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# **The Gap Measurement Technology and Advanced RVI Installation Method for Construction Period Reduction of a PWR**

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## **1. Introduction**

A nuclear power plant takes approximately 52–58 months from the first concrete construction until the completion of the performance test. Many research groups throughout the world have studied ways to shorten the construction period of nuclear power plants to 50 months. Therefore, the construction period of a nuclear power plant is one of the most important factors to make a company competitive in international nuclear energy markets. There are many advanced construction methods to decrease the construction period for new nuclear power plants. This chapter is related to the modularization of reactor vessel internals (RVI) that one of the most effective methods to reduce the construction period of nuclear power plants (Ko et al., 2009) (Ko & Lee, 2010) (Ko, 2011) (Korea Hydro & Nuclear Power Co., Ltd., 2009).

## **2. Development of reduced-scale model system for measurement system**

Generally, the RVI comprise three components: the core support barrel (CSB), the lower support structure (LSS)/core shroud (CS), and the upper guide structure (UGS). The existing method of assembly is very complicated and requires approximately 8 - 10 months to complete (Korea Electric Power Research Institute, 1997) (Korea Hydro & Nuclear Power Co., Ltd., 2002). The installation of the reactor vessel (RV) is a critical process during the construction period.

This part describes the RVI installation method using the RVI modularization which can shorten the construction period by a minimum of two months compared to the existing method. In order to modularize the RVI, gaps between the CSB snubber lug and RV core-stabilizing lug must be measured using a remote method at outside the RV. Therefore, this part includes explanation on a measuring system to measure gaps between the RV and the CSB remotely with the aim of RVI modularization. The remote measurement system was developed for use at actual construction sites of nuclear power plants using a measurement sensor, a threaded connection jig, and a zero-point adjustment device. With these, a reduced-scale model system was validated. With the remote measurement system, experiments and analyses were performed using mockups for both the RV and the CSB to

verify the applicability of the described system in a construction project. From the data acquired by the remote measurement system, shims were separately made and adjusted.

After installing the shims on RV core-stabilizing lugs, the gaps satisfied requirements within the permissible range of 0.381 – 0.508 mm. The reliability and applicability of the remote measurement method were evaluated and it was concluded that the remote measurement system enables RVI modularization with a significantly reduced construction period.

Fig. 1 shows an existing nuclear reactor installation method and the developed modularization method by remote gap measurement.

RVI is classified on a large scale into three categories: CSB, LSS/CS and UGS. When a nuclear power plant is built, the materials are delivered and assembled according to which category they fall under. It is, however, possible to modularize the installation of the CSB and LSS/CS (Ko et al., 2009) ( ABB-CE, 1995).

Gaps between CSB snubber lug and RV core-stabilizing lug can be measured at outside the RV by a remote method in order to modularize the RVI. If the CSB module (CSB and LSS/CS) is installed into RV, access to measuring the gaps is cut off by the LSS/CS. Therefore, the gaps must be measured remotely at outside the RV.

Fig. 2 shows a picture of the second step in Fig. 1(a)

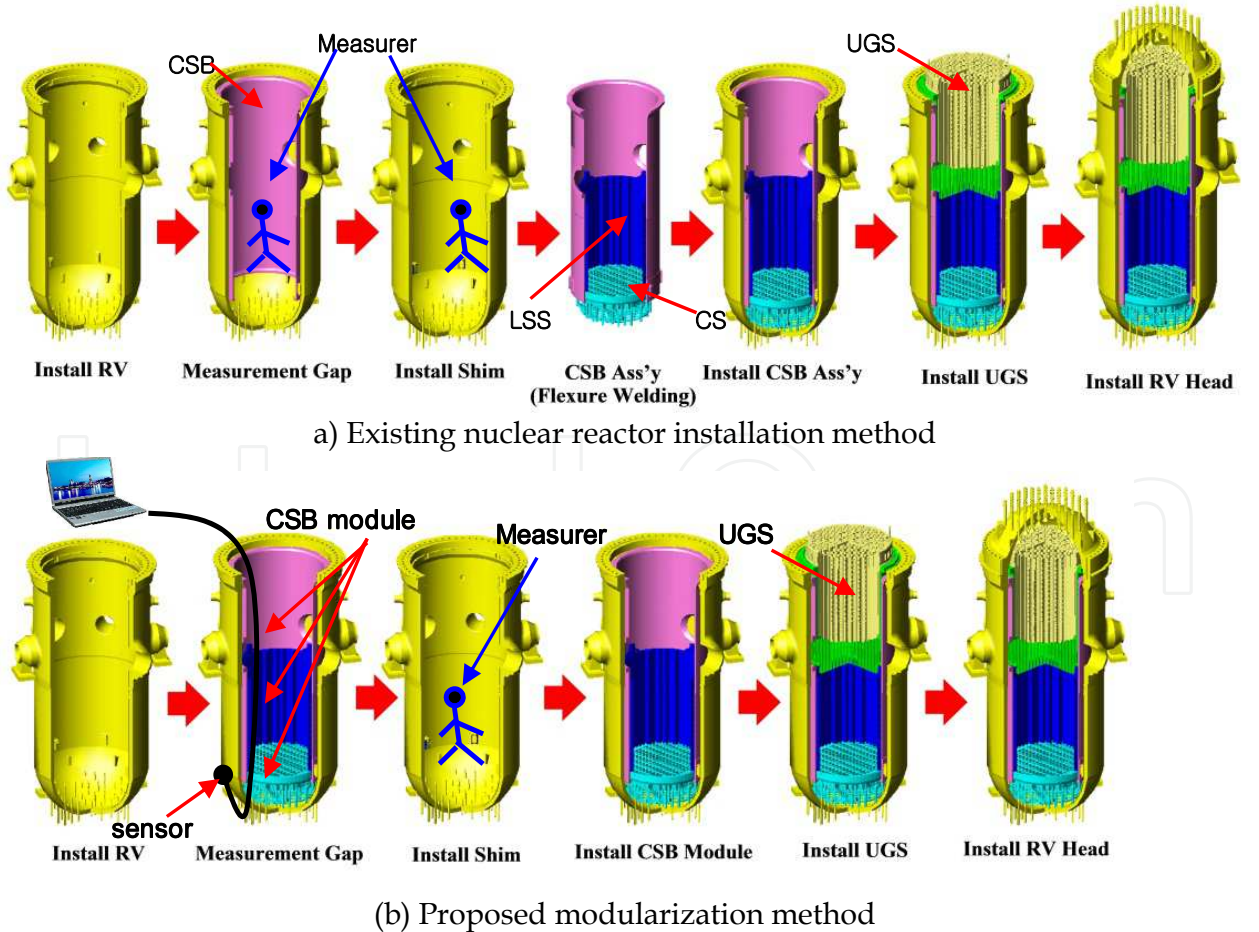


Fig. 1. Existing method and developed modularization method by gap measurement remotely

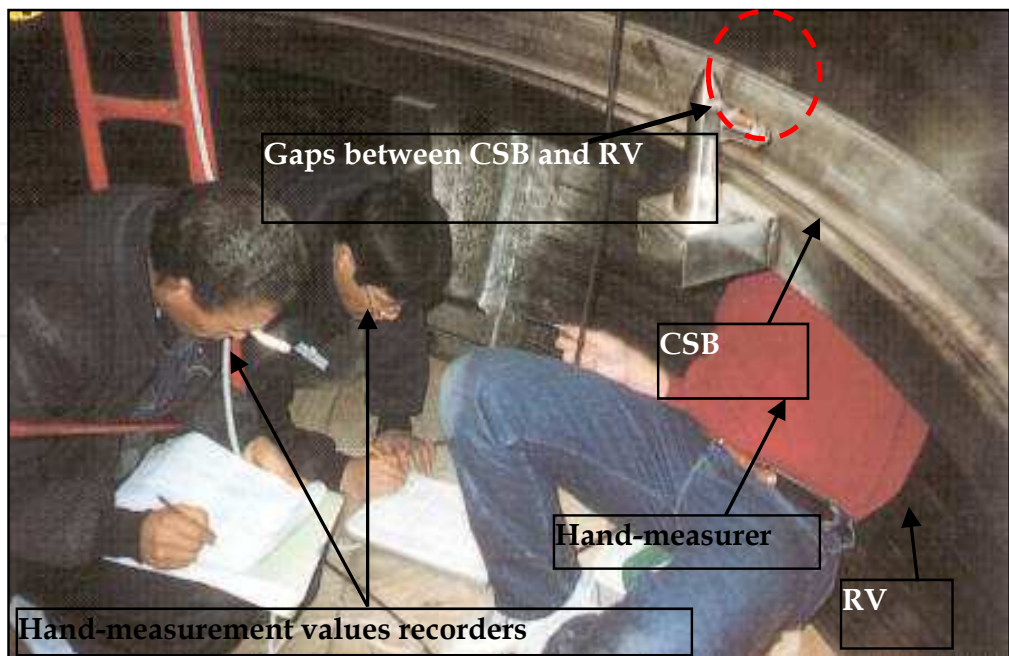


Fig. 2. Picture of the second step in Fig. 1 (a), showing manual gap measurement.

The hand-measurement of Fig. 2 takes a lot of measurement times and it occurs measurement errors by measurers. Also, a measurement space is small and narrow, and environment to measure gaps between RV and CSB is uncomfortable.

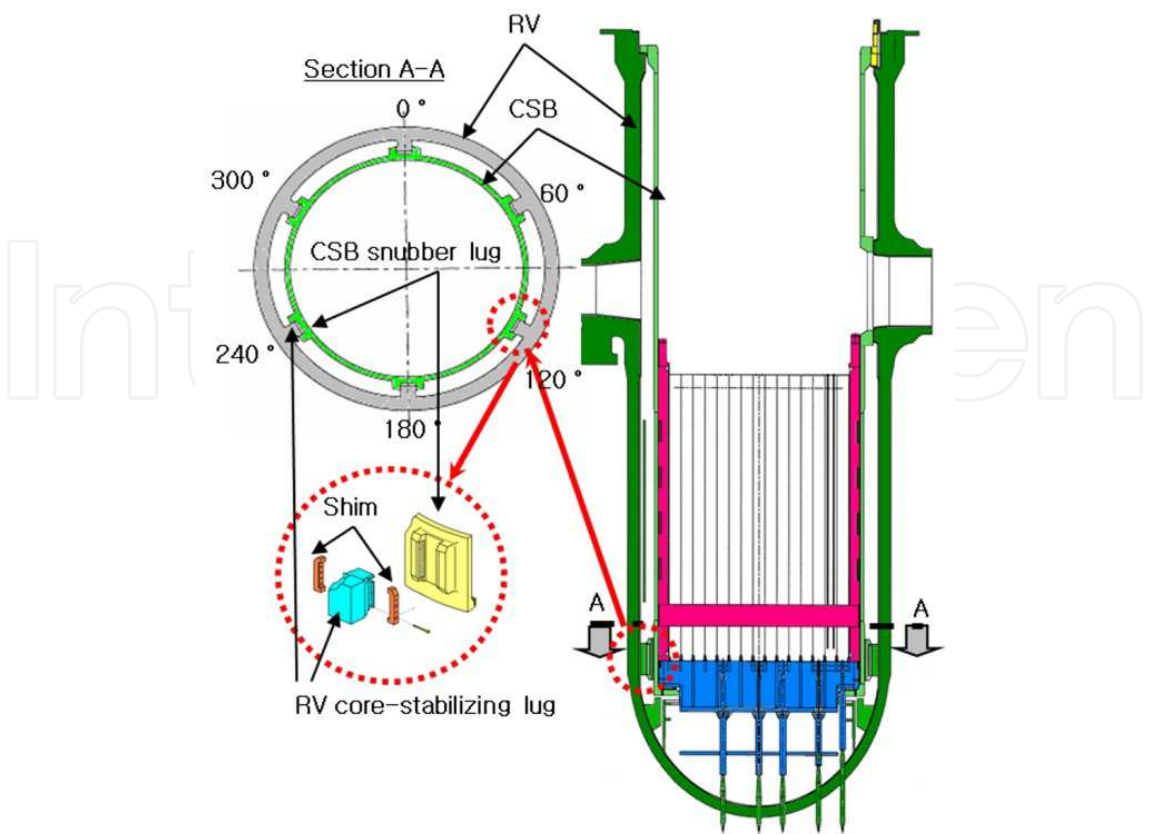
Fig. 3 shows timescales of existing installation method and developed method.

As shown in Fig. 3, developed modularization method by gap measurement remotely can reduce the critical path of the construction period by approximately 8-12 weeks. If the construction period is reduced, a construction budget expected to be saved the minimum \$ 176 million in Korea.

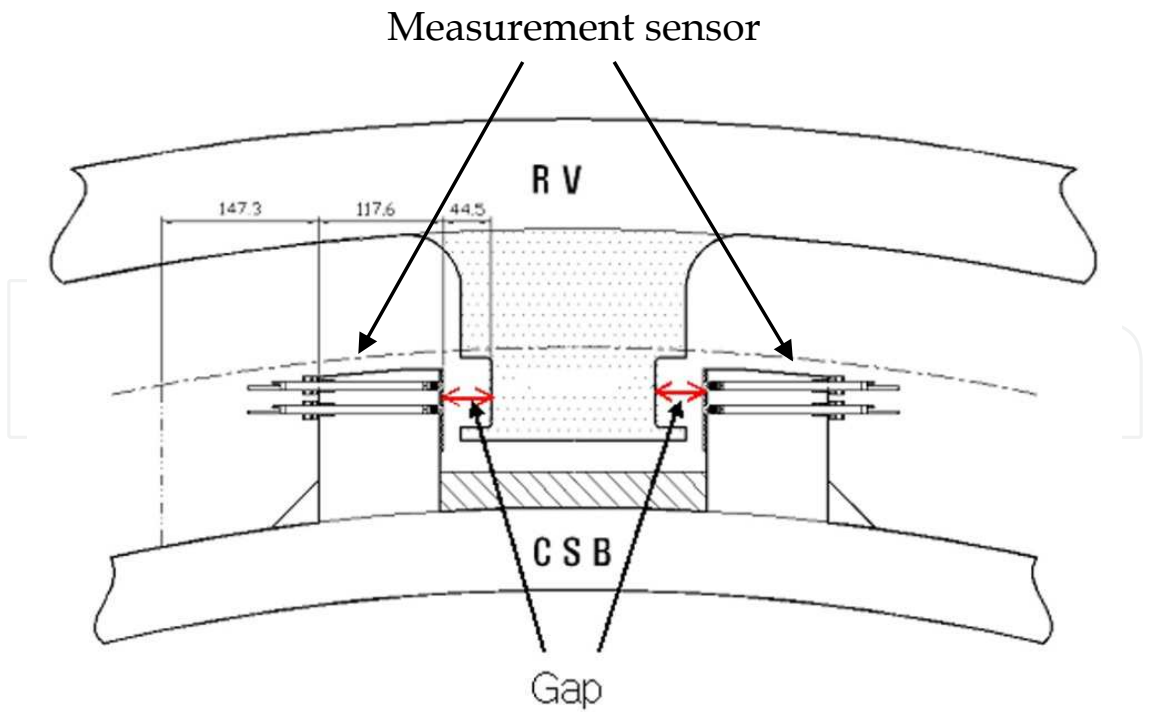
| Months                                   | 1               | 2 | 3                  | 4  | 5                              | 6  | 7               | 8  | 9  |
|--|-----------------|---|--------------------|----|--------------------------------|----|-----------------|----|----|
| Existing method<br>(ex. Uljin #5, Korea) | Install RV      |   | Install Shim       |    | Install CSB Ass'y              |    | Install RV Head |    |    |
|  | 70              |   | 34                 | 35 | 48                             |    | 12              | 25 | 14 |
|  | Measurement Gap |   |                    |    | CSB Ass'y<br>(Flexure Welding) |    | Install UGS     |    |    |
|  |                 |   |                    |    |                                |    |                 |    |    |
| Proposed modularization method           | Install RV      |   | Install Shim       |    | Install UGS                    |    |                 |    |    |
|  | 70              |   | 21                 | 26 | 12                             | 25 | 14              |    |    |
|  | Measurement Gap |   | Install CSB Module |    | Install RV Head                |    |                 |    |    |
|  |                 |   |                    |    |                                |    |                 |    |    |

Fig. 3. Timescales of existing installation method and proposed method

Fig. 4 shows a section of the RV core-stabilizing lug and the CSB snubber lug that shall be measured remotely for the modularization of the RVI.



(a) Measurement parts between RV core-stabilizing lug and CSB snubber lug



(b) Gaps between an RV core-stabilizing lug and a CSB snubber lug

Fig. 4. Measurement parts and gaps between the RV Core-stabilizing lug and the CSB snubber lug



**2.1 Design of a reduced-scale model system for the physical simulation of gap measurement**

**2.1.1 Design**

The purpose of designing a reduced-scale model system for the modularization of the reactor internals is to confirm the performance and application conditions of a remote distance measurement sensor selected. The sensor should be able to measure gaps between the CSB snubber lug and the RV core-stabilizing lug in the range 0.381–0.508 [mm].

This system was designed to be used at narrow space and small probe hole conditions and to be light easy to handle by using aluminum material. A threaded connection jig allows the remote measurement sensor to be assembled into the CSB snubber.

The block diagram in Fig. 5 shows the reduced-scale model system. The servomotors provide the movement in the up/down and front/rear directions for the reduced-scale models of the CSB snubber lug with remote measurement sensors connected. The air compressor drives the measurement sensors and the obtained data are displayed on the computer screen through the interface modules and network cables.

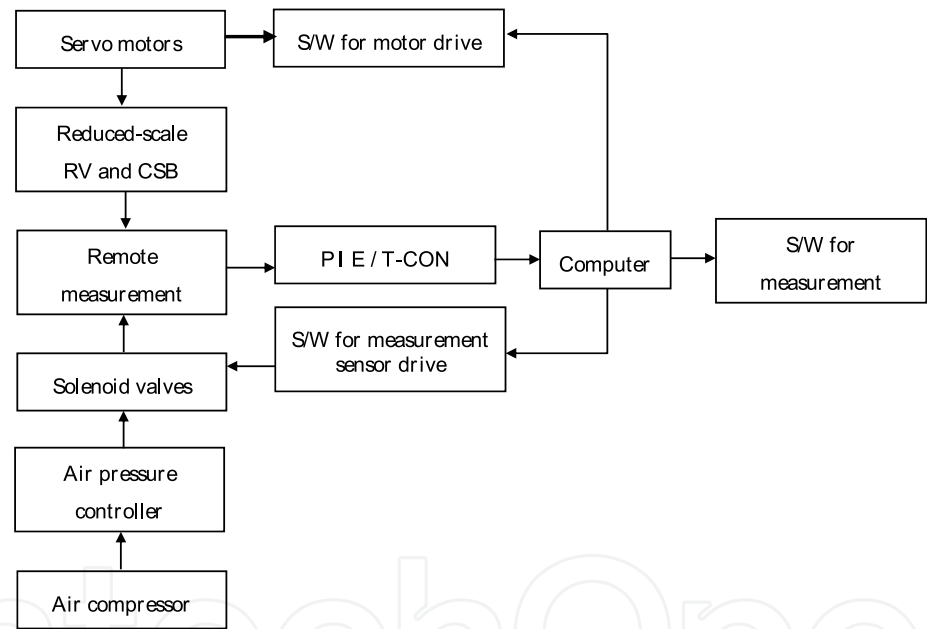


Fig. 5. Block diagram of reduced-scale model system

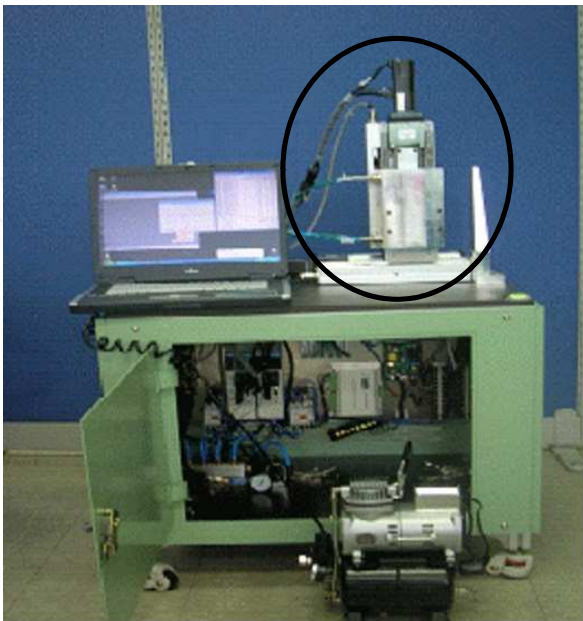
**2.1.2 Fabrication**

The picture in Fig. 6 shows the reduced-scale model system that consists of the reduced-scale CSB snubber lug , the reduced-scale RV core-stabilizing lug, 4 remote distance measurement sensors, the air supply device, 2 servo motor devices, the data interface modules and a laptop computer.

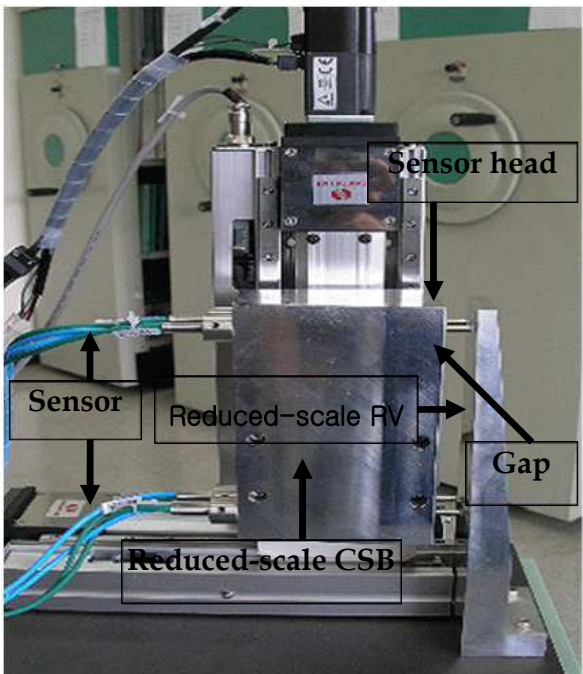
The components of the reduced-scale model system were fabricated as follows.

- The model pieces of the CSB snubber lug and RV lug were machined to precisely represent the surface and inside of the remote distance measurement sensors' hole. The material is aluminum alloy.

- The threaded connection jig of the remote distance measurement sensor was fabricated.
- The zero point adjustment device was fabricated.
- The block gauge was used to test the reliability of the remote distance measurement sensors.



(a)



(b)

(a) Overall system, (b) Enlarged circle of Fig. 6 (a) to simulate measurement of gaps between CSB snubber lug and RV core-stabilizing lug

Fig. 6. Reduced-scale model system for the modularization of reactor internals

2.2 Measurement sensor

Many essential factors in selecting a measurement sensor for the RVI modularization were studied. Namely, the measurement environment, the measured object, size of the sensor, the weight of a sensor, measurement range, drive force of the sensor, accuracy and resolution were investigated

First, contact sensors and non-contact sensors were compared (Ko et al., 2009) (ABB-CE, 1995).

Contact sensors are used to directly measure distance by moving the sensors toward the measured object. Non-contact sensors are used to indirectly measure comparatively very small distances by laser, high frequency and eddy current (Figliola & Beasley, 2000) (Beckwith et al., 1993).

Contact sensors are more suitable than non-contact sensors. Non-contact sensors are not ideal because their outside diameter is bigger than the hole diameter 8 [mm] of the CSB snubber lug, the measurement range is smaller than it is with contact sensors, and, most importantly, design changes to the CSB snubber lug are bigger in non-contact sensors than in contact sensors.

The most important principle can be directly applied without design changes to the existing reactor internals. The contact sensor of a remote distance measurement sensor must be inserted into the measurement hole of CSB snubber lug. Therefore, an essential condition of a sensor must be a probe type because a measurement sensor must pass through the measurement hole of the CSB snubber lug. The outside diameter must be 8 [mm] or less since the measured diameter of the hole in the CSB snubber lug is 8 [mm]. The length of the probe head must be 117.6 [mm] or more because the end point of the measurement hole in the CSB snubber lug must reach the RV after a zero point adjustment. Also, a sensor must span the distance from the CSB snubber lug to the RV when the RV and CSB are assembled, thus requiring the backward probe head to be 147.3 [mm] or less. Measurement range can be measured from 50 [mm].

The previous measurement was done by hand-measurement and the measured maximum value was 48.92 [mm] (Uljin #5 nuclear power plant in Korea). The resolution must be 0.0254 [mm] or below as the sensor has to measure until 0.0254 [mm] (1/1000") in the case of gap measurement between the CSB snubber lug and the shim on the RV core-stabilizing lug, after the shim was assembled onto the CSB snubber lug by cap screws.

A sensor was investigated that remote measurement was possible in at least 25 [m] or more. The following items were considered when selecting a sensor: material, space and outward shape of the reactor internals. Also, no additional devices should be installed around the RV core stabilizing lug and the CSB snubber lug in order to perform the remote measurement.

Table 1 shows the suitable specifications of a sensor that have been researched to measure gap. The shape of a sensor is probe type of a contact sensor and the measurement method is digital.

Finally, the SOLARTRON (UK) sensor (DT/20/P) was selected for the reduced-scale model system (Solartron-metrology, 2006).



|  |  |
|--|--|
| Shape of sensor                        | Probe                                  |
| Type of sensor                         | Contact, Digital                       |
| Outside diameter of probe head         | 8 [mm] or below                        |
| Length of probe head                   | 117.6 [mm] or over                     |
| Backward space of CSB snubber lug hole | From hole entrance 147.3 [mm] or below |
| Measurement range                      | 50 [mm] or over                        |
| Resolution                             | 25.4 [um] or below                     |
| Accuracy                               | ±12.7 [um] or below                    |
| Operating temperature                  | No relation                            |
| Distance of remote measurement         | 25 [m] or over                         |
| Driving force                          | Electric or Pneumatic                  |
| Numbers of synchronous measurement     | 72 points and over                     |
| Operating tool                         | Computer-based                         |

Table 1. Suitable specifications of a remote sensor for gap measurement

2.3 Experiment and result

The designed system was tested to confirm the performance and application conditions of a remote distance measurement sensor selected.

The tests were carried out repeatedly to confirm reliability, consistency, accuracy and stability of the measurement.

The reliability test method of the sensors is as follows. First, a sensor was fixed to an anchor of granite comparator stand. Second, the probe of the sensor is positioned so as to be close to the granite comparator stand at suitable heights. Third, the probe was extended so that it touches on the face of stand. This state is the zero point of the sensor. Forth, put gauge blocks of 5 [mm], 10 [mm], 15 [mm], and 18 [mm] on the stand, and measure the reliability of the sensor. Reliability test results were obtained as shown in Fig. 7.

As the size of a gauge block is large, the error of measurement sensor was increased from 0.0037 [mm] to 0.0119 [mm]. However, the reliability test was satisfied because the sensors did not exceed the maximum allowable error (0.0254 [mm]). And the measurement errors under the pressure of 0.8 [bar] and 2 [bar] are similar.

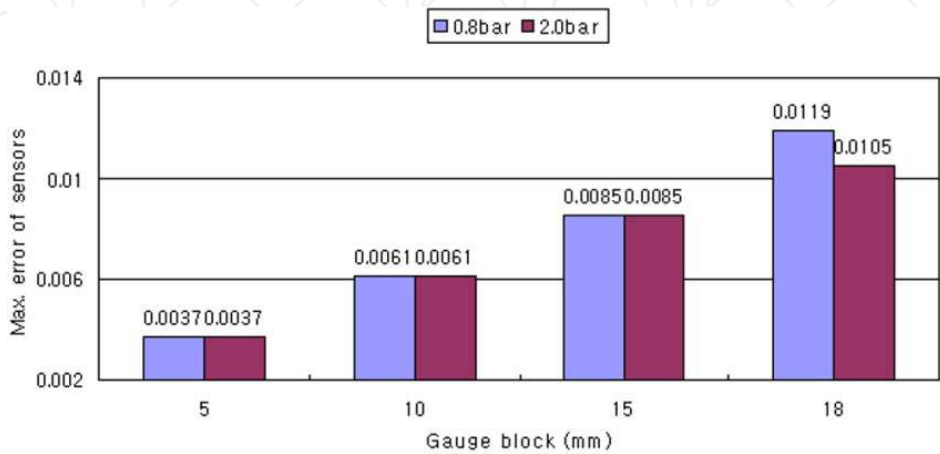


Fig. 7. Reliability test results of remote distance measurement sensors using gauge blocks

The consistency test method of connection jigs for sensors is as follows. First, a sensor was inserted into a threaded connection jig and fixed firmly. Second, insert a sensor and a connection jig to the hole of the minimized model of the CSB snubber lug, and fix it firmly by threaded connection jig. Third, when sensors have received air pressure of 0.8[bar], 1.4[bar], and 2.0[bar], the sensors measure the distance five times. Fourth, the process measurements are repeated three times and attached again after removing the connection jigs of the remote distance measurement sensors. Consistency test results under 1.4[bar] at each gauge blocks were obtained as shown in Fig. 8.

The measurement errors of sensor 2 (0.0024 [mm]) and 4 (0.0025 [mm]) were large compared with sensor 1 and 3, but consistency test were satisfied because the error did not exceed the maximum allowable error.

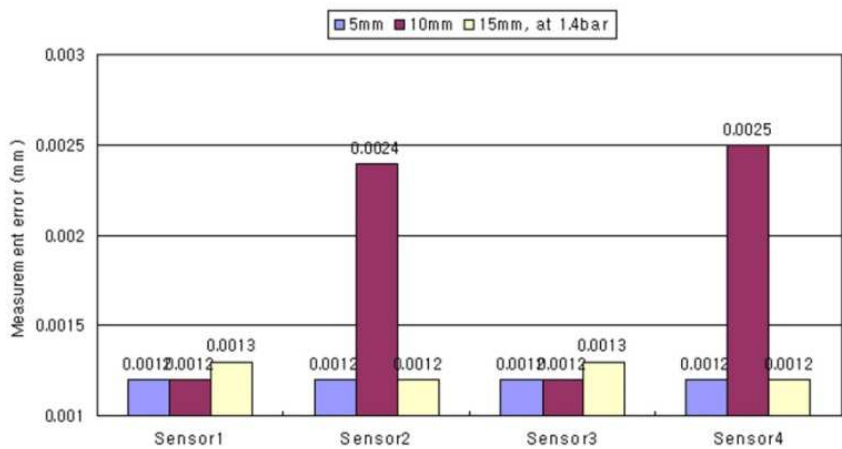


Fig. 8. Consistency test results of connection jigs for remote sensors

The accuracy test method for the zero point adjustment device for the sensors is as follows. First, a zero point adjustment device that was designed and made, binds the right and left of the minimized model of the CSB, and is fixed. Second, run the probes of the sensors installed into the minimized model of the CSB, and remove the zero point adjustment device on the minimized model of the CSB after repeating the distance measurement five times. Third, compare the distance measurements from three repetitions of the process. Accuracy test results were obtained as shown in Fig. 9.

The measurement errors of sensor 2 and 4 were large compared with sensor 1 and 3, but accuracy test were satisfied because it did not exceed the maximum error.

Switching noises and EMI (electromagnetic interference) might occur because of the use of electric lamps and transceivers to build nuclear power plants (Ko & Bae, 2006).

Therefore, the stability tests were done at no disturbance noise and in a switching noise environment, and at EMI environment.

The stability test method of sensors at no disturbance noise is as follows. The air pressure to 1.4[bar] on the remote sensors of the reduced-scale model system was set up and tested five times, repeatedly. Stability test results at remote distance were obtained as shown in Fig. 10.

There were no errors in all sensors except sensor 4. The error was only 0.0003 [mm], but it was in allowable range.

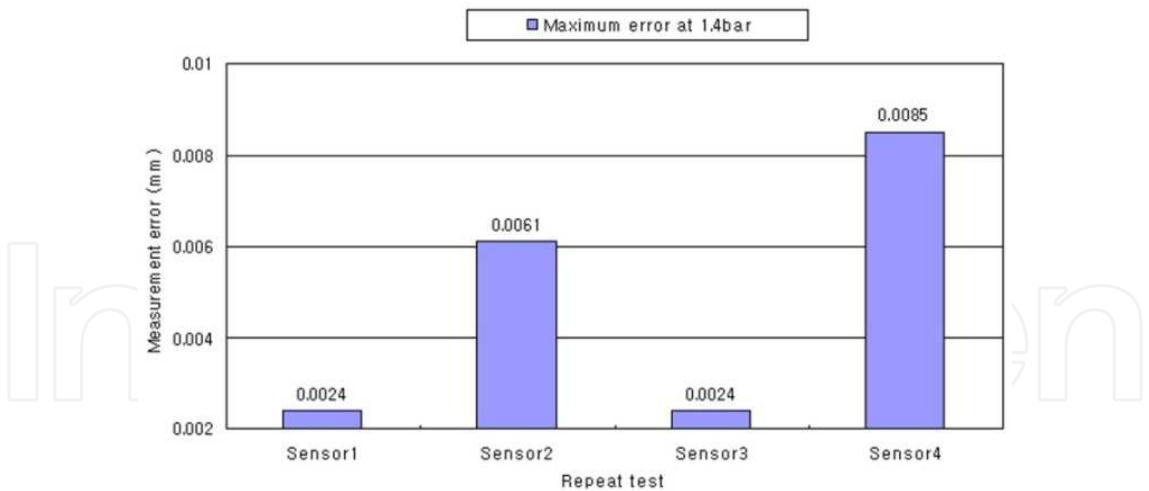


Fig. 9. Accuracy test results of a zero point adjustment device for sensors

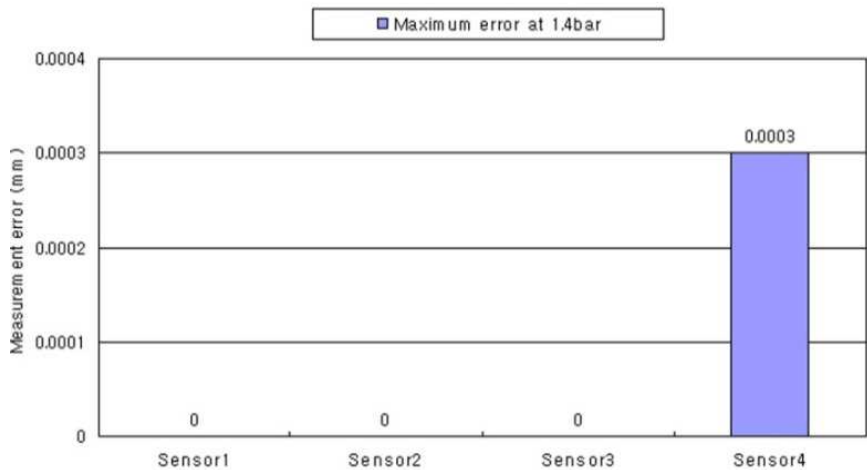


Fig. 10. Stability test results of sensors at no disturbance noise

The stability test method of the sensors in a switching noise environment is as follows. First, a 27[W] desk lamp (220V/60Hz) at 10 [cm] from the sensor probe was installed. Second, five times while turning the power on the lamp on and off were measured. During this test, the supplied air pressure was 0.8[bar] to the the sensor probe. The results at switching noise environment were obtained as shown in Fig. 11.

The measurement errors of sensor 2 and 4 were 0.0012 [mm] and 0.0008 [mm], but it were satisfied because the sensors did not exceed the maximum error (0.0254 [mm]).

Another stability test methods of the sensors at EMI environment is as follows. First, a VHF/UHF FM radio transceiver (TM-V7A/KENWOOD) and an antenna 30 [cm] away from the probes were installed. Second, five times each for the cases of 144[MHz/5W], 144[MHz/10W], 439[MHz/5W] and 439[MHz/10W] were repeatedly measured. During this test, the supplied air pressure was 0.8[bar] to the probes of the sensors. The test results at EMI environment were obtained as shown in Fig. 12.

In the environment of 144 [MHz/10W], the measurement error was 0.0003 [mm], but it was in allowable range also.

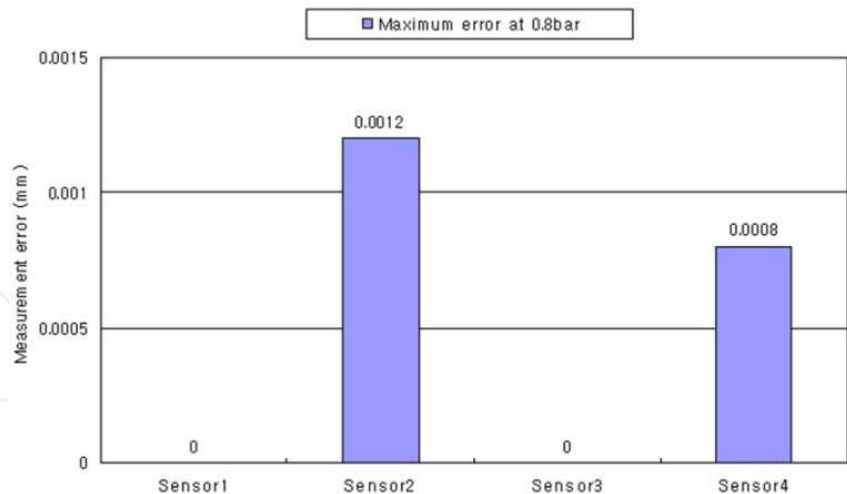


Fig. 11. Stability test results at switching noise environment

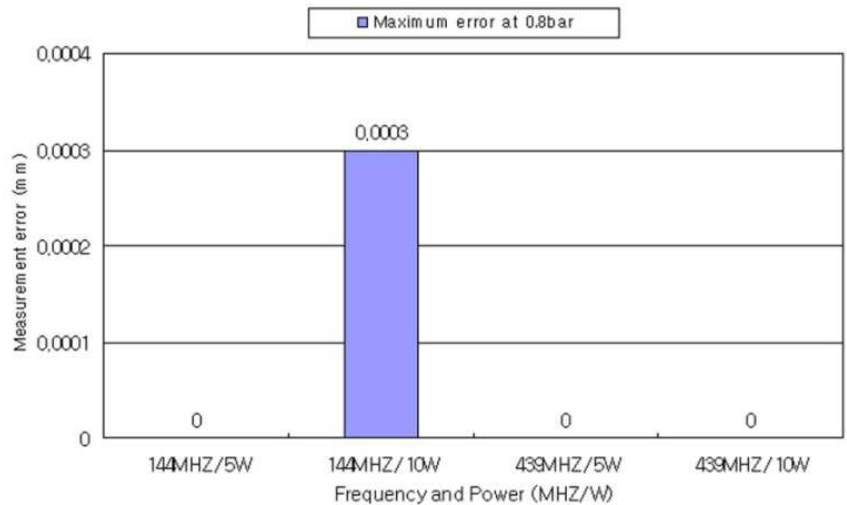


Fig. 12. Stability test results at EMI environment

As shown in the above test results, the selected sensor can be used in a remote measurement system for the modularization of reactor internals since the sensor errors did not exceed 0.0254 [mm] (1/1000”).

In the experiments and results, they were found that the measurement errors of sensor 2 and sensor 4 are bigger than sensor 1 and sensor 3. We judged that these results were occurred by something problem from self-characteristics of sensors.

2.4 Conclusion

From these results, the technology of remote measurement for the modularization of reactor internals may be advanced by design and development of the reduced-scale model system.

Also, the reduced-scale model system designed may be used as a gap measurement training system for a modularization method of reactor internals. And it needs the more suitable sensor under the consideration of the special conditions and environments in reactor internals.

3. Development of measurement system for RVI modularization

An RV mockup and a CSB mockup were also manufactured to evaluate and verify the reliability and applicability in construction sites of the developed remote measurement system. This part explains the development of the remote measurement system, including its design, fabrication and related experiments (Ko & Lee, 2010).

3.1 Development of a remote measurement system for gap measurements

3.1.1 Design

The purpose of this remote measurement design is to measure the gaps of between the RV core-stabilizing lug and the CSB snubber lug for RVI-modularization. The reason for the measurement of gaps is to set a permissible range of 0.381 – 0.508 mm between the RV core-stabilizing lug and the CSB snubber lug. The permissible range, when a nuclear reactor operates, ensures a margin by thermal expansion. This is identical to that used in current power water reactors.

For these gaps, adjustment of the shims was machined at the construction site and assembled in the RV after measurement of the gaps of the RV core-stabilizing lugs and the CSB snubber lugs.

Fig. 4 shows the placement of the six gap-measurement locations between the RV core-stabilizing lug and the CSB snubber lug. The RV core-stabilizing lugs located inside the RV and the CSB snubber lugs located outside the CSB are set at angles of 0°, 60°, 120°, 180°, 240°, and 300°. The angular positions correspond to locations 1 through 6, respectively (see Fig. 4). Also, each of six RV core-stabilizing lugs corresponds to a pair of (left and right) the CSB snubber lugs, as shown in Fig. 4. One side of the CSB snubber lug has six holes for hand-measurements in the current RVI-installation method. Therefore, one CSB snubber lug has twelve holes, and six CSB snubber lugs have a total of 72 holes, which are from the external RVI; the lengths of which should be measurable simultaneously, as shown in Fig. 13.

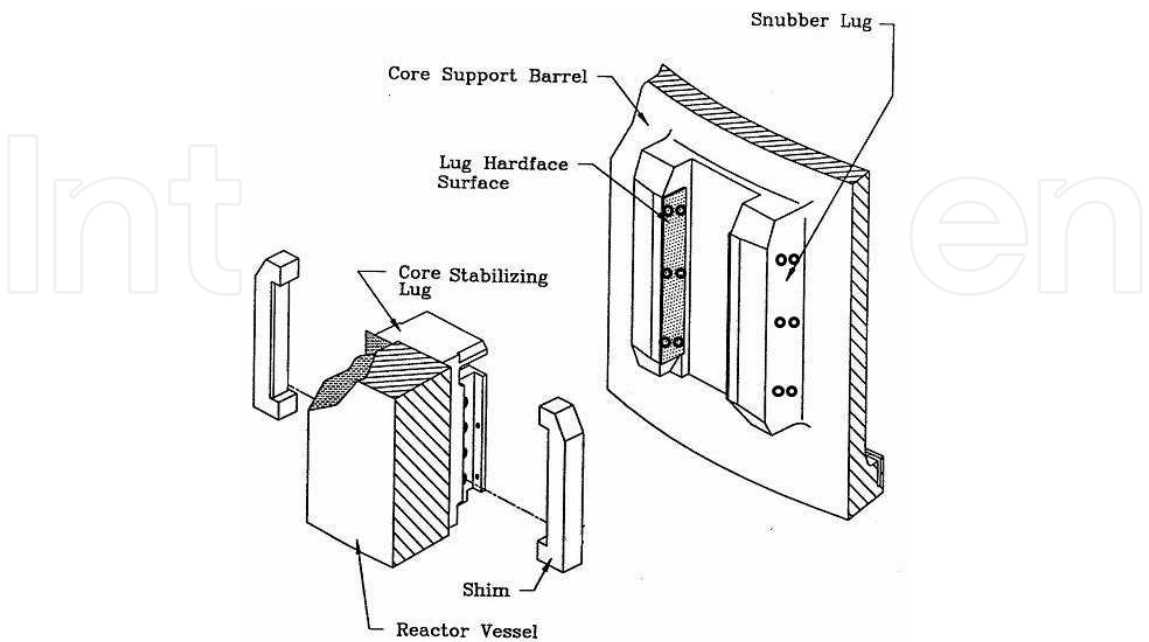


Fig. 13. RV core-stabilizing lug and CSB snubber lug



Many essential factors were studied before selecting the measurement sensors used for RVI-modularization.

Specifically, the measurement environment, the measured object, the size of the sensor, the weight of the sensor, the measurement range, the driving force of the sensor, the accuracy, and the resolution were investigated. Finally, the SOLARTRON (UK) sensor (DT/20/P) was selected for the remote measurement system (Ko et al., 2009).

The DT/20/P sensor was tested to confirm its performance and application conditions in a reliability test using gauge blocks. A consistency test was also done to check the connection jig, and an accuracy test was done for the zero-point adjustment device. Finally, a stability test was done to check the switching noise environment and the EMI (electromagnetic interference) using a reduced-scale model system. All test results were satisfactory for a sensor of a remote measurement system (Ko et al., 2009).

### 3.1.2 Fabrication

A remote measurement system was developed to measure the gaps between the RV core-stabilizing lug and the CSB snubber lug using a DT/20/P digital probe sensor. The major characteristics of the remote measurement system are as follows:

- The remote measurement system consists of a measurement sensor section, a pneumatic supply and control section, a power supply section, and a remote control computer and software program.
- The measurement sensor section is intended to measure gaps between the RV core-stabilizing lug and the CSB snubber lug. Those sensors, placed at 0° and 60°, are measured by 24 sensors with a signal cable connected to the channel box #1. Those sensors placed at 120° and 180° are measured by 24 sensors with a signal cable connected to the channel box #2, and those sensors placed at 240° and 300° are measured by 24 sensors with a signal cable connected to the channel box #3. A measurement sensor section is composed of 72 digital probes. This system is able to measure 72 points at once and operate by pneumatic actuation.
- The pneumatic supply and control section is intended to supply air to actuate the sensors by a remote control computer and a software program. The pneumatic supply section consists of an air compressor, an air filter, an air pressure regulator and an air tube. The pneumatic control section is composed of a flow control valve, a solenoid valve, a solenoid valve manifold, a USB orbit module and a T-CON. The solenoid valve and the solenoid valve manifold control operation of measurement sensors and the USB orbit module and the T-CON receive signal data of the digital probe, DT/20/P.
- The power supply section supplies electric power to the electric equipment, including the T-CON.
- The remote control computer and the software program consist of a laptop computer and the software to control digital probes and to process and store the measurement results.
- The channel box contains 24 digital probes, the T-CON, 24 solenoid valves, and four solenoid valve manifolds. The channel is designed for three channel boxes. These boxes were very easy to handle due to their suitable weight and size.
- All of the cables and air tubes are easily connected to the channel boxes.
- The network of the remote measurement system is very stable and causes no disturbance to the EMI environment.

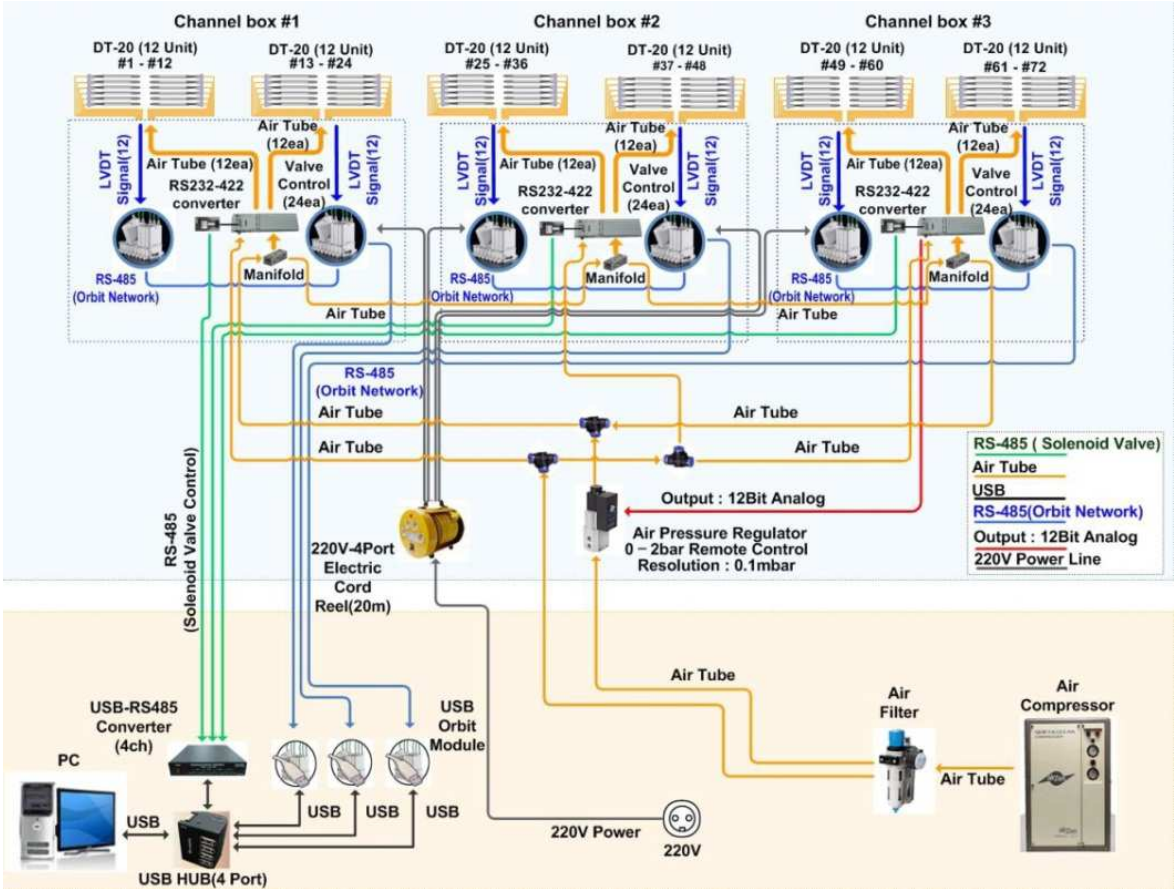


Fig. 14. Block diagram of developed remote measurement system

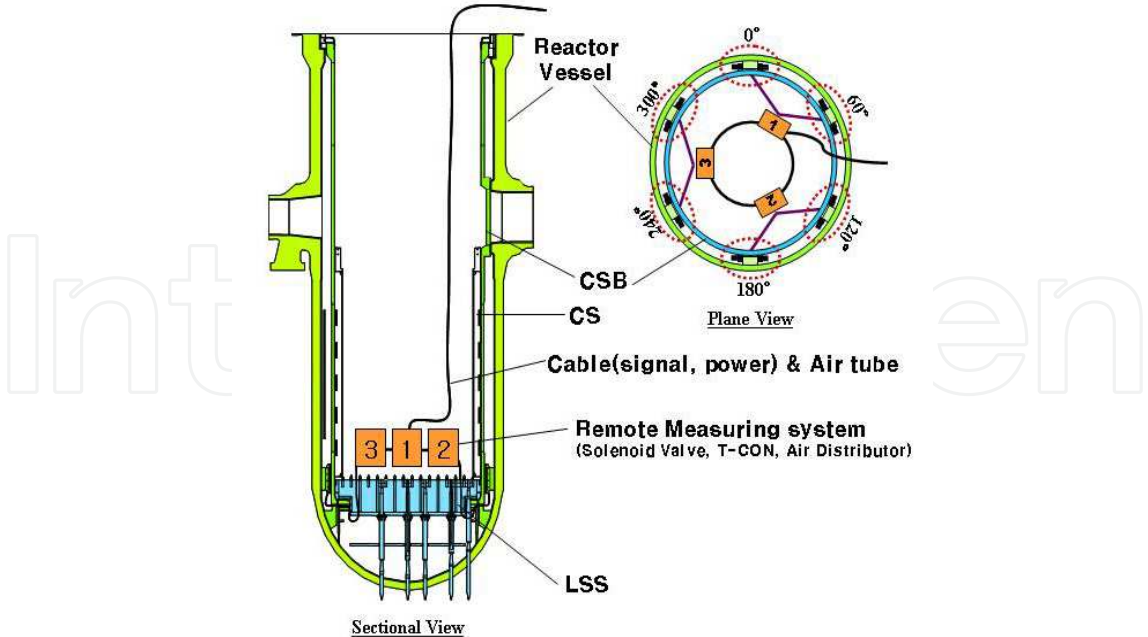


Fig. 15. Setup position of the remote measurement system

Table 2 presents a list of the parts of the remote measurement system, and Fig. 14 shows a block diagram of the developed remote measurement system.

| List of Parts                         | Amount |
|---------------------------------------|--------|
| DT/20/P digital probe                 | 72     |
| USB orbit module                      | 3      |
| AC-PSIM power supply                  | 6      |
| T-CON                                 | 75     |
| Flow control valve                    | 72     |
| Threaded connection jig               | 72     |
| 0-Point adjustment jig                | 6      |
| Solenoid valve                        | 72     |
| Solenoid valve manifold               | 12     |
| 2-line RS-485 signal cable & reel     | 3      |
| 220V-4port electric cable & cord reel | 2      |
| Air tube                              | 500 m  |
| 4-port air manifold                   | 1      |
| I/O board SMPS                        | 9      |
| 4-port USB hub                        | 1      |
| USB to RS-485 converter               | 1      |
| Air clean unit                        | 2      |
| Air compressor                        | 1      |
| Marking tool                          | 1      |
| Electric lamp & cord reel             | 2      |
| Air tube one touch reel(20 m)         | 1      |
| System storage box                    | 1      |

Table 2. List of parts for remote measurement system

As shown in Fig. 15, the channel boxes are located above the LSS in the CSB. The digital probes should be set on the CSB snubber lugs before assembly with the RV. The channel box should be connected to the air compressor, to the remote control computer, and to the electric power source after assembly of the RV and the CSB.

3.2 Design of RV and CSB mockup

An RV mockup and a CSB mockup were designed and manufactured because the remote measurement system should be subjected to a test to verify its applicability in construction projects. This was done using the RV mockup and the CSB mockup developed here.

3.2.1 Design concept of the RV and the CSB mockup

To design the RV mockup and the CSB mockup, it was necessary to follow a number of principles. First, the measurement parts of the RV core-stabilizing lugs and the CSB snubber lugs should be designed to simulate the actual size of the construction site. Second, the 72 points of the RV core-stabilizing lugs and the CSB snubber lugs should be measured simultaneously. The factors not related to any measurement part should be designed to be as simple as possible.

The RV mockup and the CSB mockup were designed to evaluate the setting suitability of remote measurement system. In particular, the RV core-stabilizing lug of the RV mockup and the CSB snubber lug of the CSB snubber lug were designed to match the RV and the CSB of an actual nuclear power plant.

Other parts of the actual RV and CSB were simply designed for usability of the experiment and out of concerns for the manufacturing budget. Thus, the thickness of cylinders was designed to be thinner than that of an actual RV and an actual CSB.

3.2.2 Design of the RV mockup

The RV inner diameter is identical to that of the original. However, the RV outer diameter, not related to the measurement, was designed so as to be thinner, making it a light RV mockup. Thus, it was designed to be different from the actual size. The RV upper flange was simply designed.

The RV upper flange-face was assembled with the CSB and was applied to actual conditions in the same manner. The RV cylinder was designed with a thin plate, including a RV core-stabilizing lug. The height of the RV mockup was minimized to 2,665 mm.

The assembled parts of the RV core-stabilizing lugs, the RV core stop lug, and the shim were designed to be identical to their real-life counterparts.

Six supports of 70 cm in height were attached to the bottom of the RV mockup to monitor the condition of the measurement sensors. The lifting lugs were welded onto the RV upper flange to facilitate assembly and separation from the CSB mockup.

Fig. 17 and Fig. 18 show the designed 3D model and an image of the manufactured RV mockup.

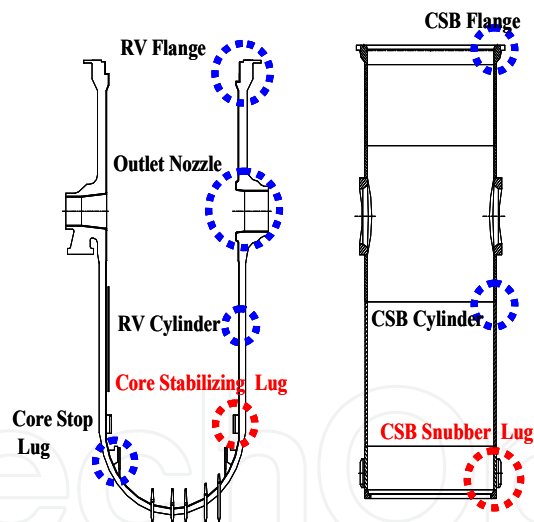


Fig. 16. Important parts of the design of the mockup

Other parts of the actual RV and CSB were simply designed for usability of the experiment and out of concerns for the manufacturing budget. Thus, the thickness of cylinders was designed to be thinner than that of an actual RV and an actual CSB.

Fig. 16 shows the important parts in the design of the RV mockup and the CSB mockup.

3.2.3 Design of the RV mockup

The RV inner diameter is identical to that of the original. However, the RV outer diameter, not related to the measurement, was designed so as to be thinner, making it a light RV

mockup. Thus, it was designed to be different from the actual size. The RV upper flange was simply designed.

The RV upper flange-face was assembled with the CSB and was applied to actual conditions in the same manner. The RV cylinder was designed with a thin plate, including a RV core-stabilizing lug. The height of the RV mockup was minimized to 2,665 mm.

The assembled parts of the RV core-stabilizing lugs, the RV core stop lug, and the shim were designed to be identical to their real-life counterparts.

Six supports of 70 cm in height were attached to the bottom of the RV mockup to monitor the condition of the measurement sensors. The lifting lugs were welded onto the RV upper flange to facilitate assembly and separation from the CSB mockup.

Fig. 17 and Fig. 18 show the designed 3D model and an image of the manufactured RV mockup.

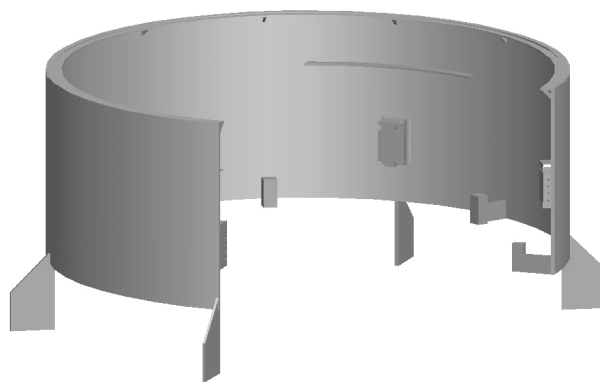


Fig. 17. 3D model of the RV mockup



Fig. 18. Image of the manufactured RV mockup

### 3.2.4 Design of the CSB mockup

The CSB outer diameter is identical to that of its real-life counterpart. However, the CSB inner diameter, not related to the measurement, was designed to be thinner, making it a light CSB mockup. Thus, it was designed to be different from the actual size.

The conditions of the CSB flange in contact with the RV upper flange were designed according to actual conditions. The CSB cylinder was designed with a thin plate including the CSB snubber lug. The height of the CSB mockup was minimized to 1,618 mm. The CSB



snubber lugs were both designed in keeping with their actual shapes and were welded onto the CSB. The lifting lugs were welded onto the CSB flange to facilitate assembly and separation from the RV mockup. A stand for the installation of the remote measurement system was designed on the inside of the CSB mockup.

Fig. 19 and Fig. 20 show the designed 3D model and an image of the manufactured CSB mockup.

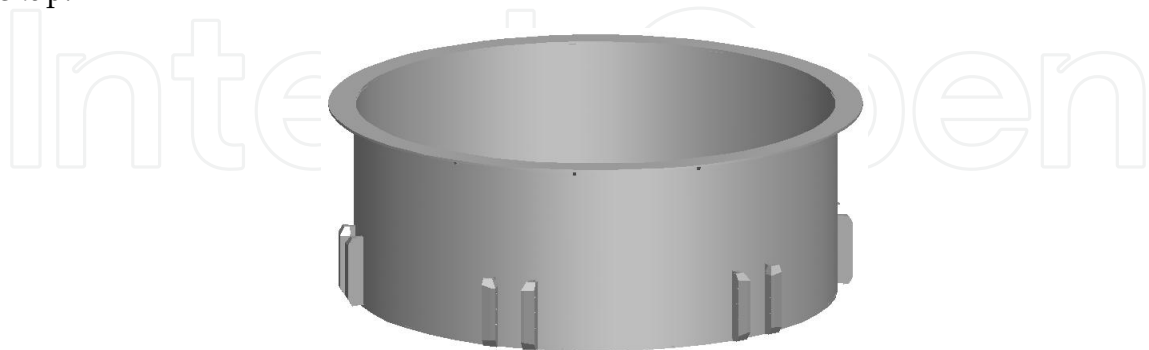


Fig. 19. 3D model of the CSB mockup



Fig. 20. Image of the manufactured CSB mockup

### 3.3 Experiment and result

#### 3.3.1 Experiment

One difference between the remote measurement method and the hand-measurement method is that measurement had to be done using the remote measurement system after assembly of the CSB on the RV. An additional difference was that it was necessary to attach a gauge block to the RV core-stabilizing lug before assembly of the CSB to overcome the length-measurement limit of the remote measurement system.

The measurement value of the gap between the RV core-stabilizing lug and the CSB snubber lug is typically measured to a maximum 49 mm in the construction sites of nuclear power plants, but the maximum measurement range of the measurement sensor in the remote measurement system was 20 mm.

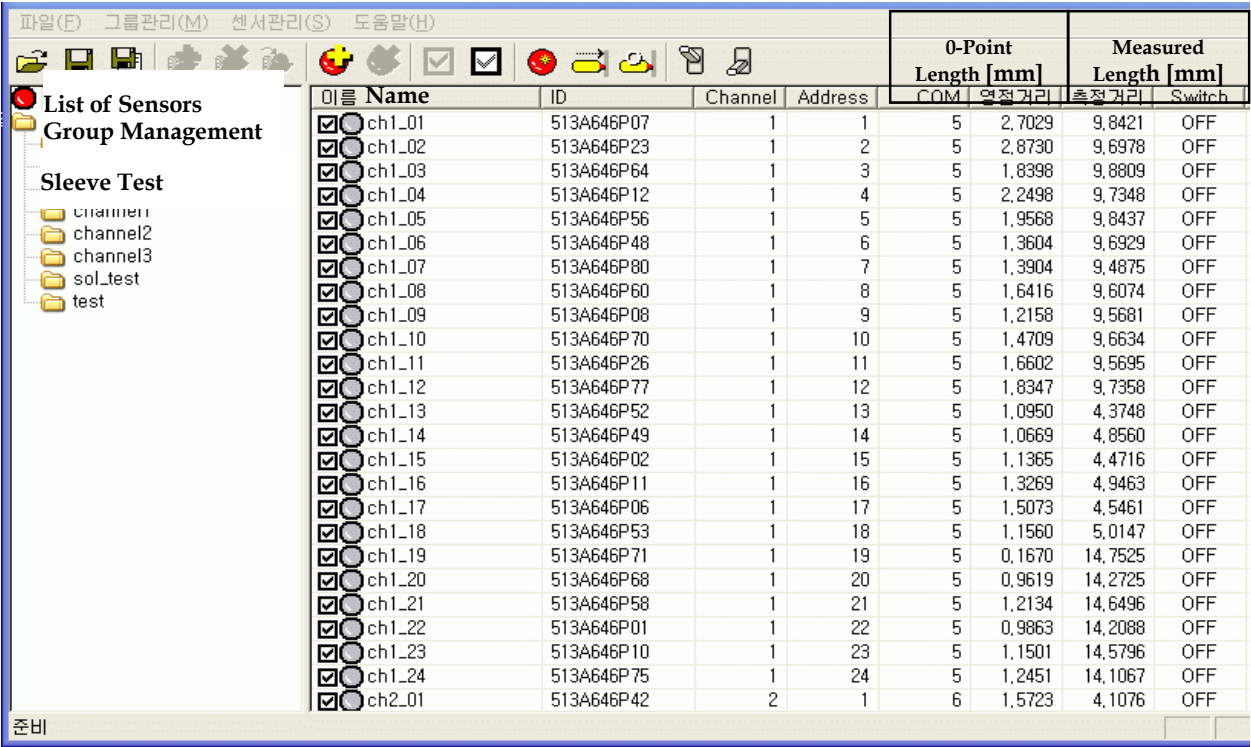
Therefore, the remote measurement method required twelve gauge blocks of 35 mm to measure 72 points simultaneously.

The experimental procedure of the remote measurement system using the RV mockup and the CSB mockup is as follows:

- Widths of six RV core-stabilizing lugs and twelve gauge blocks of 35 mm made using a micrometer were measured and attached to twelve gauge blocks to the right and the left of the six RV core-stabilizing lugs.
- The inside lengths of the CSB snubber lugs, the locations of the contact of the RV core-stabilizing lug with the CSB snubber lug, were measured using a cylinder gauge.
- The remote measurement system was installed on a stand inside the CSB mockup. The stand is used to simplify the LSS in RVI.
- 72 sensors assembled with 72 threaded connection jigs were inserted and fixed at 72 holes for measurement of the CSB snubber lugs.
- Three channel boxes are connected to air-hoses, signal cables, and electric power cables.
- The software program for remote measurement should be tested and measurement sensors should be confirmed as being capable of normal operation using the remote control computer.
- To set a start-point of the measurement sensors, six zero-point adjustment devices were installed between the left and the right areas of the CSB snubber lugs and were adjusted to the zero point. After the zero-point adjustment, the six zero-point adjustment devices were disconnected from the CSB snubber lugs.
- After the CSB mockup of the RV mockup was assembled, the gaps between the RV core stabilizing lugs and the CSB snubber lugs were measured using the remote measurement system.

The measurement test, using the remote measurement system, was carried out with the assembly and disassembly of the RV mockup and the CSB mockup three times in succession.

Fig. 21 shows a computer screen detailing the gaps as acquired by the remote measurement system.



| 이름                                  | Name   | ID         | Channel | Address | 0-Point Length [mm] |        | Measured Length [mm] |        |
|-------------------------------------|--------|------------|---------|---------|---------------------|--------|----------------------|--------|
|                                     |        |            |         |         | COM                 | 영점거리   | 측정거리                 | Switch |
| <input checked="" type="checkbox"/> | ch1_01 | 513A646P07 | 1       | 1       | 5                   | 2,7029 | 9,8421               | OFF    |
| <input checked="" type="checkbox"/> | ch1_02 | 513A646P23 | 1       | 2       | 5                   | 2,8730 | 9,6978               | OFF    |
| <input checked="" type="checkbox"/> | ch1_03 | 513A646P64 | 1       | 3       | 5                   | 1,8398 | 9,8809               | OFF    |
| <input checked="" type="checkbox"/> | ch1_04 | 513A646P12 | 1       | 4       | 5                   | 2,2498 | 9,7348               | OFF    |
| <input checked="" type="checkbox"/> | ch1_05 | 513A646P56 | 1       | 5       | 5                   | 1,9568 | 9,8437               | OFF    |
| <input checked="" type="checkbox"/> | ch1_06 | 513A646P48 | 1       | 6       | 5                   | 1,3604 | 9,6929               | OFF    |
| <input checked="" type="checkbox"/> | ch1_07 | 513A646P80 | 1       | 7       | 5                   | 1,3904 | 9,4875               | OFF    |
| <input checked="" type="checkbox"/> | ch1_08 | 513A646P60 | 1       | 8       | 5                   | 1,6416 | 9,6074               | OFF    |
| <input checked="" type="checkbox"/> | ch1_09 | 513A646P08 | 1       | 9       | 5                   | 1,2158 | 9,5681               | OFF    |
| <input checked="" type="checkbox"/> | ch1_10 | 513A646P70 | 1       | 10      | 5                   | 1,4709 | 9,6634               | OFF    |
| <input checked="" type="checkbox"/> | ch1_11 | 513A646P26 | 1       | 11      | 5                   | 1,6602 | 9,5695               | OFF    |
| <input checked="" type="checkbox"/> | ch1_12 | 513A646P77 | 1       | 12      | 5                   | 1,8347 | 9,7358               | OFF    |
| <input checked="" type="checkbox"/> | ch1_13 | 513A646P52 | 1       | 13      | 5                   | 1,0950 | 4,3748               | OFF    |
| <input checked="" type="checkbox"/> | ch1_14 | 513A646P49 | 1       | 14      | 5                   | 1,0669 | 4,8560               | OFF    |
| <input checked="" type="checkbox"/> | ch1_15 | 513A646P02 | 1       | 15      | 5                   | 1,1365 | 4,4716               | OFF    |
| <input checked="" type="checkbox"/> | ch1_16 | 513A646P11 | 1       | 16      | 5                   | 1,3269 | 4,9463               | OFF    |
| <input checked="" type="checkbox"/> | ch1_17 | 513A646P06 | 1       | 17      | 5                   | 1,5073 | 4,5461               | OFF    |
| <input checked="" type="checkbox"/> | ch1_18 | 513A646P53 | 1       | 18      | 5                   | 1,1560 | 5,0147               | OFF    |
| <input checked="" type="checkbox"/> | ch1_19 | 513A646P71 | 1       | 19      | 5                   | 0,1670 | 14,7525              | OFF    |
| <input checked="" type="checkbox"/> | ch1_20 | 513A646P68 | 1       | 20      | 5                   | 0,9619 | 14,2725              | OFF    |
| <input checked="" type="checkbox"/> | ch1_21 | 513A646P58 | 1       | 21      | 5                   | 1,2134 | 14,6496              | OFF    |
| <input checked="" type="checkbox"/> | ch1_22 | 513A646P01 | 1       | 22      | 5                   | 0,9863 | 14,2088              | OFF    |
| <input checked="" type="checkbox"/> | ch1_23 | 513A646P10 | 1       | 23      | 5                   | 1,1501 | 14,5796              | OFF    |
| <input checked="" type="checkbox"/> | ch1_24 | 513A646P75 | 1       | 24      | 5                   | 1,2451 | 14,1067              | OFF    |
| <input checked="" type="checkbox"/> | ch2_01 | 513A646P42 | 2       | 1       | 6                   | 1,5723 | 4,1076               | OFF    |

Fig. 21. Screen showing measurement results of the remote measurement system

3.3.2 Result

The ground plan for the gap between the RV and the CSB as measured by the remote measurement system is shown in Fig. 22.

Table 3 shows a comparison of the data by the remote measurement system and the hand-measurements.

The "Total" value, data by the remote measurement system, denotes the sum of the left gap (LG) and the right gap (RG), the left block-gauge length (LB) and the right block-gauge length (RB), and the width of the RV core-stabilizing lug (D). The "J" value represents the hand-measurement data using a micrometer. Therefore, the "Total - J" value denotes the error between the remote measurement system data and the hand-measurement data.

Table 3 now shows that the remote measurement system has high accuracy as the maximum error is only 0.0669 mm. The maximum error is smaller than 0.127 mm of acceptance criteria.

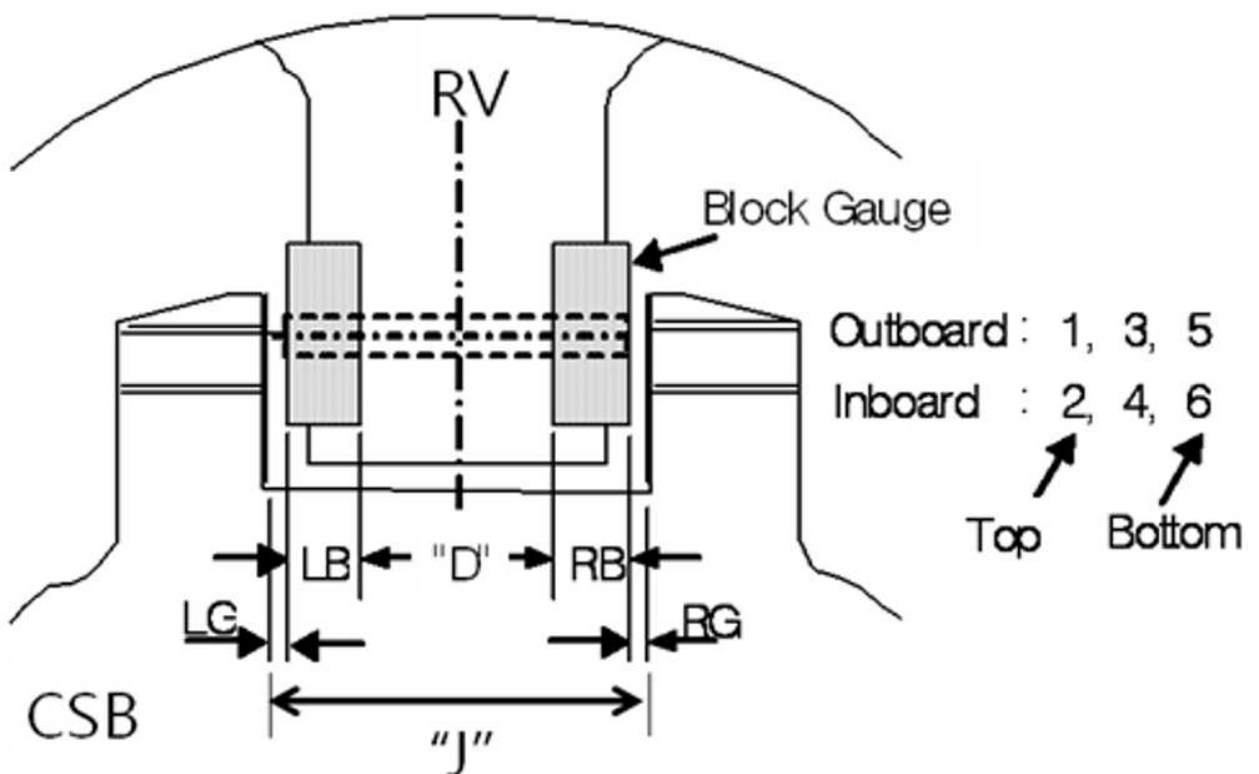


Fig. 22. Ground plan for the gap of between the RV and the CSB

The differences between the Total values and the J values are shown in Fig. 23.

On the other hand, on the basis of the permissible range, which was set to 0.381 – 0.508 mm, if there is a difference in the width that is within 0.127 mm, the requirements are considered to be satisfied. Errors in the measurement data that was used in the remote measurement system in the experiment and analyses did not exceed 0.127 mm.

Therefore, through this experiment and as demonstrated by the results, the remote measurement system was demonstrated to have reliability and the required applicability for deployment in the construction sites of nuclear power plants.

| Location |   | LG +   | LB +   | D       | + RB   | + RG    | = | Total    | J        | Total - J<br>(Error) |
|----------|---|--------|--------|---------|--------|---------|---|----------|----------|----------------------|
| 0°       | 1 | 9.9007 | 34.885 | 152.150 | 34.895 | 9.5612  | = | 241.3919 | 241.3250 | 0.0669               |
|          | 2 | 9.7528 | 34.900 | 152.130 | 34.895 | 9.6764  | = | 241.3542 | 241.3050 | 0.0492               |
|          | 3 | 9.8675 | 34.890 | 152.120 | 34.905 | 9.5639  | = | 241.3464 | 241.3250 | 0.0214               |
|          | 4 | 9.6571 | 34.965 | 152.110 | 34.905 | 9.6678  | = | 241.3049 | 241.3100 | -0.0051              |
|          | 5 | 9.8546 | 34.855 | 152.125 | 34.875 | 9.6056  | = | 241.3152 | 241.3250 | -0.0098              |
|          | 6 | 9.7016 | 34.865 | 152.100 | 34.875 | 9.7631  | = | 241.3047 | 241.3200 | -0.0153              |
| 60°      | 1 | 4.3944 | 34.885 | 152.390 | 34.900 | 14.7650 | = | 241.3344 | 241.3650 | -0.0306              |
|          | 2 | 4.8742 | 34.895 | 152.385 | 34.900 | 14.2862 | = | 241.3404 | 241.3500 | -0.0096              |
|          | 3 | 4.4628 | 34.900 | 152.420 | 34.910 | 14.6466 | = | 241.3394 | 241.3700 | -0.0306              |
|          | 4 | 4.9950 | 34.905 | 152.390 | 34.905 | 14.1700 | = | 241.3650 | 241.3450 | 0.0200               |
|          | 5 | 4.5724 | 34.875 | 152.435 | 34.865 | 14.6027 | = | 241.3501 | 241.3650 | -0.0149              |
|          | 6 | 5.0382 | 34.885 | 152.410 | 34.875 | 14.1214 | = | 241.3296 | 241.3450 | -0.0154              |
| 120°     | 1 | 4.0993 | 34.900 | 152.250 | 34.890 | 15.1549 | = | 241.2942 | 241.3200 | -0.0258              |
|          | 2 | 3.8661 | 34.895 | 152.240 | 34.895 | 15.3632 | = | 241.2593 | 241.2800 | -0.0207              |
|          | 3 | 4.1366 | 34.905 | 152.240 | 34.895 | 15.1916 | = | 241.3682 | 241.3400 | 0.0282               |
|          | 4 | 3.8756 | 34.905 | 152.210 | 34.900 | 15.3849 | = | 241.2755 | 241.2900 | -0.0145              |
|          | 5 | 4.1408 | 34.875 | 152.220 | 34.870 | 15.1761 | = | 241.2819 | 241.3300 | -0.0481              |
|          | 6 | 3.9372 | 34.875 | 152.205 | 34.880 | 15.4613 | = | 241.3585 | 241.3000 | 0.0585               |
| 180°     | 1 | 7.0775 | 34.905 | 152.145 | 34.890 | 12.3671 | = | 241.3846 | 241.3250 | 0.0596               |
|          | 2 | 7.1105 | 34.900 | 152.125 | 34.875 | 12.2970 | = | 241.3075 | 241.3250 | -0.0175              |
|          | 3 | 7.2694 | 34.900 | 152.175 | 34.900 | 12.1571 | = | 241.4015 | 241.3500 | 0.0515               |
|          | 4 | 7.2975 | 34.895 | 152.150 | 34.885 | 12.0841 | = | 241.3116 | 241.3275 | -0.0159              |
|          | 5 | 7.5123 | 34.850 | 152.160 | 34.855 | 11.9887 | = | 241.3660 | 241.3650 | 0.0010               |
|          | 6 | 7.5585 | 34.850 | 152.140 | 34.845 | 11.9393 | = | 241.3328 | 241.3350 | -0.0022              |
| 240°     | 1 | 3.0665 | 34.895 | 152.220 | 34.890 | 16.2133 | = | 241.2848 | 241.3200 | -0.0352              |
|          | 2 | 3.4621 | 34.900 | 152.090 | 34.895 | 15.9112 | = | 241.2583 | 241.2800 | -0.0217              |
|          | 3 | 3.1894 | 34.905 | 152.205 | 34.900 | 16.1000 | = | 241.2994 | 241.3150 | -0.0156              |
|          | 4 | 3.5021 | 34.905 | 152.080 | 34.905 | 15.8700 | = | 241.2621 | 241.2950 | -0.0329              |
|          | 5 | 3.3227 | 34.865 | 152.195 | 34.865 | 16.0655 | = | 241.3132 | 241.3350 | -0.0218              |
|          | 6 | 3.6515 | 34.865 | 152.085 | 34.875 | 15.8272 | = | 241.3037 | 241.3000 | 0.0037               |
| 300°     | 1 | 6.6439 | 34.875 | 152.265 | 34.895 | 12.6747 | = | 241.3536 | 241.3450 | 0.0086               |
|          | 2 | 6.5915 | 34.895 | 152.130 | 34.900 | 12.8177 | = | 241.3342 | 241.3250 | 0.0092               |
|          | 3 | 6.6015 | 34.890 | 152.260 | 34.905 | 12.7303 | = | 241.3868 | 241.3500 | 0.0368               |
|          | 4 | 6.5128 | 34.905 | 152.145 | 34.905 | 12.8487 | = | 241.3165 | 241.3350 | -0.0185              |
|          | 5 | 6.5463 | 34.860 | 152.240 | 34.860 | 12.8112 | = | 241.3175 | 241.3600 | -0.0425              |
|          | 6 | 6.5746 | 34.870 | 152.125 | 34.865 | 12.8949 | = | 241.3295 | 241.3350 | -0.0055              |

Table 3.Comparison of data by remote measurement system and hand-measurement

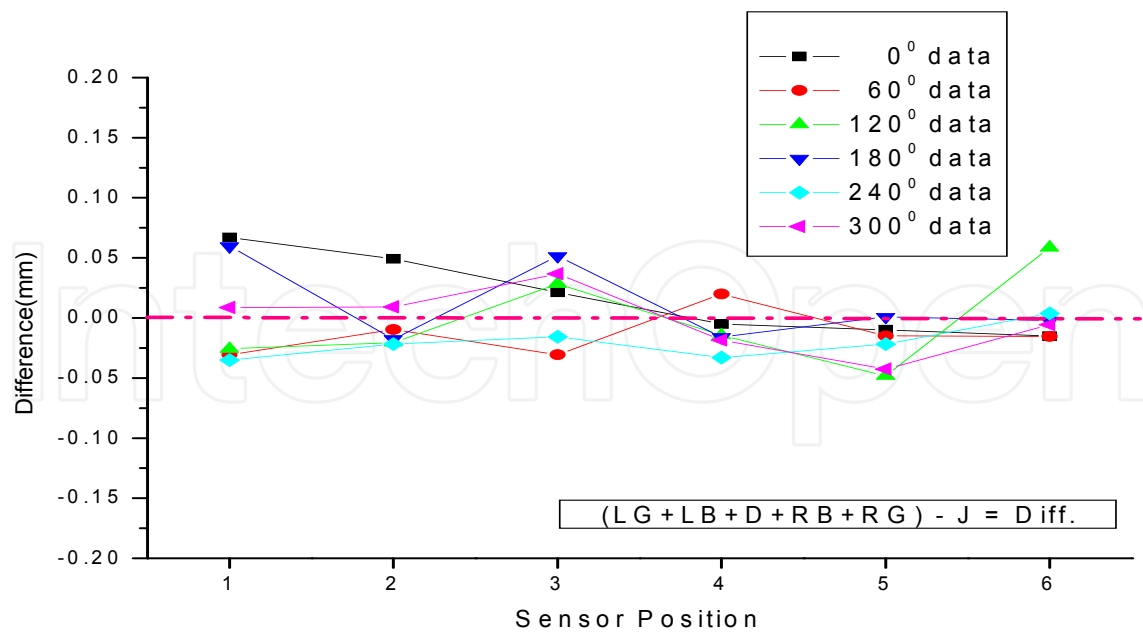


Fig. 23. Differences between the Total values and the J values

3.4 Conclusion

A system was successfully developed that can measure the gaps between the RV core-stabilizing lugs and the CSB snubber lugs remotely for RVI-modularization. To confirm the reliability of this method and its applicability to construction sites, the measurement system was designed, manufactured, and tested it using an RV mockup and CSB mockup.

It is therefore concluded that the remote measurement system reduces the construction period by nearly two months or more compared to the existing method of hand measurements.

As the developed remote measurement system can be used at actual construction sites.

4. Development of an improved installation procedure and schedule of RVI modularization

4.1 Development of an improved installation procedure for RVI modularization

Under the existing installation procedure, six snubber shims were assembled between the RV core-stabilizing lugs and the CSB snubber lugs after alignment of the CSB and the RV. Subsequently, assembly and flexure welding of the LSS and the CS were conducted. The new and improved installation procedure for RVI modularization was developed allowing assembly and flexure welding of the LSS and the CS to be performed before the main installation process. Alignment of the CSB assembly and the RV and assembly of the snubber shims were undertaken during the main installation process.

The improved installation procedure for RVI modularization (Ko, 2011) appears in Table 4 as order 1 and order 3. A detailed explanation is given below of the flexure welding of the LSS and the CS in the CSB as well as of the alignment and installation of the snubber shims of the CSB assembly and the RV.



| Order | RVI installation procedure  | Remark      |
|-------|---|-------------|
| 1     | Assembly of the LSS and the CS in the CSB, Flexure welding              | Improvement |
| 2     | Welding of the flow baffle in the RV                                    |             |
| 3     | Alignment of the CSB assembly and the RV, Installation of snubber shims | Improvement |
| 4     | Installation of the CSB assembly in the RV                              |             |
| 5     | Installation and alignment of the UGS                                   |             |
| 6     | Installation and alignment of the RV head                               |             |
| 7     | Installation of alignment keys, dowel pins and guide lugs insert        |             |
| 8     | Final alignment, Installation of head down ring and HJTC tube           |             |

Table 4. Improved installation procedure for RVI modularization

4.1.1 Alignment of the CSB and RV and calculation of the dimensions of the snubber shim

1. The dimensions between the RV outlet nozzle and the reactor coolant loop (RCL) were measured after the welding of the RCL. They were recorded along with the measured dimensions before the welding. The widths of the RV core-stabilizing lugs were also measured.
2. The measured positions were marked on RV keyways and the relative positions of the keyways on the RV centerline were measured using the widths and vertical degrees.
3. The target-hole positions of the RV flange on the RV centerline and the dimensions of the gauge blocks of the RV core stabilizing lug were also measured. Here, the dimensions of the required measurements were the heights and widths of the gauge blocks.
4. Before installation of the gauge blocks, the integrity of the RV core-stabilizing lugs and the cap screws was checked. Neolube was applied twice on both the threaded surfaces on the cap screws and the surfaces of the bearings.

4.1.2 Installation of the gauge block

1. Gauge blocks were installed and the cap screws were then tightened. They needed to be tightened according to a three-step tightness method, as follows: 160, 213 and 266 ft-lbs. The final torque was 256 - 276 ft-lbs and the tightness sequence was as follows:
2. The number of cap screws was 1, 2, 3, and 4 from top to bottom. The tightness sequence of step 1 was 2, 3, 1, and 4, and the torque was 160 ft-lbs.
3. The tightness of step 2 was identical to that of 2) and the torque was 213 ft-lbs.
4. The tightness of step 3 was identical to that of 2) and the torque was 266 ft-lbs.
5. The cap screws were unscrewed in the reverse sequence of the tightness sequence: 4, 1, 3, and 2.
6. One more time, the tightness was carried out by the sequence of 2), 3), and 4).
7. The remaining gauge blocks were installed on the CSB snubber lugs according to the sequence of 2), 3), 4), 5), and 6). After installation of the gauge blocks, the gaps between the upper part and the lower part were uniformly maintained at 0.1016 mm.

#### 4.1.3 Dimensions of the CSB Snubber Lug

1. After installation of the gauge blocks, all widths of the gauge blocks at the same six intervals were measured. Subsequently, the dimensions of the CSB snubber lugs were measured. The measured parts of the CSB snubber lugs were the inside widths of both of their surfaces. In total, six holes of the CSB snubber lugs were measured.
2. The measured positions of the CSB keyway were marked and the widths measured.
3. Four dummy alignment keys (DAKs) were installed on the RV keyways and adjusted so that they could be positioned within 0.254 mm of the RV centerline. The vertical degree of an RV head seating surface of a DAK was adjusted so that it could be positioned within 0.0254 mm/ft. The position of the DAK and the vertical degree were measured again.

#### 4.1.4 Installation of the remote measurement system

1. In order to set up the remote measurement system inside the CSB assembly, three channel boxes were mounted in the CSB assembly. As shown in Fig. 15, the channel boxes were opened and 72 digital probes were taken out of the CSB assembly through spaces between the CSB and the LSS.

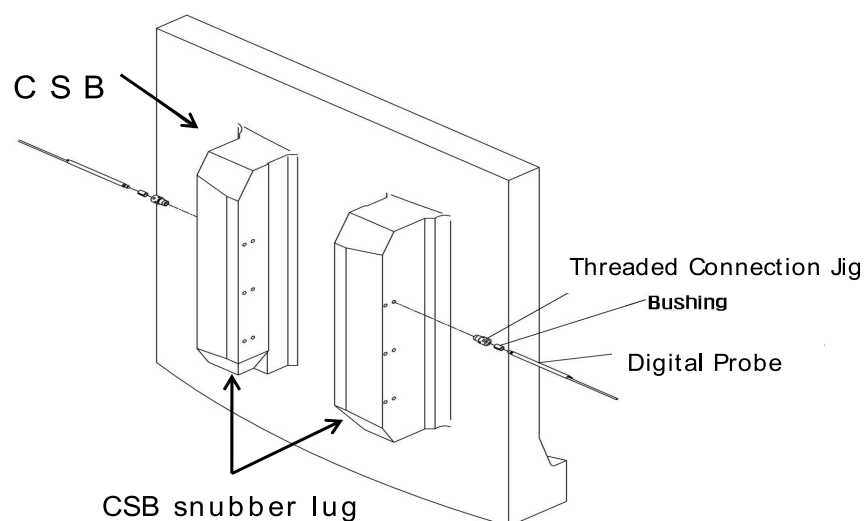


Fig. 24. Assembly of digital probe and threaded connection jig

2. As shown in Fig. 24, all 72 digital probes were installed the holes of the CSB snubber lugs after the digital probes were assembled with the threaded connection jigs. For this step, the digital probes were necessarily placed at 1 mm or more from the measured holes of the CSB snubber lug. Bolt tightening was done using a hexagonal wrench. The bolts numbered 1, 2, 3, and 4 were clockwise and the tightening order was 1, 3, 2, and 4. All remaining sensors were installed via the methods described above.
3. The electric power cords, air hoses, and signal cables between the channel boxes were connected and taken out of the RV. The air hoses were connected with an air compressor.
4. The signal cables were linked with a USB-orbit module and an RS-485 converter. The USB ports of the USB-orbit module were linked with a USB hub. The USB hub and USB ports of the RS-485 converter were connected to the USB ports of a remote measurement computer. Table 5 shows the remote measurement system guideline.









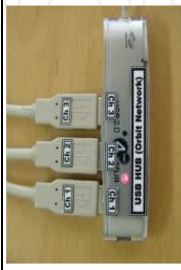


| Object                      | Status  | Operation   | Object  | Status   | Operation   |
|-----------------------------|---|---|---|--|---|
| Air-compressor              |    | Electric power turned on and pressure adjusts to 0.8MPa; air valve open | RS-232 to 485 Converter                       |    | Solenoid valve links with RS-232 to 485 converter |
| RS-485 Converter            |    | RS-485 converter links with solenoid valve cables                       | Air regulator                                 |    | Air regulator links with solenoid valve           |
| USB orbit module            |    | Orbit cables link with USB orbit module                                 | Solenoid valve & AC adapter                   |    | Channel boxes supply electric power               |
| USB hub                     |   | USB ports of orbit module link to USB hub                               | RS-485 Converter                              |   | Computer power on                                 |
| Remote measurement computer |  | USB ports of computer link to USB ports of RS-485 converter and USB hub | USB Hub                                       |  | Computer power on                                 |
| Solenoid valve & AC adapter |  | Solenoid valve link AC adapter  | Software program of remote measurement system |  | Software program executes                         |

Table 5. Remote measurement system guideline

5. Electric power supplies were checked in order with the remote measurement system first, followed by the air compressor, and then the remote measurement computer to verify whether or not the connections worked exactly according to the operating guide.
6. The air pressure was set to 0.8 – 1 bar using a software program on the remote measurement computer. At this stage, the digital probes had to be checked using a software program to verify whether or not they operated normally. Fig. 14 shows the configuration of the remote measurement system.

#### 4.1.5 Zero-point adjustment of the remote measurement system and marking

1. In order to attach a zero-point adjustment device firmly onto the CSB snubber lug, a zero-point adjustment plate and a connector on the gap control section were tightened. The remaining zero-point adjustment devices adhered to the CSB snubber lug as described above. Fig. 25 shows the zero-point adjustment device mounted on the CSB snubber lug.
2. Length measurement was done using the software program of the remote measurement computer. Measurements were taken five times. The average values were then used to set the zero-point data. When the setting of the zero-point data was complete, the zero-point data were saved and recorded.
3. The zero-point adjustment device was detached from the CSB snubber lug and a marking tool was attached to the CSB snubber lug. Digital probes were stained with a red stamping ink and their correct operation was confirmed using the software program of the remote measurement computer. The remaining digital probes were executed in the same way.
4. The marking tool was removed from the CSB snubber lug and the channel boxes in the CSB assembly and air compressor were then separated from the air hoses, electric power cords, and signal cables connected to the remote measurement computer. The disconnected cords and cables had to be arranged so that a disturbance did not result from the combination of the RV and the CSB assembly. Fig. 26 shows the marking tool assembly attached onto the CSB snubber lug.

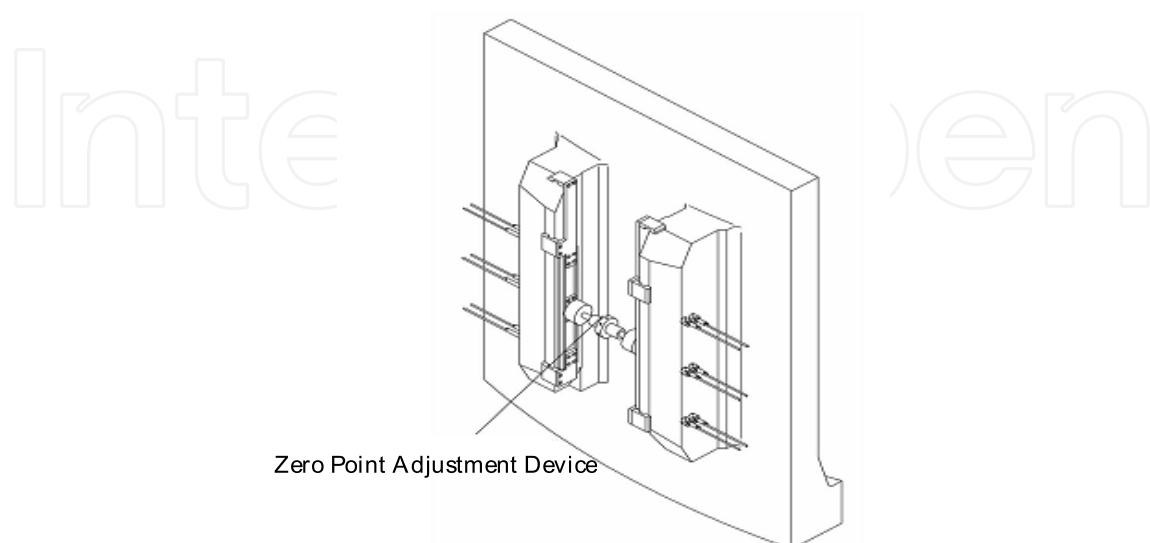


Fig. 25. Installation of zero point adjustment device

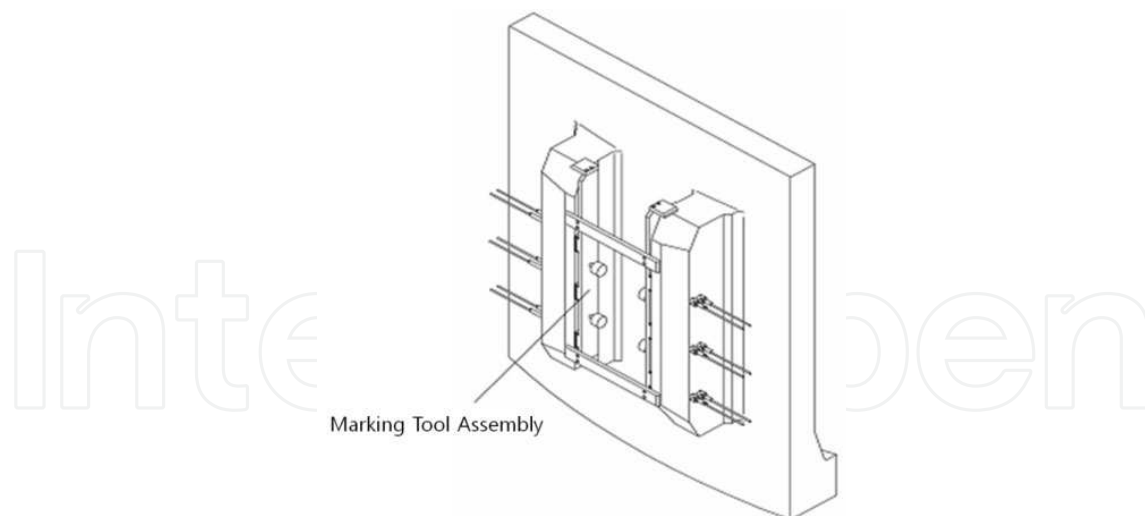


Fig. 26. Installation of a marking tool

#### 4.1.6 Combination of the CSB assembly and the RV

1. The CSB assembly was aligned to the RV centerline and the CSB assembly was inserted in the RV. The CSB assembly was turned at  $45^\circ$  and was lowered to prevent damage to the DAK. It was then combined after the CSB assembly was turned to the original position before ensuring a 50 cm interval between the CSB assembly and the RV.
2. When the CSB assembly was installed, the load measured by a hydra-set was continuously checked. In addition, when the CSB assembly was at a height of approximately 30 cm from the RV head seating surface, the bottom surface (datum "B") of the CSB upper flange was used to stop the descent of the CSB assembly. A basis surface (datum "B") of the CSB upper flange was used for a parallel adjustment to within 0.381 mm of the RV head seating surface.
3. The load of the hydra-set was decreased to 10,000 lb and was checked given that the CSB came in contact with the RVI installation surface. The RV centerline and the CSB centerline were aligned within 0.0254 mm by CSB position devices (8 EA).
4. The vertical degree for the CSB keyway and the datum hole were measured and their relative positions on the CSB centerline were confirmed.
5. The gaps between the RV head seating surface and the upper surface of the CSB flange were measured in  $45^\circ$  intervals. The gaps (2.1336 – 2.9464 mm) of the RV outlet nozzle and the temperatures of the nozzle area were also measured.
6. The alignment of the RV/CSB centerline and the requirements of the nozzle gap were checked. If the requirements were not satisfied, it was necessary to repeat this procedure. If the position of the DAK changed before and after the installation of the CSB due to the checking of the position of the DAK, the measurements had to be done again and the existing checklist was invalidated. All installation requirements were met; the final adjustment conditions and the variation of the CSB centerline on the RV centerline were measured and recorded.

#### 4.1.7 Length measurement using the remote measurement system

1. The channel box of the internal CSB and the air hose, compressor, electric power cord, power supply and signal cables of the external CSB were connected. Electric power was then supplied.



2. Using a software program running on a remote measurement computer, the length was measured a total of five times. The pressure for the measurement was adjusted to 0.8 ~ 1 bar; this was set to have a zero length to ensure that the data were entered correctly. The average value of the measured lengths was used as the data. Once the measurement was completed, the data were stored and the measured length was recorded.
3. After the gap measurements were completed, all electric power was turned off. After the RV and the CSB assembly were detached, the air hose, electric power cord and signal cable were respectively separated from the compressor, electric power, USB hub and RS-485 converter. Once separated, the air hose, electric power cord and signal cable were temporarily fixed in the CSB assembly to ensure that they would not interfere with the disassembly of the CSB assembly.

#### 4.1.8 Separation of the CSB Assembly and RV

1. The CSB assembly was separated from the RV and set on a storage stand. The CSB assembly was lifted at 45° turns after vertical lifting of approximately 50 cm in order to prevent the DAKs from being damaged. The CSB assembly was checked continuously via a load measured by a hydra-set.
2. After the checked positions of the gauge blocks were marked using digital probes, the widths of the marked positions were measured. After removing the gauge blocks, the gaps between the CSB snubber lugs and the RV core-stabilizing lugs were used to calculate the processing dimensions of the snubber shims; the gaps were calculated at 0.381-0.508 mm as a permissible range.

#### 4.1.9 Installation and measurement of the shim on the RV core-stabilizing lug

1. The dimensions of the refined shims were measured and a penetration test was conducted. Before installation of the shims, the RV core stabilizing lugs and the cap screws were checked to confirm the integrity of each screw. Neolube, a dry film lubricant, was applied twice to the threaded surfaces of the cap screws and bearing surface. Fig. 13 shows the assembly of the snubber shims on the RV core-stabilizing lug.
2. When the shims were installed, the cap screws were assembled by hand and tightened according to a three-step tightness method: 160, 213 and 266 ft-lbs. It was important that after the shims were installed, the upper gaps and lower gaps were maintained as constant (0.1016 mm).
3. After the shims were installed, their full widths were measured in six positions to measure the equal intervals. The DAKs were adjusted to vertical degrees at 0.0254 mm/ft for the RV head seating surface. At this point, the vertical degrees of the DAKs and the status of the installed positions were recorded.
4. According to section 2.6 "Combination of the CSB assembly and the RV," the CSB assembly was installed in the RV. When the RV core-stabilizing lugs and the RV snubber shims were connected, they were lowered using the hydra-set. The RV centerline and the CSB centerline were adjusted within 0.0254 mm using the DAKs, and the CSB assembly was completely lowered. If the positions of the DAKs changed, the measurements had to be done again.
5. The gaps between the RV and the CSB outlet nozzles were recorded and the offsets of the CSB keyways regarding the DAKs were recorded as well. The offsets of the CSB centerline in relation to the RV centerline were also calculated and recorded.

6. The air hoses, electric power cords and signal cables of the remote measurement system were reconnected to the compressor, electric power, USB hub and RS-485 converter, and electric power was supplied. The length of the snubber shims was measured five times. Once the measurement was complete, the measured data were stored and the measured lengths were recorded. The measured lengths of the shims were confirmed to be within a permissible range (0.381 - 0.508 mm). If the measured lengths of the shims exceeded the permissible range, they would be used after reprocessing.
7. All electric power was turned off, and the air hoses, electric power cords, and signal cables were respectively separated from the compressor, electric power, USB hub and RS-485 converter. Separated air hoses, electric power cables and signal cables were temporarily fixed in the CSB assembly when the RV and CSB assembly were detached in order to avoid interference with cables and pieces of equipment. Finally, the gaps between the CSB and the RV core-stop lugs were measured.

**4.1.10 Separation and confirmation of the remote measurement system**

1. The CSB assembly was separated from the RV and set down on a storage stand. The channel boxes and digital probes, threaded connection jigs, air hoses, electric power cables, and signal cables were completely removed from the CSB assembly.
2. After removing the CSB assembly, snubber shims were confirmed in the combined state. All heads of the cap screws were dug with holes of  $\Phi$  3.0226 mm at a depth of  $19.05 \pm 0.762$  mm.
3. All holes of the heads of the cap screws had pins inserted and their installation status was checked. Plugs ( $\Phi$  12.7 mm) installed to fix the pins were inserted; after welding the plugs, penetration tests were carried out.

**4.2 Development of improved installation schedule for RVI modularization**

Table 6 presents a comparison of the existing RVI installation process at the Shin-kori #1 nuclear power plant and the modularization installation process developed.

Compared with the existing method, it was found that the developed installation process using RVI modularization can shorten the installation period to about 67 days in the critical path. This can reduce the construction period, as follows: RV & CSB dimension check (15 days), CSB alignment & gap measurement (13 days), RV & CSB & LSS/CS alignment (13 days), flexure welding (20 days) and CSB assembly installation & alignment check (6 days).

The RV & CSB dimension check (15 days), flexure welding (20 days) and CSB assembly installation & alignment check (6 days) are conducted through a concurrent process before the determination of the critical path in the existing installation process. In addition, the CSB module alignment & gap measurement (13 days) and RV & CSB module alignment (13 days) are correspondingly reduced using the remote measurement system and the improved installation procedure.

Fig. 27 shows the existing RVI installation schedule in the critical path at the Shin-kori #1 nuclear power plant in Korea. It consists of the following steps: (1) the RV & CSB dimension check (2) the CSB alignment & gap measurement (3) snubber shim machining & installation (4) the RV & CSB & LSS/CS alignment (5) flexure welding (6) the CSB assembly installation & alignment check and (7) the upper guide structure (UGS) & RV head installation & alignment check. Therefore, the RVI installation period at the Shin-kori #1 nuclear power plant should be required approximately 129 days in the critical path.

|  | Unit. Day                                    |  |
|--|--|--|
|  | Existing Method<br>(Ex. Shin-kori #1, Korea) | Proposed Modularization Method             |
| RV & CSB Dimension Check                     | 15   | -  |
| CSB Alignment & Gap Measurement              | 18   | CSB Module Alignment & Gap Measurement (5) |
| Snubber Shim Machining & Installation        | 21   | 21   |
| RV & CSB & LSS/CS Alignment                  | 28   | RV & CSB Module Alignment (15)             |
| Flexure Welding                              | 20   | -  |
| CSB Assembly Installation & Alignment Check  | 6  | -  |
| UGS & RV Head Installation & Alignment Check | 21   | 21   |

Table 6. Comparison of existing RVI installation period and modularization installation period

Fig. 28 shows the RVI modularization installation schedule. To use RVI modularization in an actual construction project, modularization installation schedule was developed. The RVI modularization schedule in the critical path consists of the following steps: (1) CSB module alignment & gap measurement (2) snubber shim machining & installation (3) RV & CSB module alignment (4) and UGS & RV head installation & alignment check. Therefore, it was determined that the RVI modularization installation period should require about 62 days in the critical path.

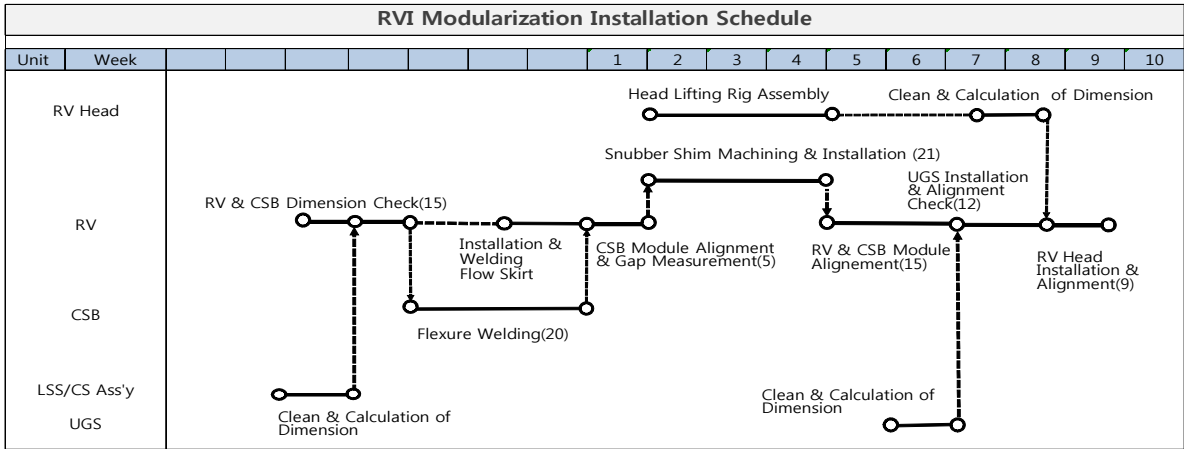


Fig. 27. Existing RVI installation schedule

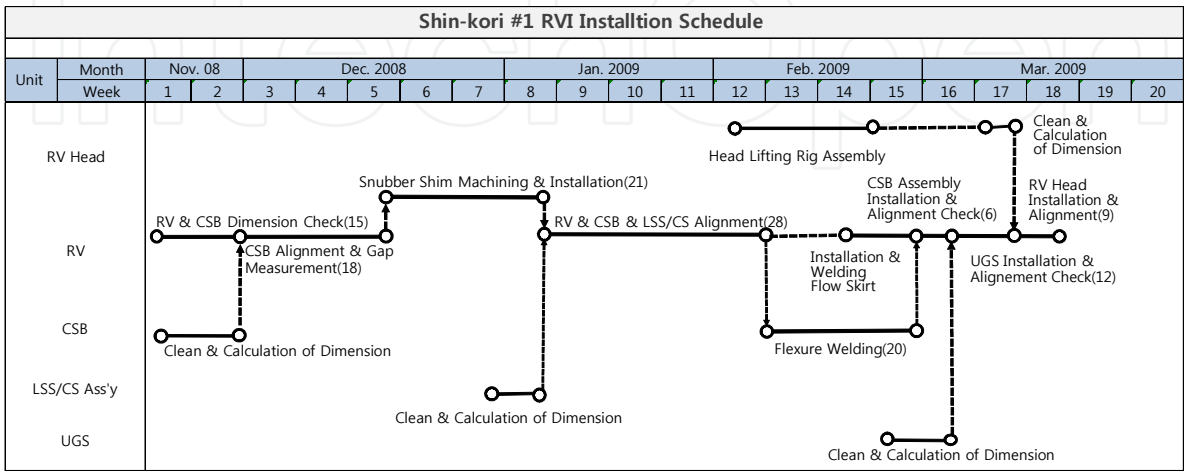


Fig. 28. Developed RVI modularization installation schedule

### 4.3 Results

An improved installation procedure and schedule for RVI modularization were developed. These developments facilitated a RV & CSB dimension check, flexure welding of the LSS and the CS in the CSB and a CSB assembly installation & alignment check before the main installation process. The new procedure and schedule also facilitated a CSB alignment & gap measurement and a RV & CSB module alignment, as undertaken during the main installation process.

According to the improved installation procedure for RVI modularization, the gaps between the RV core-stabilizing lug and the CSB snubber lug of the RVI mockup are measured by a remote measurement method. The results measured by these methods are analyzed with design shims attached to the assembly between the RV core-stabilizing lug and the CSB snubber lug. After the shims on the RV core-stabilizing lug were installed, The measured gap values satisfied the requirements within the permissible range, 0.381 – 0.508 mm, were found.

### 4.4. Conclusion

The development of an improved installation procedure and schedule is one of the most important technologies for RVI modularization. The improved installation procedure and schedule developed here can be used at nuclear power plant construction sites. The improved installation procedure through an experiment using a verified remote measurement system was validated and then manufactured mockup.

On the basis of these studies, technologies for RVI modularization using the improved installation procedure and schedule will be applied to the construction project.

## 5. Acknowledgements

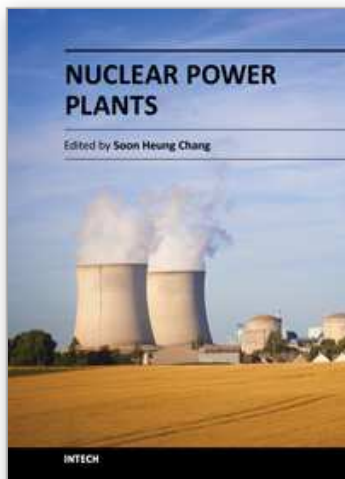
Korea Hydro and Nuclear Power Co., Ltd. applied for international patents on all R&D results in this chapter.

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