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MEASUREMENT OF DIAMETER CHANGES DURING IRRADIATION TESTING

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ABSTRACT

New materials are being considered for fuel, cladding, and structures in advanced and existing nuclear reactors. Such materials can undergo significant dimensional and physical changes during irradiation. Currently in the US, such changes are measured by repeatedly irradiating a specimen for a specified period of time and then removing it from the reactor for evaluation. The time and labor to remove, examine, and return irradiated samples for each measurement makes this approach very expensive. In addition, such techniques provide limited data and handling may disturb the phenomena of interest. Therefore, in-pile detection of changes in geometry is sorely needed to understand real-time behavior during irradiation testing of fuels and materials in high flux US Material and Test Reactors (MTRs). This paper presents development results of an advanced Linear Variable Differential Transformer-based test rig capable of detecting real-time changes in diameter of fuel rods or material samples during irradiation in US MTRs. This test rig is being developed at the Idaho National Laboratory and will provide experimenters with a unique capability to measure diameter changes associated with fuel and cladding swelling, pellet-clad interaction, and crud buildup.

Key Words: In-Pile Deformation and Measurement Instrumentation
1 INTRODUCTION

Real-time data for evaluating changes in fuel and cladding diameter during irradiation testing can be used to characterize phenomena such as pressurization from fission gas release, pellet-clad interactions, and buildup of “crud” that can adversely affect heat transfer. Such diameter data could prove to be critical in advancing the knowledge base related to irradiation effects on fuels and cladding.

Three international laboratories are developing test rigs [1], [2] capable of measuring cladding diameter during irradiation testing in materials test reactors (MTRs). The first is the Institute for Energy Technology/Halden Reactor Project (IFE), the second is Commissariat à l’Énergie Atomique (CEA), and third is the Idaho National Laboratory (INL). The IFE and CEA test rigs are described below to provide background information. The INL test rig is discussed in Section 2.

1.1 IFE Diameter Gauge Test Rig

The IFE diameter gauge [3], [4] enables real-time in-pile measurement of cladding diameter for assessing cladding creep, pellet-clad interaction, fuel creep / relaxation, and the buildup of fuel rod crud deposits. A representative IFE standardized test rig is shown in Figure 1a. IFE relies on linear variable differential transformer (LVDT)-based technology in their diameter gauge. The diameter gauge is shown in Figure 1b with two primary coils and two secondary coils wound on a ferritic bobbin. A change in distance between each of the secondary coil loops and the armature alters the balance between the signals generated in the two secondary loops, leading to a change in the output signal (difference of the two secondary coil signals). The output signal is then used to detect fuel rod diameter changes.

![Figure 1. IFE fuel pellet cladding interaction/crud deposition test rig (a) with diameter gauge (b).](image)

In some test rigs, the diameter gauge travels along the fuel rod using an in-core hydraulic drive and positioning system, while in other test rigs (see Figure 1a); the fuel rod is moved by the hydraulic drive. The accuracy of the diameter gauge is ± 2 μm, and a calibration is performed in conjunction with each diameter trace by having calibration steps on both fuel rod end plugs. The standard diameter gauge can
operate up to 165 bar and 325 °C. However, modifications to IFE LVDTs, as discussed in references [5] through [8], should allow its operation at much higher temperatures.

1.2 CEA Diameter Gauge Test Rig

Recently, CEA, IFE, and the Technical Research Center of Finland collaborated on the Mechanical Loading Device for Irradiation Experiments (MELODIE) test rig [9]. Specific LVDT components related to elongation and diameter measurements have been irradiation tested in the OSIRIS reactor. Ultimately, this test rig will be deployed in the new Jules Horowitz Reactor.

As shown in Figure 2, the MELODIE test is designed to provide real-time biaxial elongation and diameter change data. The test rig will be used to collect data in-core from a pre-oxidized pressurized water reactor (PWR) fuel cladding tube (90 mm in length) at 350 °C, irradiated at peak fast neutron fluxes as high as 4.5x10^{14} n/cm^2-s (E >0.1 MeV), with nuclear heating up to 9.5 W/g. The MELODIE test rig, with a length of 1.60 m and a diameter of 23.5 mm, was designed so that it could be deployed in a sodium-potassium filled double-walled container often used as a standardized test rig in the OSIRIS reactor. Stress and biaxial strain are applied in the MELODIE test rig using three independent high pressure helium circuits.

![Figure 2. MELODIE test rig with individual components [9].](image)

2 INL DIAMETER GAUGE TEST RIG

INL researchers have recently initiated evaluation of an IFE diameter gauge to identify enhancements required for deployment in the Advanced Test Reactor (ATR). This section summarizes the
status of these efforts to develop an appropriate diameter gauge and associated testing equipment (e.g., electronics, test rig, etc.)

Figure 3 illustrates the conceptual design of the diameter gauge test rig proposed by INL researchers for use in ATR. As indicated in this figure, the test rig employs the IFE diameter gauge similar to that shown in Figure 1(b). This gauge is capable of measuring diameters from 9 – 10 mm with a reported accuracy of ± 2 µm. Design parameters include a maximum temperature of 325 °C with an allowable working pressure of 165 bar. Unlike the IFE and CEA test rigs, which both use an LVDT-type device to track axial displacement of the diameter gauge, this test rig relies on a constant velocity hydraulic ram and a characteristic calibration zone to record displacement.

To evaluate this design, a test specimen was developed. Figure 4 shows the test specimen with metrology information. Diameter data will be recorded as function of time when the test specimen is pulled through the diameter gauge at a constant velocity (~1.25 mm/sec). When the diameter gauge travels across the various calibration zones machined into the specimen, characteristic peaks will be recorded by the diameter gauge. The distance between characteristic peaks is a known value, so axial displacement will be evaluated by interpolating between the characteristic peaks (i.e., superimposing the displacement scale over the time scale). Figure 5 shows simulated data and the corresponding travel.
Hydraulic ram data suggest that the variation in velocity could result in a displacement error of ± 20 µm over the 110 mm of travel. Another source of displacement error may be attributed to the diameter gauge pad contact with respect to the specimen. Figure 6 is a radiograph of the diameter gauge with the test specimen inserted. Measurements take on the radiograph indicate that the error caused by the
contact/alignment of the pad with the specimen is greater than the velocity error. Pad wear will also result in measurement error. Computed tomography (CT) provides a higher degree of accuracy than radiography. CT scans are planned to evaluate pad alignment, contact and wear.

![Figure 6](image.png)

**Figure 6. Radiograph of specimen inserted into diameter gauge.**

Benchtop and autoclave testing using the specimen (see Figure 4) has been planned. Bench top evaluations will be used to characterize the performance of the diameter gauge to determine diameter measurement accuracy, axial measurement accuracy, and scan speed variation. Three autoclave tests are planned. All tests will be conducted in water. The first test is planned at the maximum allowable working pressure for the diameter gauge (165 bar). This test is to be conducted at room temperature. The second planned test is to be conducted at typical PWR conditions (315°C and 155 bar). The final test is an elevated temperature test at the maximum working temperature of the diameter gauge (325 °C). Benchtop evaluations will be repeated at the conclusion of the autoclave testing to verify that diameter gauge performance was unaffected by temperature and pressure testing.

3 CONCLUSIONS

The conceptual design of a new irradiation test rig, capable of measuring real-time changes in specimen diameter, has been completed. A series of defined laboratory evaluations will be initiated when test rig components are received. Once laboratory evaluations are completed, this new test rig will provide ATR users with much-needed capabilities for real-time measurement of diameter changes caused by fuel and cladding swelling, pellet-clad interaction, and crud buildup during irradiation testing.
4  ACKNOWLEDGMENTS

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5  REFERENCES


