Vibration Test Using Sub-Scaled Tokamak Model to Validate Numerical Analysis on Seismic Response of Fusion Reactor

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Abstract. This paper describes the latest status of the fabrication and testing of a sub-scaled tokamak model for the vibration test to validate numerical analysis on seismic response of fusion reactor. The sub-scale model referred to the 1998 ITER design and the scale was decided as to be 1/8 considering the capacity of test facility and the scaling ratio was chosen so that the stress becomes equivalent to that of the real machine. The partial test had been performed with the gravity supports and TF coil case, and their vibration characteristics were verified.

1. Introduction

Tokamak Fusion Reactors consist of many components which work at different temperatures: the vacuum vessel is operated at 150 °C while the superconducting coils are kept to be 4 K. Therefore the support structures, such as the gravity support for coils, must be flexible in the radial direction to absorb the deformation caused by the temperature difference between initial assembly and operating condition while it must withstand seismic loading. Flexible support systems make the eigen frequency of the reactor relatively low. For example, the gravity support in the International Thermonuclear Experimental Reactor (ITER), shown in Fig. 1, is composed of plate springs as shown in Fig. 2 and the eigen frequency of the machine is 2.1 Hz in the horizontal direction [1]. The vibration characteristics, such as the low eigen frequency, affect on the seismic design of the tokamak reactor. Currently the vibration mode and the dynamic response are analyzed using numerical calculation codes but the numerical model has not been verified by the experiment yet.

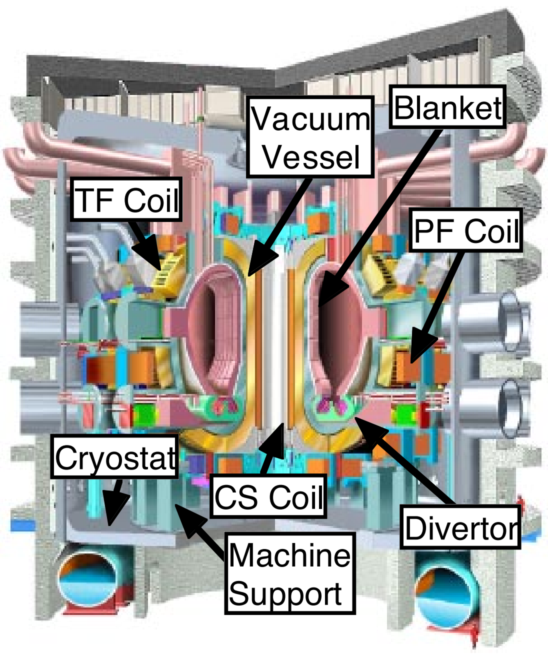

FIG. 1. Overall Layout of ITER

Therefore, the vibration test using a sub-scaled tokamak model had been planned in order to validate the numerical analysis.

The model referred to the 1998 ITER design [2] but the result can be applied also to the other tokamak fusion reactors which use flexible supports such as plate springs.

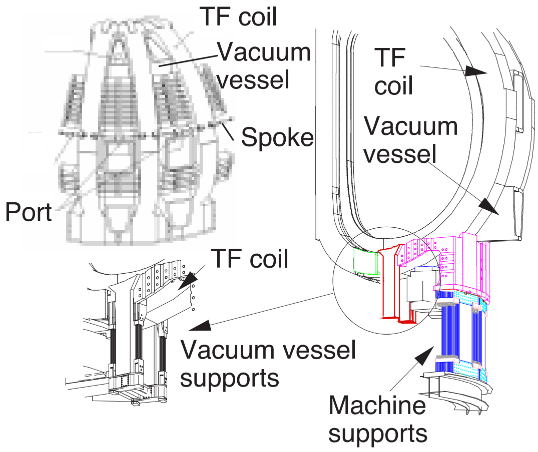

FIG. 2. Gravity Support of ITER

2. Scaled Model of Tokamak

The dimensional scale of the model was decided as 1/8 considering the capacity of test facility. The stress of the scaled model should be equivalent to that of the real machine to verify the fracture mode. Steel was selected for material so the Young's modulus and the density are almost same as the real machine. The scaling ratios of other parameters are calculated from the ratios mentioned above. The scaling ratios are summarized in Table I.

The main components and support structures were designed so as to simulate weight and stiffness, respectively. Figure 3 shows the design of the 1/8-scaled tokamak model. The gravity supports, the inter-coil structures and the toroidal field (TF) coils have been fabricated by now. Figure 4 shows the current appearance of the model after the preliminary assembly.

TABLE I: SCALING RATIO FOR THE TOKAMAK MODEL

Dimension	Stress	Young's Modulus	Density	Weight	Frequency	acceleration
1/8	1	1	1	1/512	8	8

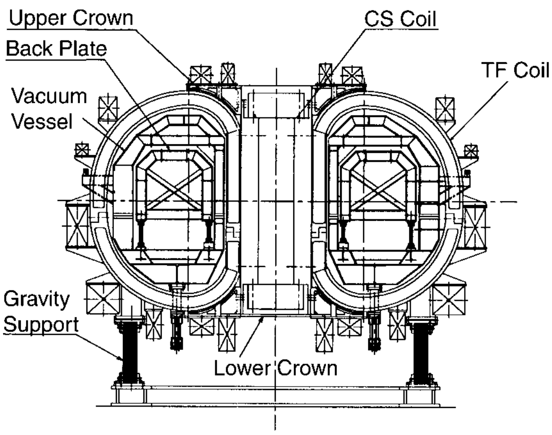

FIG. 3. 1/8-Scaled Tokamak Model

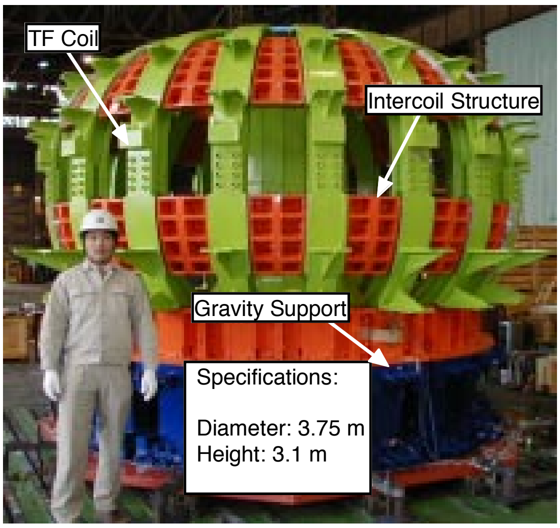

FIG. 4. Assembled Model

3. Vibration Test of Gravity Support

As the first step of the vibration test for the tokamak, a partial test was performed using scaled gravity supports. In the ITER design in 1998, the gravity supports sustain all the weight and rules the vibration modes of the tokamak. Consequently, their vibration characteristics, such as stiffness and damping ratio, must be confirmed by the experiment.

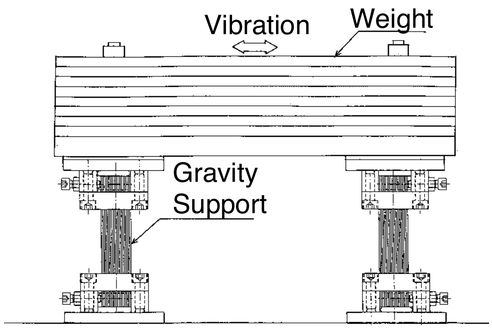

FIG. 5. Experimental Configuration (Flexible Direction)

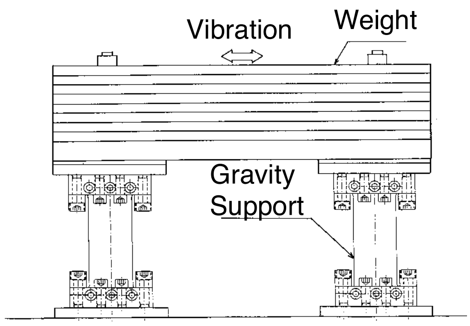

FIG. 6. Experimental Configuration (Rigid Direction)

The gravity support is composed of 20 plate springs and spacers tightened by bolts. The connections between supports and TF coil or floor are also bolted. From the configuration of the support, it is flexible in the radial direction while it is rigid in toroidal direction. In order to clarify mechanical characteristics of the support in these two directions, the test was performed under two different arrangements as shown in Figures 5 and 6. The system was composed of two supports and dummy weights. Four gravity supports were used for the test in total and two pairs of supports were selected randomly and named as pair “A” and “B”. These two pairs were compared to check the manufacturing deviations caused by the scattering of dimension. The supports were pulled in the horizontal direction by a chain, which was released after an enough load had been applied. The load was controlled using a load cell. The vibration was measured using a gap sensor. The damping ratio was calculated from the logarithmic decrement of the free vibration. The results were summarized in Tables II and III.

TABLE II RESULT OF VIBRATION TEST (FLEXIBLE DIRECTION)

Weight (kg)	2,740		5,247		7,754	
Pair	A	B	A	B	A	B
Frequency (Hz)	6.62	6.60	4.81	4.80	3.94	3.93
Equivalent Stiffness (MN/m)	4.74	4.71	4.79	4.77	4.74	4.72
Damping ratio (%)	0.15	0.15	0.14	0.16	0.16	0.17

TABLE III RESULT OF VIBRATION TEST (RIGID DIRECTION)

Weight (kg)	2,740		5,247		7,754	
Pair	A	B	A	B	A	B
Frequency (Hz)	64.7	64.5	48.8	49.9	39.6	39.2
Equivalent Stiffness (10^2MN/m)	4.53	4.50	4.93	5.15	4.79	4.70
Damping ratio (%)	1.25	1.52	2.60	2.14	1.92	2.33

The result of the flexible direction shows that the deviation of the products does not affect on the vibration characteristics. The result also indicates that the damping ratio does not depend on the frequency. This suggests that the damping is not viscous but structural. The same tendency can be seen in the result of the rigid direction but the dispersion is relatively large. One of the reasons of this is that the supports tend to vibrate in the flexible direction rather than the rigid direction. The vibration in the flexible direction is superimposed on the wave of the rigid direction.

Again, the damping ratio does not depend on the frequency as shown in each of Tables II and III. However, the ratio of the rigid direction is ten times larger than that of the flexible direction. This fact suggests that the mechanisms of damping are different in these two cases. The most suspicious factor is the friction between the spring plate and the spacer, and between the plates and the bolts. The difference of the damping ratio between the rigid and flexible direction can be explained as follows: friction by the relative movement of the plates is caused during the vibration in rigid direction while the plates are fixed strictly in the weak direction.

The damping ratio obtained by the experiment will be used in the dynamic response analysis of the 1/8-scaled model.

In order to clarify the effect of the angled load, the other test had been performed with the vibration in the 60-degree direction to the support. The experimental configuration is shown in Fig. 7. Four gravity supports were set with the angle of 60 degree and the weights were put on the supports. Since the stiffness of one support

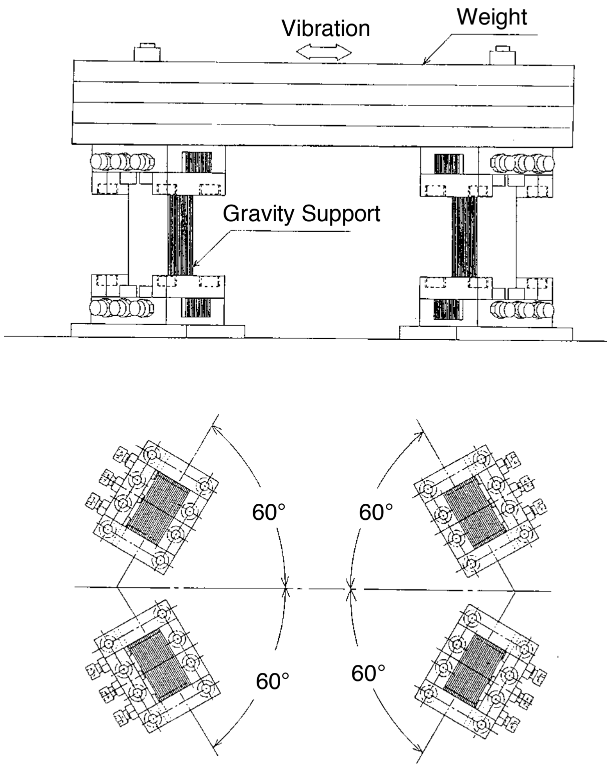

FIG. 7. Experimental Configuration (60-degree Direction)

in the rigid direction obtained by the experiment was 2.4×10^8 N/m, the stiffness in the 60-degree direction can be predict as 0.60×10^8 N/m theoretically. However, the measured stiffness of the support was 0.47×10^8 N/m. It is considered that this discrepancy was caused by non-linearity, such as the sliding motion between the plates and/or the stiffness drop caused by the deformation. Further investigation is needed to clarify the dependency of this non-linearity on the angle of the load.

4. Vibration Test of TF Coil Case

Concerning with the TF coil case, the eigen vibration modes were measured using the tapping method as shown in Fig. 8. Figure 9 shows the first mode, in which the case was twisted. Measured frequency was 58.4 Hz while the result of the numerical calculation was 52.2 Hz. The discrepancy between these results was about 10 % and was caused by rough modeling of the bolt-jointed part. The TF coil case is composed of upper and lower parts and bolts connect them while the actual coil case is fabricated only with welding. This part makes behavior of the scaled model different from that of the actual reactor so it must be improved in the final test.

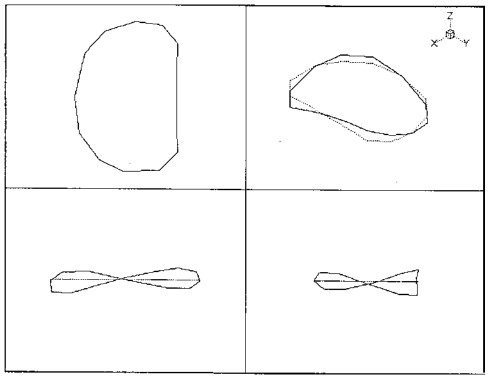

FIG. 9. Eigen vibration mode of TF coil case

5. Conclusion

A sub-scaled tokamak model is under fabrication to verify dynamic response of the tokamak components that behaves in low frequency of about 2Hz due to flexible machine supports. The sub-scaled model of machine supports composed of spring plates was fabricated and the first test indicates the equivalent stiffness of about 4.7 MN/m in the radial direction, which is in good agreement with the design value. The TF coil case was also tested and the eigen vibration was observed.

The fabrication of the scaled model is proceeding now. After the completion of the coil system, the partial vibration test is planned. The final test will be performed with a vibration table when the whole model is completed.

References

[1] S. Tado, T. Tsunematsu, E. Tada, "Dynamic Analysis of ITER Tokamak Applied Seismic Isolation", PVP-Vol. 379, pp. 197-207 (1998)

[2] "Technical Basis for the ITER Final Design Report, Cost Review and Safety Analysis", International Atomic Energy Agency, Vienna (1998)