Online Measurement of Fuel Stack Elongation

Sung Ho Ahn, Jintae Hong, Chang Young Joung, Tae Ho Yang, Sung Ho Heo, Seo Yun Jang

***Abstract*—**The performances of nuclear fuels and materials are qualified at an irradiation system in research reactors operating under the commercial nuclear power plant conditions. Fuel centerline temperature, coolant temperature, neutron flux, deformations of fuel stack and swelling are important parameters needed to analyze the nuclear fuel performances. The dimensional stability of nuclear fuels is a key parameter measuring the fuel densification and swelling. In this study, the fuel stack elongation is measured using a LVDT. A mockup LVDT instrumented fuel rod is developed. The performances of mockup LVDT instrumented fuel rod is evaluated by experiments.

***Keywords*—**Axial deformation, elongation measurement, in-pile instrumentation, LVDT.

I. Introduction

FOR a fuel performance analysis, it is invaluable to have access to direct measurements of the parameters related to the in-pile performance of fuel. The important direct measurement parameters are the onset temperature for fission gas release, fuel operating temperature, and dimensional stability of the fuel stack. A variety of in-pile instruments have developed for on-line monitoring and measurements during fuel and material irradiation tests [1], [2]. The fuel temperature measurement is an essential requirement for fuel performance evaluation. Fuel centerline temperature can be measured with a thermocouple or expansion thermometer. The fission gas release mechanisms and fuel rod internal pressure are key issues for extending the burn-up of fuel in power reactors. An LVDT (Linear Variable Differential Transformers) is used for monitoring the position of the magnetic core, and thus the fuel rod internal pressure can be monitored. The neutron flux is measured with SPND (Self Powered Neutron Detector). And the coolant temperature is measured with thermocouples.

The dimensional stability of nuclear fuels is a key performance parameter measuring the fuel densification and swelling [1], [3]. Fuel densification and swelling are of interest because they impact the development of gap closure. The deformations in fuel stack length can be monitored with an in-core fuel elongation detector. LVDTs are applied for measurement of dimensional deformations in the fields of fuel and material irradiation as well as general industries [4]-[6].

In this study, an online elongation deformation measurement device of the fuel stack is developed using LVDT. A magnetic core is attached to a spring loaded plate in contract with the fuel pellet at one end of the fuel stack, which follows the expansion and contraction of the fuel stack. As the magnetic core, housed within the fuel rod end-plug, changes the position relative to the LVDT that surrounds the fuel rod end-plug, it generates a signal that can be converted into the change in length. The performances of the developed elongation deformation measurement device are evaluated experimentally using a mockup LVDT instrumented fuel rod. The experimental results show that the developed device has an excellent measurement performance for the elongation deformation of the fuel stack.

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II. Displacement Measurement Using LVDT

LVDT has been used throughout many decades for the accurate measurement of displacement and within closed loops for the control of positioning [7], [8]. Fig. 1 shows the cross-sectional view of the LVDT core and windings [9].

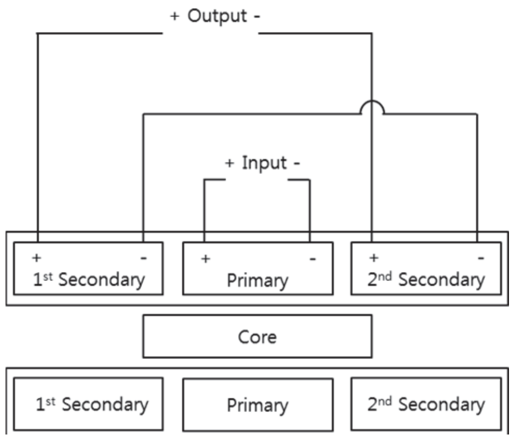

Fig. 1 Cross-sectional view of LVDT core and windings

The LVDT consists of a coil assembly and a core. The coil assembly consists of a cylindrical array of primary and secondary coils. And the coil assembly consists of three coils of wire wound on the hollow form [9]. A magnetic core connected to the fuel stack can move freely through the center of primary and secondary coils. When the primary is excited by an AC input, the magnetic flux is coupled to the two secondary coils. The output gives DC or 4-20 mA output proportional to the core movement and also indicates its directions, positive or negative from the central zero point.

Fig. 2 shows that the magnitude of the differential output voltage varies with the core position. The output value at the maximum core displacement from the null depends upon the amplitude of the primary excitation voltage and the sensitivity factor of the particular LVDT. The phase angle of this AC output voltage by the primary excitation voltage stays constant until the center of the core passes the null point, where the phase angle changes abruptly by 180 degrees, as shown in Fig. 3. The 180 degrees phase shift can be used to determine the direction of the core from the null point by means of appropriate circuitry such as a phase sensitive demodulator and low pass filter. Fig. 4 shows the polarity of the output signal, which represents the core's positional relationship to the null point [10].

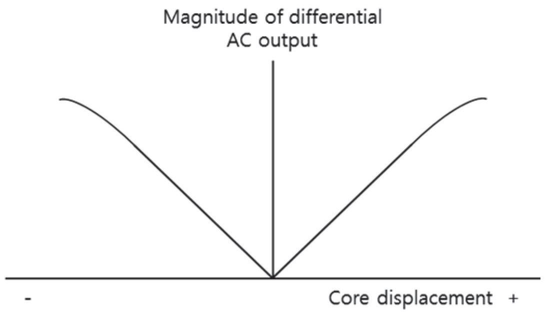

Fig. 2 LVDT response for core displacement

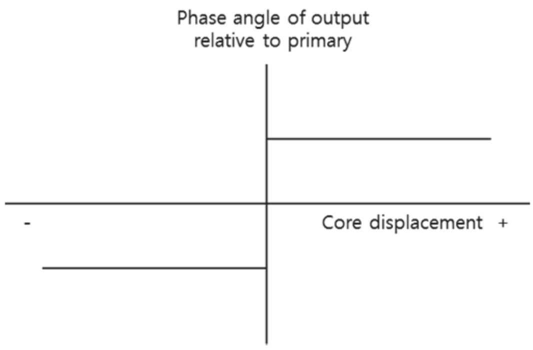

Fig. 3 Phase angle for core displacement

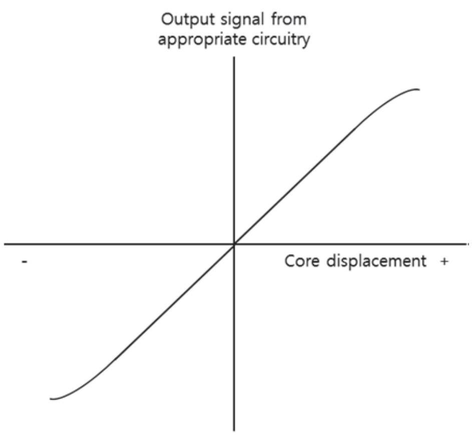

Fig. 4 Output signal from appropriate circuitry

III. MOCKUP LVDT INSTRUMENTED FUEL ROD

The temperature of a nuclear fuel is increased when the fuel is irradiated by neutrons. Thus, the on-line deformation measurement of the fuel stack is needed when the irradiation test is performed. The fuel stack length elongation can be monitored using an in-core fuel elongation detector. An online elongation deformation measurement device of the fuel stack was developed using an LVDT. The LVDT core connected at one end of the fuel stacks is located at an end plug type of the test fuel. In addition, the core can move freely within the end plug for the elongation of the fuel stacks. The core moves with compression of the spring when the fuel stacks are expanded. Moreover, it moves to the opposite direction with the elasticity of spring when the fuel stacks are contracted. The test fuel is manufactured to withstand the internal pressure increasing by the neutron irradiation.

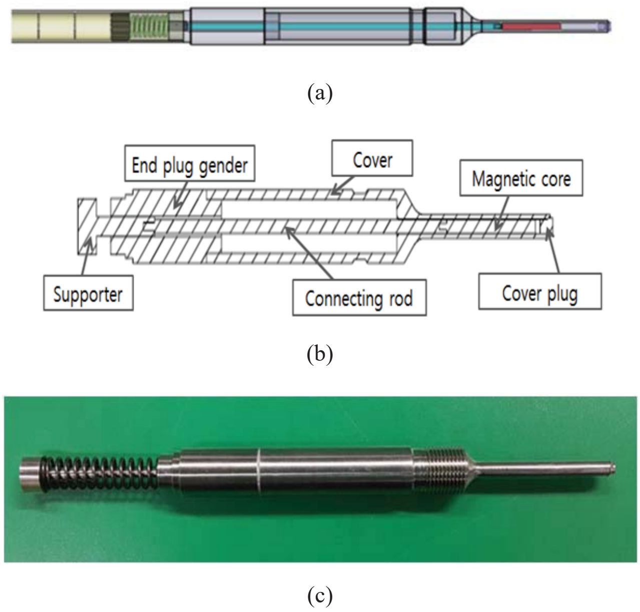

Fig. 5 Upper part of mock-up fuel rod with LVDT core (a) Schematic diagram, (b) Composition, (c) Assembled LVDT core

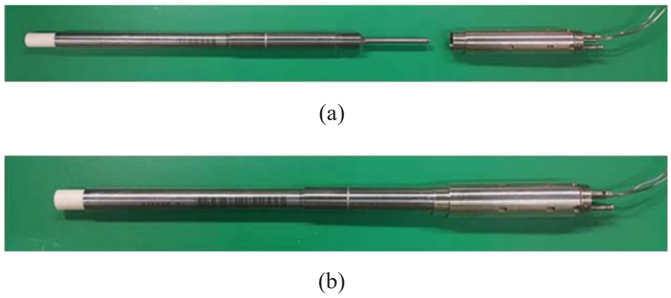

Fig. 6 Mock-up LVDT instrumented fuel rod (a) Before assembling, (b) After assembling

The upper part of a mock-up fuel rod with an LVDT core is shown in Fig. 5. It consists of a magnetic core, connecting rod, cover plug, cover, end plug gender, and supporter. The LVDT core for the fuel stack elongation measurement should not be affected by the cladding elongation. Thus, the supporter, connecting rod, and LVDT core are installed to be affected only by the fuel stack elongation. A magnetic core is attached to a spring loaded plate located at one end of the fuel stack, which follows the expansion and contraction of the fuel stack. Fig. 6 shows the mock-up LVDT instrumented fuel rod. The end part including the magnetic core is inserted into the LVDT coil assembly, consisting of a cylindrical array of the primary and secondary windings. The end plug and the cover are welded.

IV. Experimental Results

A. Experiments

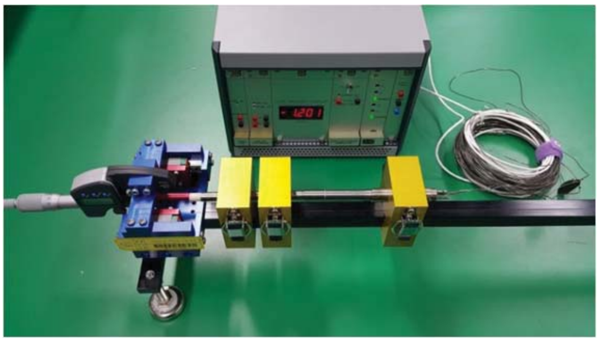

Fig. 7 Experiment for fuel stack elongation measurement

The mock-up LVDT instrumented fuel rod is installed at a test device. The test device consists of a mock-up LVDT instrumented fuel rod with an LVDT, a fuel stack elongation simulator connecting to micrometer, and signal readout, as shown in Fig. 7. The fuel stack elongation simulator is connected in close adhesion on the fuel stack. The initial point of the LVDT core is established by keeping away from the dead zone. When the fuel stack is moved through handling of the micrometer, the LVDT core is moved. Finally, the signal readout displays the voltage signals using the LVDT sensing signals.

B. Measurement Results

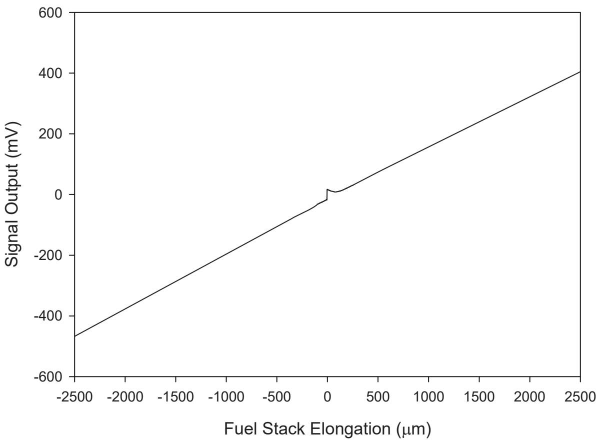

Fig. 8 Signal output from readout

The performances of the developed elongation deformation measurement are evaluated by experiments using a mockup LVDT instrumented fuel rod. Fig. 8 shows the measured signal output from the signal readout for the fuel stack elongation. The measurement sensitivity is about 1 mV/ 6 μm. There is a dead zone between -4 μm and 87 μm near zero a crossing point, as shown in Fig. 9, because of high sensitivity and structural shape of the primary and secondary coils. The measurement range including the dead zone is about from -2,500 mm to 2,500 mm. Fig. 10 shows the feasible measurement range (from 100 mm to 2,500 mm), which can be applied to measure the fuel stack elongation. The initial position of the LVDT core can be established by keeping away from the dead zone. It is concluded that the developed device has an excellent measurement performance for the elongation deformation of the fuel stack.

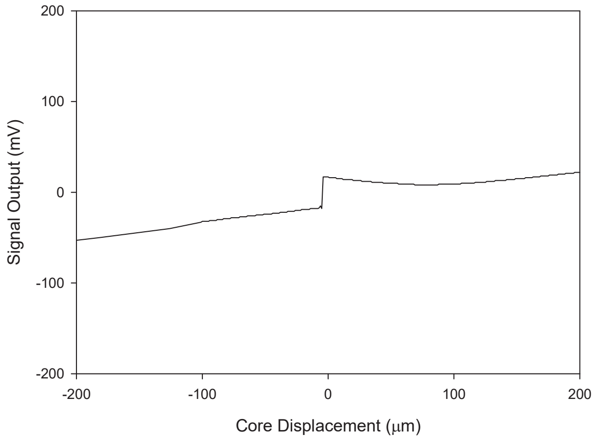

Fig. 9 Nonlinear characteristics at dead zone

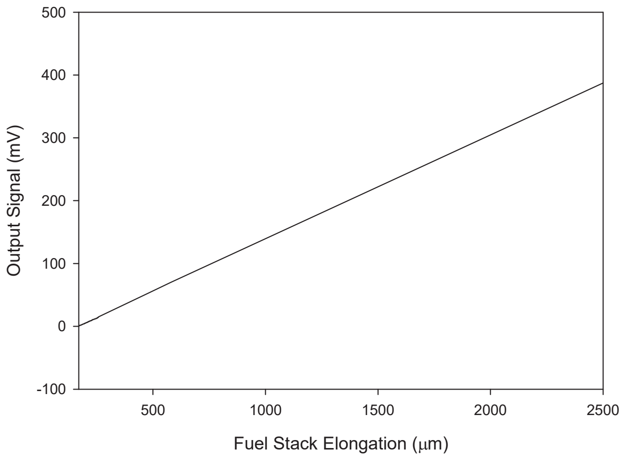

Fig. 10 Feasible measurement range

V. Conclusion

The developed fuel stack elongation measurement device has an advantage that the precise fuel stack deformation measurement is possible without friction. The developed device can be applied to the nuclear fuel and material irradiation tests using research reactors. The further studies based on this research result include the manufacturing of a real test fuel rod based on the mock-up device, and application in a neutron environment.

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