DETECTION AND MEASUREMENT OF DEFECTS IN BUTT WELDS

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INTRODUCTION

Sheet metal is produced in rolling mills in the form of coils of finite length. However, stamping and forming plants use these coils as a continuous stream of material to produce all the products we take for granted throughout society. Thus, the middle of this production chain must contain a "shock absorber" where the end of one coil is welded to the beginning of another. If this weld fails, expensive damage can result and productivity is definitely slowed down. Figure 1 shows this process in a schematic form and indicates that the welding is performed in between two clamps that hold the ends of the coils together while the weld is made. Special storage sections are included in the line so that the downstream flow of metal is not interrupted during the time in which the upstream flow is stopped for the weld. This welding machine not only forms the joint but knives clean off the weld bead on the top and bottom of the plate so that a smooth surface is presented to the downstream machines.

During the time that the plate is held fixed immediately after "scarfing" represents an excellent time to perform a rapid inspection of the weld but the space between the clamps is confined and the metal is hot so conventional ultrasonic or eddy current techniques are severely restricted. If the ultrasonic transducer could be scanned across the plate at a location outside the clamps where the metal is cool and flat there would be considerable simplification in implementation of an automatic inspection device.

This paper describes feasibility tests of an EMAT-based inspection concept in which the EMAT is located outside the clamp as shown in Fig. 1 and inspects the weld with an ultrasonic plate wave mode that propagates through the clamped region to and from the weld. A pulse-echo technique indicates the presence of weld flaws and quantitative measurements of the reflected echo are made in order to guide the accept/reject decision.

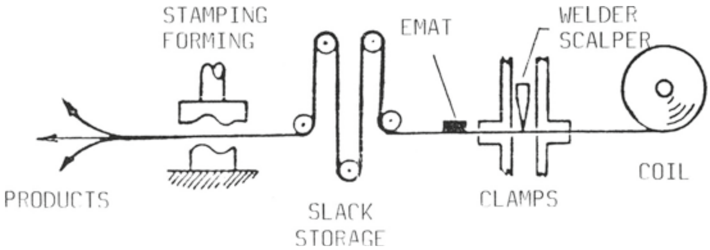

Fig. 1. Schematic diagram of a production line in which sheet metal in the form of a coil is converted into products. The left hand side of the diagram operates continuously while the right side must be interrupted to allow the end of one coil to be welded to the start of the next coil.

EXPERIMENTAL PROCEDURE

EMATs generating the n=0 SH wave plate mode with a wavelength of .25 inches (500 kHz) were used to interrogate the welded joint. The n=0 SH wave plate mode was used because it has several characteristics that make it attractive for butt weld flaw detection:

1. It is independent of plate thickness and therefore one transducer and frequency will operate over a wide range of plate thickness.

2. It is insensitive to fluids (i.e., oil, grease) on the surface of the plate and the plate can even be clamped between the holding jaws of a fixture without introducing undesirable attenuation.

3. It reflects from defects without mode conversion allowing simple interpretation of the reflected signals.

Operating with long wavelengths (long compared to the depth of the flaw) has several desirable features:

1. The reflected signal amplitude increases nearly linearly with flaw depth.

2. Reflected signal amplitudes are less sensitive to flaw orientation and irregularities.

3. Since EMAT signals fall off exponentially with increasing air gap to wavelength ratio, the longer wavelengths make this effect much smaller and therefore the electronic and mechanical parts of the system can be of a simpler design.

An experimental setup was assembled consisting of a Magnasonics Four Channel Unit, a transmitter/receiver EMAT pair, and a strip chart recorder. The transducer arrangement used is shown in Fig. 2. SH waves were launched by the transmitter meander coil EMAT into steel plate samples with a thickness of 0.1 inches. A separate receiver EMAT was placed eight inches away. This allowed the transmitted signal as well as the signal reflected by the flaw to be monitored. Pulsed electromagnets produced the needed magnetic field ($\sim$1500 Oe) for magnetostrictive generation of SH waves. The complete transducer assembly was

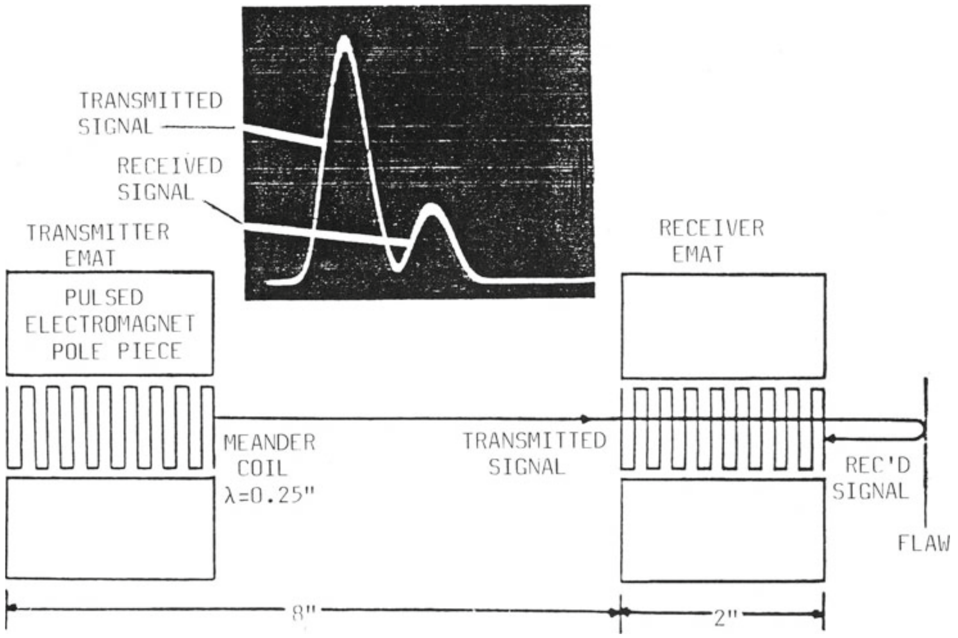

Fig. 2. Configuration of a transmitter/receiver pair of magnetostrictive EMATs arranged to allow the wave amplitude reflected by a flaw to be normalized by the amplitude of the wave transmitted to the flaw. An example of the oscilloscope display of the receiver signal in the area of a flaw is shown in the inset.

mounted on wheels so that it could be easily scanned across the plate. Fig. 2 also shows an oscilloscope photograph of the transmitted signal and the reflected signal from a one-inch long 0.045-inch deep notch.

The four channel unit signal processing electronics contained two gates and thus allowed the peak amplitude of the transmitted signal and the peak amplitude of the echo from the flaw to be measured separately. The electronics could also divide the reflected signal amplitude by the transmitted signal amplitude and produce the ratio A_R/A_T. This ratio eliminates signal variations due to changes in transducer efficiency and provides a quantitative number that can be related directly to the flaw. These peak signal amplitudes and ratios were sent to a two channel strip chart recorder for monitoring.

The electronics were set up to record the amplitude of the transmitted signal on Channel 1 with a vertical scale of 0 to 10V, and the reflected to transmitted signal ratio, A_R/A_T, on Channel 2 with a vertical scale of 0 to 1:2. Fig. 3 shows the strip chart recordings observed when the EMAT pair interrogated the three calibration notches with a receiver EMAT to flaw separation of three inches. (This separation insures that the reflections are well removed from the transmitted signal.)

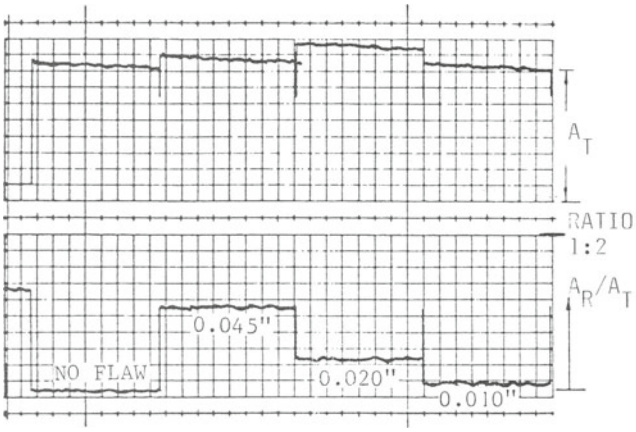

Fig. 3. Example of the strip chart output for a sample containing notches to simulate flaws. The top trace shows the transmitted signal amplitude while the bottom trace is the ratio of the reflected to transmitted amplitudes.

CALIBRATION

Measurements were taken on calibration notches and from the weld samples. Three calibration notches were provided in sample A5-4. The notches were one-inch long and 0.01, 0.02 and 0.045 inches deep. Fig. 4 shows the ratio of reflected to transmitted signal as a function of separation between the receiver EMAT and the flaw for the three notches. Note that excellent signal amplitudes are still present at separation distances of over eight inches. Fig. 5 shows the ratio A_R/A_T plotted as a function of flaw depth with a receiver to flaw separation of three inches. Its linearity over a large range of flaw depths shows that the ratio A_R/A_T can be used as a reliable measure of flaw depth.

EXPERIMENTAL RESULTS

The butt welds were scanned by moving the transducers along the weld line while recording the reflected signals on a strip chart recorder. Because the scanning was done by hand, the horizontal scale is not exactly calibrated as a function of distance across the plate. Figs. 6 and 7 show the results obtained from scanning past "good" and "bad" welds with a receiver EMAT to weld separation of $\sim$4 inches. On each strip chart recording the levels corresponding to the calibration notches have been drawn in as horizontal straight lines.

Qualitatively, the reflected to transmitted signal ratios appear to agree with the weld quality as determined by visual inspection. Small reflections were obtained in welds that appeared good and the largest reflections correspond to welds that appeared to be the worst. The primary cause of bad welds was an overlap of the two sheets and a joint that was not a simple butt weld but a weld between the bottom of one sheet and the top of the other. When an overlap joint is cut back to the original sheet thickness, a wedge-shaped groove is left on the top and bottom surfaces and the welded metal is less thick than the two sheets. Thus, such a joint is weak. The inspection technique described

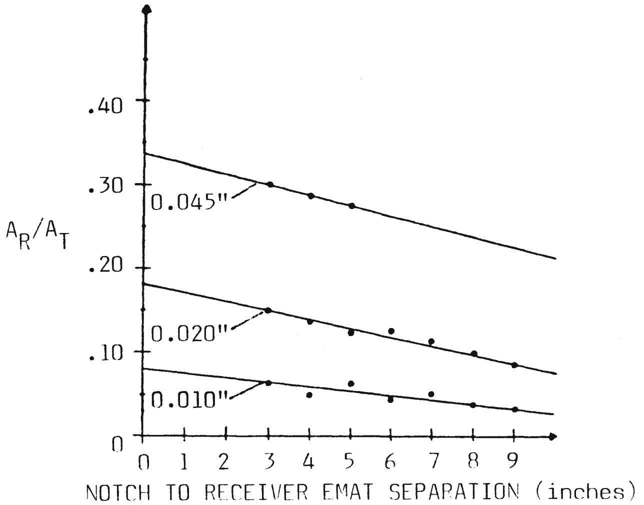

Fig. 4. Graph of the reflected-to-transmitted signal amplitude ratio as a function of notch to receiver separation for notches of three sizes.

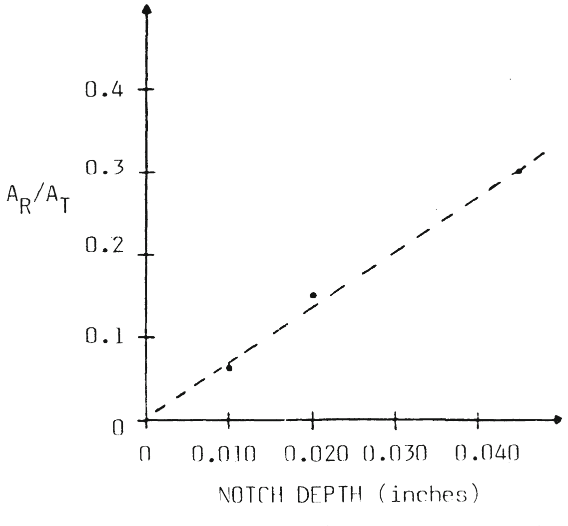

Fig. 5. Graph that demonstrates the linear relationship between signal amplitude ratio and flaw depth.

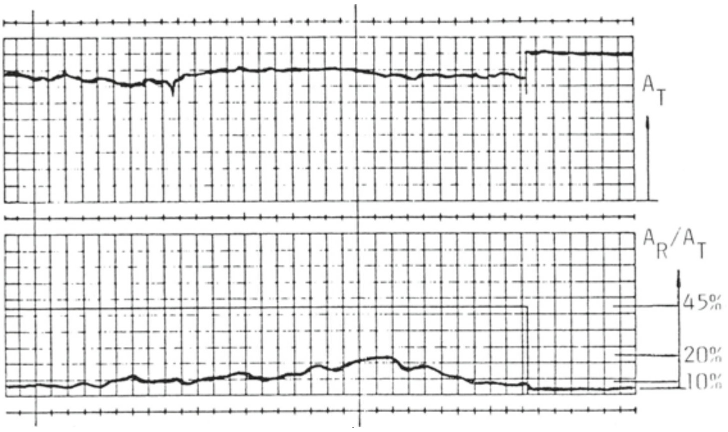

Fig. 6. Strip chart recording from an SH wave scan along a "good" joint between 0.1-inch thick plates. The worst region of this weld generated a value for the reflection ratio A_R/A_T that was characteristic of a 20 percent through wall notch.

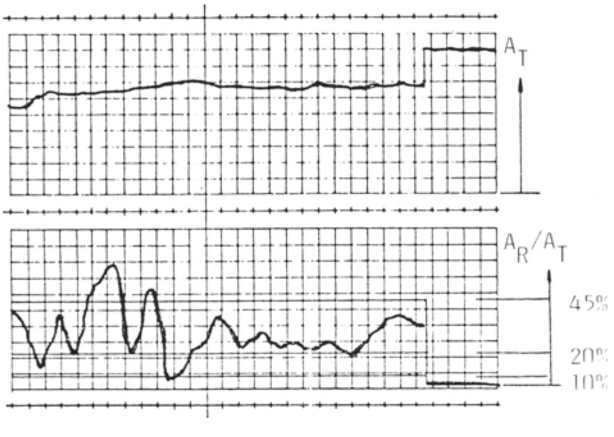

Fig. 7. Strip chart recording from an SH wave scan along a "bad" weld. Most of the weld reflects more signal than a 20 percent notch and in two places the reflected signal exceeds that from a 50 percent notch.

here measures the thickness of the welded region and hence correlates with the strength of the joint.

In order to demonstrate this correlation, the strip chart recordings from each joint were analyzed to determine the location along each weld where the reflected signal was larger than the reflection from a 45 percent notch. These locations were cut out of the sheet sample and the joint was sectioned in a metallographic laboratory. Tracings of the cross section of the sheet in the vicinity of the weld were then prepared. Fig. 8 displays these tracings in columns for the cases in which the reflection ratio was greater than that from a 50 percent notch, for those cases in which the ratio was approximately equal to a 50 percent notch and for the cases with ratios equal to a 25 percent and 10 percent notch. Cross section drawings for the 50, 25 and 10 percent notches are included for comparison. The wavelength of the ultrasonic waves used is also shown in order to provide a reference dimension. (The plate thickness for these experiments was 0.1 inches.) Qualitative examination of the cross sections show that the samples that gave large reflection amplitudes had the largest wedge-shaped grooves near the weld and a smaller cross sectional area of well bonded metal.

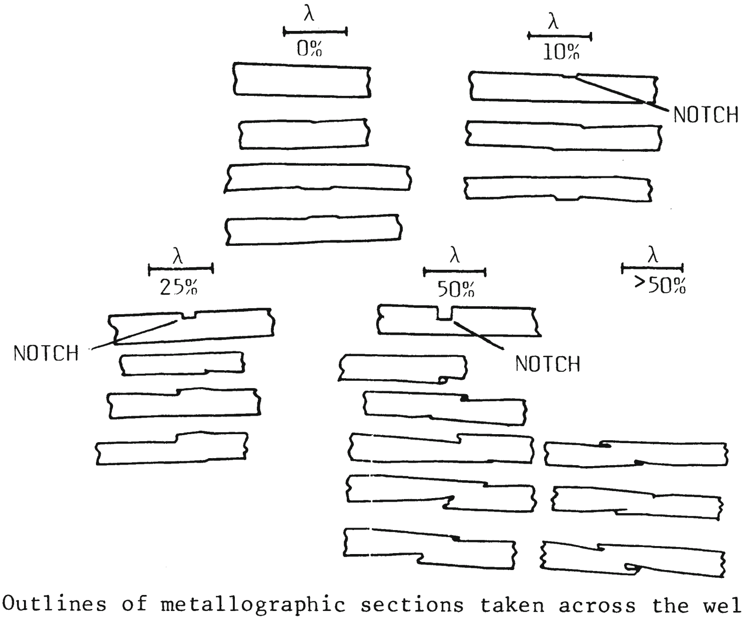

Fig. 8. Outlines of metallographic sections taken across the welded joints. The sections are displayed in columns according to the reflected signal amplitudes that were greater than a 50 percent notch, equal to a 50 percent notch, equal to a 25 percent notch and equal to a 10 percent notch. Those sections that showed reflectivity comparable to no notch are also shown.

CONCLUSIONS

EMATs generating and detecting the n=0 SH wave mode can be used to interrogate a weld line while it is still clamped in the welding fixture.

Signals reflected by the weld line, when normalized by the signal incident on the weld line, show a linear relationship with the fraction of the cross sectional area that is not welded.

Metallographic sections of several butt welds show that strong reflections from the welded joint can be associated with small areas of actual bonding and hence poor strength.