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EDDY-CURRENT FUEL
ELEMENT FLAW DETECTOR

by

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EDDY-CURRENT FUEL

ELEMENT FLAW DETECTOR

Summary: An eddy current fuel element flaw detector designed for field use in NRX cold flow tests is described. Estimates of the time required for probing of fuel elements and suggestions for proper use of the detector are given.

1. Background

One of the major purposes of cold flow tests on NRX cores is to check the mechanical reliability of the fuel elements. An early indication of failure is fuel element cracking. The question is how does one detect cracking before the condition becomes serious enough to affect the operation of the core. Ideally remote monitoring would be used that would indicate element cracks during a run. Such measurements on a large scale seem impractical.

The next most desirable system would check the integrity of the fuel elements between runs without dismantling the core. With this goal in mind, various nondestructive testing techniques as well as several "far out" ideas were considered. Eddy current probing of the fuel element coolant channels seemed by far the most practical of these.

II. Eddy Current Systems

Eddy current flaw detectors work on the principle of back EMF caused by eddy currents induced in the material being tested. A probe coil is driven with an alternating current. If the a-c flux set up by this current passes through a conductor, eddy currents are induced which cause a counter flux and back EMF in the coil. Any interruption of these eddy currents, such as might be caused by a crack in the conductor, results in less back EMF. If such changes can be detected then flaws in the conductivity can be spotted. Since graphite is a fair conductor, this method of detecting flaws is applicable.

Changes in back EMF can be treated as changes in induced voltage or as changes in the impedance of the probe coil. In either case one of the most convenient techniques for measuring the signal is with a bridge circuit in which the probe coil is balanced against a similar standard coil.

The system basically detects changes in conductivity near the probe. These changes may be caused by large or small deviations in the distance between the probe and the test material, alloy composition, purity, internal stresses, etc. For flaw detection it is desirable to place both the probe coil and the "standard" coil of the bridge in a single probe. If the two coils are separated by a short distance gradual conductivity changes and changes due to spacing between the probe and test material can largely be cancelled out. Only changes that affect one coil at a time are detected. In quality control associated with the manufacture of fuel elements this would probably be a mistake since gradual changes may indicate a serious condition. However, the simplicity of operation gained by this technique is considered important for flaw detection in the field.

As long as one is going to use a differential coil technique the bridge circuit can be eliminated by adding a third coil as shown in Figure 1c. In this system a drive signal is fed through the differential coils and any difference in the flux linking the center coil is picked up as a voltage signal. (Alternatively, the single coil can be used for the drive signal and the differential coil used as the pick-up.) Using this system one

a. single coil

b. differential coil

c. differential coil with separate pick up

Figure 1 Coils for Eddy Current Probes

simply has to measure the pick-up coil voltage to detect unbalances between the coils.

III. Features of Design

An eddy current detector utilizing a differential coil with separate pick-up was chosen as the system to be used for detecting fuel element cracks in the NRX-A1 core.

Although the probes are harder to make than for other systems, the simplicity of operation should make the device more practical for field use.

The probe coils are wound small enough to go into coolant channels in the fuel. The leads are brought out through stainless steel tubing, also small enough and long enough to probe the fuel element channels. (These combinations of coils and tubing are referred to as probes.)

The depth of penetration* of the magnetic field into the fuel element is inversely proportional to the square root of the frequency used to drive the coil. If surface defects in the coolant channels are to be detected a very high frequency can be used. For example 5 Mc corresponds to a depth of penetration in graphite of about .025 in. If deeper flaws are to be detected a lower frequency should be used. Unfortunately the sensitivity for a given size probe coil goes down with lowering frequency. Therefore the frequency chosen must be a compromise between the desire to emphasize deep flaws relative to surface flaws and the desire for high sensitivity. The size of the probe coil is also involved. The probe coil should be roughly the same length as the depth of penetration. As the coil is made larger than the dimensions of the flaws to be detected the sensitivity decreases but the speed at which the probe can be used increases.

On the basis of experiments and the above considerations a frequency of 200kc with a pick-up coil length of 1/8 in. was chosen. 200kc gives a depth of penetration of 0.120 in. in graphite. A schematic diagram of the probe is shown in Figure 2.

Figure 2 Schematic Diagram of Probe

A tuned amplifier and demodulator were designed to detect the pick-up signal. A microammeter is mounted on the chassis for signal output. In addition circuits are being designed to supply a recorder drive signal at low impedance, an alarm light which can be preset to any desired signal level and contacts which close on the alarm for use in external circuits.

All of the circuitry will be transistorized and mounted in a portable box 5" x 6" x 8". The probe will be attached to the box by two coaxial cables. A block diagram of the system is shown in Figure 3.

* The depth of penetration is the distance for the magnetic field to fall to 1/e of its value at the surface.

Figure 3 Block Diagram of Flaw Detector

IV. Use of Eddy Current Flaw Detector

A sketch of the circuit output when the probe passes a crack is shown in Figure 4.

Figure 4 Output Signal of Detector

The probe is centered over the flaw when the zero axis is crossed between the two peaks. The signal for various types of fuel element cracks can be related to the signal for holes drilled into a coolant channel. For example, a .040 in. diameter hole corresponds roughly to a crack completely across the channel. Present plans are to relate various cracks to drill holes. The setting of the alarm circuit will be done by requiring it to alarm on say a .030 in. hole but not on a .025 in. hole. This type of calibration will make possible quick manufacture of a standard.

Fuel elements can be probed using the detector to check for cracks on an alarm basis and strip charts can be made if these are desired. However, if strip charts are required it would seem desirable to connect a drive system between the recorder and the probe so that the position along the fuel element could be accurately determined. Operation of such a system would undoubtedly be much slower than simple probing on an alarm basis. For example, assume that one hour is allowed for probing between runs. If a drive system has to be set up approximately 30 minutes will be required. The strip charts could probably be taken at one per minute. Therefore, approximately 30 channels could be checked in the 30 minutes left. However, if only the alarm circuit is used and no charts are required it should be possible to check at least 600 channels in an hour with no set-up time required. The above figures are estimates but should be of the proper order of magnitude. Possibly

some strip charts should be made before a test. Then if some elements fail, the points of failure could be compared with the original charts. Comparison with Quality Control X-ray records on the elements would seem to be more practical since the type of discontinuity can be determined better from an X-ray than from an eddy current trace. No matter what is done before the test, it seems unnecessary to make strip charts between runs except possibly around points of failure located by the alarm. Los Alamos experience with the KIWI-B-4A cold flow test indicates that finding a cracked fuel element (among elements still in place) is a very rare occasion, even after severe vibrations in the core.

Some thought should go into what coolant channels to probe. A statistical sampling covering the core would be desirable. A complete lack of probing in a section that may fail should be avoided. This could happen if a thorough program is started from one radial line on the core and time runs out before 360° has been covered. If a limited time is available the program should be set up to ensure a sampling of the entire core with additional channels checked between the others if there is time. Consideration should be given to checking corner holes in the elements since these positions are probably where cracks start. (It is to be noted that it will be impossible to check coolant holes where the coolant flow is fed to an adjacent hole in the core outlet support blocks.)

If an alarm is received in a given coolant channel, the channel should be rechecked. Then adjacent channels should be checked to determine whether the flaw is local or a major crack. In this manner the extent of the crack can be checked.

The present design is for use in uncoated fuel elements. The proposed coating for hot test experiments has a much higher conductivity than graphite. It seems unlikely that the detector will do more than detect variations in coating conductivity under these circumstances. Experiments are planned to evaluate eddy current probing of coated fuel elements after completion of the present model.

One detector of the present model will be supplied to Engineering Mechanics for use in the E-1 testing program and two will be supplied to the Nevada Test Site for the NRX-A-1 cold flow test program.

G. A. Gilmour