Prototype Engineering Test Platform of ITER Magnet Gravity Support

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Abstract ITER magnet gravity support (GS) has been redesigned as a structure of pre-assembled multi-flexible plates instead of the original welded structure. In the past several years, engineering tests of the new structure have been proposed. A prototype engineering test platform is being developed. In order to apply the loads/load combinations onto the test mock-up, seven hydraulic bolt tensioners in three directions have been applied to simulate various loads (forces and moments), through which the deformation of bolts, flexible plates and clamp blocks, the stress distribution in the flexible plates, the friction between the contact surface, etc. can be monitored/tested. The measurement and control system includes seven sets of synchronization controller, a 16-channel strain gauge, 25 sets of displacement sensors, etc. Principles of EDC220 digital controller and development of multi-channel control software are also demonstrated.

Keywords: ITER, gravity support, engineering test, FEM analysis, measurement and control system

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1 Introduction

The gravity support (GS) is one of the key components to support all the superconducting magnets of ITER. The components of this system have to withstand various kinds of forces, such as deadweight of coils, thermal load during coil cooling down from room temperature to 4 K, electromagnetic forces (plasma burning, plasma disruptions (DIS) and vertical displacement events (VDE)) and seismic loads if any [1,2]. The support was always designed using 21 flexible plates welded to the upper and lower flanges (for each pedestal), through which displacement along the radial direction is possible, as shown in Fig. 1(a). However, manufacturing the support requires welding the flexible plates to both the upper and lower flanges, which is currently difficult to achieve. In the past few years, an new design of the TF coil support without welded connection was made, in which various connection bolts, short spacer plates and shear keys were used to assemble all the flexible plates and flanges together, instead of welding the flexible plate to the flanges [3], as shown in Fig. 1(b). FEM analysis shows that the flexible plates have no severe stress concentration under normal operation [4], or even under accidental conditions, such as an earthquake and VDEs or under all the 32 kinds of possible load conditions/combinations. Further GS bulking analysis [3] and fatigue analysis results confirmed that the structure is safe enough according to the ITER design criteria [6].

However, ITER is designed as one of the large nuclear facilities with a high standard requirement. This means that it should be safe enough and without need for repair during the 20 years operation. Any design should not only satisfy the safety requirement but also pass the mechanical qualification test. Therefore, we designed a special test platform to simulate the ITER loading condition to test the new GS structure. In this article, we present the design of the mock-up test platform and the proposed test methods.

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2 Structure of the mock-up test platform

The GS mock-up model comprises four outer plates — two on either side — and one central plate. The prototype of the GS test platform consists of iron basement, iron floor, four columns on each side connected with two beams, one top loading plate, two upper beams and one back beam. High strength bolts are used to connect each part of the structure. The schematic of the GS prototype test is illustrated in Fig. 2.

![GS mock up](image)

**Fig.2** Schematic of GS prototype test platform. Loading system consists of 7 hydraulic cylinders (color online)

In order to add the loads/load combinations onto the mock-up, seven hydraulic bolt tensioners in three directions are applied to simulate various loads (forces and moments). The details are as follows: one set of 200 kN cylinders in the X-direction, two sets of 1000 kN cylinders in the Y-direction and four sets of cylinders (1 x 2000 kN+3x1000 kN) in the Z-direction. The forces in the the Y- and X- directions are applied on the mock-up by Y-hydraulic bolt tensioners and one X-hydraulic bolt tensioner, respectively and the forces (including the forces converted into the moments $M_x$ and $M_y$) in the Z-direction are applied by Z-hydraulic bolt tensioners. The series of torque can be separated into A, B, C and D areas \[^5\] to simplify the moments in the X, Y and Z directions. The loads are scaled down from the GS assembly design loads by a ratio of 5/21, as listed in Table 1 \[^1\].

Furthermore, to evaluate the deformation of the test platform frame, an FEM analysis using ANSYS software was employed for the whole of the mainframe. The deformation analysis resulting in the most serious loading condition (DW+CD+EOB+ASU VDE-III, as shown in Table 1) is shown in Fig. 3. From the result, the maximum deformation is less than 1 mm in this frame.

3 Control system of the test platform

The electronic control system consists of seven sets of EDC controller, computer system, a 16-channel quasi-dynamic strain gauge, 25 sets of displacement sensors, 7 sets of load and displacement sensors in the cylinders, etc. Fig. 4 shows the schematic of control system, through which the deformation of the bolts, flexible plates and clamp blocks, the stress distribution in the flexible plates, the friction between the contact surface, etc., can be monitored/tested.

Table 1. Load cases and load combinations of TFS mock-up

<table>
<thead>
<tr>
<th>TEM</th>
<th>$F_x$ (kN)</th>
<th>$F_y$ (kN)</th>
<th>$F_z$ (kN)</th>
<th>$M_x$ (kN·m)</th>
<th>$M_y$ (kN·m)</th>
<th>$M_z$ (kN·m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dead weight</td>
<td>-</td>
<td>-</td>
<td>-1368</td>
<td>-</td>
<td>-91</td>
<td>-</td>
</tr>
<tr>
<td>Cool down</td>
<td>-71</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>End of burn</td>
<td>-</td>
<td>-22</td>
<td>-9</td>
<td>-1168</td>
<td>-709</td>
<td>404</td>
</tr>
<tr>
<td>ASU VDE-II</td>
<td>-</td>
<td>600</td>
<td>-1104</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>ASD VDE-II</td>
<td>-</td>
<td>240</td>
<td>1248</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>ASU VDE-III</td>
<td>-</td>
<td>960</td>
<td>-1920</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>ASU VDE-III</td>
<td>-</td>
<td>960</td>
<td>2040</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>DW+CD+EOB (Name: CLD01)</td>
<td>-71</td>
<td>-22</td>
<td>-1375</td>
<td>-1168</td>
<td>-800</td>
<td>404</td>
</tr>
<tr>
<td>DW+CD+EOB+ASU VDE-II (Name: CLD02)</td>
<td>-71</td>
<td>578</td>
<td>-2479</td>
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<td>-800</td>
<td>404</td>
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<tr>
<td>DW+CE+EOB+ ASD VDE-II (Name: CLD03)</td>
<td>-71</td>
<td>218</td>
<td>-127</td>
<td>-1168</td>
<td>-800</td>
<td>404</td>
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<tr>
<td>DW+CD+EOB + ASU VDE-III (Name: CLD06)</td>
<td>-71</td>
<td>938</td>
<td>-3295</td>
<td>-1168</td>
<td>-800</td>
<td>404</td>
</tr>
<tr>
<td>DW+CD+EOB+ASD VED-III (Name:CLD07)</td>
<td>-71</td>
<td>938</td>
<td>665</td>
<td>-1168</td>
<td>-800</td>
<td>404</td>
</tr>
</tbody>
</table>

Note: $F_x$, $F_y$, and $F_z$ are the loads along the direction in Fig. 2, $M_x$, $M_y$ and $M_z$ are the moments around the X-, Y- and Z-axis.

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The hard core of the control system is the German EDC 220 controller [7] in which the functions of loop control and acquisition measurement are integrated. The industrial computer and EDC group controller are connected with the router through the network interface, which can further improve communication speed and stability. The EDC group controller is composed of 7 sets of EDC controller to achieve synchronized control, each EDC has an independent address from 1 to 7. Thus, the software in the computer can send orders to each EDC controller via its address to complete accurate loop control. Furthermore, the precision of the control system composed by EDC controller and load cell can reach 1/180000 of full scale. The resolution of the displacement measuring system composed by EDC controller and magnetostrictive sensor can reach 1 µm.

The working principle of the control system is as follows: when the EDC controller receives a control instruction of displacement or loading command sent by the industrial computer, it will transfer a voltage value to ATOS proportional valve to control its working window, which means to control the flow rate of oil source to influence the loading/unloading speed of the cylinder. At the same time, the load cell or magnetostrictive sensor on the cylinder will return a signal to the EDC controller. Then the EDC controller will increase or decrease the flow rate of oil source by judging the deviation between the feedback and the original signals. Therefore, it can guarantee the stability of the loop control.

4 Test items and proposed test method

As to the load combinations described in Table 1, for each of them, the detailed test items of ITER GS mock-up are as follows: a. the forces in the extremity studs (eight studs in total) of each bottom clamp and each bottom pre-stressing bar using load cell; b. the maximum bending and membrane strains in the upper and lower neck region of each flexible plate; c. potential slippage between each pre-stressing bar and its neighboring plate; d. potential slippage between the central flexible plate and neighboring spacers; e. the displacement in the X, Y and Z directions at points A, B, C and D from the four sides.

According to the required test items, the proposed test method includes two measuring systems. One is a strain measuring system, which consists of a high speed static gauge and strain foil gauge. The other one is a displacement measuring system, which consists of an Altair PCI data acquisition card and high precision grating sensor. For example, as shown in Fig. 5(a), the displacements on points A/B/C/D in the X/Y/Z direction can be measured by the grating displacement sensor. In this process, the grating sensor will be installed on an independent racket which is fixed on the
iron floor to reduce the effect caused by the deformation of mainframe. In Fig. 5(b), the maximum bending strain and membrane strain in the neck region of all flexible plates can be measured by the foil gauge stuck on the flexible plate. In Fig. 5(c), measuring units on the mid panel will be used to measure the displacement between the neck region of the flexible plate and central plate. As Fig. 5(d) shows, the vertical displacement of the top and bottom flexible plate to the clamping bolt will be measured by the grating sensor. Besides, we can measure the stress value of the 8 bolts on four edges of the supporting base in the vertical directions using ultrasonic load cell.

5 Summary

The test platform consists of a high stiffness steel plate for the mainframe and high strength bolts to connect each part, 7 channels of hydraulic loading cell in three directions and an electronic control system which can not only achieve stable loop control but also accomplish accurate data acquisition to guarantee reliable test results. As to the proposed test method, the distribution of measurement points, the arrangement of gauges and the test process to control the error and guarantee test precision need to be further developed and perfected. The test platform of 5.4 meters in height and 20 tons in weight has been set up in our lab, as shown in Fig.6, and the measurement results will be presented soon.

Furthermore, there are still some questions which need to be discussed. In addition to the load combination, an extra load test shall be considered to determine the effect of loss of preload in the GS tie-rods. When a displacement of $-31 \text{ mm}$ is applied along the $X$ axis on the top of the GS, full bolts’ preload need not change in the mock-up test. Also for the bolts’ loads release test, reducing 10% each time until zero is demanded to meet the ITER requirements, but in fact, it seems that test number reduced to three times, such as 50%, 20% and 5% of preload are enough.

**Fig.6** The test platform of 5.4 m in height and 20 tons in weight (color online)

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