Transactions of the Korean Nuclear Society Autumn Meeting
Pyeongchang, Korea, October 30-31, 2014

Modal Testing of the CEDM Assembly

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1. Introduction

As part of APR Plus (Advanced Power Reactor Plus) development project, some design changes for the Control Element Drive Mechanism (CEDM) have been introduced comparing to the conventional ones. Major features of the design changes are such as integration of motor housing and nozzle by full penetration welding; length increases of the CEDM nozzle due to diameter increase of the reactor vessel closure head; reinforcement of the upper shroud; increase of the CEDM coil turns [1]; and adoption of 4-latch type grippers instead of 3-latch type, etc.

These kinds of design changes affect the structural dynamic characteristics of the CEDM. Since the loads acting on the subparts of the CEDM are calculated by structural analyses, it is important to understand the dynamic characteristics of the CEDM.

Therefore, modal tests based on the transfer-function method recommended by IEEE 344 [2] were performed for various types of supporting conditions. In this paper, the detailed procedure and typical results of the testing are presented and reviewed.

2. Mounting and Test Preparation

2.1 Mounting

The CEDM specimen was mounted on the KIMM's largest shake table. The shake table was selected in consideration of the height over 6.8m and the weight of about 500kgf of the CEDM assembly. The CEDM specimen was centered on the shake table with supporting jig structure as shown in Fig. 1.

The shake table for this testing has 6-degree of freedom and its major specifications are as follows:

Table Size:	4.0m x 4.0m
Max. Loading:	30 ton
Control Axes:	Translation 3 axes, Rotation 3 axes
Max. Displacement:	H = ±100mm, V=±67mm
Max. Acceleration:	H = ±1.5g, V=±1.0g
Excitation Mechanism:	Electrohydraulic Servo

A square steel plate with 3 inches of thickness is welded to the bottom of the nozzle to mount the CEDM specimen. The bottom plate (as shown in left part of Fig. 2) is then strongly fixed with high-tension bolts on the shake table.

2.2 Supporting

The CEDM specimen was tested in the each of the following three types of horizontal supporting conditions:

1) Free standing(vertical cantilever type)
2) Single support
3) Double support

The CEDM support limits horizontal displacement of the CEDM during vibration excitations. Dynamic characteristics of the CEDM can vary greatly according to the supporting conditions. As the number of support increases, horizontal displacement of the CEDM reduces and the natural frequency of the CEDM tends to go up. In case that the number of supports is increased, it is disadvantageous in the viewpoint of fabrication, installation, and maintenance. However, the loads acting on the CEDM assembly can be reduced by introducing double support.

Fig. 1. Mounting of CEDM specimen with jig structure

The jig structure was designed to attach, hold and replace the CEDM support in accordance with the test steps. It was also designed to have much higher natural frequency in order to avoid resonance with the CEDM specimen. The CEDM supports are designed to be installed on the Integrated Head Assembly [3].

2.3 Assembly

The CEDM specimen was composed of all the real subassemblies and parts of the full set of a CEDM. The CEDM basic structures are the pressure housings and integrated nozzle. The pressure housing is composed of motor housing and upper pressure housing, and these parts constitute a portion of reactor coolant pressure boundary together with the CEDM nozzle. Outside the pressure housing, the coil stack assembly, upper shroud, and two Reed Switch Position Transmitters (RSPTs) were installed.

And inside the pressure housing, motor assembly and the drive shaft of control element assembly (CEA) were installed. The length of the drive shaft inside the pressure housing was determined to simulate the full withdrawal position of the CEA which is corresponding to the normal operating condition. And the pressure housing was also filled with water (supplied at the bottom of nozzle and vented at the top of pressure housing). The movement of the CEA drive shaft was restrained only at the bottom, so it can be shaken in lateral direction within the gap inside the pressure housing.

2.4 Instrumentation

Accelerometers were used to measure dynamic characteristics of the CEDM. A total of 30 accelerometers were attached on the outer surfaces of the pressure housing and the upper shroud as shown in Fig. 2. Depending on the position, two or three-directional accelerometers were attached.

In addition, strain gauges were attached to the position on which the load was expected to be comparatively large for monitoring stress level during the test.

3. Modal Testing

Three different kinds of the modal tests were conducted for each type of the supports described in the paragraph 2.2 of this paper.

3.1 Impact Tests

Impact test is a simple way to determine the natural frequency and vibration mode of the object by applying a small impact force with a rubber hammer. In this test, 5 times of impact with 10 second intervals were given to the CEDM specimen in two horizontal directions at two elevations respectively and the average values of measured transfer functions were obtained.

3.2 Sine Sweep Tests

Sine sweep tests were conducted in both horizontal directions respectively. The acceleration amplitude of 0.1g and the constant frequency change ratio of 1 octave/min were applied in the sine sweep tests to measure the vibration responses. The frequency showing the maximum response can be rated as resonant frequency.

3.3 Random Excitation Tests

In this test, broad band random signal of 1Hz~50Hz was used as vibration excitation. Various level of vibration input was applied for each direction within a range not exceeding the yield stress between the maximum values, 0.1g~0.7g to check whether there is any significant change of the dynamic characteristics depending on the excitation level.

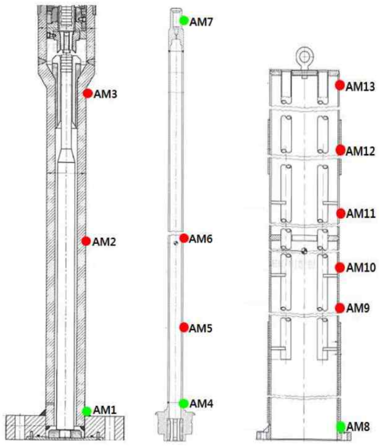

Fig. 2. Location of accelerometers

4. Results of Modal Testing

As the impact test results, typical natural frequency transfer functions and the first mode shapes with the three types of supports are shown in Fig.3. The differences of the result data in the two horizontal directions are very small.

In cases of displacement constraints, i.e., single or double support, the holding methods for the CEDM also yielded meaningful results. There were more than 3Hz differences according to the methods for holding the CEDM upper shroud. Tight holding showed a tendency to increase the natural frequency of the CEDM than applying gap or rubber cushion between the support and the CEDM upper shroud.

Although the natural frequencies of the CEDM depending on the test methods in the same constraint conditions had little differences mutually, the random excitation test results showed intermediate levels between the results of impact tests and sine sweep tests.

The damping coefficients of the CEDM obtained by the random excitation test in free standing condition exhibited an increasing tendency along with the increase of the excitation level (g-value) within the range of 5~9% which was comparatively larger than that of upper constraint condition.

The damping coefficients of the CEDM were reduced in the upper constraint condition comparing to the free standing condition although larger excitation level was applied to the shake table.

In the upper constraint condition, double support type showed slightly increased damping coefficients than single support type. Generally, the damping coefficients of the CEDM increased with the increase of excitation level, but did not increase any more over a certain degree.

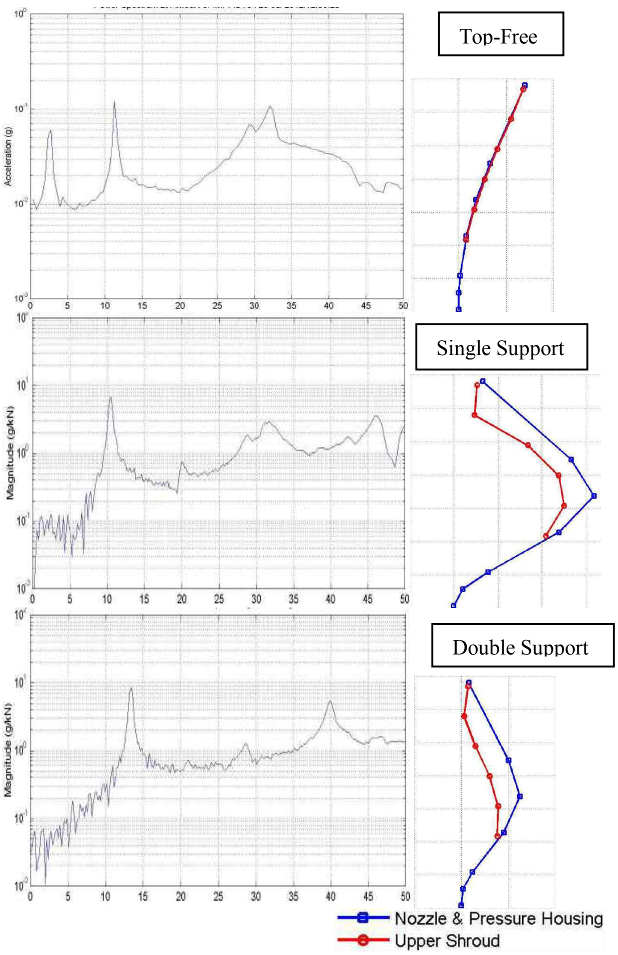

Fig. 3. Typical transfer functions and 1st mode shapes of the CEDM according to the supporting condition

5. Conclusions

The CEDM assembly generally needs lateral supports because of its longish shape. So, for testing, a special jig was designed and fabricated for holding the supports during the tests. Three kinds of modal testing were performed for various types of supporting conditions and the results were successfully obtained.

From three kinds of modal testing results, the natural frequencies, mode shapes, and damping coefficients of the CEDM were obtained and those data can be used as references for establishing structural analysis model in accordance with the design conditions. Since the data contained in this paper are only typical test results which are chosen from a number of test cases, it should be noted that these data cannot be used directly as basis of any specific design related with the CEDM. First of all, the detailed supporting design such as gripping methods or condition of constraints for the CEDM should be considered.

Acknowledgment

The work described herein was performed by the financial support from the Ministry of Trade, Industry & Energy (MOTIE) of the Republic of Korea and the Korea Hydro & Nuclear Power Company (KHNP) in accordance with the Contract for the Common Essential Technology Development of APR+ System Design between KHNP and KEPCO-E&C.

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