DIVERTOR REMOTE MAINTENANCE

D. Maisonnier[1], G. Cerdan[2], S. Chiocchio[3], C. Damiani[4], J.-P. Friconneau[2], R. Haange[5], M. Irving[4], E. Martin[3], J. Palmer[1], A. Poggianti[6], M. Siuko[7], E. Tada[8], N. Takeda[8], A. Tesini[5], R. Tivey[3], A. Turner[9]

1 EFDA, Boltzmannstr. 2, 85748 Garching, Germany
2 CEA, DTA/DPSA/STR, BP6, 92265 Fontenay aux Roses Cedex, France
3 ITER Joint Work Site, Boltzmannstr. 2, 85748 Garching, Germany
4 ENEA, CR Brasimone, CP 1, I-40032 Camugnano (Bo), Italy
5 ITER Joint Work Site, Naka, Naka-machi, Ibaraki-ken, 311-01 Japan
6 ENEA, via Martiri di Montesole 4, 40129 Bologna, ITALY
7 IHA, Korkeakoulunkatu 2, Box 589, FIN-33101 Tampere, Finland
8 JAERI, 2-4 Shirane, Shirakata, Tokai-mura, Naka-Gun, Ibaraki 319-11 Japan
9 NNC Limited, Booths Hall, Chelford Road, Knutsford, Cheshire, WA16 8QZ, England

e-mail contact of main author: maisond@ipp.mpg.de

Abstract. Remote replacement of the ITER divertor will be required several times during the life of the machine. To facilitate its regular exchange the divertor is assembled in the vacuum vessel in 54 cassettes, each being introduced into the vessel through one of three equispaced handling ports. The remote replacement of plasma facing components in the hot-cell allows the cassette bodies to be re-used and to minimise the amount of activated waste. An R&D project was conceived during the ITER EDA to demonstrate the feasibility of divertor remote maintenance operations. Two test platforms have been set up and are being used to evaluate equipment and procedures. Following a short description of the test facilities set up at ENEA Brasimone, Italy, this paper reports the test results which confirm the overall feasibility of the proposed maintenance and refurbishment schemes.

1. Divertor Maintenance

Remote replacement of the ITER divertor is estimated to be required up to eight times during the life of ITER. To facilitate its replacement, the divertor is assembled in the vacuum vessel in 54 cassettes, each being introduced into the vessel through one of three equispaced handling ports. A *radial mover* transports each cassette along radial rails through the handling port and into the vessel where a *toroidal mover* lifts and transports the cassette to its designated position. To do so the toroidal mover inserts, under the cassette, two forks which include a set of jacks to lift the cassette by a few millimetres. The jacks are driven by pressurised water whilst the toroidal mover is equipped with pinions, driven by electric motors, operating against racks on the rails to index the cassette around the vessel. The central cassette (in front of the access duct) and the second cassettes, (on either side of the central cassette) are transported radially and are positioned into the vessel by the radial mover equipped with an ad-hoc end-effector. Once at its final position, a cassette is locked to the toroidal rails such that it can sustain the off-normal electro-magnetic loads and is accurately aligned in both poloidal and toroidal directions. A further requirement on the divertor is to minimise the amount of activated waste to be sent to a repository. The replacement of plasma facing components in the hot-cell, i.e. the *refurbishment* process, allows the cassette bodies (10 t out of a total cassette weight of 12 t) to be re-used.

2. Design Changes between the 1998 ITER Design and ITER-FEAT

The divertor handling scheme has not changed but it has been modified to suit the new geometry [1]. The total number of cassettes has been reduced from 60 to 54, the cassette weight from 25 to 12 t and the available space between the cassette bottom and the vessel from 240 to 70 mm. This last change, which prevents the support of a cassette from underneath during its radial translation, has led to the adoption of a cantilever multifunctional mover (CMM) for all radial transport operations. The CMM is driven by a rack-and-pinion mechanism and it moves along 2 rails fitted inside the port. It carries a manipulator arm for all dexterous operations and a 2 DOF front-end plate (lifting & tilting) that can be fitted with a number of end-effectors. The cassette toroidal mover (CTM) concept has remained unchanged. Its detailed design is being amended to accommodate the new position of the toroidal rails. Finally, the cassette cooling pipes, originally straight, need to be bent because of space limitations in the ports.

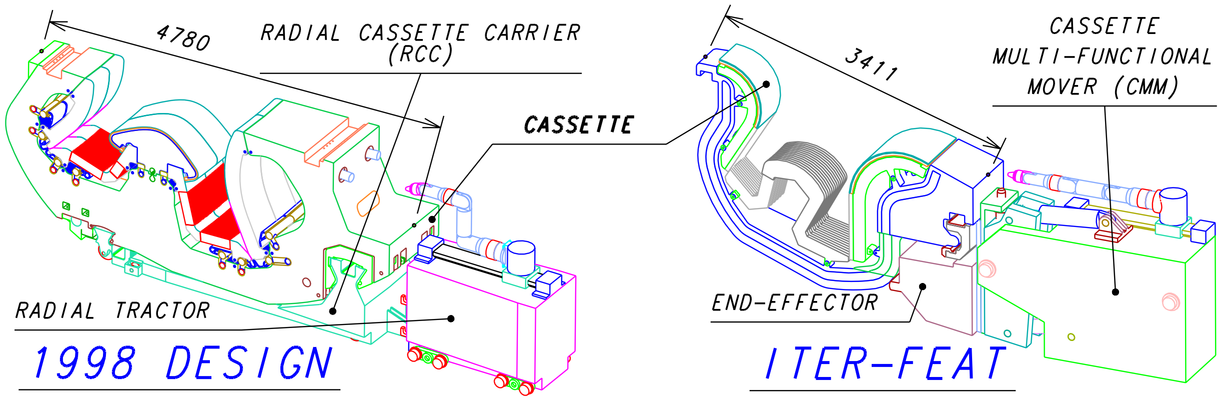

FIG.1. Radial mover concepts, evolution between the 1998 design and ITER FEAT

3. The ITER Divertor Maintenance R&D Project

3.1 Objectives

The objectives of the ITER divertor maintenance project were to demonstrate the feasibility of divertor maintenance and refurbishment and to set up two facilities for the future optimisation of the handling equipment, of the handling features incorporated into the components being handled, and of the maintenance and refurbishment procedures [2].

The Divertor Test Platform (DTP) allows full-scale simulation of all handling operations inside the vacuum vessel whilst the Divertor Refurbishment Platform (DRP) allows simulation, also at full-scale, of the most critical operations to be realised in the hot cell. Both facilities have been set up at the ENEA Research Centre of Brasimone, Italy.

3.2 The Divertor Test Platform (DTP)

The DTP includes a 72 degree portion of the lower region of the vacuum vessel, complete with mock-ups of divertor cassettes, vacuum plugs and cassette cooling pipes. Prototype remote handling equipment, operating in the DTP, include the cassette mover prototypes and auxiliary equipment for plug handling and cooling pipes cutting and welding and weld inspection. The test equipment comprises sensors, the data acquisition, supervisory and control systems and a remote viewing system. The basic feasibility of in-vessel divertor maintenance operations was demonstrated in 1998 [3]. Extensive simulation of cassette handling operations were simulated successfully in 1999-2000, which confirmed the preliminary results of 1998.

The following results are of particular interest [4]:

- the accuracy of the various movers allows cassette handling and positioning in accordance with the ITER requirements;
- furthermore, the toroidal mover is able to cope with any realistic cassette misalignment (up to 10 mm along the toroidal direction) and is able to accommodate horizontal gaps and vertical steps between adjacent rails of up to 2 mm;
- the equipment used for operations in the access duct (e.g. VV plug removal and installation), and the Bore Tooling System used for the cutting, welding and weld inspection of the cassette cooling pipes were successfully commissioned;
- in parallel with the main DTP experimental activities, a set of technological tests have been carried out to qualify, under relevant environmental conditions (vacuum, temperature, radiation), special materials and components for the cassette locking systems and for the handling equipment.

FIG. 2. Mock-up of the lower portion of the vacuum vessel in the DTP

FIG. 3. Mock-up of the divertor access duct in the DTP

The operating procedures are being optimised in view of their execution in full remote conditions. This includes the development of advanced control tools to support the operator, in particular a supervisory control and data acquisition system, a 3D kinematic simulator and a remote viewing and metrology system. Using the DTP experimental evidence, 256 hours of continuous operation are required for the removal/installation of 60 cassettes in series. Detailed studies indicated that the overall duration of the divertor change-over will significantly exceed the *in-vessel handling time* proper, even assuming parallel work in different quadrants of the machine, because of the time required for machine shutdown and reconditioning, of the operations to be carried out in the access duct before and after cassette handling proper, of logistics limitations and because of unforeseen events. The experimental evidence confirms this result, which is often difficult to accept by non remote handling experts.

3.3 The Divertor Refurbishment Platform (DRP)

To simulate divertor refurbishment operations, the DRP includes handling equipment (overhead crane, manipulators, PFC handling tools,), a 3D metrology system, cassette components mock-ups, a viewing systems, a data acquisition system and a control room separated from the hot-cell environment. The basic feasibility of divertor refurbishment was demonstrated in 1998 [3]. Extensive simulations in 1999-2000 confirmed the preliminary results of 1998 [5].


FIG. 4. Specialised PFC's handling tool in the DRP

The first attachment concept between the PFC's and the cassette body was based on shear keys and was extensively tested in 1998-1999. The tight mechanical tolerances required to satisfy the thermo-mechanical requirements also required very accurate alignment during handling, which is difficult to achieve. Moreover, the insertion of the last key (4 keys used to hold each PFC) is particularly delicate and not always possible. A new scheme, the so-called multi-link concept, is now under investigation. A first series of tests has given very promising results. In parallel with the main DRP activities, a set of technological tests have been carried out to qualify, under relevant environmental conditions, special materials for the cassette-to-PFC attachments. Currently, a series of enhancements is being carried out to facilitate the simulation of operations in full remote conditions.

4. Future Developments

The feasibility of divertor handling and refurbishment has been confirmed. Both the DTP and DRP facilities are being upgraded to allow the simulation of operations in full remote conditions. This requires advanced viewing and metrology systems and adequate control and data acquisition systems. In parallel, detailed analyses will highlight the design modifications required to ensure a high reliability. Finally, the ability to cope with accidental events will also have to be simulated and validated.

5. References

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