Eddy current testing of zirconium wires

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SYNOPSIS

Zircaloy-2 wires of 1·25 mm and 1·63 mm dia. are used as spacers in the fabrication of nuclear fuel bundles for Rajasthan Atomic Power Project. These wires are spot-welded at regular and close intervals on zircaloy-2 fuel sheaths which contain UO_2 pellets. In order to get a consistent good quality of spot welds, it is imperative that the wires must be free from seams, internal voids, welded joints, etc. Out of the various non-destructive test methods like ultrasonics, radiography, etc., for quality evaluation, eddy current testing affords a quick and reliable mode of testing the wire on a 100% basis for the detection of the above defects. This paper deals with the preliminary investigations on the eddy current testing of zircaloy wires. The preparation of various defect standards and the standardisation of the equipment for the defects are also described along with the necessary photographs and recording charts. The details of the arrangement proposed for automatic inspection of wires are given at the conclusion of the paper.

FUEL bundles for Rajasthan Atomic Power Reactor, as per the design, consist of a cluster of 19 elements held together by zircaloy end plates and spaced by wire helices on the six elements of the inner ring and alternate elements of the outer ring. Each element is a zircaloy-2 tube 495 mm long, 15·24 mm in diameter and of 0·4 mm wall thickness containing the nuclear fuel in the form of sintered uranium dioxide pellets and sealed at both ends. In order to provide the required spacing between the elements, zircaloy wire of 1·25 mm dia. is spot-welded around the elements in the helix form. The wire helices serve to separate the elements to maintain the dimensions of the coolant sub-channels between them and to increase the mixing of coolant between inner and outer sub-channels. Zircaloy wire of 1·63 mm dia. is spot-welded on the outer elements so as to provide bearing surfaces for the bundle when it moves through the fuel channels in the coolant assemblies.

As in the case of all other reactor materials, the zircaloy wire also needs to be inspected 100% to avoid any defective part entering the reactor system. The requirement of rigid specifications on the quality of wire, or for that matter any material intended for reactor use, need not be over-emphasised here. The zircaloy wire must be free from defects like seams, internal voids, welded spots, etc., apart from the dimensional and metallurgical requirements.

Considering the large quantity of the wire to be inspected and since 100% of the wire is to be scanned, the testing procedure adopted must be non-destructive and fast enough and at the same time capable of detecting and differentiating the defects mentioned above. Radiography, as is well known, is a slow intermittent process and also the seams and welded joints cannot be readily detected. Ultrasonic method, on the other hand, intrinsically is not suited for such small diameter wire owing to the limitations such as dead zone, resolution, pulse width, etc. Other non-destructive tests such as penetrant test, etc., are suited only for specific types of defects (which are open to the surface) and hence those methods are not applicable to our problem. Eddy current testing has been found to be only the ideally suitable method to detect the flaws in the thin wire and being an electro-magnetic method, the testing can be done at a very rapid rate.

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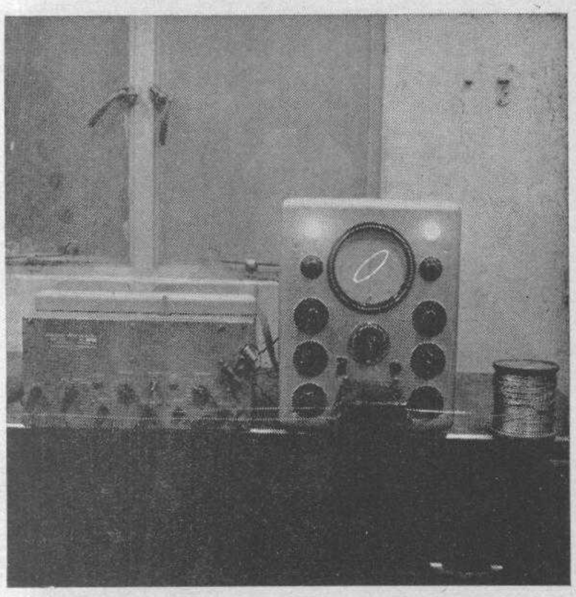
Principle of eddy current testing

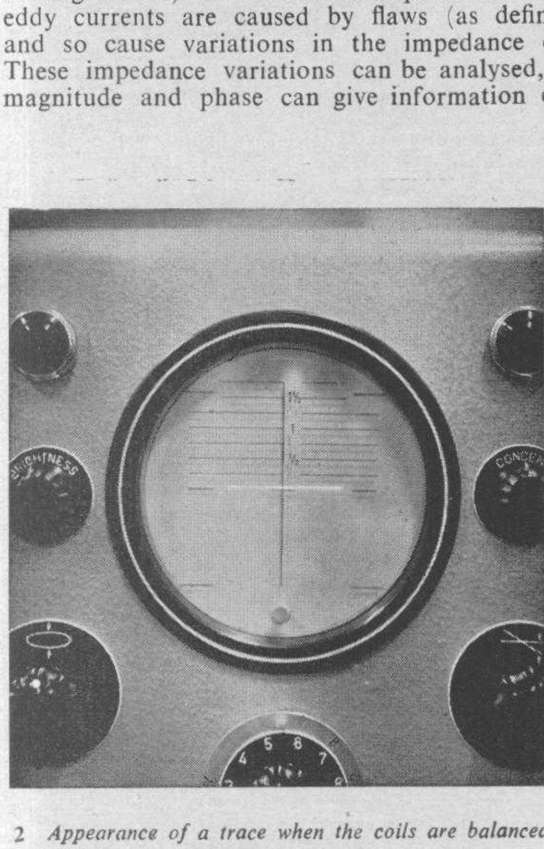
The eddy current test is an electro-magnetic test applicable to the examination of electrically conducting test specimens for detecting any flaw. For eddy current testing the word 'flaw' has a much wider meaning than it has for X-ray inspection, ultrasonic inspection, and other forms of non-destructive testing. Not only cracks and voids can be found, but also differences in alloy, conductivity, differences in diameter of the wire, eccentricity of tubing, etc. can be found and measured.

In eddy current testing, high frequency alternating current is caused to flow in the test coil which, in consequence, produces magnetic field in the vicinity of the coil. If a conducting test specimen is introduced into this field, currents known as Foucault or Eddy currents are induced in the specimen by electro-magnetic induction, The quantity or the path of the eddy currents depends upon various factors such as the

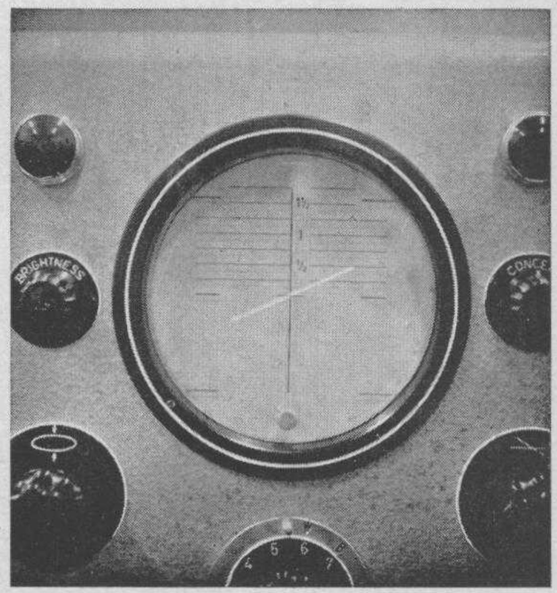


1 *Eddy current wire tester with recorder*

conductivity, magnetic permeability, size, defects, etc., of the specimen. These eddy currents react on the exciting coil (or upon a secondary coil used as a sensing device) and affect its impedance. Variations in eddy currents are caused by flaws (as defined above) and so cause variations in the impedance of the coil. These impedance variations can be analysed, and their magnitude and phase can give information concerning



2 *Appearance of a trace when the coils are balanced*



3 *Test wire with 2% variation in diameter*

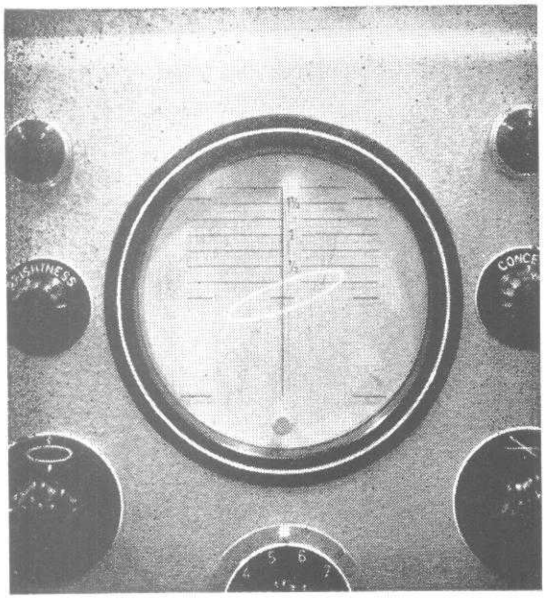
the identification and severity of the flaw. Like most other non-destructive tests, the eddy current test is an indirect evaluation of the characteristics of the test specimen. Hence, the effects of these eddy currents are observed and compared to those caused by currents which flow or which would flow in a standard or acceptable specimen under similar *set* of conditions.

Three general types of coils are in common use. Most common one among them is a circumferential coil through which the test part passes and this type is also called feed through coil. In the feed through differential coil type, there are two coils having a primary and a secondary each. The coils can be placed either co-axially wherein one part of the specimen (wire) is compared with another as the specimen is pushed through the coils, or in different axes wherein a standard acceptable specimen is placed inside one coil and the specimen under test is pushed through the other. The primaries of the two coils are connected in series and a high frequency alternating current is made to pass through them. The secondaries are connected differentially so as to get the difference between the induced voltages in the secondaries. The other types are called the probe and bobbin coils and are not described here.

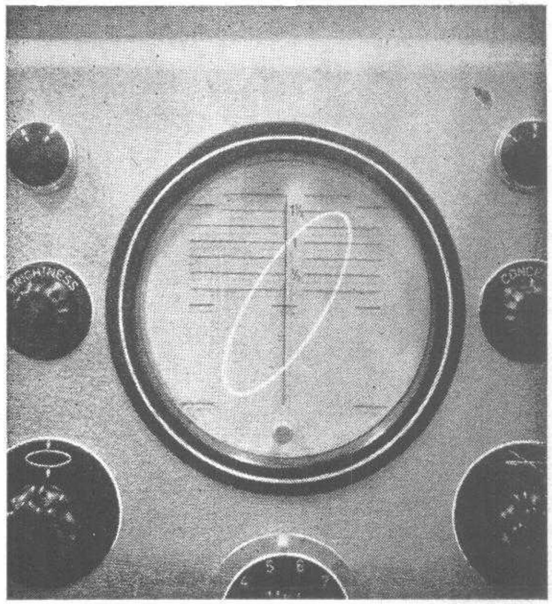
Test procedure and results

Description of the unit

The eddy current wire tester (Fig. 1) model FW 201 supplied by Messrs Magnaflux Corporation, has been used in our preliminary studies on zircaloy wire. The unit has a fixed frequency oscillator tuned to 625 kc/s. The feed through differential coil set having the two

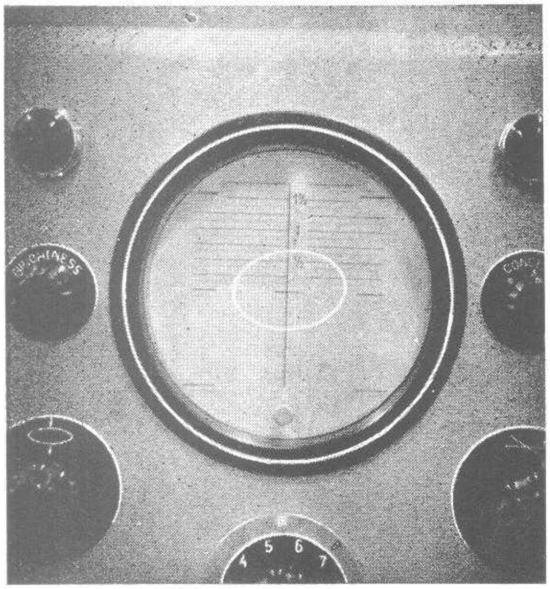


4(a) *Test wire with 16 thou diameter hole*



5 *Test wire with a butt weld joint (at a reduced sensitivity)*

coils in different axes is plugged into the unit. Special teflon guides have been made to suit the zircaloy wires under investigation. The unit has DC output for DC recorder attachment and a Dynograph strip chart recorder has been used to record the traces. An oscilloscope is provided with the equipment for a visual indication of the defects. The X-plates are energized by the sweep generator at the same frequency as that of the alternating current through the primaries of the test coil. The Y-plates are fed with the differential output from the secondaries. Balancing circuits are provided in the unit both resistive and inducive so as to make the differential secondary output zero when the wire specimen in both coils are "identical".



4(b) *Test wire with 24 thou diameter hole*

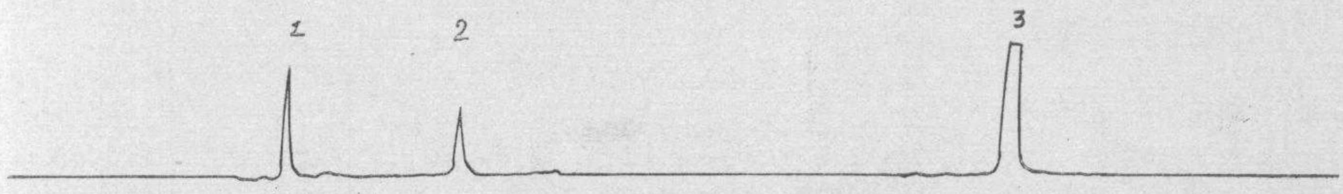
Defect standard

Before proceeding with the routine testing of wires, it is imperative that the eddy current unit is standardised using wires with simulated defects. The normal defect standards suggested are drilled holes, surface notches and welded and filed joints. The unit can be standardised with any specified defect standard and the threshold level can then be adjusted such that, in the actual wire testing any defect indication more than that of the defect standard can be made to trigger an alarm. The indications can also be continuously recorded while the wire is pushed through the coils. In some units there will be a provision to actual spraying of paint at the defective portion of the object under test.

Preliminary investigations

0·4 mm dia. hole drilled through and through and perpendicular to the axis of the wire, 0·4 mm dia. hole drilled half way, good electron beam welded and filed joint and a fine notch cut on the surface have been made as defect standards for 1·25 mm dia. wire. 0·4 mm dia. hole drilled half way at one place and drilled through completely have been made as defect standards for 1·63 mm dia. wire.

The eddy current unit is put on and is allowed for stabilization. Proper connections are made for the recorder and the recorder also is put on. Through one



6 *Typical recorder chart*

of the coils, a round (defect-free) sample of 1·25 mm wire is kept and through the other defect standard is passed. Initially a sound portion of the defect standard is balanced against the other wire.

Then the artificial defects are passed through the second coil and the corresponding oscilloscope and recorder indications are noted. Figs. 2 to 5 show oscilloscope indications for the wire with and without various defects. The splitting as well as the inclination of the horizontal line can be observed in these defects. It may also be noted that the oscilloscope indication obtained while passing the welded joint through the coil, is actually much more and for representation in the figure the sensitivity had to be cut down by two steps as compared to the other type of defects. Similarly the test conditions are standardized for 1·65 mm dia. wire. Typical recorder chart is as given in Fig. 6.

It may be noted that the pattern of indications on oscilloscope are different for different types of defects. In a normal production line, wire is fabricated starting from a given ingot through different main stages of processing such as extruding and/or rolling into smaller sections which are further drawn to the specific sizes. In such cases like the ones we contemplate, the standard flaws that can be expected are dimensional variations and defects like cracks, voids or seams. Since the type of coils that we are using are of differential type, other variables (that could affect eddy current distribution) such as hardness, composition, heat treatment conditions, are balanced out. As such it will be easier to a good extent to resolve the type of defects depending on the type of patterns indicated on the oscilloscope. The magnitude of the defect can only be recorded on the chart and it is not possible to differentiate the type of defect from recording trace.

For production line inspection, the zirclaoy wire to be inspected will be mechanically driven through the test coil from one intake spool to the other spool, keeping a short length of standard acceptable type of wire (same dimension as that of the test wire is expected to be) in the other test coil. Good reproducible results have been obtained when the speed of the testing is of the order 50 mm/sec and there is a scope for improvement.

Eddy current testing on other materials

It may be of interest to note that eddy current testing techniques are widely used for evaluation of non-ferrous products like copper or brass wires and other sections. The units selected shall have an appropriate frequency depending upon variables like size, type and resistivity of the material.

These techniques are widely employed in other countries even to ferrous materials, incorporating D.C. saturation in addition to the normal requirements to overcome the effects of magnetic permeability of the test objects. Units such as Magnatest eddy current systems are commercially available for the detection of seams in cold drawn carbon or alloy steel wire ; for automatic testing of hot-rolled cars of 25 mm dia. and larger to detect longitudinal defects such as seams, laps, stringers, slivers, scabs, etc.

Multifrequency, and phase sensitive instruments are also available for special job s like coating or plating thickness measurments, sorting non-ferrous or ferrous materials, checking the heat treatment conditions.

Summary

Zircaloy wires, that are used as a spacer and bearing pads on the fuel pencils in the fabrication of RAPP fuel bundles, will have to undergo one hundred per cent non-destructive examination. The wires should be free from defects like voids, cracks, seams, etc. besides meeting the dimensional and other requirements. The eddy current inspection techniques are presently the best and appropriate ones over the other conventional non-destructive testing techniques such as radiography, ultrasonics. The general principle involved in the testing and the equipment employed for the test are described with the test results along with the photographs and recording traces wherever necessary.

Acknowledgements

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Discussions

Mr U. P. **Mullick** (Institute of Consulting Engineers, Calcutta) : From which country was obtained the Eddy Current wire tester model FW 201 supplied by M/s. Magnaflux Corporation ?

Mr V. A. Chandramouli (Author) : Our Eddy Current wire tester model FW 201, has been manufactured by Institut Dr Forster, Reutlingen, West Germany, for Magnaflux Corporation, Chicago, Illinois, U.S.A.