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EDDY CURRENT TESTING AND ULTRASONIC REFERENCE STANDARDS FOR DEP--ETC(U)
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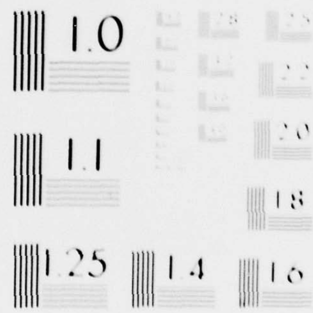
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EDDY CURRENT TESTING AND ULTRASONIC REFERENCE STANDARDS FOR DEPLETED URANIUM BARSTOCK

by
C. W. ANDERSON
Weapons Systems Department

prepared for
DEPARTMENT OF DEFENSE
EXPLOSIVES SAFETY BOARD

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The design and testing of ultrasonic test standards for one-half inch (12.7mm) diameter depleted uranium barstock is discussed. This report also explores the feasibility of testing the barstock for near surface flaws using an eddy current technique. It is shown that eddy current testing is the most efficient means available for detecting surface and near surface flaws in the barstock material.

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FOREWORD

This report presents the results of a task performed in-house at NSWC by the Material Sciences Branch of the Survivability and Applied Sciences Division for the Ammunitions Design Agent of the Gun Systems and Munitions Division.

This report was reviewed and approved by Mr. J. D. Hall, Head, Material Sciences Branch, and Mr. D. S. Malyevac, Head, Survivability and Applied Sciences Division.

Released by:

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Head, Weapons Systems
Department

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INTRODUCTION

The effort reported herein was initiated to solve two problems. The first problem was the absence of any ultrasonic test standards for depleted uranium barstock purchased for the CIWS MK 149 penetrator. Such ultrasonic standards are required if the material is to be tested in accordance with Materials Specification XWS-16691[1] for depleted uranium barstock containing two percent molybdenum. To solve this problem, a series of ultrasonic test standards was designed, fabricated and tested.

The second problem was the inspection of the surface and near surface region of the barstock. The ultrasonic procedure developed for testing the barstock is not capable of detecting surface and near surface flaws[2] which is the most critical region.[3] To solve this problem, an eddy current inspection technique was developed, and a prototype inspection system was demonstrated.

The presence of material flaws in the barstock is of concern since they can lead to stress corrosion cracking and degraded ballistic performance of the penetrator.

ULTRASONIC TEST STANDARDS

Materials Specification XWS-16691 states that the Material Sciences Branch at NAVSWC/Dahlgren is responsible for providing ultrasonic test standards for depleted uranium barstock as may be required by the manufacturer. The specification calls out a maximum permissible flaw size of .020 inches (.508mm) for internal defects.

A set of ultrasonic standards has been fabricated as depicted in Figure 1. These standards consist of a series of holes drilled into ends of barstock sections to represent flaws over a range of depths beneath the outside diameter. This series of holes allows for the calibration of the ultrasonic test as specified in XWS-16691 paragraph 4.4.3.1.

It should be noted that the barstock utilized for fabricating the standards mentioned above represents an "as-extruded" and thus worst case condition in terms of surface roughness (250rms). Such roughness adversely affects the performance of ultrasonic testing. Surface condition requirements are not quantitatively addressed in XWS-16691. These requirements are left to be specified in the procurement contract along with precise dimensional tolerances. Thus, standards used to accept or reject material must be fabricated from barstock which is

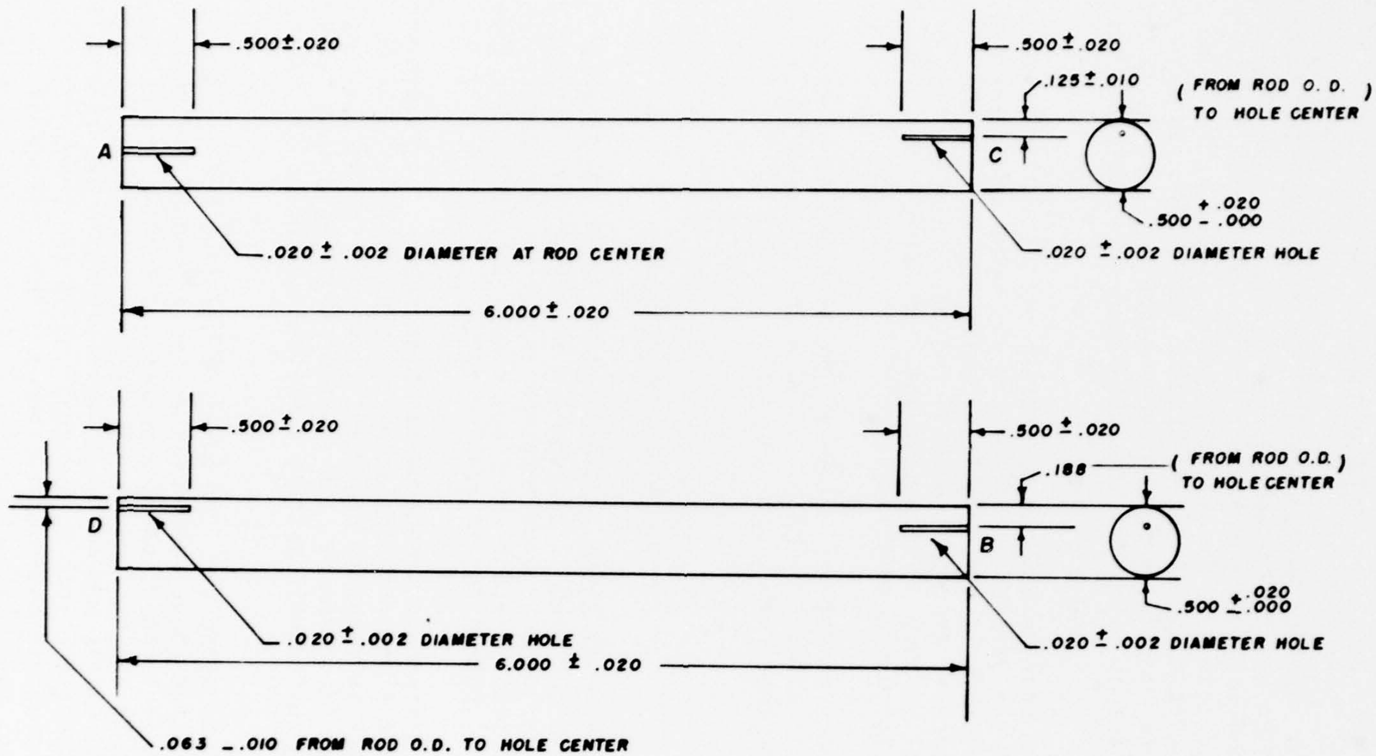

Figure 1. Ultrasonic Test Standards for
.5" Depleted Uranium Barstock
(All dimensions in inches)

representative of the condition of material used for the particular procurement. However, in demonstrating that standards fabricated from "as-extruded" barstock will work, it is automatically assured that similar standards can be fabricated for any smoother surface condition likely to be specified in the contract.

The testing of the ultrasonic standards was conducted in accordance with the procedure specified in XWS-16691. The only difference is that the output was displayed on the cathode ray tube instead of on a strip chart recorder.

Ultrasonic A-scan traces of the artificial defects in the "as-extruded" reference standards appear in Figures 2-7. The large signal on the left represents an ultrasonic reflection from the near surface of the barstock. The indication furthest to the right is the back surface echo. Echoes from the simulated flaws appear between the front and back surface indications. Each of the offset holes was detected at two depths with the exception of hole "D". This was accomplished by rotating the bar 180° so that the simulated defects were at their nearest and farthest points from the inspection transducer. Hole "D" is concealed by the front surface reflection when it is closest to the transducer. Figure 8 represents a section of barstock that is free from internal defects.

Figure 9 shows ultrasonic reflections form a smoothly machined section of barstock containing no flaws. Note the large relative increase in backwall echo amplitude in the case of a smooth surfaced (16rms) specimen. Subsurface flaws in such a specimen would be more easily detected than in the "as-extruded" specimens. The artificial defects in the extruded specimen represent the lower level of detectability and as such may not be detectable with less sensitive ultrasonic equipment. However, when the barstock surface is smooth, as with Figure 9, the signal to noise ratio is greatly improved and detection is enhanced.

Figure 10 identified a problem with the ultrasonic technique in detecting flaws near the barstock surface. The same smooth surfaced sample was used as in Figure 9. The transducer was positioned directly over a natural flaw greater than .070" which was visible from the surface (Figure 11). The flaw did not produce a discernable echo. Instead, the backwall echo disappeared indicating that the sound was being absorbed by the flaw. Rotating the barstock by 180° produced identical results. Clearly, either the backwall echo must also be monitored, which is not mentioned in XWS-16691, or an alternative technique should be used to locate near surface flaws.

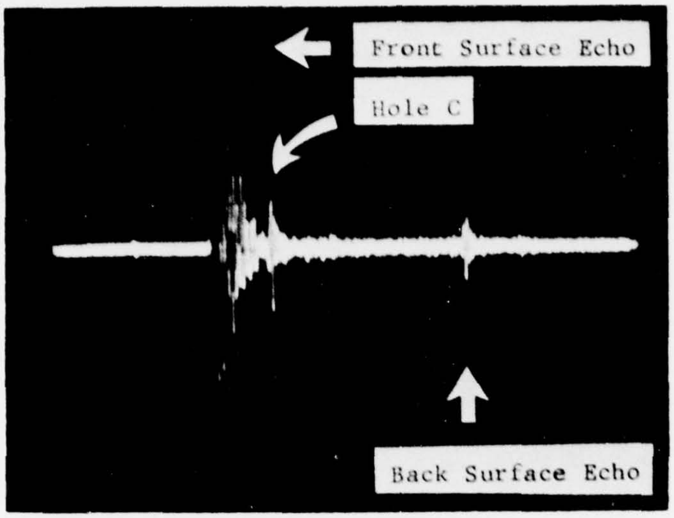

Figure 2.
Ultrasonic A-Scan of Hole C
at Nearest Point to Transducer

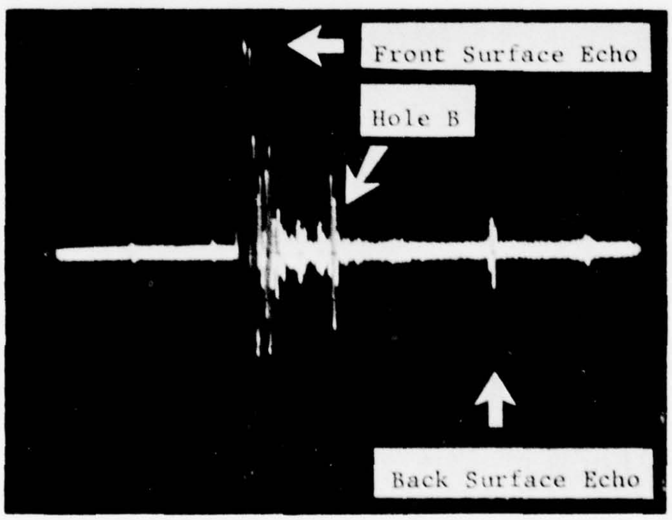

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Figure 3.
Ultrasonic A-Scan of Hole B
at Nearest Point to Transducer

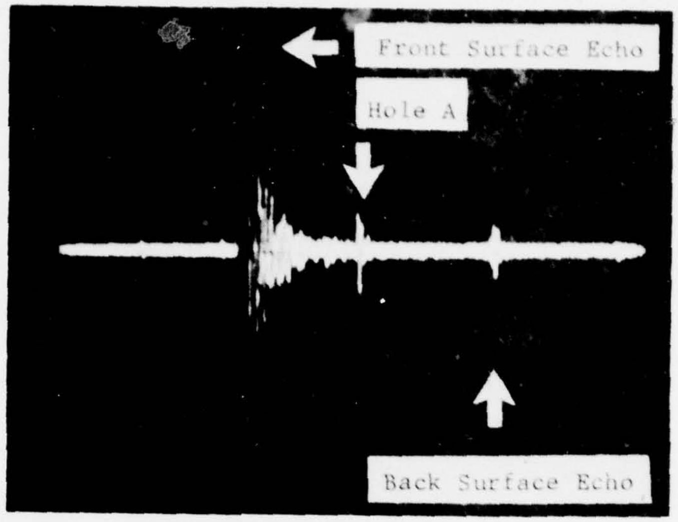

Figure 4.
Ultrasonic A-Scan of Hole A
at Center of Barstock

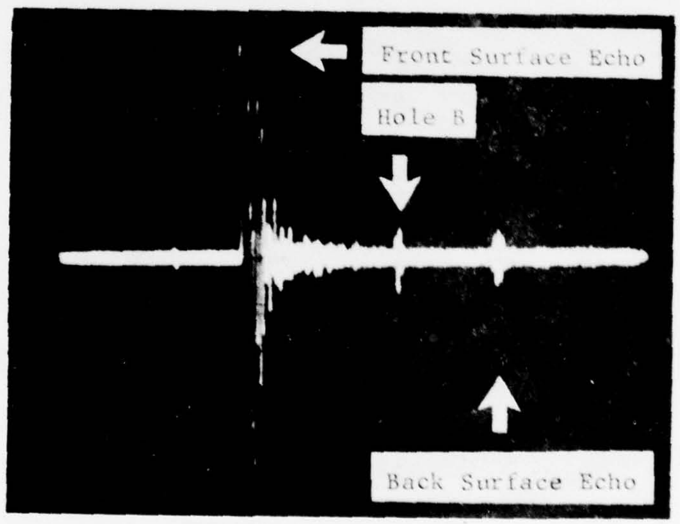

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Figure 5.
Ultrasonic A-Scan of Hole B
at Farthest Point from Transducer

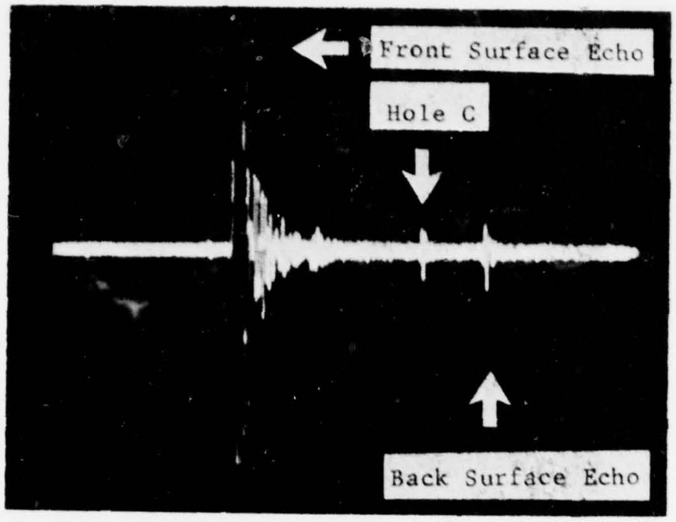

Figure 6.
Ultrasonic A-Scan of Hole C
at Farthest Point from Transducer

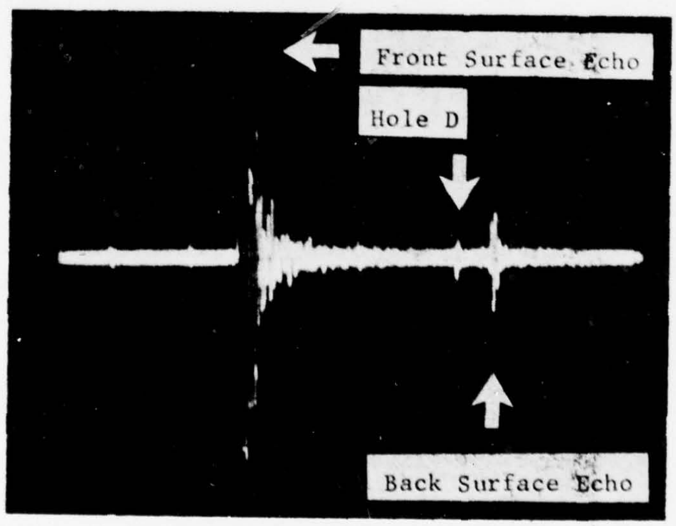

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Figure 7.
Ultrasonic A-Scan of Hole D
at Farthest Point from Transducer

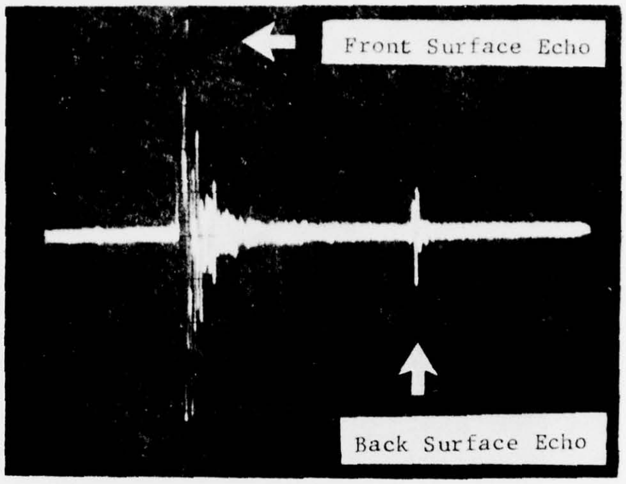

Figure 8.
Ultrasonic A Scan of Unflawed
Specimen of Extruded Rod

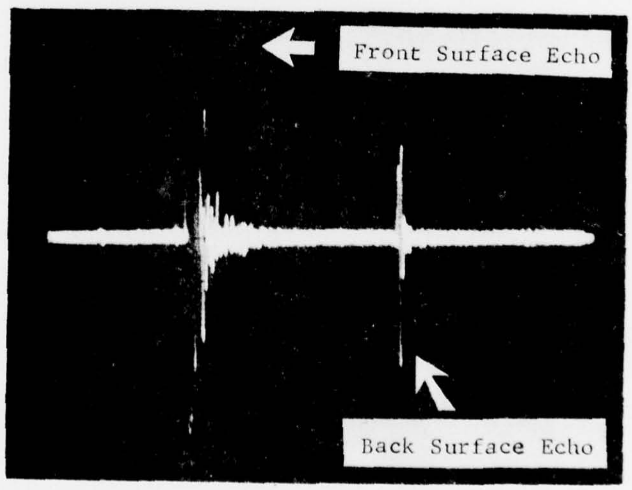

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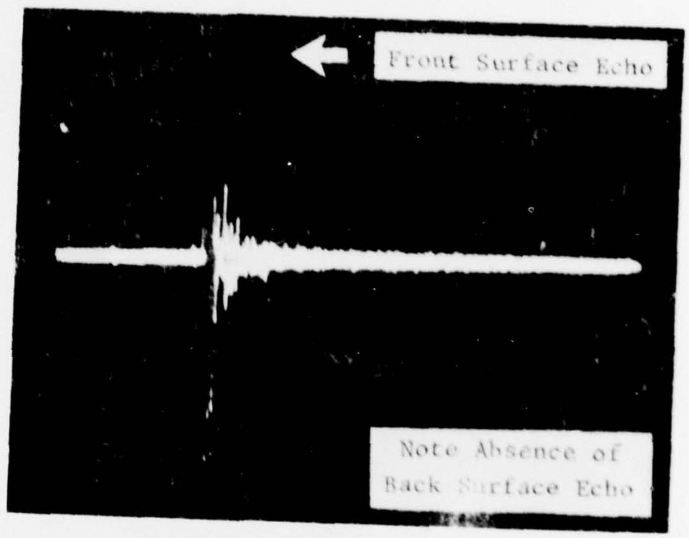
Figure 9.
Ultrasonic A Scan of Unflawed
Specimen of Smooth Machined Rod



PHD-0616-2-79 Figure 10.
Ultrasonic A-Scan of Naturally Flawed
Region of Smooth Machined Rod

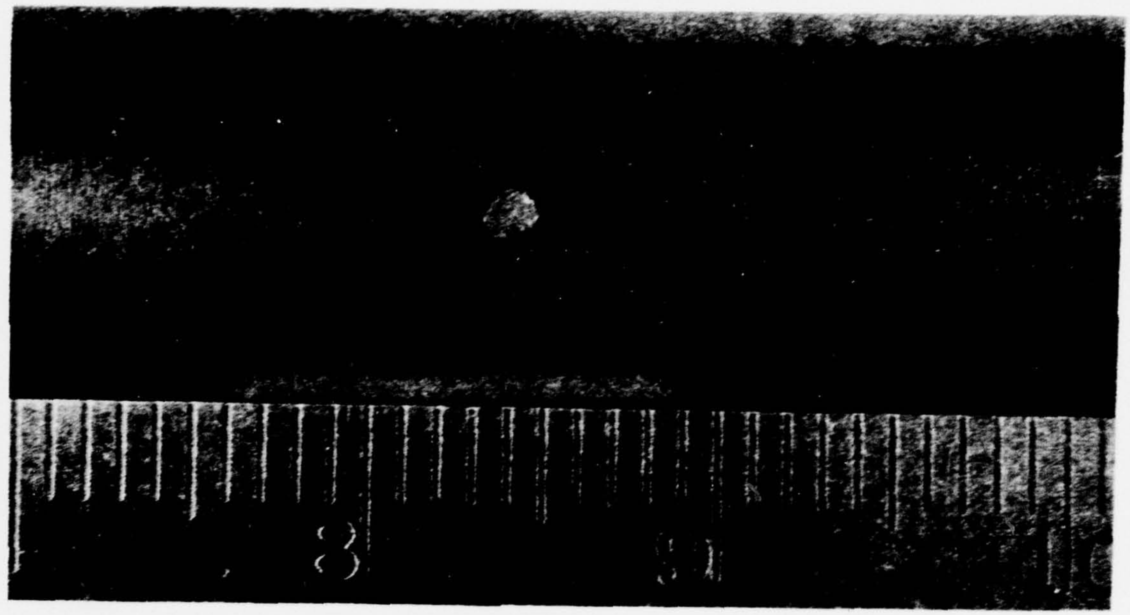


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Figure 11.
Naturally Occuring Flaw in
Barstock Material
(Scale in cm.)

Note that the amplitudes of the reflections from the side drilled holes are dependent on the distance of the hole from the transducer. This is caused by the high ultrasonic attenuation of uranium, focusing of the ultrasonic beam at the center of the barstock, and the near field effects of the 15MHz transducer. This nonuniformity in inspection sensitivity can be compensated for by using a time-amplitude-correction module to equalize the reflection amplitudes. Such a module is not mentioned in XWS-16691; however, without it, the reject level will have to be set at the lowest of the reference flaw amplitudes to assure flaw detection.

EDDY CURRENT TESTING

Eddy current testing has a great potential for quickly and inexpensively detecting near surface flaws in depleted uranium barstock. Such near surface flaws represent the greatest threat to the structural integrity of the material.[3] They are more subject to corrosion and are higher stress concentrators than interior flaws.

In order to demonstrate the technique, a breadboard prototype inspection system was assembled and an eddy current reference standard was machined. The prototype inspection unit consisted of an Automation Industries EM-3300 eddy current test instrument, a pair of differential test coils, and a threshold sensing alarm circuit (Figure 12). Although both the coils and the alarm circuit were assembled in the laboratory, similar equipment can be purchased from a number of suppliers. A sketch of an eddy current standard appears in Figure 13. The .020" deep notch constitutes the standard. The .020" depth of the notch is based on the critical defect size for internal defects as specified in XWS-16691.

The eddy current instrument is a differential impedance detecting device. It compares the impedances of the two test coils driven with an alternating current at a particular test frequency, and displays the result on a storage cathode ray tube which represents an impedance plane. The position of the illuminated spot on the cathode ray tube is a function of the difference in impedance between the two test coils. When the barstock is inserted into the pair of coils, slight changes in the electrical properties of the barstock surface cause the CRT spot to be displaced. Thus, whenever a defective portion of barstock passes through the coils, a flaw indication is recorded on the CRT.

Figures 14, 15, and 16 show three different indications from the CRT of the eddy current instrument. Figure 14 shows the effect of wobbling the barstock within the slightly oversized test coils. The phase setting of the instrument was adjusted so that this indication was in

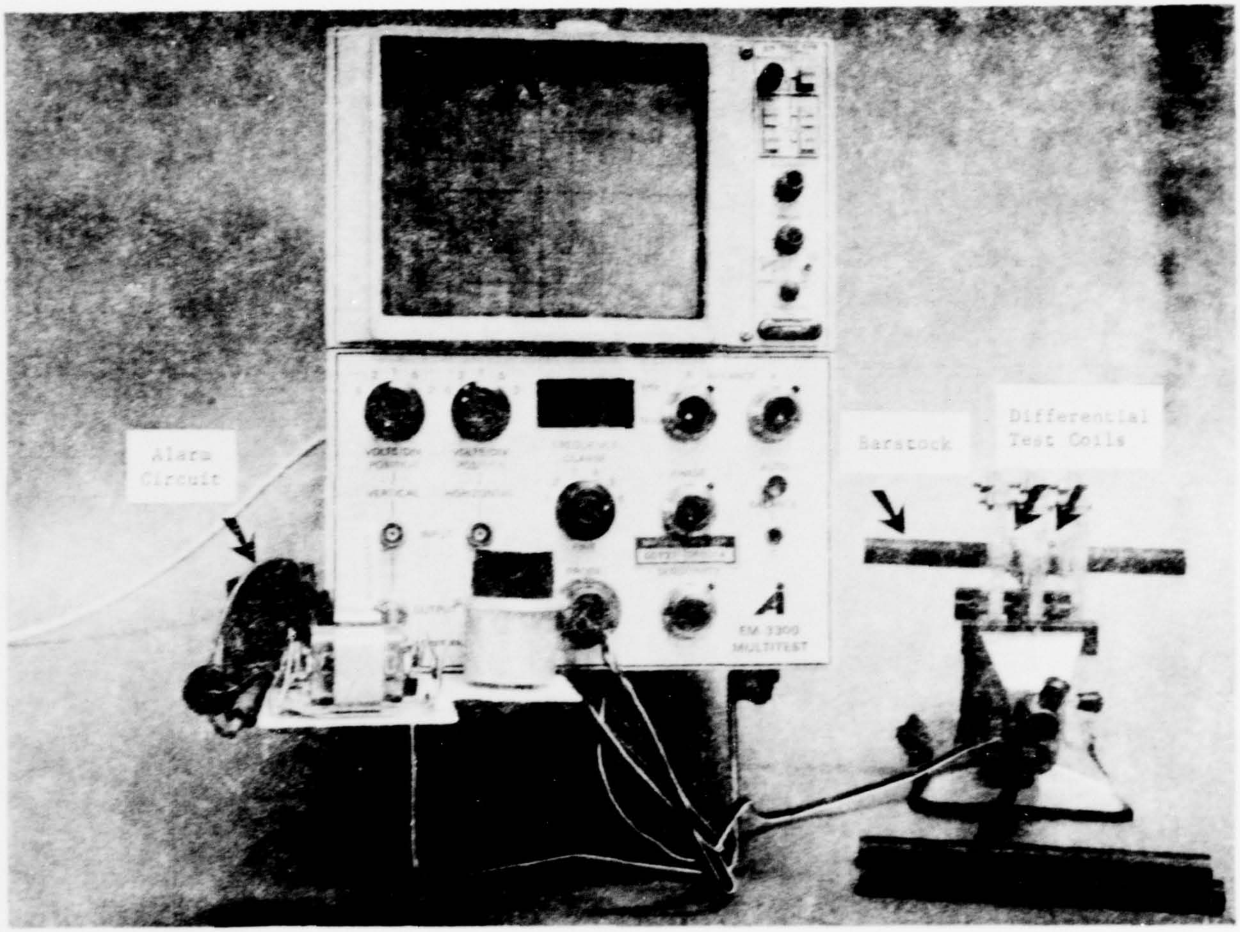

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Figure 12.
Eddy Current Test System

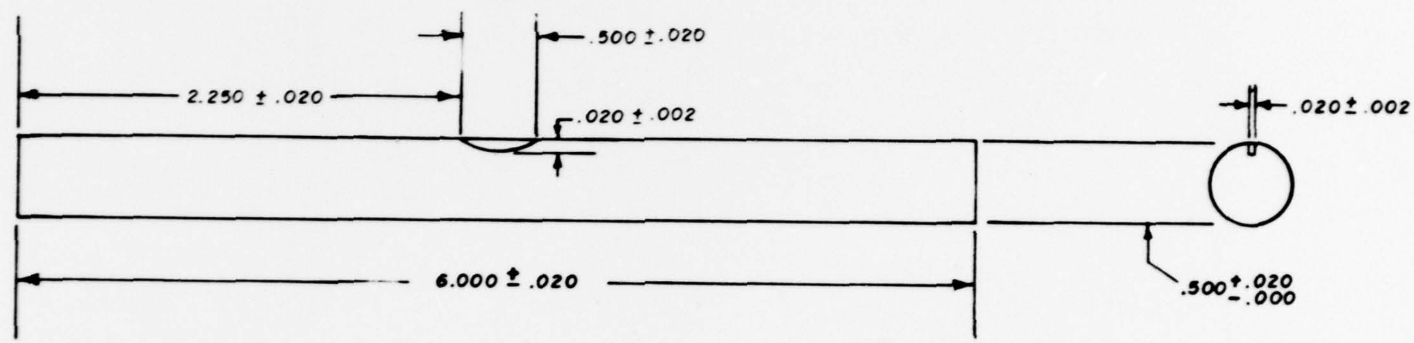

Figure 13. Eddy Current Test Standard for
.5" Depleted Uranium Barstock
(All dimensions in inches)

Figure 14.
Eddy Current Indication Caused by
Barstock Wobble Within Test Coil
(Unflawed Specimen)

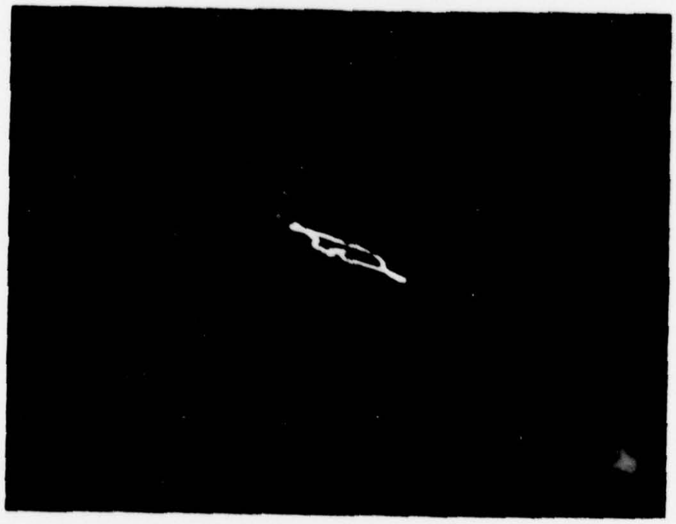

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Figure 15.
Eddy Current Indication Caused by
.020" Deep Notch in Test Standard

the horizontal direction. Figure 15 shows the CRT indication caused by a .020" deep notch machined into the bar surface. Notice the indication has a vertical component in both the up and the down directions causing a "Figure 8" type of indication. This is caused by the defect passing from one coil to the next. The indication is reversed depending on which coil contains the defect at a particular instant. Figure 16 shows the indication caused by a naturally occurring defect. This is the same defect which was not detected by the ultrasonic technique.

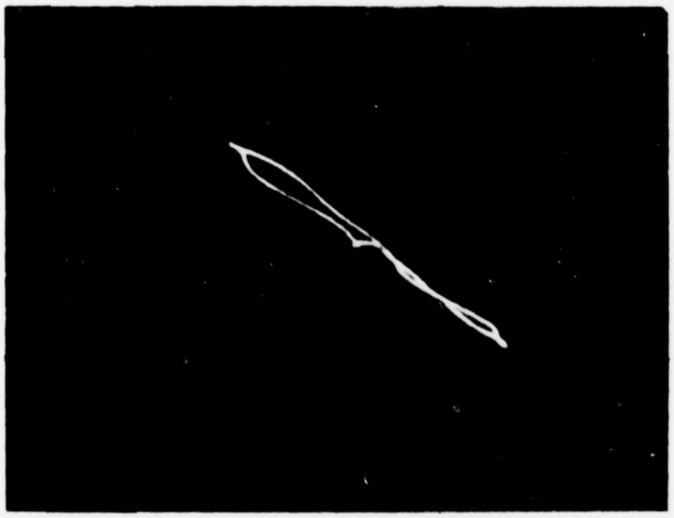
An alarm circuit was connected to the vertical output of the test instrument. The alarm was adjusted so that when the vertical component of a flaw indication exceeded a threshold, audible and visible alarms were triggered.

The testing discussed above was performed at a frequency of 10KHz. This frequency was chosen because it is high enough to allow for good differentiation between barstock wobble indications and defect signals, and yet is low enough to provide a respectable eddy current penetration into the barstock. At 10KHz, the skin depth in uranium is .106 inches. This means that the electric field at a depth of .106 inches within the barstocks falls off to 37% or (1/e) of its strength at the barstock surface. This electric field diminishes exponentially and approaches zero near the barstock center. Thus, the further a defect is located beneath the surface, the larger it must be to be detected.

INSPECTION RATES & COSTS

The maximum speed at which the .5" diameter barstock can be inspected by ultrasonics will in all practicality be limited by the automatic handling equipment involved as well as the barstock straightness. The maximum ultrasonic test speed will depend on the rate at which the barstock can be rotated past the inspection transducer. For example, rotation at 300 rpm would yield an inspection speed of 15 inches per minute allowing for a 50% overlap between adjacent passes of a .1" wide ultrasonic beam. When rotating barstock at such speeds, the straightness of the material becomes critical. Thus, the ultrasonic inspection rate could well be determined by the straightness of the barstock material instead of the capabilities of the inspection system.

Eddy current testing does not require rotation of the barstock, and thus the speed would not be governed by the limitations of a rotational handling system. Eddy current testing has been demonstrated at a rate equivalent to 200 inches per minute with the test hardware described in this report. This was accomplished by manual insertion of the barstock through the test coil. Inspection speeds in excess of 1000 inches per minute could be achieved with the aid of a motorized conveyor



FRD-0619-2-79 Figure 16.
Eddy Current Indication Caused by
Naturally Occuring Flaw

to feed the barstock through the test coil.

To produce 120 penetrators per minute an inspection system must be capable of inspecting at least 240 inches per minute. A single ultrasonic test system will most likely fall far short of this rate. The added expense of parallel inspection stations will most likely be required for ultrasonic inspection.

Ultrasonic test instrumentation, excluding the handling system, is currently available for less than $10,000. The cost of ultrasonic handling systems currently on the market is about $50,000 per unit. In order to meet a production rate of 120 penetrators per minute, a single ultrasonic handling system would have to rotate the barstock at no less than 4800 rpm. This is assuming that a single transducer is used. Since this rotational speed is not practical, one would have to resort to multiple inspection units, or at least, multiple inspection stations on the same unit. The number of stations or units required will depend on the maximum rate of rotation which depends on the straightness of the barstock.

Eddy current instrumentation can also be purchased for less than $10,000. In all likelihood, an eddy current inspection station could be set up on the same handling equipment as would be used to feed the manufacturing process. Thus, the cost of a separate handling system for eddy current testing can probably be avoided. A single automated inspection system could also keep up with a production rate of several hundred penetrators per minute.

RECOMMENDATIONS

Based on the results of this investigation, it is recommended that:

* Standards for nondestructive testing be prepared based on configuration and surface conditions of the barstock or penetrators as specified in the contract.

* Eddy current inspection be required in conjunction with ultrasonic inspection to detect both surface and subsurface defects.

* Eddy current standards be prepared and made available to penetrator producers.

* An NDT Systems study be undertaken to define systems costs, reliability and impact on systems performance. The ultimate goal should be aimed at defining a system that provides the optimum inspection capability at the cheapest unit cost of the finished machined penetrator. A major portion of this effort should be to determine which size defects are cause for rejection based upon stress corrosion cracking and ballistic performance requirements.

CONCLUSIONS

The ultrasonic test standards fabricated from "as-extruded" barstock demonstrate that similar ultrasonic standards can be fabricated from material with any surface condition likely to be encountered (better than 250 rms).

Complementary eddy current testing can provide a reliable and inexpensive near surface testing technique and can be applied to regions which the ultrasonic technique cannot (i.e., surface and near surface).

A single ultrasonic inspection station will most likely not be able to keep up with a barstock production rate of 240 inches per minute. Stations operating in parallel will be required.

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