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Water-Side Oxide Layer Thickness Measurement of the Irradiated PWR Fuel Rod by NDT Method

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Abstract

It has been known that water-side corrosion of fuel rods in nuclear reactor is accompanied with the loss of metallic wall thickness and pickup of hydrogen. This corrosion is one of the important limiting factors in the operating life of fuel rods. In connection with the fuel cladding corrosion, a device to measure the water-side oxide layer thickness by means of the eddy-current method without destructing the fuel rod was developed by KAERI. The device was installed on the multi-function testing bench in the nondestructive test hot-cell and its calibration was carried out successfully for the standard rod attached with plastic thin films whose thicknesses are predetermined. It shows good precision within about 10% error. And a PWR fuel rod, one of the J-44 assembly discharged from Kori nuclear power plant Unit-2, has been selected for oxide layer thickness measurements. With the result of data analysis, it appeared that the oxide layer thicknesses of Zircaloy cladding vary with the length of the fuel rod, and their thicknesses were compared with those of the destructive test results to confirm the real thicknesses.

1. Introduction

This technique is to apply the principle of eddy current generation to the thickness of zirconium oxide layers on irradiated PWR fuel rods. The eddy current coil carries a high frequency current which induces an eddy current flow in the Zircaloy cladding substrate. This produces alternately an opposing electrical field which affects the impedance of the coil. The net coil impedance is affected by the proximity of the coil to the metal, and therefore the coil impedance provides an estimate of the distance of the coil from the metal substrate. The distance from the coil to the metal substrate is sum of the thickness of the insulating oxide layer and the separation of the coil from the wear resistant diamond probe tip. This latter dimension can be accounted for by calibration.

The water-side corrosion of Zircaloy fuel cladding does not limit the operation of PWRs for typical coolant conditions and design burnups of nearly around 35 GWD/MTU. The current trends in the nuclear industry are to increase coolant inlet temperatures to improve thermal efficiency and to extend design burnups to 50 GWD/MTU to lower fuel cycle costs and to reduce spent fuel storage requirements. Such modifications will increase Zircaloy water-side corrosion. It is essential to estimate the amount of corrosion under these more demanding conditions and to evaluate its effects on the proposed new design limits[1].

Oxide layer thickness data of Zircaloy cladding have been traditionally obtained by destructive test of selected fuel rods in hot-cell. This involves a careful preparation of metallographic sections from which zirconium oxide thickness can be obtained. This method is expensive, time-consuming, and limits the number of data points which can be obtained. It also prevents an ability to track a progress of cladding oxidation from increasing exposure on individual fuel rods during successive refueling outages.

In this work, an eddy current probe of general use and peripherals were modified and designed for existing hot-cell use to nondestructively measure zirconium oxide layers which have formed on irradiated PWR fuel rods. The usefulness of this device has verified by the result of destructive test on the specially selected positions of the H-08 fuel rod of J-44 assembly discharged from Kori nuclear power plant Unit-2.

2. Descriptions

2.1. Preliminary Inspection of Feasibility for Installing the Device in Hot Cell

It was important to check a space where the oxide layer thickness measuring device can afford to be put on the NDT bench, and to confirm wether the device can normally operate without severe problems in hot cell before designing and fabricating it. But there hasn't been any space because of having many testing devices such as X-ray radiography system, axial gamma scanning collimator, eddy current testing package and dimensional profilometer on the same bench. Although we couldn't find any space to accommodate the oxide layer thickness measuring device on the bench, we came across our mind on the feasibility of employing the eddy current testing package on the bench. We thought that this idea was reasonable but some problems might be in designing the device, because its dimension should be limited in the size of the eddy current testing device in width and height. But if the inside dimensions of the parts composed of the device are able to change, those problems will not be serious ones. And so we decided for designing and fabricating the device.

2.2. Design and Fabrication of the Device

The mechanical positioning was designed to position the eddy current probe normal to the fuel rod while translating the probe along the length of the rod in the eddy current test package on the examination bench in the nondestructive test hot-cell. Since a high degree of precision is required to maintain orthogonality, a lot of parts composed of the oxide layer thickness measuring device were designed and fabricated as show in Fig.1.

The geometrical structure of the main body has to be fixed in the external shape and size of the eddy current testing device because the rectangular hole of the eddy current testing package will be directly employed by inserting the oxide layer thickness measuring device into the hole. Also we should lessen the weight of the oxide layer thickness measuring device and make prominence and depression of the external shape of the device in order to manipulate easily with the remote manipulator, because the operator inserts the device into the rectangular hole in the package by using manipulator from working area.

The main body is composed of two major holes, one is for inserting the eddy current probe and another for putting the nuclear fuel rod into the guide hole.

2.2.1. Parts for Moving the Eddy Current Probe

A linear bearing is used to minimize the friction of the eddy current probe in operating lift-off movement, and to deal softly with a sudden displacement by irregularity of fuel rod surface. In order to satisfy these things, the size of a linear bearing in inner diameter must be exactly equal to that of eddy current probe. The longer in length of the bearing, the more stable in movement without fluctuation.

Additional Bearing Bushing attached to the original bearing bushing plays a role in preventing the secession of the ball cage from the bushing. It is composed of two parts and their connection are carried out by a screw after putting the ball cage and bearing bushing into the additional bushing.

The eddy current probe has to carry out the lift-off movement so as to measure oxide layer thickness but it is impossible for the probe to do that movement itself. And then a coil spring is used for the movement and there must be a medium to operate the lift-off movement by using the spring. Sliding tube is made for that purpose and incorporated with the probe by fixing pin.

The function of the spring as mentioned above is to carry out the lift-off movement and to keep on softly contacting the probe with the fuel rod.

Spring Supporter plays a role in supporting the spring as well as skidding the sliding tube incorporated with the eddy current probe. The friction between the sliding tube and the supporter hole is reduced by attaching a bearing in the supporter.

2.2.2. Parts for Guiding the Fuel Rod

Fuel rod is scanned contacting with this guide parts composed of a bearing and its coverings. A friction may be occurred when the fuel rod is scanned through a hole of the covering without having a bearing. The bearing not only prevents a damage on the surface of the fuel rod but also smooths the scanning movement from friction due to the contacts. The size of the bearing is determined taking account of the size of 14x14 and 17x17 PWR fuel rod in diameter and that of covering in height.

Covering plays a role in both the fuel rod guide hole and a bearing bushing. Its dimension is set limit to the size of the main body in height and to that of the bearing in diameter.

2.2.3. Part of Lift-Off Movement

It is not easy to operate lift-off movement of eddy current probe by using the remote manipulator out of the hot-cell working area because of power adjustment of handler. Thus a lift-off mover to deal conveniently with the manipulator was devised. This part is connected to main body of the oxide layer thickness measuring device taking account of a distance of lift-off movement.

After all of the parts composed of the oxide layer thickness measuring device have designed and fabricated, they were assembled for the performance evaluation test in cold laboratory and hot-cell.

3. Experiments and Results

3.1. Performance Evaluation

3.3.1. Performance Evaluation Test in Cold Laboratory

The preliminary performance test of the oxide layer thickness measuring device before installing it in the NDT hot-cell has to carry out in the cold laboratory. To do such a test, we need to have standard calibration rod. The amplitude of the eddy current signal generated in the probe become different according to the materials and the frequencies used in the test. The cladding material of the PWR fuel rod is zirconium alloy. Therefore it is to be wished that the standard calibration rod is the same material as the fuel rod cladding to exactly convert the eddy current signal into the real oxide layer thicknesses. In order to obtain these thickness from the signal, the thickness calibration of the system was carried out in the cold laboratory by using the standard calibration rod attached with plastic thin films whose thickness are 12μm, 24.5μm and 35μm. Also it was difficult to attach exactly them on the surface of standard calibration rod without any adhesive, but we solved that problem by using a method of hollowing out a groove, putting the films in the groove and fixing a rectangular pin by small bolt.

After preparing the standard rod and calibrating the thickness, we carried out thickness measuring test scanning the standard rod in the direction of axial. The result of the test is as shown in Fig.2 and shows good correspondence within 10% error.

3.1.2. Performance Evaluation Test in Hot-Cell

The standard thickness calibration rod attached with thin plastic films whose thickness are 11.9μm, 24.4μm and 48.8μm was loaded on the examination bench from the working table in the NDT hot-cell using the remote manipulators and then it was inserted in the guide hole of the eddy current package by operating the controll pannel. And the position of the films on the calibration rod is able to search from the reference position marked in advance. After preparing all of the thickness calibration test, the test was carried out scanning the whole length of standard calibration rod. The calibration result shows good precision that is the same as in the cold laboratory test as shown in Fig.3.

3.2. Application of this technique to the irradiated fuel rod

Since the PIE faclity at KAERI was originally designed for PWR fuels, we can not choose but examine them only. A fuel rod H-08, one of the J-44 assembly discharged from Kori nuclear power plant Unit-2, has been selected for oxide layer thickness measurements. The measurements were carried out on the whole length of the rod, the data acquired from the scanning of the rod on the examination bench was stored in personal computer and plotted on stripe chart recorder. With the result of data analysis, it appeared that the oxide layer thicknesses vary with the length of the fuel rod, and the minimum value is at a nearby bottom of the rod while the maximum one is close to 3,000mm from the bottom as shown in

Fig.4. Also it shows that several downward peaked points of the spectrum correspond to the grids of fuel assembly. And their thicknesses were compared with those of the destructive test results to confirm the real thicknesses as shown in Table 1. In Fig.5, Microscopic photographs of eight specimens taken at 2490~2510mm from bottom of the fuel show oxide layer and Zircaloy cladding. Although there are some differences between the nondestructive test results and the destructive ones, the NDT method seems to be sufficiently applicable.

Table 1. Oxide Layer Thickness Measuring Values of the H08 Fuel Rod by Means of NDT and DT Methods

Oxide Layer Thickness Measuring Values along the Fuel Rod Position, μm														
measuring position, mm		160 ~ 180	490 ~ 510	830 ~ 850	990 ~ 1010	1290 ~ 1310	1490 ~ 1510	1760 ~ 1780	1990 ~ 2010	2290 ~ 2310	2490 ~ 2510	2790 ~ 2810	2990 ~ 3010	3290 ~ 3310
testing method	NDT	1	3	2	5	2	13	8	13	15	20	16	23	17
	DT	2.1	3.2	2.9	3.7	3.7	8.5	6.4	12.2	11.7	20.1	17.3	24.7	21.9

4. Conclusions

The oxide-layer thickness measuring device which provides some merits compared to former metallographic examination was developed. Cold laboratory and hot-cell test for investigation of the measuring accuracy for the device notified practical enough accuracy. And then this technique was applied to the irradiated fuel rod selected in the J-44 assembly discharged from Kori nuclear power plat Unit-2. With the results of data analysis, it appeared that the oxide layer thicknesses vary with the length of the fuel rod. And their thicknesses were compared with those of the destructive testing results to confirm the real thicknesses.

Some advantages of this technique are that it will reduce the testing time and cost because it can measure nondestructively the oxide-layer thickness without destructing the fuel rods, is possible to measure all of the regions of fuel rod, and will be applied for irradiated fuel rods as a part of fuel verification test for high burnup and so forth. Therefore, it is expected to be useful for estimation of fuel rod usability.

Reference

1. F. Garzarolli, A.M. Garde et al., Waterside Corrosion of Zircaloy Fuel Rods, EPRI-NP-2789, 1982.

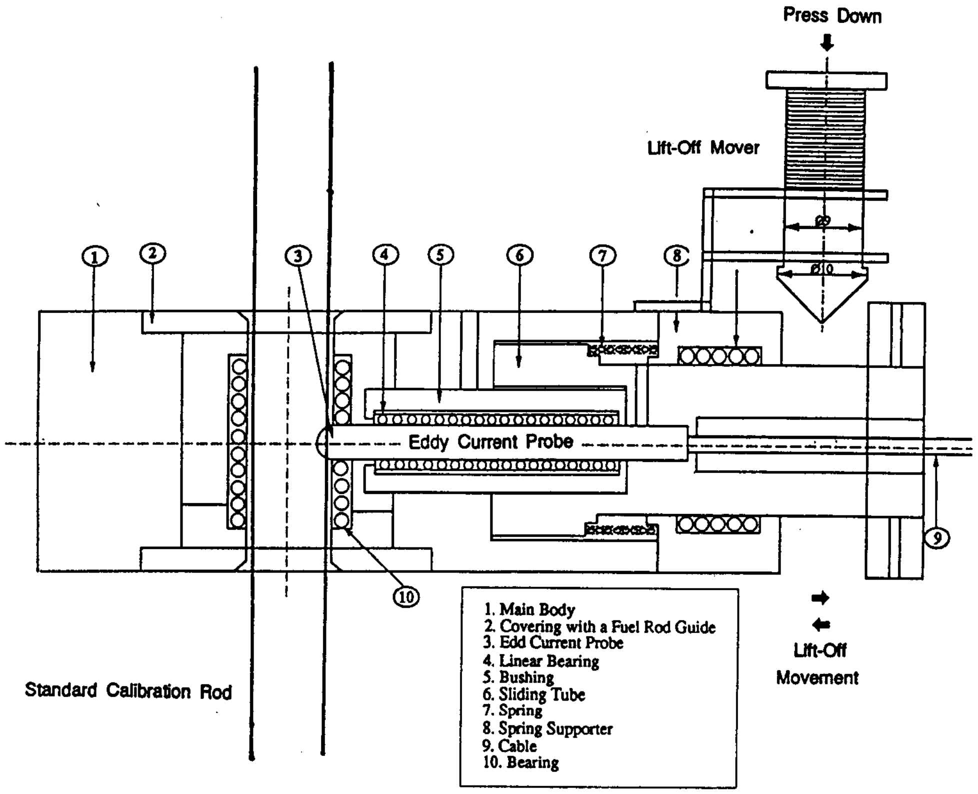

Fig. 1. Schematic Drawing of the Oxide Layer Thickness Measuring Device Assembled with the Component Parts.

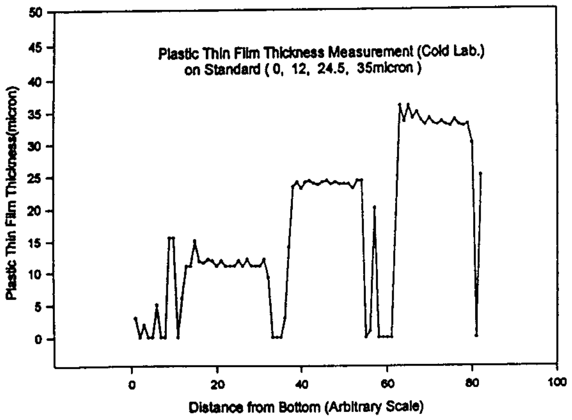

Fig.2. Schematic Drawing of Sliding Tube for the Lift-Off Movement of Eddy Current Probe.

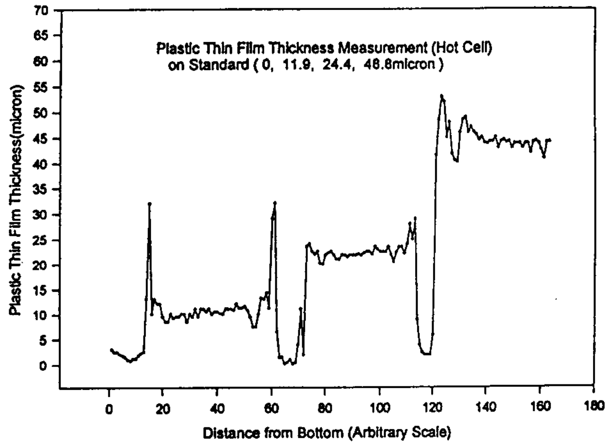

Fig.3. Coverings for Guiding the PWR Fuel Rod and for Holding a Bearing.

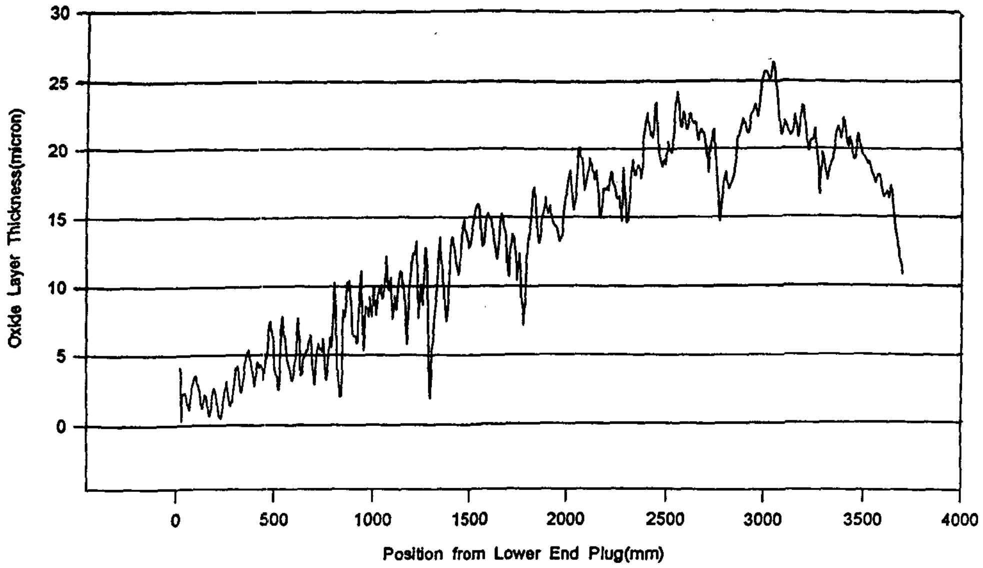

Fig.4. Distribution of Oxide Layer Thickness along the Axis of H08 Fuel Rod at 0 Degree.

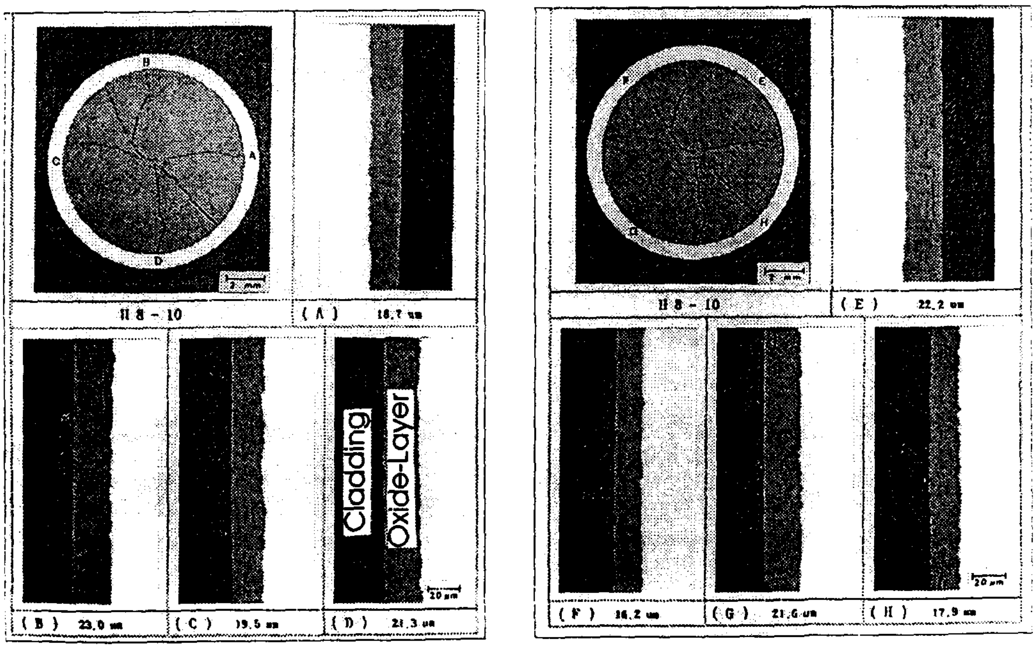

Fig.5. Photographs of Oxide-Layer Thickness of Eight Specimens Taken at 2490~2510 mm from Bottom of H-08 Fuel Rod.