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**Masked Eddy Current Probe for Detection
of Rover Fuel Element Coating Cracks**

by

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MASKED EDDY CURRENT PROBE FOR DETECTION OF ROVER FUEL ELEMENT COATING CRACKS

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ABSTRACT

A masked probe has been designed to provide eddy current inspection of the protective coating quality on Rover fuel elements. The probe design and electronic circuitry for the inspection equipment are described. Typical results of inspections are shown and discussed.

INTRODUCTION

In the development of Rover fuel elements, it became desirable to know the condition (number and size of cracks) of the element coating. The elements being investigated are six-sided rods about 52 inches in length and have 19 coolant channels that are about 0.1 inch in diameter. They are generally composed of a graphite-metallic carbide compound which is formed, cured, and graphitized. The interior of the coolant channels is coated with vapor deposited niobium or zirconium carbide to provide a protective layer. This report covers the efforts of the US and EMT Section of Group GMX-1 in developing an eddy current test to do this coating evaluation. The application of this test is only applicable to circumferential cracks in the coating.

METHOD

It was felt that the circumferential crack frequency in "good" elements would be less than 20 cracks per inch. The first attempt made to count these cracks was to make a physically narrow coil of the standard bore probe configuration which is an insertion probe with the coil axis parallel with the bore axis. Several coils

were built but did not give satisfactory results; they lacked the desired resolution, and were of such low impedance that the frequency required to develop a reasonable signal was very high - in the order of 25 to 50 MHz. Also, at these frequencies any movement of the cables caused the capacity variation effects to be very large as compared to the desired signal.

In April 1969, Argonne National Laboratory released a report describing work done with conductive masked probes in pulsed eddy systems.⁽¹⁾ It was felt that the masking could concentrate the field into a narrow band such that individual coating cracks could be resolved if two adjacent coat cracks were separated by about 0.050 inch. The GMX-1 eddy current systems used in the past have been CW and it was decided to attempt to use a CW system on this test.

The mask designed is shown in Fig. 1. The window shown as 0.005 inch was made the following widths: 0.020 inch, 0.005 inch,

⁽¹⁾ C. W. Cox and C. J. Renken, The Use of the Conducting Mask in Pulsed Electromagnetic Testing, Argonne National Laboratory Report ANL-7172, April 1969.

Fig. 1. High-Resolution Eddy Current Probe.

and 0.002 inch. The material used was brass. The 0.020-inch and 0.005-inch windows were cut with circular saw blades; the 0.002-inch window was made by electro-discharge machining. The coil was wound of 0.003-inch-diameter wire and shaped to conform to the 0.073-inch-inside diameter of the mask. The coil was positioned in the mask as shown. This causes the induced eddy currents to flow along the axis of the bore and therefore they are primarily sensitive to circumferential cracks. The coil has 50 turns and at the 8-MHz driving frequency, gives reasonable amplitude signals and is not overly sensitive to capacity changes due to probe and cable movement. The 8-MHz driving signal will not penetrate the 0.006-inch brass wall, and the depth of penetration in the coating is about 0.006 inch.

The block diagram of the electronic system used to drive the probe and to develop the crack signal for recording is shown in Fig. 2. The oscillator used is a 10-Hz to 10-MHz laboratory sine wave generator. The isolation resistor makes the probe operate in an effective constant current mode, and the probe voltage is proportional to the probe impedance which is, in turn, affected by the conductivity of the material around the probe. The rectifier and filter change the varying amplitude 8-MHz probe signal to a varying DC voltage. The RC time constant of this fil-

Fig. 2. Block Diagram of Electronic System.

ter is 1 millisecond. The conductivity of the fuel element coatings have a slow variation from end to end due to the temperature profile of the furnace. To eliminate this effect, which is very large as compared to the effect of a coating crack, it was necessary to filter out this portion of the probe signal. This is done by the High Pass Filter which has a gain of 20 and a cut off frequency of 3 Hz. An Adjustable Gain Amplifier allows compensation for variations in sensitivity of different probes. This signal is called the raw EC data signal. The Non-Linear Response Amplifier is used to enhance the effect of small crack signals. The initial amplifier gain for low-amplitude signals is high and decreases as the input signal amplitude increases. The signal from this amplifier is called the Crack Count Signal. The schematics of these units are shown in Fig. 3. As shown, the outputs of the Adjustable Gain Amplifier and the Non-Linear Response Amplifier are fed to a strip chart recorder, and a permanent record of the basic data is made. To simplify the reporting of the results of this inspection, these two signals are also fed to two special circuits; the first circuit provides a DC voltage which is proportional to the peak-to-peak amplitude of the raw EC signal; the second provides a DC voltage proportional to the number of times the Crack Count Signal has exceeded some arbi-

Fig. 3. Crack Count EC Amplifier.

rary level. The two DC signals are recorded on an X-Y-Y' recorder where X is calibrated to correspond to the probe position in the element. The circuit which generates the DC signal proportional to the signal amplitude is shown in Fig. 4. The first stage is a variable gain non-inverting amplifier with a maximum gain of 2,000; this gain is normally adjusted to approximately 1,000. The AC signal is clamped to zero and fed through the diode to a capacitor. The capacitor is then charged to the peak voltage value of the AC signal through the low forward resistance of the diode, but its discharge path is through the 100K pot and the time constant of this path is about 10 seconds. This voltage value is plotted on the report graph as the relative amplitude of the eddy current signal.

The second circuit which generates the DC signal corresponding to the number of cracks is also shown in Fig. 4 and operates in the following manner. The signal from the Non-Linear Response Amplifier is fed to a 7410C High Speed Differential Comparator. The output of the comparator changes state every time the input signal exceeds the reference voltage. The comparator output is used to trigger a Monostable Multivibrator. The Monostable Multivibrator puts out a pulse of fixed amplitude and width every time it is triggered. This pulse is fed to a capacitor through a diode and variable resistor. The charging

Fig. 4. X-Y-Y' Recorder Adaptor.

time constant and the discharge time constant are both adjustable, thus the DC voltage on the capacitor is proportional to the number of pulses it has received. This value is plotted on the report graph as indications per inch on the report.

RESULTS

Due to the size and fragility of the coolant channels being tested, actual correlation of the results obtained above with the condition of the element coatings is extremely difficult to obtain. At the time of this report, this has been done directly on only one element. This result will be discussed later. Correlation of the results is based on previous destructive metallographic examination of elements of the same class. Elements can be categorized by various classes based on combinations of compositions and processing. For each of these classes, there is a characteristic crack frequency distribution along the length of the element. With very few exceptions, the eddy current data have correlated with the characteristic distribution. Three examples are listed below.

Figure 5 shows the high resolution eddy current trace from a bore of an element in a class that characteristically has a high crack frequency of 30 to 40 circumferential cracks per inch. The cause of the lower indicated crack frequency from station 0 to 20 is possibly due to a craze pattern where the cracks have a significant

Fig. 5. High-Resolution Eddy Current Inspection - Element "A"

Fig. 7. High Resolution Eddy Current Inspection - Element "C"

Fig. 6. High-Resolution Eddy Current Inspection - Element "B"

Fig. 8. High-Resolution Eddy Current Inspection - Element "C" After Simulated Usage.

longitudinal component.

Figure 6 shows the high-resolution eddy current trace from a bore of an element in a class of elements that exhibit a crack distribution of over 10 circumferential cracks per inch from station 0 to 10, and 5 to 10 circumferential cracks per inch from station 10 to 52.

Figure 7 shows the high resolution eddy current trace from a bore of an element in

a class that is characterized by a good crack structure of 2 to 8 circumferential cracks per inch along the entire length. Figure 8 shows the trace of the same bore in the same element after a simulated usage. Note that the crack structure is essentially unchanged up to station 33 and then exhibits a high crack count to station 52. This element was destructively examined at this stage and exhibited a crack count

shown in the table below.

<u>Station</u>	<u>Circumferential Cracks per Inch</u>
20	6
38	20
45	30

This indicates an apparent abnormality in correlation at station 45. Analysis of the raw data at this point indicates that the cumulative responses of the electronic systems under certain conditions fall off

rather than increase and that this has occurred here.

The results as determined by this test coincide generally with the conditions existing in the coatings, but not always in a direct fashion. Further study is now being initiated to determine the cause of some of the discrepancies and the methods of data processing that can indicate more accurately the coat condition. The results of that study will be published in a later report.