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Technical Survey and Feasibility Review for Development of IV-CEAPI

Jang Yongtae*, Park Jinseok, Lee Myounggoo, Cho Yeonho, Kim Hyunmin
KEPCO Engineering & Construction, Inc. 989-111 Daedukdaero, Yuseong-gu, Daejeon, 305-353, Korea
*Corresponding author: YTJang@kepco-enc.com

1. Introduction

Control element assembly position indicator (CEAPI) is an instrument to monitor vertical position of the control element assembly (CEA) in nuclear reactors. The CEAPI is installed in each control element drive mechanism (CEDM). The conventional CEDMs are installed outside the reactor vessel (RV) with nozzles penetrating the RV head. However, it has been demanded to develop in-vessel CEDMs (IV-CEDM) and in-vessel CEAPIs (IV-CEAPI) because they provide advantages of low possibility of the severe events such as rod-ejection and LOCA through the nozzles.

The purpose of this paper is to establish the development direction of the IV-CEAPI. The paper presents the technologies of the existing CEAPI and other linear displacement sensors. The paper also presents feasibility review of those technologies for the IV-CEAPI considering its environmental conditions as shown in Table 1.

Table 1. In-vessel Environmental Conditions

	Requirement
Design Temperature	343 ˚C (650 ˚F)
Design Pressure	17.2 MPa (2,500 psi)
Radiation	Gamma : 8.76 x 10^4 Gy/yr Neutron : 1.67 x 10^{14} n/cm^2
Other	Submerged in the coolant

2. Various Technologies for CEA Position Indication

2.1 Reed Switch Type

The reed switch type has been used for most of the Korean nuclear power plants including OPR 1000 and APR1400. Lots of reed switches are assembled on a circuit board with a certain interval. Resistors are also assembled together with the reed switches to produce a discrete voltage signal. The reed switches turn on and off as depending on the position of the permanent magnet installed on the drive shaft, which is connected to the CEA, varies.

The reed switch type is a proven technology. However, it is difficult to be applied for the IV-CEAPI because all the essential parts such as reed switches, resistors and silicone molding are not usable inside the RV due to the high temperature condition.

2.2 Solenoid Type

Solenoid types have been used in various fields including nuclear industry.

Inductive linear position transducer is a non-contact linear position sensor that relies on a change of inductance that results from the movement of a permeable core connected to the object to be monitored. When the coil is energized, an electromagnetic field is formed. This magnetic field varies with relative distance between the permeable core and the coil to change inductance of the coil. The change of inductance is electronically converted into an output signal to indicate the position. [2]

While inductive linear position transducer senses the inductance directly, the linear variable differential transducer (LVDT) uses the principle of the transformer. The LVDT consists of three or more coils. The coils surround a magnetically permeable core that is connected to the object to be monitored. The primary coil is driven by an alternating current source and couples with the secondary coils by mutual inductance. The output voltage of the secondary coils varies by the position of the movable core, the number of coil turns and the voltage of the primary coil [2].

Rod Position Indicator (RPI) is a representative of the solenoid type position indicator in nuclear industry. It has been used for control rod drive mechanism (CRDM). There are two types of RPI; Analog type (ARPI) and digital type (DRPI).

The ARPI consists of primary coil and secondary coil. As the ferromagnetic drive rod connected to the control rod assembly (CRA) moves within the primary coil, the secondary coil induces different level of output voltage to indicate CRA position.

The DRPI is a modified design of the ARPI. It is comprised of 42 discrete coils with coil sensing resistors to make 2 separate data channels with 21 coils for each channel in order to indicate the position of the CRA even in case of a single coil failure. The coils of each channel are connected in parallel and alternating voltage source are supplied to the coils. A sensing resistor is connected to each coil to produce different level of voltage signal depending on the position of the CRA.

The solenoid type is a non-contact position sensor and has operating experiences in nuclear industry. The simple structure just comprised of a permeable core and coils has the big advantage for the IV-CEAPI design. Since there is a coil operable inside the RV, the solenoid type can be a strong candidate for the IV-CEAPI.

2.3 Magnetostrictive Linear Position Transducer

Magnetorstictive linear position transducer is a non-contact direct reading device using magnetostriction which is a characteristic of ferromagnetic materials such as nickel, iron and cobalt. When a ferromagnetic material is placed in a magnetic field, the materials change shape or size and form a restriction to the passage of a current pulse. The ferromagnetic material serves as a waveguide for a short duration current pulse and the mechanical torsional pulse that is produced at the location of a position magnet that surrounds waveguide. This pulse travels back to a detector at a sonic speed. The time required for the current pulse to travel to the restriction and the time for the torsional pulse to return to the detector represents the position of the magnet and the device being monitored [2].

This sensor can measure the object with long range and high accuracy, but the detector is unable to operate in the extreme harsh conditions inside the RV.

2.4 Ultrasonic Sensor

Ultrasonic sensor is also a non-contact device that can be used for detecting a position of an object. This sensor measures ultrasonic energy in high frequency range of about 20 kHz. The ultrasonic pulses from the sensor are reflected on the surface of the object, and return to the sensor. The distance between the sensor and the object is measured considering the ultrasonic speed and the taken time.

The sensor has a space called dead band which is unable to measure the position of the object. The length of the dead band is proportional to the frequency of the ultrasonic pulse and its resolution.

The current sensor is unusable in the RV environment, so it cannot be used for the IV-CEAPI.

2.5 Fiberscope Image Transmitter

Fiberscope image transmitter is an optical instrument generally used for industrial and medical endoscopy. This device is composed of a lens and fiber cable. The lens obtains the images of an object and the optical fiber cable transmits it to the monitoring system.

This device can be used as a CEA position indicator by sensing patterns on a surface of the drive shaft. FIGR-10 of Fujikura has been used for the research reactor, JoYo to monitor nuclear fuels [3]. However, it can just endure maximum 300 ℃ and 6.9 MPa, so it is not usable for the IV-CEAPI.

3. Conclusions

To select the type of the IV-CEAPI, technical surveys on linear displacement sensors were performed. Feasibility of those sensors was reviewed considering the environment conditions, experience, reliability and simplicity. The result is summarized in Table 2 which implies that the solenoid type is considered to be the best suitable types for the IV-CEAPI.

Table 2. Comparison of Linear Displacement Sensors for IV-CEAPI

Type	Experience	Environment	Reliability	Simplicity
Reed Switch	○	△	□	△
Solenoid	○	⊙	□	⊙
Magnetostrictive	○	△	⊙	□
Ultrasonic	○	△	⊙	□
Fiberscope	○	□	⊙	⊙

*legend: ⊙ (high), □(medium), △(low)

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