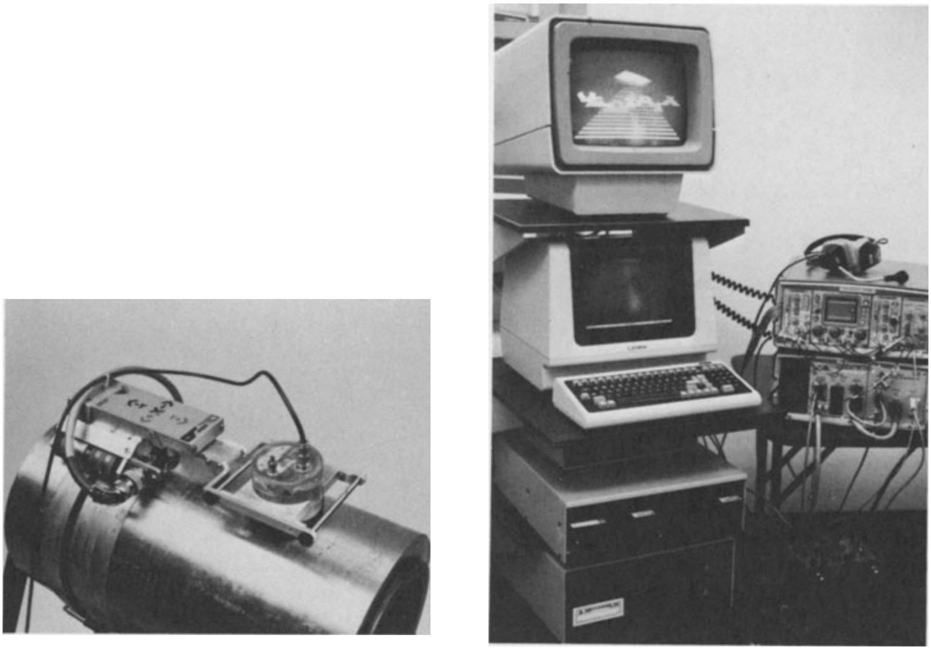


Image Display, Control Terminal and IntraSpect Processor Mounted on Standard On-Site Instrument Cart

AMAPS Scanner and Search Unit Mounted on a Test Pipe

Figure 1. IntraSpect Imaging System and AMAPS Scanner

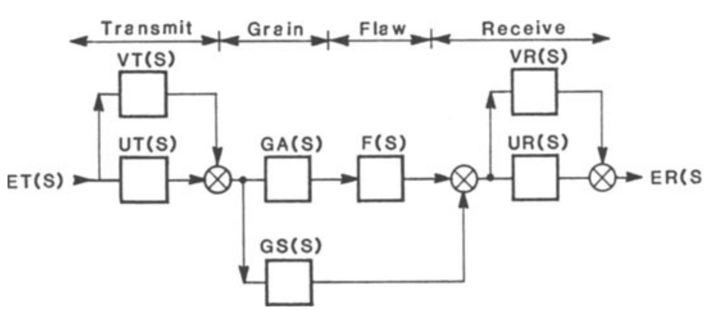


Figure 2. Ultrasonic Instrumentation Model

PIEZOELECTRIC INSTRUMENTATION

Any system analysis of an inspection system requires that a model of the ultrasonic system be developed. Figure 2 shows a model of the transmit portion and the receive portion of the piezoelectric instrumentation. The grain and flaw characteristics are also included in that model. The excitation voltage ET[S] represents the pulser input to the transmit portion of the piezoelectric search unit. UT[S] represents the desired characteristics of the piezoelectric transducer, and BT[S] represents the anomalistic performance of the transducer (such as the radial modes of vibration of the transducer). The grain is represented as GA[S] for the absorption and GS[S] for the back scatter. The flaw of F[S] represents the signal characteristics of a flaw, the receiver portion is modeled similar to the transmit. The physical limitations of the transmit and receive piezoelectrics are the key to system performance.

FLAW TARGET CHARACTERISTICS F[S]

In practice, man-made types of target responses commonly include EDM notches, flat-bottomed holes, and side-drilled holes used in calibration. Naturally occuring models of these targets include thermal and stress-corrosion cracks (which are surface breaks), material interfaces, and inclusions in grain and dendritic structure.

The response characteristics F[S] for the planer defect has been studied by Auchenbach, and Figure 3 shows the model and its frequency characteristics.(1) The significance of Figure 3 is that the spectra of the received return signals is increased with frequency (or K[S] = F[S]. Figure 4 shows the frequency spectra obtained from a crack tip. In this case, the tip produces much lower amplitudes and a fairly strong high-low frequency characteristic. Due to the linear nature of these target responses, the combination of corner and tips may be found by using super-position theory to determine the composite frequency response.

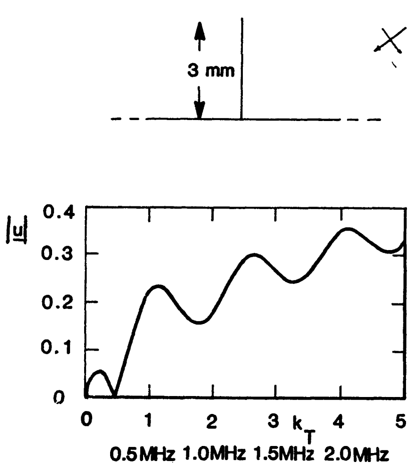


Figure 3. Corner Reflector Frequency Spectra

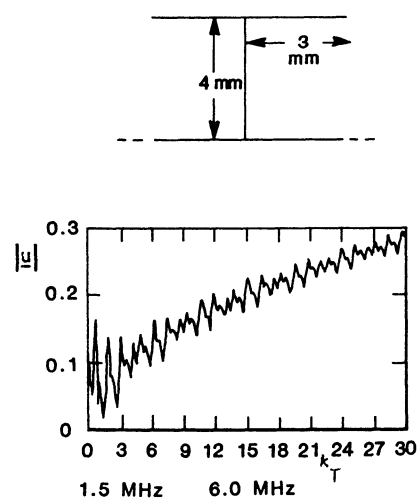
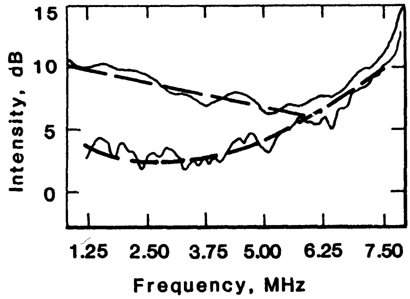


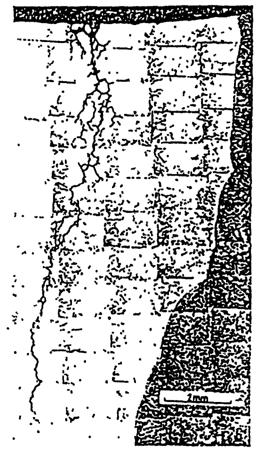
Figure 4. Tip + Corner Frequency Spectra



Comparison of Scattering from Grains and IGSCC, MHz

Dotted lines show interpretation of Rayleigh and non-Rayleigh components.

Figure 5. Grain Scattering Effects



Metallographic Cross Section of IGSCC in HAZ of 304 SS Weld Area

Figure 7. IGSCC Dimension

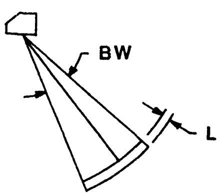


Figure 6. Grain Averaging Along the Direction of Propagation

GRAIN SCATTERING

Grain scattering has been measured in the laboratory and models built to quantitatively predict effects of grain scatter. In Figure 5, Beller results show that the effects of grain scattering in austenitic stainless steel are fairly flat with frequency up until about 5 MHz (at which time, these increase at an λ^4 exponential rate).(2)

Figure 6 is a sketch of a transducer and a beamwidth (BW) along which a spherical wave is propagating having duration L. Newman, et al, showed that the amplitude of the grain is proportional to L.(3) Typically, the grain size in stainless steel is between 0.1 mil and 1 mil (Figure 7). Therefore, the total volume of the total number of grains in a representative volume would be on the order of 10^5 to 10^8. The output from the transducer will vary depending on the transducer beamwidth and pulse length.

PULSE GRAIN AVERAGING

In this model for grain response, it can be presumed that the grain structure is either regular or irregular. If it's regular, the improvement will be a linear function pulse length; and, if it's irregular, the improvement in signal-to-grain estimates will be proportional to the square root of L. The use of pulse length to separate grain from target requires broad-band transducers, which presently are being utilized for this effort.

GRAIN AVERAGING SPATIALLY

The grain response can also be averaged by spatially moving the probes so that a new grain volume is sampled with the same target characteristics. There are several restrictions that need to be observed: (1) the target response will not change with the angular changes, and (2) the grain statistics must be established and physical motion sufficient to assure a proper sample is computed. The distance that the probe position must be moved has not been developed completely. The work is presently in progress to develop these relationships.

GRAIN FREQUENCY CHARACTERISTICS

The grain response characteristics for the models presented can be represented as the product of GS[S] and the transducer response U[S]. The grain response is broad-band spectra and constant amplitude with frequency (see Figure 5) while the transducer bandpass U[S] is relatively narrow band. The resulting spectra for GS[S] U[S] shows no particular advantage in selecting one frequency or another below 5 MHz, because of grain scattering characteristics, except that bandwidth should be maximized to accomplish minimum pulse length considering the constraint of material attenuation and the electronic noise limitations.

The signal (flaw) characteristics developed by Achenbach show that the signal is proportional to frequency. The mose important result is that the time response of the signal will exhibit higher frequency characteristics, because of the target response, than is observed from the grain response.

SURFACE CONDITIONS

Surface condition effects are organized into three conditions. Condition 1 classifies surface variations where the beam width is equal to or less than the roughness. Examples of these situations include diametrical shrink, pipe welds, elbows, elbow radiuses and safe ends in pipes. The effects are shown in Figure 6. These effects are readily correctable.

Condition 2 represents variations where the roughness is much smaller than the beam width. These conditions cause a loss in resolution as well as signal level. A criteria for limiting the amount of degradation is shown in Figure 9 where the location of the flaw in

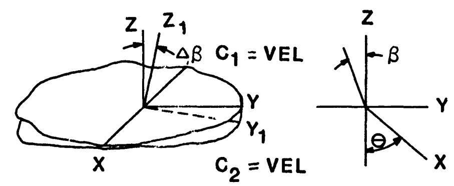


Figure 8. Correction for Surface Orientation

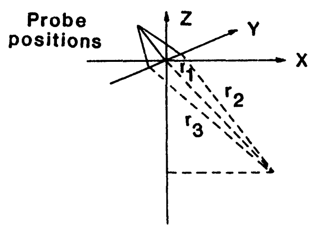


Figure 10. Grain Averaging Spatial

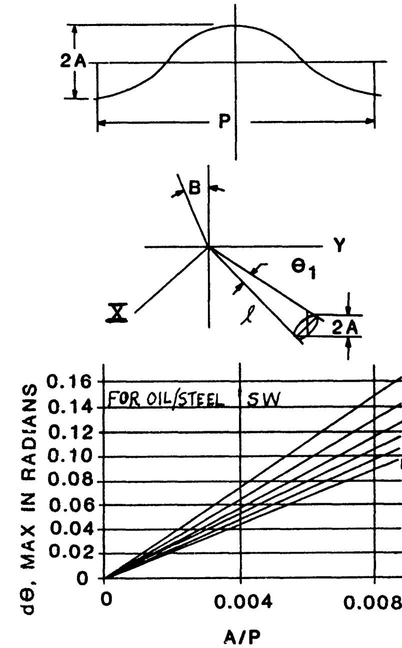


Figure 9. Criteria for Surface Finish

the material under test is shown as a function of the peak-to-peak surface roughness and the surface distance between peaks.

Surface Response

The effects of the surface response can limit the ultrasonic subsystem performance unless highly damped transducers are utilized. Since high gain is required where material attenuation limits performance, it becomes especially important to carefully select the transducer beamwidth and transient response. Spatial averaging, using the a priori knowledge of target characteristics to determine the averaging features are important. An example where spatial averaging is utilized to improve the accuracy of observations in the Y direction is shown in Figure 10. (4)

SUMMARY

Modeling physical limitations and the development of techniques that can improve the ability of an ultrasonic system to locate and classify targets can be readily improved using relatively straightforward techniques. The use of an imaging system such as the IntraSpect system has been used to demonstrate the benefits of such corrections. It is noteworthy that nearly all corrections are largely signal level independent, while spatial relationships are significant. Spatial relationships are critical when locating, sizing, and classifying anomalies in stainless steel.

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