Status of the Extended Performance Tests for Blanket Remote Maintenance in ITER L6 Project

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Abstract. Mechanically attached blanket module insertion tests were carried out considering the misalignment between module and back plate. Through the insertion tests, the module was successfully inserted up to the misalignment of ±10 mm under the clearance of ±0.16 ~ ±0.18 mm between key and groove. This was achieved by the passive compliance due to the flexibility of the manipulator through the assistance of the chamfer configuration of the key for smooth insertion. In addition, the "correlation coefficient" based on the results obtained by the strain gages located at the end-effector was found to be useful in order to estimate the forces of the complicated end-effector during module insertion for the development of the sensor based control.

1. Introduction

In International Thermonuclear Experimental Reactor (ITER), the blanket maintenance requires the 4-tonne module handling with high positioning accuracy of ±2 mm. For this, a rail-mounted vehicle manipulator system, which consists of vehicle manipulators working on a rail transporter forms a toroidal ring structure, has been adopted, and the development of full-scale remote handling equipment aiming at a remote handling demonstration of the ITER blanket has been conducted in ITER-EDA period as one of the Large Seven R&D Projects. The Blanket Test Platform (BTP) has been completed in 1998 and the basic feasibility of the system has been successfully demonstrated through the first integration tests [1]. In addition to this, the extended performance tests to improve the manipulator control technology are being carried out as the R&D activity in the EDA-Extension period. In order to minimize the dynamic deflection and vibration caused by the dead load transfer during installation and removal of blanket module, a new suppression control scheme [2] has been developed and its feasibility has been successfully verified using the full-scale vehicle manipulator system. The current R&D efforts are focused on the verification of the feasibility of mechanically attached module replacement based on sensor based control. The key issue is to establish the control technology based on the kinematics of analytical model in the virtual reality space and the feed back control using force and distance sensors attached on the end-effector. In particular, the structure of the interfaces for module installation composed of two keys and a positioning pin with installation clearance less than ± 0.25 mm has to be considered for the development of the sensor based control. This paper describes the results of the mechanically attached module installation tests considering the misalignment between key and pin in order to gain the basic data for the sensor-based control during module installation.

2. Estimation of Reaction Force during Module Insertion

2.1 Procedures of module insertion

The procedures of the module insertion into the back plate are shown in Fig. 1 and described as follows.

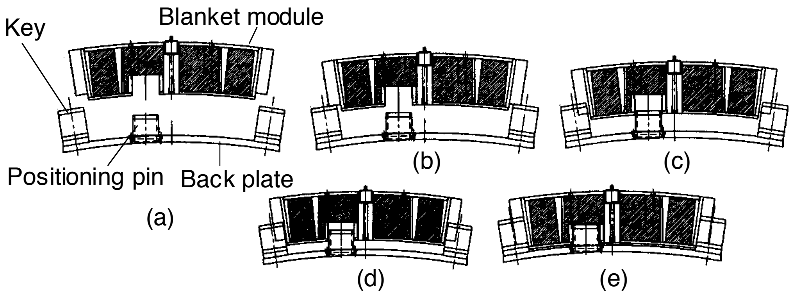

FIG.1 Procedure of the module insertion

1) Measurement of the relative position between module and back plate by the position and distance sensors (Fig. 1(a)).
2) Grooves of the module are positioned in front of the keys within the allowable misalignment (Fig.1 (b)).
3) Module is positioned in front of the positioning pin after inserting along the interface between key and groove (Fig. 1(c)).
4) Module is inserted along the keys and pin (Fig.1 (d)).
5) Module is installed at the final position (Fig. 1(e)).

In the procedures, the gap management of two stepped interfaces, i.e., key and pin during module insertion, is the critical operation. It is however difficult to manage the small gap such as ±0.25 mm by the position or distance sensors. In general, force feed back control is applicable to solve the gap management issue using a six axes force/torque sensor located at the wrist of the robot arm. However, there is no experience of the application of the force feed back control to the complicated end-effector for handling heavy components such as 4-ton module up to now. In addition, the configuration of manipulator is required to be compact in order to handle the large and heavy module in the restricted space inside of vacuum vessel. For these requirements and conditions, the most critical issue is to develop the force/torque measurement technique for reliable module insertion without any impact on the manipulator size and its configuration.

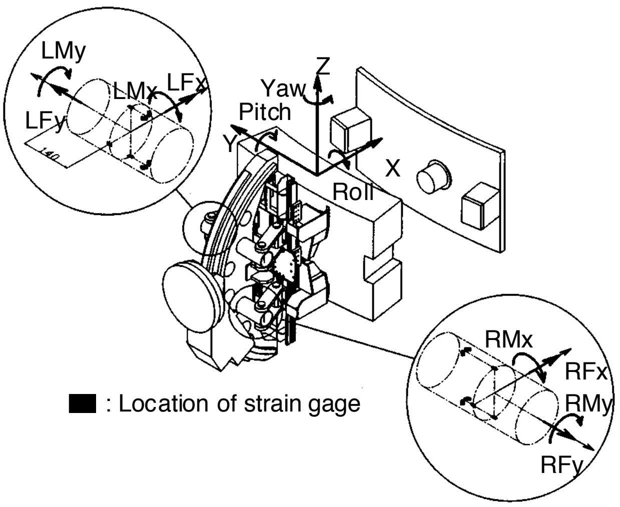

FIG.2 Definition of motion and force/torque

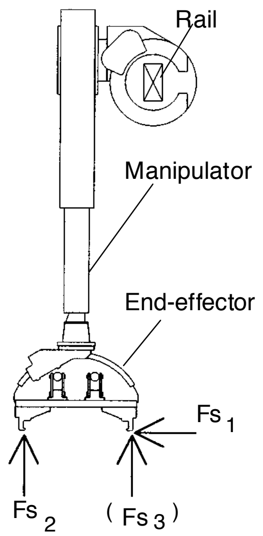

FIG.3 Basic loading test

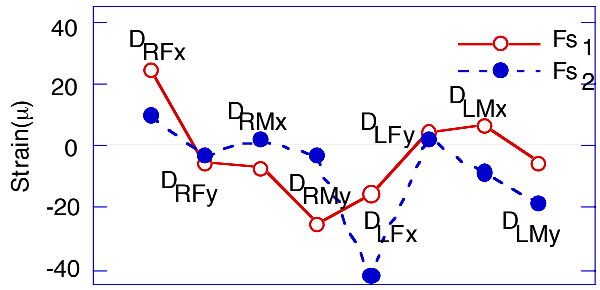

FIG.4 Results of basic loading test

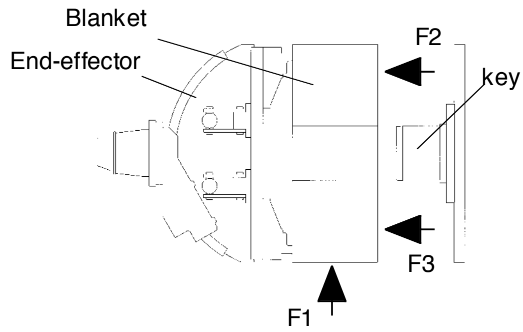

FIG.5 Definition of F_1,F_2 and F_3

2.2 Basic behaviors of end-effector under typical loads

As a first trial of the development of the force feed back control for heavy component handling, twelve strain gages were installed on the respective beams of the yaw mechanism of the end-effector in order to measure the forces (Fx and Fy) and torque (Mx and My) of the end-effector in the two dimensional (vertical) plane, as shown in Fig. 2. The feature of this technique is that an additional mechanism is not required for the measurement of the force and torque of the end-effector. The basic loading tests on the end-effector were carried out to calibrate the measured forces and torque under the standard load of one tonne, i.e., longitudinal (Fs1) and traverse (Fs2) loads on two of four grippers, respectively (see Fig. 3). As the results shown in Fig. 4, different patterns of the strain were appeared between two standard loads, Fs1 and Fs2. The pattern under the load of Fs3 is assumed based on that of Fs2 considering point symmetry. Using the relation between two different patterns and forces, if a set of the results is obtained by the strain gages measurement, the respective forces of F1, F2 and F3 at the end-effector can be estimated considering the correlation between measured pattern and standard patterns (see Fig. 5).

2.3 Technique of force estimation

Based on above expectation, the estimation of the forces is tried using "correlation coefficient"[3]. Resulting force Fi (I=1,2,3) of the end-effector are estimated by using the equation(1).

$$Fi = (R\bullet |D| / |P|)\bullet Fsi \qquad (1)$$

Where, R : correlation coefficient between D and P

D : measured strain

D = { DRFx, DRFy, DRMx, DRMy, DLFx, DLFy, DLMx, DLMy}

P : strain generated by Fsi

P = { PRFx, PRFy, PRMx, PRMy, PLFx, PLFy, PLMx, PLMy}

Fsi : standerd force (1 tonne), i= 1, 2, 3

The correlation coefficient R between D and P is defined by rhe equation (2).

$$R = c(D,P) / (s(D)\bullet s(P)) \qquad (2)$$

Where, s2(D), s2(P) : variance D, P, respectivery,

C(D,P) : covariance of D and P

3. Module Insertion Test

3.1 Test conditions

The clearance between key and module (groove) as well as pin and module during module insertion tests were measured. The clearance was ±0.16 mm between left key and module groove, ±0.18 mm between right key and module groove and ±0.17 mm between pin and module, respectively. The respective measured values are satisfied with the requirement less than ±0.25 mm.

Module insertion tests were performed under the following typical misalignment conditions between module and back plate, i.e., key and groove (see Fig.6).

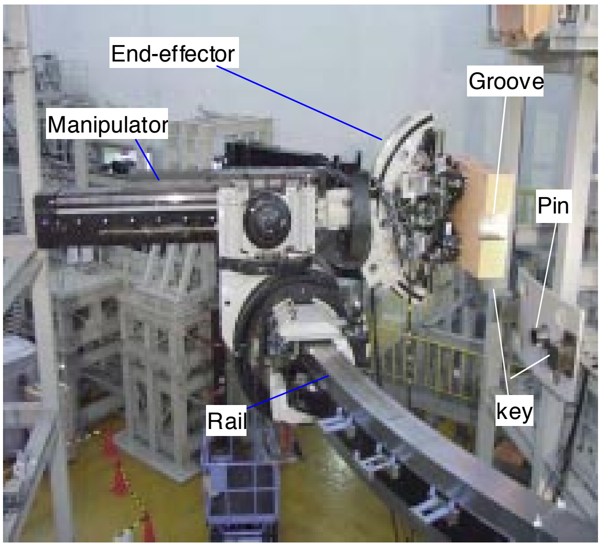

Fig.6 Test stand for module insertion test

1) Case 1 : negligible misalignment between key and groove
2) Case 2 : upward misalignment of +10 mm, i.e., the lower surfaces of key and groove are overlapped by 10 mm, which corresponds to the chamfer size of the key
3) Case 3: downward misalignment of -10 mm, i.e., the upper surfaces of key and groove are overlapped by 10 mm, which is corresponds to the chamfer size of the key
4) Case 4: misalignment over the chamfer size (10 mm) of the key

3.2 Test results

The results obtained by the module insertion tests are summarized in Fig. 7 and Table 1. In case of the negligible misalignment for Case 1, the key and the pin were smoothly inserted with the increased forces up to 2.76 kN. In the Case 2, the key and pin were successfully inserted under the misalignment of +10 mm although the estimated forces up to 7.95 kN were larger than those of the Case 1. In case of the misalignment of -10 mm (Case 3), the key and pin were also successfully inserted although the relatively large forces up to 11.15 kN were occurred during module insertion. These were achieved by the passive compliance due to the flexibility of the manipulator through the assistance of the chamfer configuration of the key for smooth insertion. It was also found that the estimated forces due to the downward misalignment (-10 mm) were larger than those due to the upward one (+10 mm). This was occurred because of the misalignment of ±10 mm is not symmetric for the posture of the manipulator and end-effector. In the Case 4, the module was not successfully inserted because the misalignment of module was larger than the chamfer size. In the failure of the insertion under the unallowable misalignment, the force of F3 is much smaller than those of F1 and F2 because the module was contacted by the key at the F2 side only. Therefore, it was found that the constraint condition of the module due to the unallowable misalignment and the location of the misalignment can be expected by the estimated imbalance reaction forces. Based on this, the unallowable misalignment will be able to be adjusted within the allowable level by the force feed back control using the estimated forces.

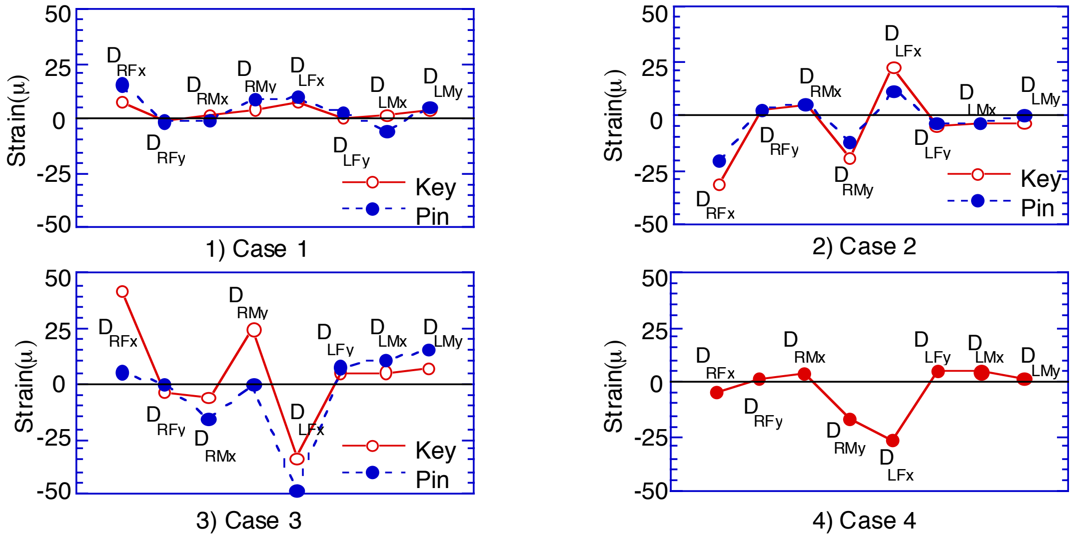

FIG.7 Results of strain gages corresponding the forces and torque during module insertion

TABLE.1: RESULTS OF ESTIMATED FORCES DURING KEY AND PIN INSERTION

Force	Case 1		Case 2		Case 3		Case 4	
(kN)	Key	Pin	Key	Pin	Key	Pin	Key	Pin
F_1	0.36	0.46	-4.95	3.20	7.05	5.73	4.12	-
F_2	-1.06	-0.30	6.55	3.85	9.51	7.32	4.32	-
F_3	-1.04	2.76	7.95	4.95	-11.15	3.88	-0.29	-

4. Conclusion

The blanket module insertion tests were carried out considering the misalignment between module and its supporting structure. In order to estimate the forces of the end-effector during module insertion, strain gages were installed on the yaw mechanism without any change of manipulator configuration. In addition, the "correlation coefficient" was applied to the estimation of the forces of the complicated end-effector based on the results of the strain gages. Through the insertion tests, the module was successfully inserted up to the misalignment of ±10 mm under the clearance ±0.16 ~ ±0.18 mm between key and groove. This was achieved by the passive compliance due to the flexibility of the manipulator through the assistance of the chamfer configuration of the key for smooth insertion. It was also found that the constraint of the module during module insertion due to misalignment can be expected by the imbalance of reaction forces. This showed the future possibility of the adjustment of the unallowable misalignment within the allowable level by the force feed back control using the estimated forces. Based on these results, the sensor-based control using distance and force sensors will be developed for the module replacement, including study of the optimization of the chamfer configuration of the key and pin.

Reference
[1] S. Kakudate et al., "Remote Handling Demonstration of ITER Blanket Module Replacement", 17th IAEA Fusion Energy Conference (1998)
[2] S. Kakudate et al., "Mechanical Characteristics and Position Control of Vehicle/Manipulator for ITER Blanket Remote Handling", 5th International Symp. on Fusion Nucl. Tech., (1999)
[3] Y. Okada, "Statistics", Kyoritsu Syuppan (1972) (in Japanese)