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SUBJECT: Eddy-Current Measurement of Clad Thickness on Mark X MTR Fuel Plates

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Introduction

At the request of the Alloy Preparation Group, the Nondestructive Test Development Group investigated the feasibility of determining the clad thickness on Mark X MTR Fuel Plates. As the use of induced eddy-currents was considered to be the most promising approach, a prototype instrument and probe coil utilizing this principle was developed to measure clad thickness. The results of the investigation conducted with this instrument indicate that the clad thickness of this type fuel plates can be measured to within ± 0.001 in.

The Mark X MTR Fuel Plates are composed of a 0.022-in. nominal thickness core of 48 wt per cent aluminum-uranium alloy clad with 0.020-in. nominal thickness of 6061 aluminum alloy. The deformation characteristics of the core and clad alloys are not the same; hence, during the rolling of the plate to a uniform thickness the deformation of the core is frequently non-uniform. The result is a thick section at each end of the core, the longitudinal cross section of which resembles a "dog bone". As the plate is of uniform thickness, the clad over the thick sections at the extremities of the core is, of course, much thinner than the 0.020-in. nominal thickness. The possibility of from 0.003 to 0.005 in. of corrosion necessitates the location and rejection of fuel plates which have excessive "dog boning".

Experimental Procedure

To facilitate the investigation of this problem and determine the best operating parameters for the eddy-current test, a prototype instrument was constructed as indicated in the block diagram of Fig. 1. Since the original purpose of this instrument was to determine the best coil design and optimum operating frequency, it is more complex and contains more controls than would be required on a production inspection instrument.

Fig. 1

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The instrument consists of a variable frequency oscillator which supplies low distortion alternating current to the probe coil through an isolating network, and to a balancing network. The isolating network prevents the presence of the probe coil from affecting the voltage supplied to the balancing circuitry, and supplies the probe coil with current of constant amplitude. Since the probe coil current is constant in amplitude, the voltage at the terminals of the probe is directly related to its impedance, which in turn is influenced by the metal specimen in proximity with it.

The balancing network alters the input voltage until it is equal to the voltage of the coil, under same initial test condition, in both amplitude and phase. Any change of the test condition changes the voltage at the coil, in phase or amplitude or both. The difference in the voltage of the coil and of the balancing network is amplified, hence any change in coil voltage causes a meter deflection.

After some experimenting a probe design was determined as shown in the drawing of Fig. 1. The coil consists of approximately 540 turns of No. 40 enameled copper wire in a small, cup-shaped ferroxcube core (Ferroxcube Corporation type 3C ferroxcube). The coil, after connection with the instrument cable, is potted with an epoxy resin into the end of a short length of micarta tubing. This coil assembly is contained in a heavy brass holder which spring-loads the probe against the metal specimen. The use of this mechanism eliminates spurious signals caused by the varying coupling associated with a "hand-held" probe.

The following three considerations were of primary importance in selecting an optimum test frequency:

1. Sufficiently high to sensitively detect the difference between the 6061 aluminum alloy cladding (conductivity = 45 per cent IACS) and the U-Al alloy core (conductivity = 22.8 per cent IACS).
2. Sufficiently low to penetrate the nominal 0.020-in. cladding and detect small changes in its thickness.
3. Sufficiently high that the 0.022-in. core underneath the 0.020-in. clad appears infinitely thick (i.e., no eddy-current penetration through the core).

Twenty kilocycles were determined experimentally to be the optimum frequency satisfying these conditions. Condition 3 is necessary to prevent the clad thickness on the "back side" of the plate from influencing the thickness determination made on the side under surveillance.

Correlation of the meter deflection with the clad thickness was experimentally determined by first adjusting the instrument to read near full scale when the probe coil was placed on a specimen of bare U-Al core and zero when placed on an apparent "infinite" thickness of the 6061 aluminum alloy. Shims of the cladding alloy, varying from 0.003 in. to 0.020 in. in thickness were then placed on the core material and the corresponding meter deflection recorded. This information was plotted in the form of the calibration curve shown in Fig. 2.

Of three Mark X fuel plates furnished by the Alloy Preparation Group for this investigation, only one showed sufficient variation in cladding thickness to warrant a more detailed inspection. This plate was scanned on both sides, each pass of the probe coil overlapping the previous pass to insure complete coverage of the surface. The greater portion of the cladding was indicated to be from 0.017 to 0.020-in. thick. All deviations from this range were marked for later destructive examination.

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Fig. 2 Eddy-Current Signal Calibration Curve for
Mark X MTR Fuel Plates.

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Four of the most significant areas noted during this investigation were sectioned and subjected to a metallographic examination for correlation and evaluation of the eddy-current measurements. Sections 3 and 4 were taken from one end of the plate where the cladding was very thin as a result of the "dog bone" effect previously mentioned. Section 1 was taken through the thickest portion of cladding on the core while section 2 was taken through the thinnest portion of cladding noted, excluding the very thin cladding over the ends of the core. For the location of these sections see Fig. 3.

Additional investigation of the metallographic sections was performed using photo-electron microradiography to determine if any uranium had diffused into the cladding beyond the apparent core-cladding interface. In this method, x-rays are directed through a fine grained, high contrast photo-emulsion placed in intimate contact with the metal surface. The x-ray energy used is sufficiently great to produce a high density of photo-electrons from the atoms of high atomic number and to have a low absorption in the photographic emulsion. X-rays generated at about 250 Kv appear to have the optimum energy for this technique. Since photo-electron generation increases with increasing atomic number, other factors being constant, a high contrast is observed between elements having widely different atomic numbers. Photo-electrons have a low energy, hence, only those generated at the metal surface are detected by the emulsion and are totally absorbed by the emulsion.

The results of the metallographic measurements are summarized in Table I and are shown in Fig. 3. All measurements shown were made on one side of the plate only. The measurements for section 1 were made on the side of the plate containing the thickest portion of cladding while the remaining sections were measured on

Location of Sections Taken for Metallographic Examination (Mark X MTR Fuel Plate).

Fig. 3 Cross Sections of Mark X MTR Fuel Plates. Cladding—6061 Al Alloy.
Core—48% U by wt., Alloyed with Al.
"Original Magnification 10 X"

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the side containing the minimum cladding.

TABLE I

<u>Section</u>	<u>Eddy-Current Measurement</u>	<u>Metallographic Measurement</u>
1	0.021-in. Maximum Clad	0.020-in. Maximum Clad
2	0.010-in. Minimum Clad	0.009-in. Minimum Clad
3	0.003-in. Minimum Clad	0.003-in. Minimum Clad
4	0.003-in. Minimum Clad	0.002-in. Minimum Clad

It should be noted that in all cases where the metallographic measurement differs from the eddy-current measurement, the difference is 0.001-in. below the value obtained by eddy-current.

Further verification was obtained from the photo-electron microradiographs shown in Fig. 4. These indicate that no diffusion occurred beyond the visible core-cladding interface. In several places the interface is better defined in the microradiographs, particularly in section 4 taken across the end of the core material.

It is therefore concluded that upon choosing the optimum operating parameters the clad thickness on Mark X MTR Fuel Plates can be determined within ± 0.001 in. by the principles of induced eddy-currents.

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PLATE THICKNESS = 0.062-in.

Location of Sections Taken for Metallographic Examination. (Mark X MTR Fuel Plate).

Fig. 4 Reflective Microradiographs of Cross Sections from Mark X MTR Fuel Plates.
Cladding—6061 Al Alloy Core—48 % U by wt., Alloyed with Al

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