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FEASIBILITY OF EDDY CURRENT  
MEASUREMENT OF FERRITE CONTENT  
IN STAINLESS STEEL WELDS

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U. S. ATOMIC ENERGY COMMISSION  
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Stainless Steels  
Weld Properties

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# FEASIBILITY OF EDDY CURRENT MEASUREMENT OF FERRITE CONTENT IN STAINLESS STEEL WELDS

*Gordon D. Lassahn and Roger L. Moment*

**Abstract.** A phase-sensitive eddy current system was used to measure the presence of ferrite in an austenitic stainless steel matrix. Measurements were made on pressed powder specimens and on a weld in type 304L stainless steel. The data obtained showed that small amounts of ferrite, on the order of 1 to 3%, could easily be detected. Variation in ferrite with position within the weld was also detected with good reproducibility. Absolute values for the ferrite content were not obtained as accurate standards for calibration were not available.

## INTRODUCTION

To circumvent the problem of microcracking in 304L stainless steel welds, a filler metal that forms a small amount of ferrite in the austenite matrix is usually used. In many cases, it is also desirable to limit the amount of ferrite formed to the minimum needed for suppressing microcracks, and this level falls within the range of 3 to 8 volume percent.<sup>1</sup> Many magnetic methods have been developed for detecting ferrite in austenite, but the methods have a precision of about 3 percent at these levels.<sup>1</sup> This work was done to determine whether eddy current measurements can be used to measure the ferrite content of stainless steel welds.

## THEORY

The magnetic permeability of austenite is essentially 1, and that of ferrite is on the order of 2000. If a specimen consists of austenite with many small, roughly spherical regions of ferrite distributed randomly throughout the specimen, then the average permeability of the specimen is approximately

where  $F$  is the volume of all the ferrite divided by the volume of the specimen. If the ferrite is columnar rather than spherical, as is usually the case in welds, the permeability will have a directional dependence determined by the orientation of the column. This directional dependence should then be taken into account in the relation between permeability and ferrite content, but is omitted in this discussion. The main point of interest is that, whether the ferrite regions are spherical or columnar, the permeability of the specimen is strongly dependent on the ferrite content. Permeability measurement should enable determination of the specimen's ferrite content if appropriate standards are used for calibration.

## EDDY CURRENT SYSTEM

Eddy current testing<sup>2</sup> is a nondestructive test method which is sensitive to electrical resistivity, magnetic permeability, and certain aspects of the geometry of the specimen. The eddy current system used in this work was a Kervonics instrument,\* used with a probe having a nominal radius of 20 mils (0.5 mm). In this system, an oscillator causes a sinusoidal current to flow through a simple solenoidal driver coil in the probe (Figure 1). The specimen surface is held against or close to one end of the driver coil. The changing magnetic field created by the driver coil induces current to flow in small loops in that part of the specimen near the driver coil. These current loops are the eddy currents, so called because of their similarity to eddies in turbulent fluid flow.

A pair of pickup coils are positioned inside the driver coil in such a way that the current in the

$$\mu = 1 + 1999 F$$

\*Commercially available from Tennelec, P. O. Box D, Oak Ridge, Tennessee.

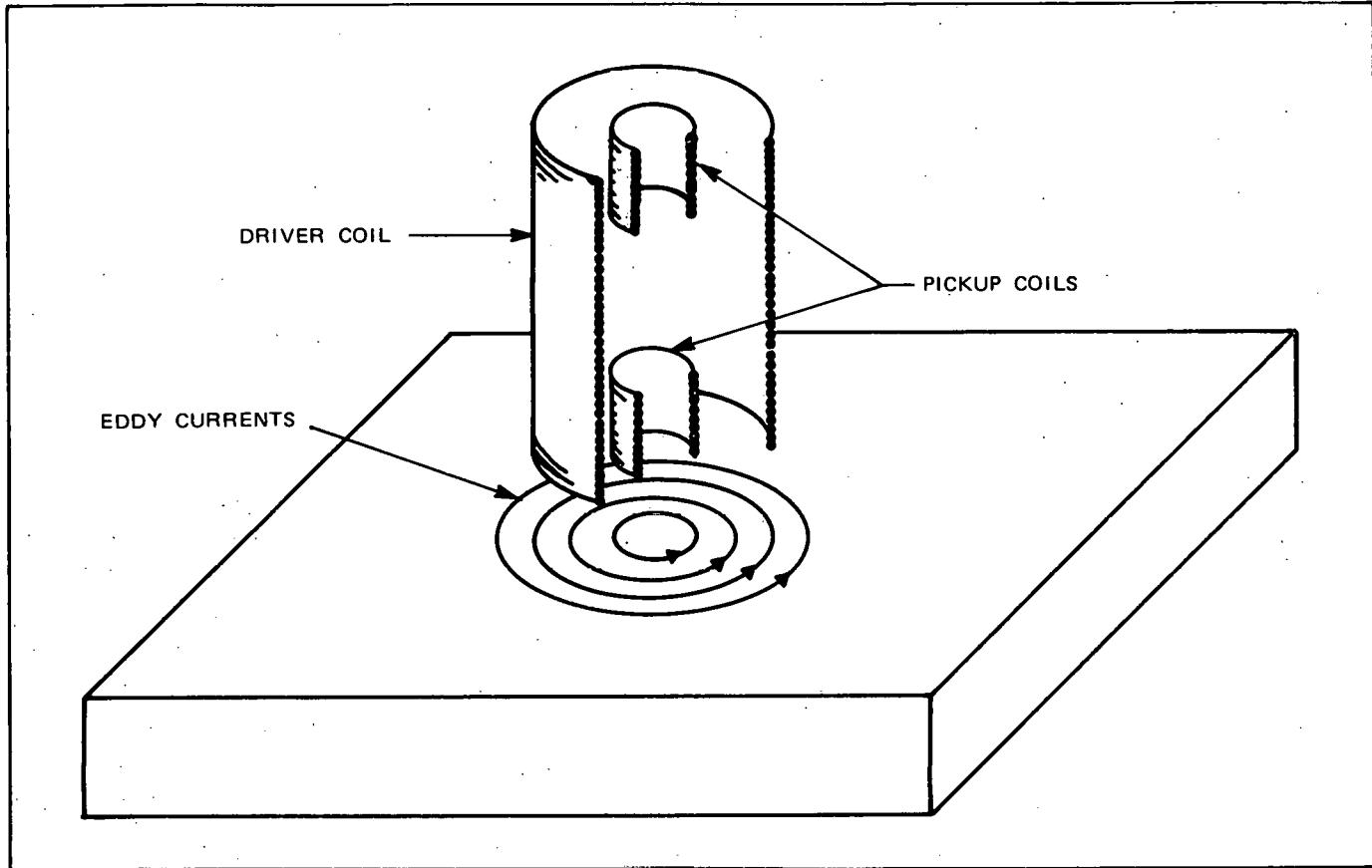


Figure 1. Diagram of Eddy Current Probe.

driver coil does not directly induce voltage in the pickup circuit, but the eddy currents in the specimen do induce a signal in the pickup circuit. This signal is a voltage with the same frequency as the driver current, but with a different phase. The phase difference is measured and displayed by the instrument, and it is this phase reading that is used to derive information about the permeability, conductivity, and geometry of the specimen. The particular instrument used in this work was adjusted to display the phase to the nearest 0.01 degree, and it had a reproducibility of about  $\pm 0.02$  degree.

#### CALCULATED SENSITIVITY

The response of the system was calculated for stainless steel specimens with electrical resistivity of

$72 \mu \Omega \text{ cm}$ . These calculations were made using a computer program published by Simpson, et al.,<sup>3</sup> which solves the electromagnetic field boundary value problem numerically. The calculated phase reading versus permeability is shown in Figure 2. The previously mentioned relationship between permeability and ferrite content was used to construct the "Ferrite Content" scale in Figure 2. For ferrite content near 5%, the slope of the curve is about 0.5 degree per 1% ferrite content. If the phase-measurement error is taken to be  $\pm 0.02$  degree, this implies that the ferrite content can be measured to  $\pm 0.04$  percent.

This estimate of the accuracy of the eddy current method depends on the particular relation previously specified between permeability and ferrite content; however, the general utility of the eddy current method does not depend on the accuracy

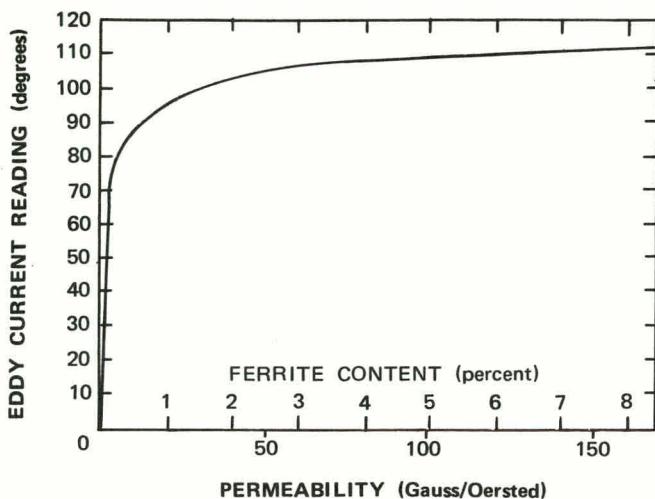


Figure 2. Calculated Eddy Current Reading versus Sample Permeability.

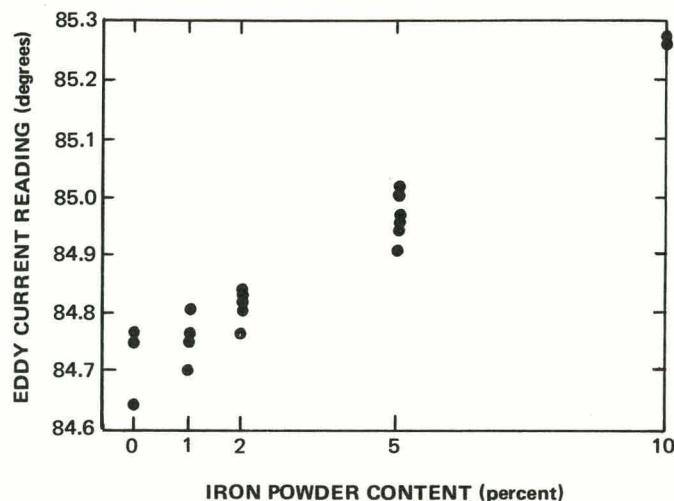


Figure 3. Eddy Current Readings versus Iron Powder Content for the Compacted Samples.

of that relation. All that is required is that the permeability be some definite function of ferrite content, with the function having a finite and non-zero slope. It is necessary, however, to use a set of specimens of known ferrite content to determine experimentally what this function is.

## EDDY CURRENT MEASUREMENTS

Compacts were pressed from type 304L stainless steel powder containing various amounts of iron powder. These specimens were not sintered and thus had much lower electrical conductivities than cast metal. Eddy current readings versus iron content for these samples are shown in Figure 3. These measurements should be used only to give an indication of the general shape of the calibration curve for ferrite in austenite. Scattering of the points in the figure is due to differences in the readings at different points on the specimens. At any given point, the readings were reproducible within 0.04 degree, which is accounted for by surface roughness and scratches, and by variations in probe pressure and position. From these results it appears that eddy current testing can be sensitive enough to detect small variations in ferrite content.

Additional measurements were made on a metallographically polished section of a weld in type 304L stainless steel. Type 308L filler wire was used in the weld. The resulting ferrite content for this weld should be in the range of 3 to 11 volume percent.<sup>4</sup> Measurements were made along a line passing through the weld zone as indicated in Figure 4. The two darker regions on either side of the weld center of Figure 5, in which the ferrite appears most concentrated by metallographic examination, give significantly higher readings on the eddy current equipment. The readings versus position along the line are plotted in Figure 6. We can conclude from this data that the eddy current technique is capable of easily detecting variations of ferrite within a weld zone. In this case, the readings varied between 50 and 127 degrees. The probable error for a single reading was estimated to be well under one degree. While the feasibility of the technique is thus demonstrated, the lack of accurate ferrite standards to calibrate the instrument prevents conversion of the data to absolute values of ferrite content.

## SPATIAL RESOLUTION

The depth of penetration of the eddy currents into the specimen (that is, the depth of the region

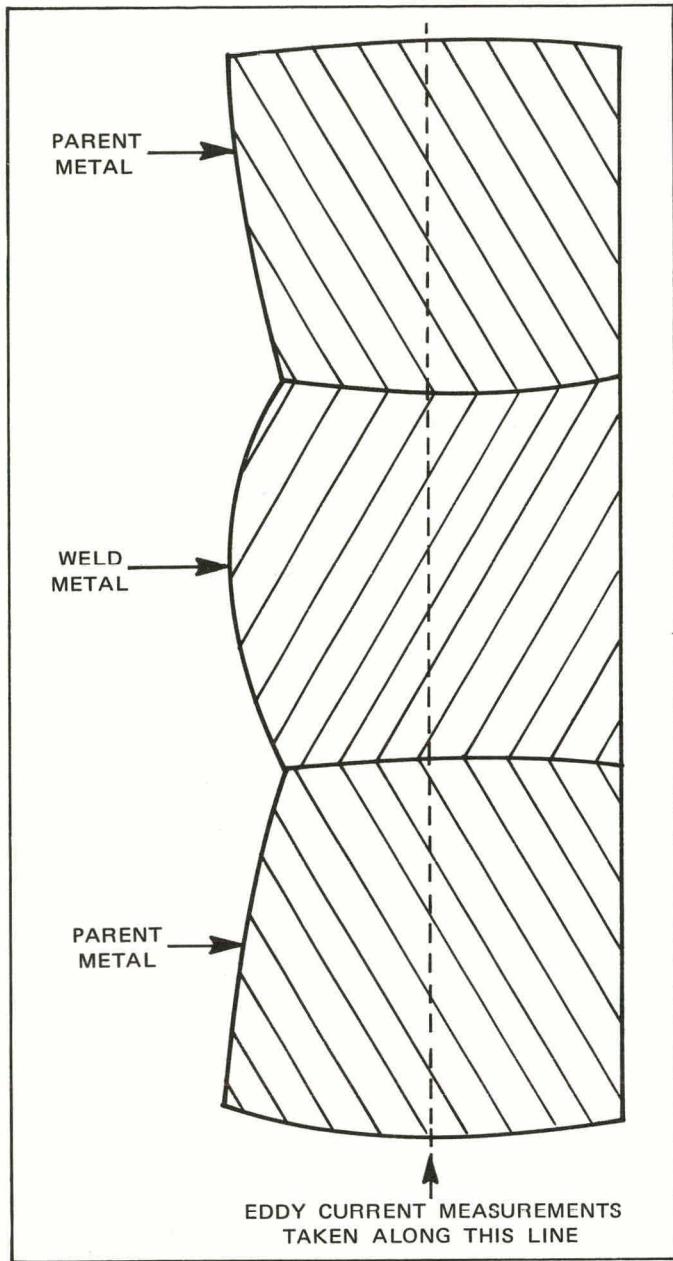


Figure 4. A Sketch of the Weld Cross Section.

sampled by the eddy current system) can be adjusted by changing the operating frequency of the system. The width of the region sampled depends more on the width of the probe used. There are probes much wider than the one used in this work, but it would be very difficult to make a probe significantly narrower.

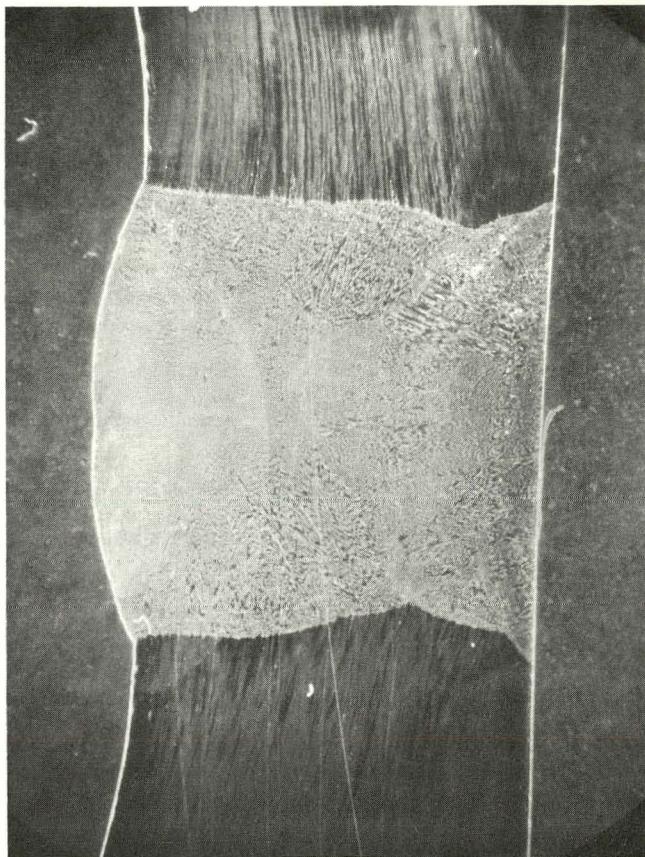


Figure 5. Photomicrograph of the Weld Cross Section. 9X.

As an indication of how wide an area was sampled by the probe used in this work, measurements were made at 0.1 mm intervals as the probe passed across the interface between the parent metal and the weld metal. Figure 7 shows a graph of eddy-current reading versus position. Ninety percent of the reading change occurred in an interval about 0.75 mm wide. If it is assumed there was a sharp transition from pure austenite to austenite with ferrite at this interface, then 0.75 mm is a reasonable representation of the spatial resolution of this probe. If the transition region is somewhat diffuse, as is suggested by Figure 5, then the spatial resolution might be less than 0.75 mm; however, consideration of the electro-magnetic field distribution around the probe suggests that the resolution is probably not much better than 0.75 millimeter.

In addition to this spatial resolution, it is necessary to consider practical limitations imposed by the physical size of the probe. Probes of this type are

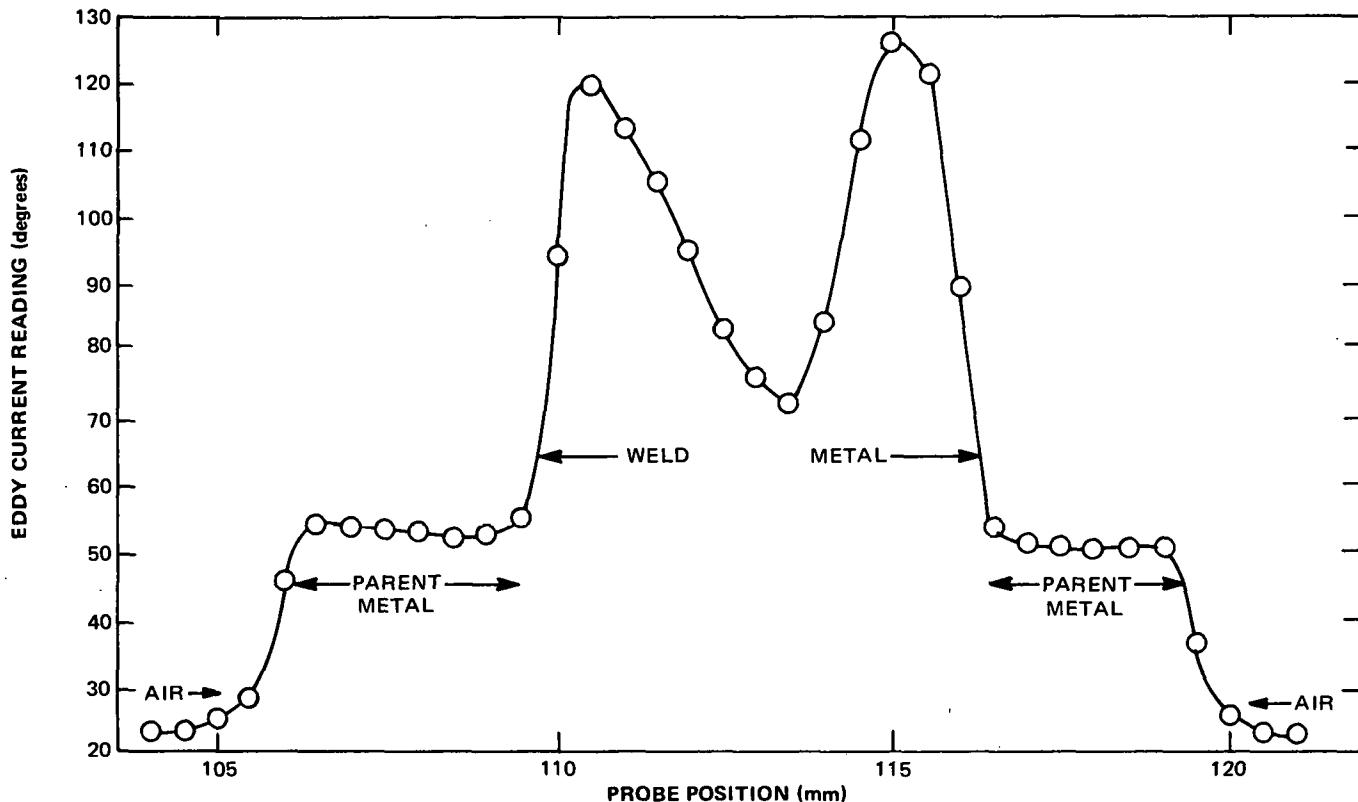
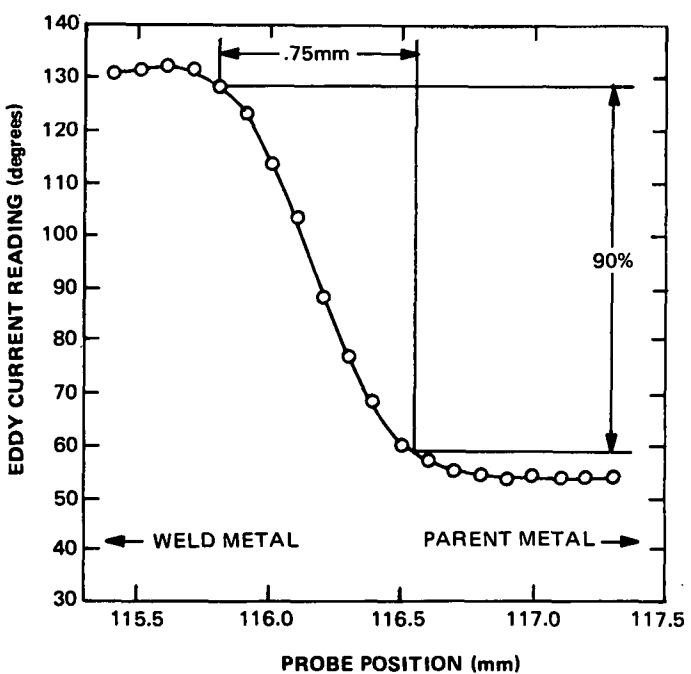


Figure 6. Eddy Current Reading versus Position Across the Weld Cross Section.

Figure 7. Eddy Current Reading versus Position Across the Austenite-Weld Interface.



commercially available\* in cylindrical housings as small as 3.2 mm in diameter. Good stability and signal-to-noise ratio require that the end of the probe be within about 0.1 mm of the specimen surface, which implies that this eddy current technique can not be readily applied to concave surfaces with a curvature radius less than about 13 millimeter.

## CONCLUSIONS

This study indicated that eddy current testing can be used to measure ferrite content in stainless steel welds. Calculations indicated that the potential accuracy of the ferrite content determination is about  $\pm 0.04\%$ , but this has not been confirmed experimentally because no standards with known ferrite content were available. The experimentally determined spatial resolution was about 0.75 millimeter.

\*Sold by Tennelec, P. O. Box D, Oak Ridge, Tennessee.

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