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Risultati delle prove di manutenzione remotizzata per il ricondizionamento e per la sostituzione del target assembly di IFMIF

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Report RdS/PAR2013/210

RISULTATI DELLE PROVE DI MANUTENZIONE REMOTIZZATA PER IL RICONDIZIONAMENTO E PER LA SOSTITUZIONE DEL TARGET ASSEMBLY DI IFMIF

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Indice

Sommario

La validazione del progetto del concetto Europeo del target per IFMIF passa necessariamente dalla verifica delle sua mantenibilità e ricondizionamento. Infatti le condizioni operative ed ambientali in cui il target assembly di IFMIF si trova ad operare sono molto critiche (riscaldamento, neutroni+ fotoni) e pertanto il ciclo di manutenzione preventiva previsto per il ricondizionamento o per la sostituzione di tale componente deve essere eseguito ogni anno ed avere una durata massima non superiore a 7 giorni.
Per soddisfare il requisito di massima durata della manutenzione, e per garantire quindi la continuità di esercizio di IFMIF, è stata implementata una strategia di manutenzione del target assembly che permette di affrontare tale fase con la giusta flessibilità: sostituire il bersaglio(backplate) e ricondizionare la parte restante del target assembly, e/o sostituire l'intero target assembly con uno nuovo solo se necessario .
Questo approccio consente il raggiungimento degli obiettivi che rappresentano le basi dell'intero concetto di target Europeo: la riduzione delle quantità di materiale attivato da smaltire (la sostituzione del bersaglio comporta una riduzione dell'80% del materiale da smaltire);la possibilità, in caso di guasto, di ripristinare le funzionalità del target cambiando solamente il bersaglio, e la semplificazione delle operazioni di manutenzione.
La validazione sperimentale delle procedure di manutenzione, tenendo in conto di tutti gli scenari previsti dalla strategia implementata, è stata eseguita presso la Divertor Test Platform (DRP) dell'ENEA Brasimone. In particolare le seguenti operazioni di manutenzione sono state validate:

1) sostituzione del bersaglio rimovibile del target di IFMIF;
2) sostituzione dell'intero target.

Le operazione di manutenzione, le cui procedure sono state ottimizzate per mezzo delle simulazioni in ambiente di realtà virtuale, sono state validate utilizzando i prototipi in scala reale del target e della test cell (l'area di IFMIF in cui il target è installato).

In totale sono state eseguite quattro operazioni di sostituzione del bersaglio ed altrettante del target.

Le prove di manutenzione eseguite hanno consentito di dimostrare la fattibilità delle principali operazioni da eseguire per la sostituzione del target entro i tempi d'intervento previsti. Malgrado vi siano ancora delle operazioni di manutenzione non validate, come la pulizia delle flange di tenuta, i tempi residui per il completamento delle operazioni di sostituzione/ricondizionamento lasciano ampi margini per la finalizzazione dei rimanenti tasks di manutenzione da eseguire su tali componenti.

1 Introduction

IFMIF will be provided with a lithium target assembly (TA) to generate the neutron flux required for the irradiation of sample materials to be adopted for the construction of future fusion power plants. Two TA concepts were designed and investigated during the EVEDA phase : the integral target (IT) and the target based on the so-called removable backplate(BBP). The first one has been developed in Japan while the other in Europe. This report deals only with the EU concept of the TA for IFMIF.
One of the most technically challenging activities of the IFMIF facility is the maintenance and the refurbishment of its components, and among these the TA appears to be critical since it is located in side of the test and target cell (TTC) which is the most severe region of neutron irradiation. The EU TA design is based on a removable backplate[1], which is also the most heavily exposed component to the high neutron flux and, thus, its substitution is expected to be carried out at least every year, together with the TA, if not more frequently. Then an effective and efficient remote handling replacement of the BBP and of the TA becomes a precondition to fulfill the stringent requirement of IFMIF plant availability. The achievement of such high effectiveness of the remote handing operations to be performed requires the validation of the implemented maintenance procedures with the scope to evaluate their feasibility and potential improvements.
The annual preventive maintenance of IFMIF plant, whose duration has been fixed in 20 days, during which the TA is substituted or refurbished, is the main parameter to be fulfilled, and according to the RH maintenance strategy for IFMIF all maintenance operations for the TA have to be completed within 7 days[2]. To satisfy this ambitious requirement all maintenance procedures for the components to be maintained must be fully validated.
A first RH test campaign aimed at validating the BBP and TA replacement operations and at optimizing the RH maintenance procedures for these components has been carried out and completed. This activity has been performed in the DRP facility at ENEA CR Brasimone.

2 Maintenance of the EU Target assembly concept

The maintenance of the TA has to be executed at scheduled interval (preventive maintenance) as well as in case of failure. The design of the backplate concept for the EU TA was driven by the need to approach its maintenance with the right flexibility: change the backplate alone while the target only if needed. To this purpose the EU TA concept was designed as modular component to allow the backplate replacement in case of failure of one of components in the test cell or even of the backplate itself.

2.1 Requirements for the maintenance of the EU TA

The IFMIF facilities are designed to guarantee the high availability required for the IFMIF plant. Although the intervention times for the remote handling maintenance of IFMIF components are not validated yet, a reasonable evaluation of them has been carried out on the basis of past studies and experience with the IFMIF's components themselves. Accordingly the duration of the maintenance of components for the annual shutdown has to be completed within 20 working days+ 3 days per year for the accelerator[2]. A general scheme of IFMIF maintenance scenario is shown in Fig. 1.

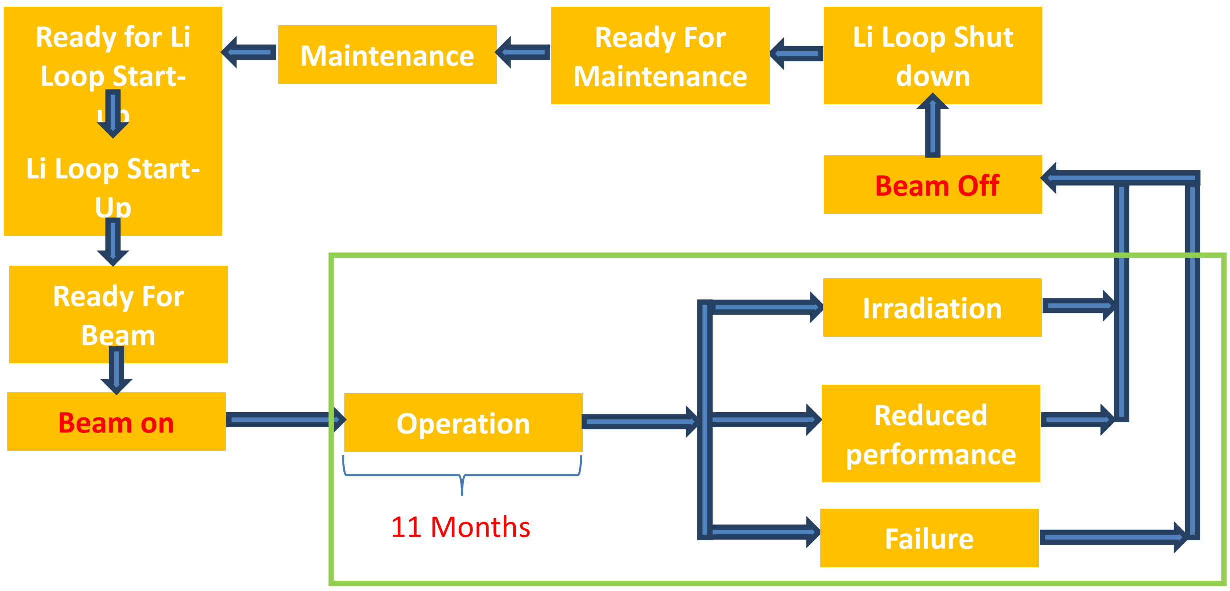

Fig. 1. General scheme of IFMIF operation

The 20 days for the preventive maintenance starts from the “beam off” and finishes with the “beam on” phases. The maintenance of the TA, whose phase has to be completed within 7 days, starts with the “Ready for maintenance” phase and finishes with the “Ready for Li loop start-up” phase. According with this maintenance scheme, it is assumed that all the preliminary activities, like: opening of the TC, removal of the TMs, conditioning of the TC, etc.., to start with the maintenance of the TA, have been already performed.

2.2 The EU TA concept design

The European TA concept, known as bayonet concept, was conceived with the objectives to simplify the replacement and the refurbishment operations to be performed for this component during the preventive and corrective maintenance periods of IFMIF plant, and to reduce the material for disposal as well. A 3D model of the EU TA concept is shown in Fig. 2. It consists of two main components: the body and the removable backplate. The body is attached to the lithium loop, in the inlet and outlet channels and in the beam side, by means of fast disconnecting systems (FDSs)[5].

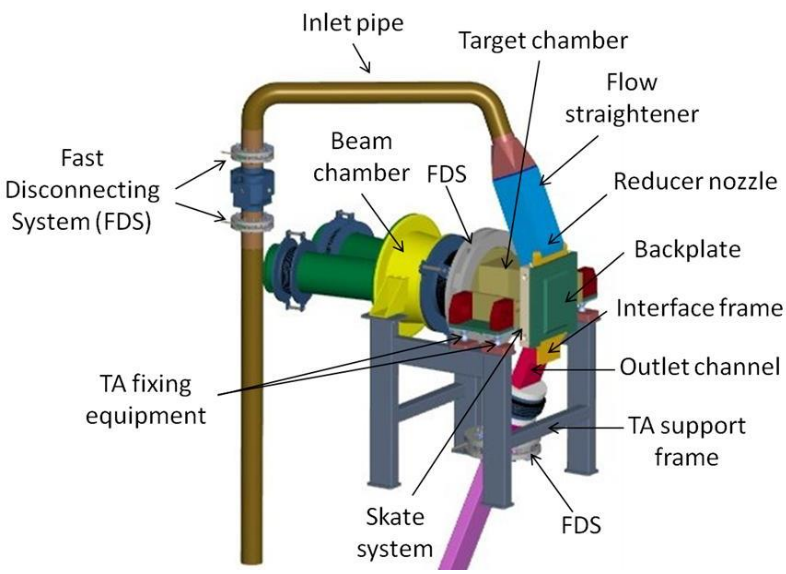

Fig. 2. The EU target system

This latter system, used in place of standard bolted flanges, allows the TA replacement by maneuvering only few bolts, typically 2 or 3 bolts for each FDS connection, so that the intervention time for its substitution is reduced. A custom design of this connecting system, see Fig. 3, was already validated in the past [6].

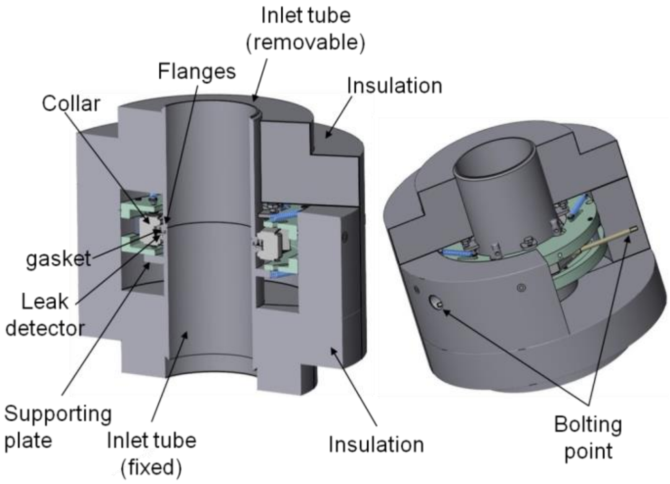

Fig. 3. The FDS for the inlet connection

The current bayonet concept foresees the extraction/introduction of the BP from the top of the fixed frame, by sliding it along the vertical direction. A 3D view of the backplate bayonet design is shown in Fig. 4

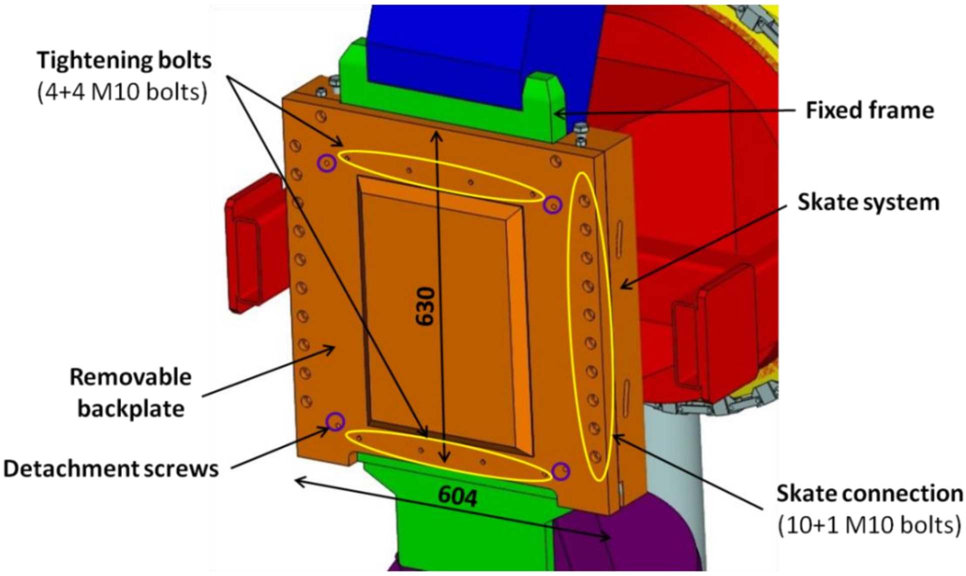

Fig. 4. The FDS for the inlet connection

A special locking system was developed in the past[1] to provide the demanding force required by the backplate to maintain the vacuum gradient between the target chamber and the TTC, and to prevent any lithium leakage. Sealing of the target chamber is ensured by metallic gasket. The locking system consists of 2 skates, located in the lateral sides of the backplate itself, and of 8 bolts, 4 located on the upper and 4 on the lower sides.

2.2.1 The TA prototypes for the RH validation activities

A full scale prototype of the TA and ancillary systems in the surrounding area of the TA itself have been procured and installed in the DRP facility at ENEA research centre Brasimone (IT).
According to the purpose of the activities to be carried out, the TA and ancillary systems were designed taking into account the following main requirements:

- Be representative of the TA of IFMIF;
- Be representative of the environment around the TA.
- Be provided with all interfaces for the TA connections and positioning.

On the basis of these requirements, the TA mock-up and ancillaries for the RH purpose were designed and manufactured considering the following topics:

- The backplate is a full scale prototype. Machining of this component is within the required accuracy;
- The external shapes and dimensions of the target as the weight and CoG match the design model of the IFMIF EU TA;
- For all parts of the target assembly not relevant for the remote handling purpose, no particular machining accuracy is required.
- Connections of the inlet and outlet channels are performed by means of Fast Disconnecting System (FDS);
- Connection of the inlet pipe is performed only with one FDS in place of two as foreseen by the EU TA design;
- Connection between the beam duct and the target chamber is performed by means of standard bolted flange.;
- Plan dimensions of the TC mock up are the same of the IFMIF one; height of the TC mock up is of about 3 m;
- The TA support and positioning are as the reference one.

Full description of the design and fabrication of the prototypes can be found in [7].
In Figs. 5,6 the prototypes designed and manufactured are shown.

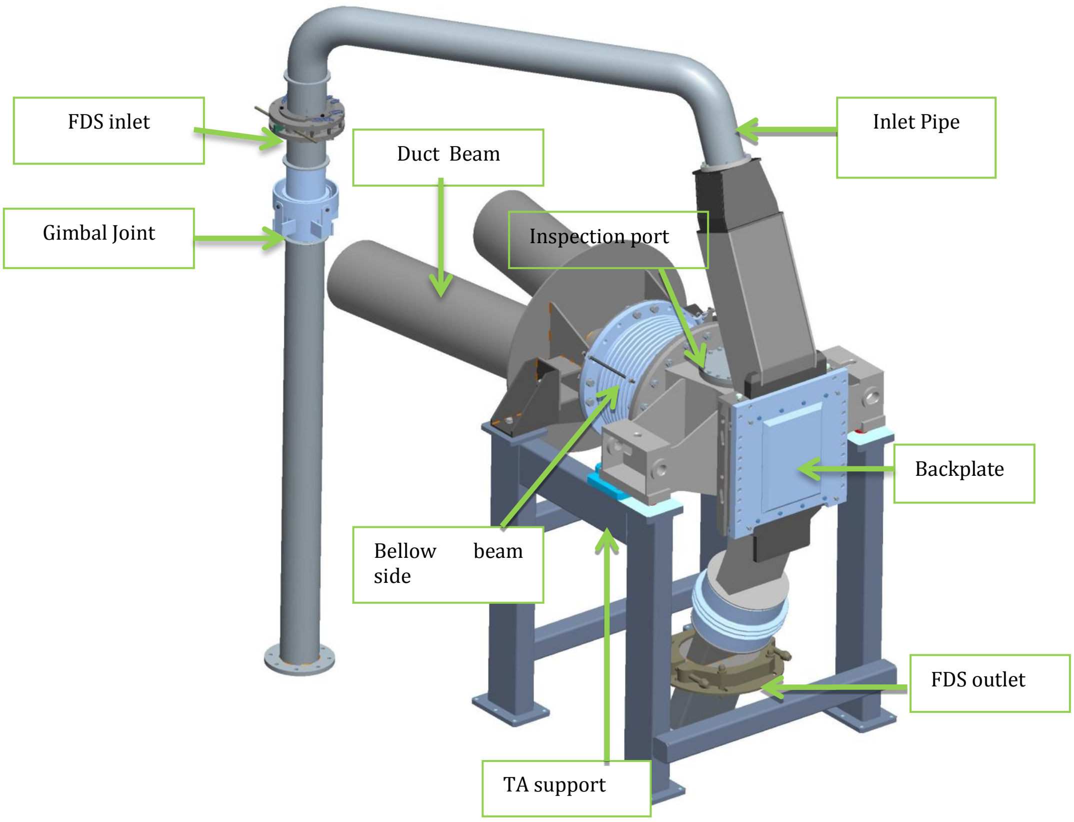

Fig. 5. 3D model of the EU TA for the RH purpose

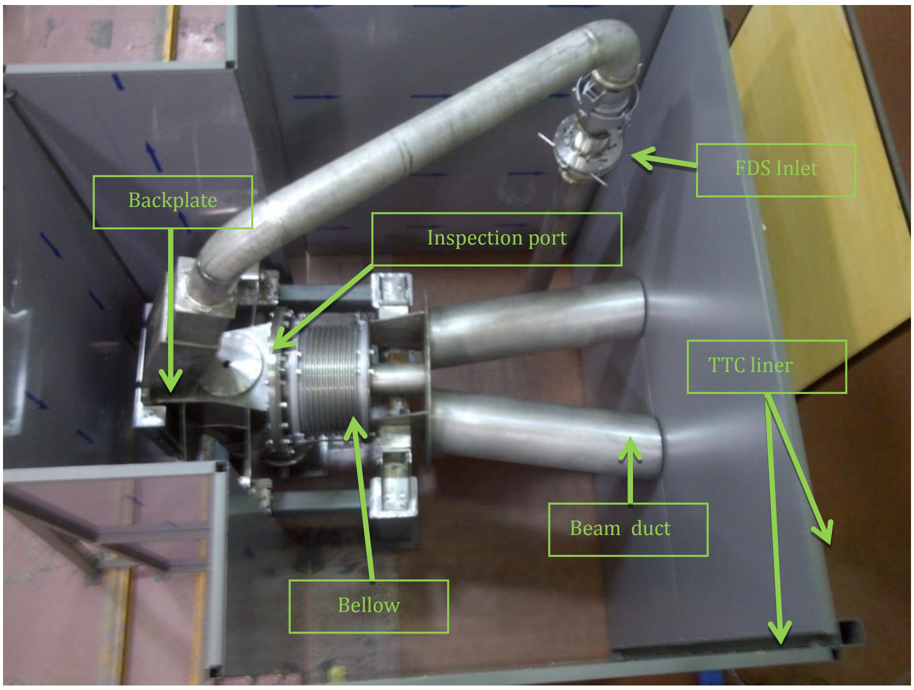

Fig. 6. The TA prototype and ancillary systems

2.3 The maintenance process of the TA

Two maintenance scenarios have been developed: the first one is the backplate replacement which leads to a consequent in situ refurbishment of the target body, while the second one is based on the replacement of the entire TA. This latter approach, which relies on the availability of a new TA ready for the installation or, if possible, on a TA previously refurbished, has the following advantages:

- The TA replacement with a new one entails the execution of only few in situ refurbishment operations, like inspection and cleaning of the connecting flanges;
- The refurbishment of the replaced TA can be performed in a dedicated hot cell, during the IFMIF operation, whose duration is 11 months, in a safer and relaxed way;
- Tests that cannot be performed in situ, like the lacking of steps in the lithium channel between the backplate and the frame, could be carried out easily offline increasing, at the same time, the accuracy and the reliability of the assembled components.

The main in situ refurbishment tasks for the TA are the following:

- Backplate removal;
- Inspection of the TA body to verify its status;
- Exchange of diagnostics, if needed;
- Clean the fixed frame from solid lithium;
- Backplate installation
- Test of the new refurbished target.

Among these tasks someone have not been addressed yet. It is the case, for instance, of the TA diagnostics exchange and testing of the new refurbished TA. These two maintenance tasks are the most challenging operations to be performed for this component for the following reasons:

- Diagnostics exchange has to be performed from the small window left by the backplate once removed;
- Testing of the new refurbished TA requires the accessibility of some of its parts that are in side of the TA itself. It is the case of the checking the lack of steps between the Li channel on the backplate and the Li channel on the fixed frame.

These two tasks that were not included in the activities carried out until now will be part of the future R&D programme.
The TA replacement, instead, is much ”simpler”. The following tasks are needed to be carried out for the TA replacement:

- Disconnect the TA from the lithium loop;
- Disconnect all electric connectors;
- Clean the flanges from lithium solid deposition
- Inspect the flanges;
- Install a new TA;
- Test the new TA.

Based on the preliminary estimation of the intervention time carried out, through computer simulation, there are no significant differences between the two maintenance approaches. In fact, both replacement procedures can be completed within the 7 days (3-4 days are the best estimation for the TA replacement) foreseen for the exchange operation of the TA. However, as anticipated, there are still maintenance operations not developed and validated, but the residual margin of 3-4 days should be sufficient to accomplish also these remaining tasks

3 RH Validation Test Campaign

The RH activities for the validation of the maintenance procedure for the IFMIF TA involve a number of tasks, as follows:

- Study of the optimal positions of the TA and ancillary prototypes inside of the DRP facility;

- Optimisation of tools set up and interfaces (i.e. tools calibration; bolting tools velocity ramps; etc..)
- Development of the installation and removal procedures for the backplate and the TA;
- RH trials themselves.

3.1 The DRP Facility

The RH maintenance activities for the IFMIF TA prototypes have been carried out in the DRP facility. This facility originally set up as a hot cell for the refurbishment operations for ITER divertor cassettes is general enough to host various types of RH activities, as well as being equipped to carry out the RH activities required for the IFMIF TA.
The DRP consists of the following areas and systems:

- The hot cell simulation area;
- The operator area;
- The metrology area;

Hereinafter the main systems and areas of the DRP facility used to perform the TA RH maintenance activities are briefly described. Since the metrology area has not been used for the test campaign, it is not described.

3.1.1 The Hot cell simulation Area

Fig. 7 shows a general view of the hot cell area specially configured to carry out the RH activities for the TA.

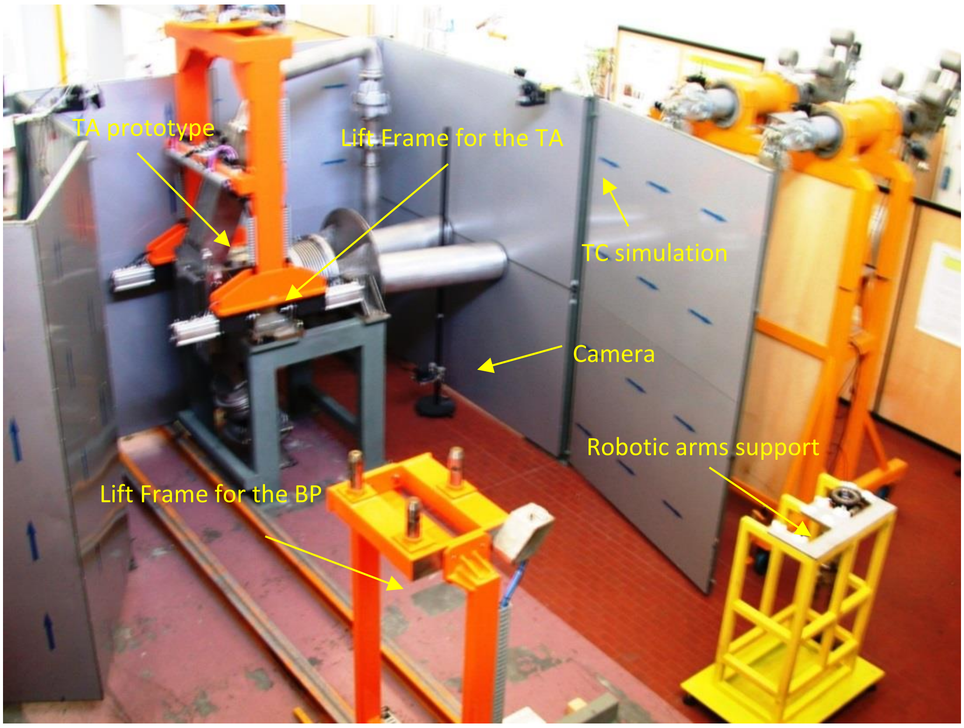

Fig.7. Configuration of the hot cell area of the DRP facility

The hot cell is equipped with a crane on which a heavy telescopic manipulator system (TMS) is installed. The crane and its auxiliary equipment are shown in Fig. 8.

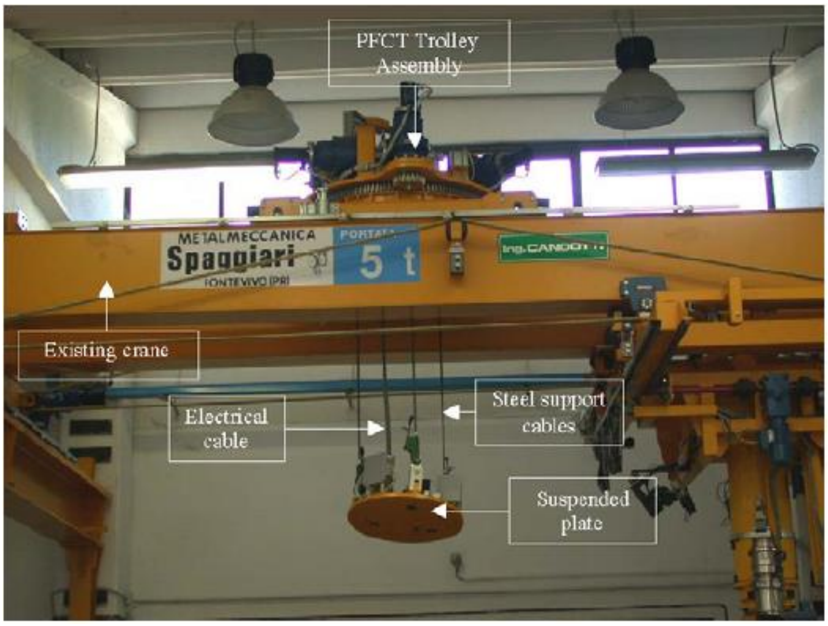

Fig. 8. Crane and auxiliary equipment of the DRP facility

On the crane it is also installed a special machine, called plasma-Facing components Transporter (PFCT), that is used to positioning the TA and the backplate onto the corresponding supporting structures. The PFCT machine is described in [8,9].
The TA mock-up is installed at the end of the hot cell so that enough space is left for the positioning of the other components and devices, like the lift frames for the TA and BP prototypes. Three cameras inside of the TC simulation area enable the operator to choose the best view point during the execution of the RH operations.
The hot cell area is hidden to the operator behind a number of opaque screens.

3.1.2 The operator Area

The operator area, Fig. 9, consists of the following systems:

- The viewing, monitoring and recording systems;
- The control panel used to drive the bridge crane and heavy manipulator;
- The software system for the handling of the PFCT and the two lifting frames;

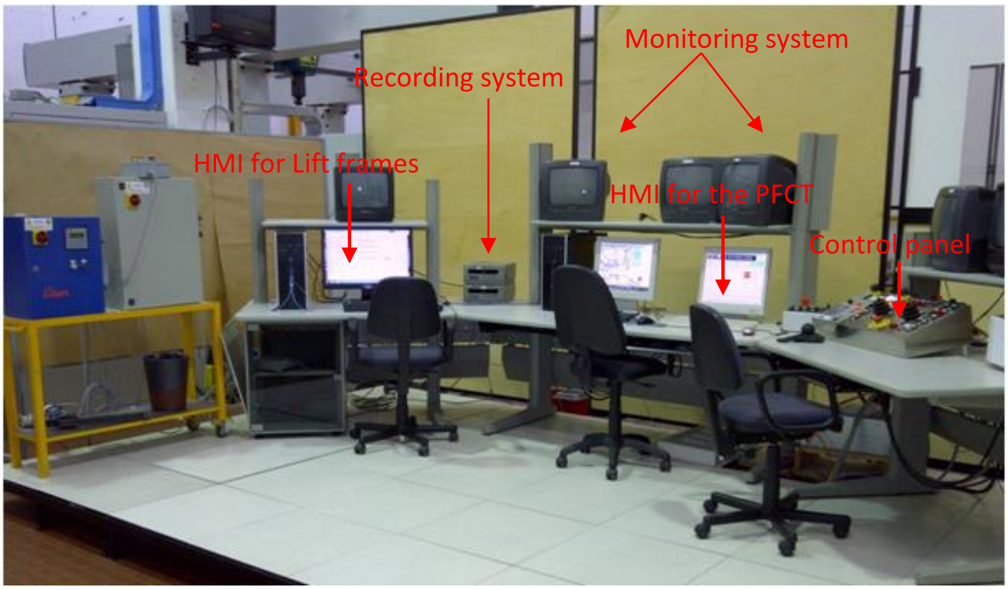

Fig. 9. Operator area of the DRP facility

The **viewing system** represents the heart of the RH activities and its optimization, in terms of number and positions of cameras, is one of the goal of the tests performed. It consists of the following parts:

- Monitoring system, and
- Video cameras system.

The monitoring system comprises 8 monitors and a video matrix to assign the camera to the desired monitor. Handling of the video matrix is performed by means of a software application.
The video camera system comprises 8 cameras (7 Panasonic and one Sony) with integral pan&tilt mechanism. Three cameras are installed inside of the TC simulation, two are on the telescopic arm and the remaining one on the walls of the DRP facility.
Handling of the robotic systems, like the PFCT, the lift frames and the robotic arm, is performed by means of software applications. It is shown in Fig. 10.

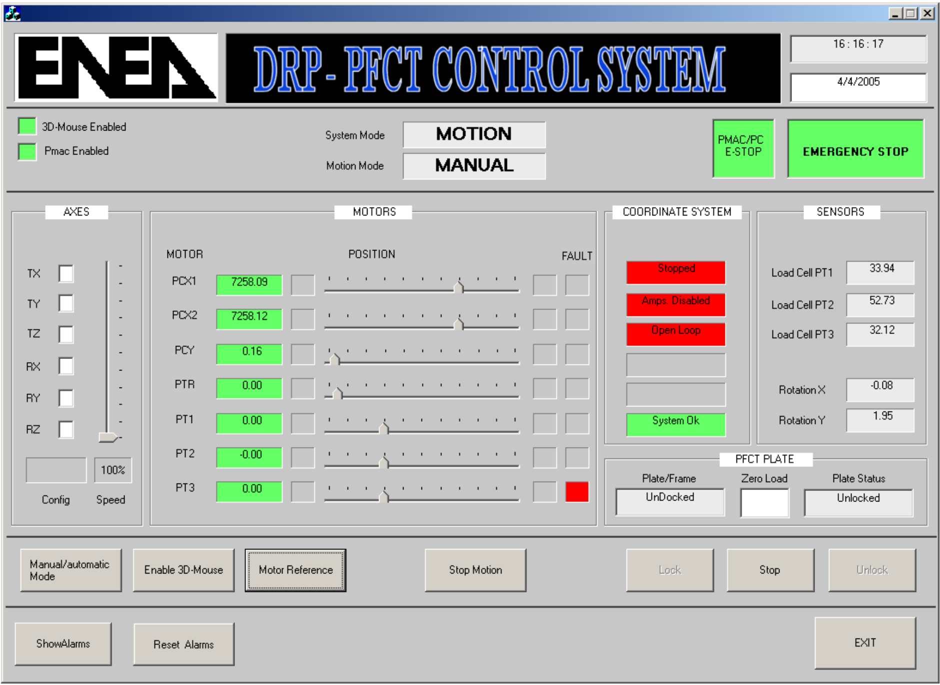

Fig. 10. HMI of the robotic equipment of the DRP facility

3.2 *The Remote handling Equipment and tools*

The remote handling equipment (RHE) and tools used for the RH test campaign are described in [8] and then they are only briefly described hereinafter.
The following RHE and tools were used:

1) The crane to transport all components and tools inside of the operation area of the DRP facility;
2) The PFCT (see Fig.8 and Tab. 1) to position the backplate and the TA during the exchange operations;
3) The lift frames for the BP and the TA (see Fig. 11 and Tab. 2): they represent the interfaces between the BP/TA and the PFCT and permit the positioning of the BP/TA onto the corresponding supports inside of the TC.

4) The telescopic arm (TMS) to reach all screw locations to be manoeuvred for the connection//disconnection of the BP and TA.
5) The light manipulator (see Fig. 12 and tab 3): it is attached to the TMS and It brings and keeps in place all tools inside of the TC , like bolting and cleaning tools;
6) The bolting tools (see Fig. 13 and Tab. 4) to perform all the screwing and unscrewing operations for the BP and the TA replacement.

Tab. 1. *General* characteristics of the PFCT

Items	Parameters
Degrees of freedom	6
Overall payload	5 tonnes
Payload per rope	2 tonnes
Working area	10.5m×3.2m×5m (x, y, z)
Rotation Z axis	0–90∘
Rotation X, Y axes	up to ±25∘
Positioning repeatability	< ±0,25 mm
Speed ranges	***************************
X axis	0.3–30 mm/s
Y axis	0.3–30 mm/s
Z axis	0.3–30 mm/s
Rotation speed	***************************
X axis	0.1–1∘/s
Y axis	0.1–1∘/s
Z axis	0.1–1∘/s

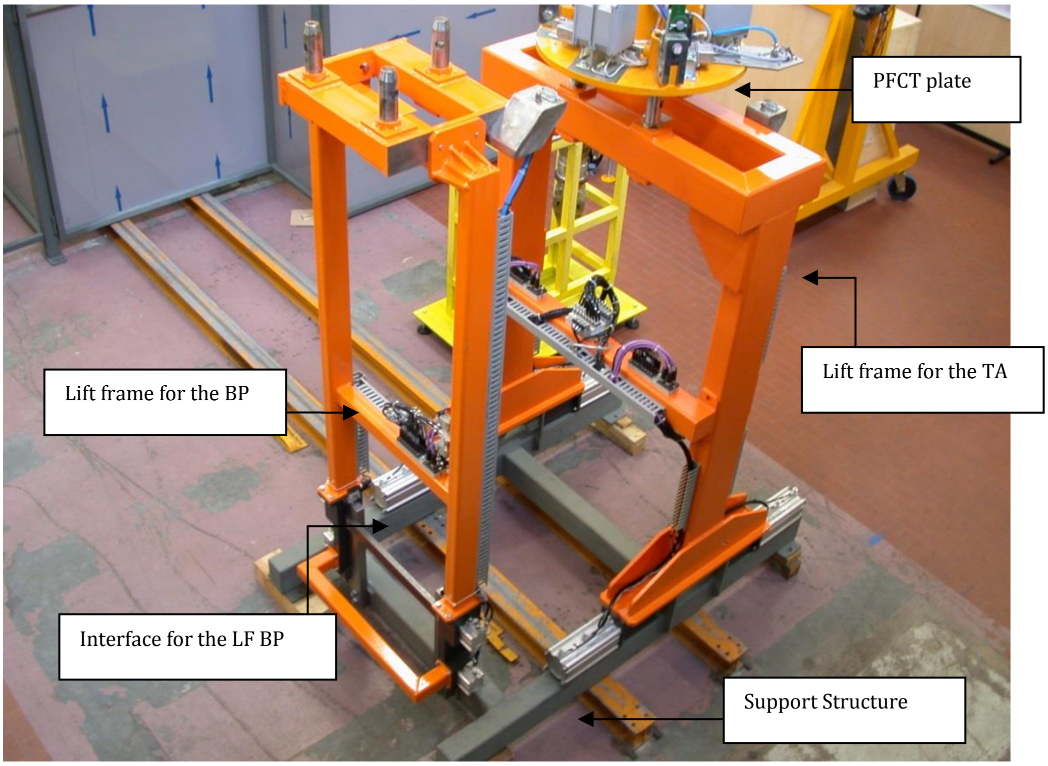

Fig. 11. Lift Frames for the BP and TA

Tab. 2. General characteristics of the BP and TA lift frames

Lift frame for BP	
Load capability	250 kg
Interface Vs PFCT	3 Pins
Interface Vs BP	4 pneumatic actuators
Lift frame for TA	
Load capability	1,5 t
Interface Vs PFCT	3 Pins
Interface Vs BP	4 pneumatic actuators

Fig. 12. Light manipulator attached to the TMS

Tab. 3 Main characteristics of the light manipulator

Topic	Parameters
Payload	15 kg
DoF	4 (roll, pitch, pitch, roll)
Shoulder roll	± 130°
Shoulder pitch	± 135°
Elbow pitch	± 115°
Elbow roll:	± 150°
Nominal joint speed is:	
Shoulder roll:	50°/s
Shoulder pitch	50°/s
Elbow pitch:	50°/s
Elbow roll:	50°/s

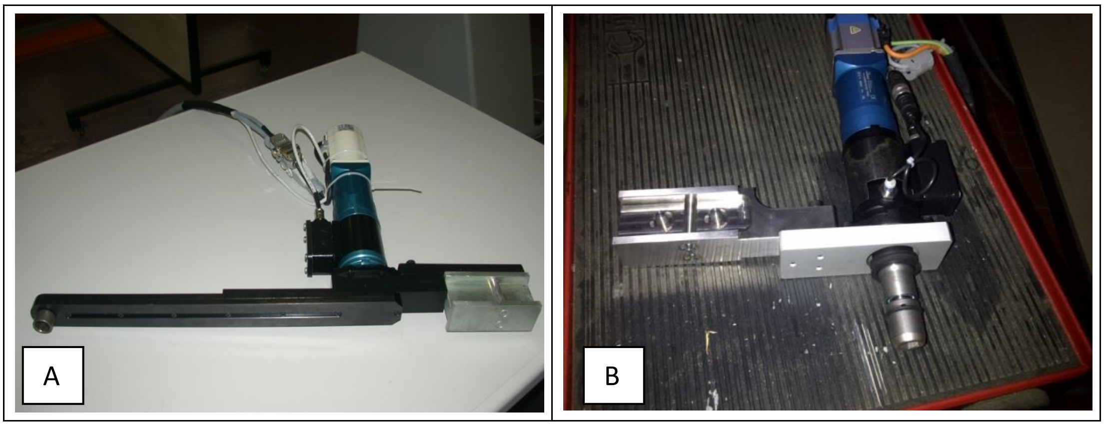

Fig. 13 Bolting tools (A: angular bolting tool; B bolting tool)

Tab. 4 Bolting tools characteristics

Angular Bolting tool (ABT)	Bolting tool
Torque range: 40 Nm	Torque range 150 Nm
Speed: 1-250 rpm	Speed:1- 250 rpm
Accuracy: 3%;	Accuracy : 3%
Controllable in torque and in angle	Controllable in torque and in angle

3.3 RH procedures

According to the RH strategy set up for the maintenance of the TA, the following preliminary procedures were developed:

- Procedure for the backplate replacement;
- Procedure for the TA replacement.

Backplate replacement

The backplate replacement operation of the bayonet concept has been already proved several times in the past [1]. The new backplate concept design is almost the same, from the RH point of view, to the previous one and then no significant variations are expected, in terms of procedures and intervention times.

TA replacement

This is the first time that the TA replacement operation has been carried out. The procedures developed take into account that also the refurbishment of the TA could be required.

The RHE and tools to be used for the TA are the same of those used for the Backplate replacement plus an additional Angular bolting tool (ABT).

The two procedures implemented for the BP and TA replacement are detailed in the annex 1 to this document. These procedures are the outcomes of RH simulation activities carried out (see RdS/2013/xxx).

It should be noted that in the procedures a few steps are written in green and highlighted in yellow. These steps, that were not tested in the DRP facility, have been included because in the real environment of IFMIF there will be the need to transfer the TA or the BP to/from the hot cell. In addition, It should be pointed out that: testing of the assembled TA is not included; some RH tasks are not covered by these procedures, like the plug and unplug of the electric connectors for the power supply and signals and the exchange of diagnostics. These RH tasks will be performed in the next experimental test that will be performed in the next year.

3.4 Remote Handling trials

The RH trials first addressed the validation of the TA and BBP design to demonstrate its remote maintainability and the possibilities of design improvement.

The trials of the TA and BP replacement were carried out using both manual and automatic sequences. The objective of the manual procedure was to perform each step of the replacement procedures from the operator area of the DRP using only the hardware control panel and the software (HMI), while another operator, inside of the hot cell simulation area, found the best positions of the telescopic manipulator and of the crane to complete the operations. In this way the preliminary replacement operations were tested and optimised. During these stages, the coordinate positions of the RHE were saved in a database to be used afterwards for the implementation of the automatic sequences.

Apart from the preliminary trials, the RH operations for the replacement of the TA and the BP were executed remotely from the operator area , with man-access to the interior of the hot cell simulation area completely forbidden.

3.4.1 RH validation of the Backplate replacement procedure

In total, four RH replacements of the BBP were performed: two manual and two automatic sequences. In the Annex 1 record the procedures adopted together with the intervention times measured are reported. The residence time of the RHE inside of the TTC have been recorded.

No matters were found in the implemented procedures for the BBP replacement and almost all the intervention times were confirmed.

In the following pictures some of the RH operations are shown.

Fig. 14 Backplate preparation (Overview of the facility at the start of RH operations)

Fig. 15 Backplate installation

Fig. 16 Backplate positioning

Fig. 17 Bolting of the skate system

Fig. 18 Bolting of screws

The BP and the interface frame were checked by visual inspection before and after each BP replacement operation. This test was aimed at verifying:

1) Lacking of steps in the lithium channel.
2) Damages occurred to the BP during its replacement.

The initial torque value adopted to tight the skate systems and the bolts to seal the edges of the backplate was of about 26 Nm. However, after the first inspection, a small step at the interface between the lithium channels on the BP and on the interface frame was discovered. To overcome this problem, the torque applied to the bolts and to the skates was increased up to 28 Nm. At this torque value the lithium channel was fully formed without any step.
Marks were found on the interface frame on the TA side. These were caused by the pins on the backplate that during the insertion prevent the damaging of the gasket. However the marks were outside of the surface where the gasket acts to seal the edge of the backplate(see fig. 19).

In addition to this, small damages were found in the lower side of the backplate and in the guides of the lift frame and on the backplate (lateral side) as shown in fig. 20).

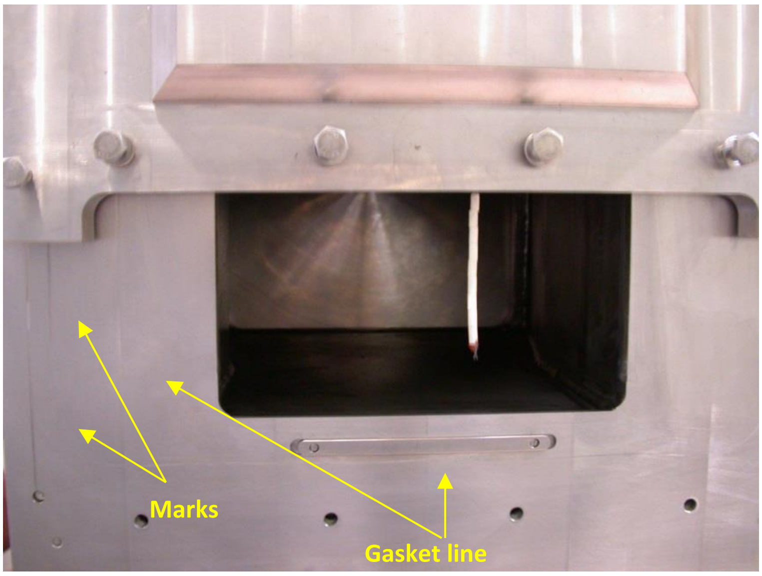

Fig. 19 Marks found on the Interface frame during the BP replacement

Fig. 20 Damages occurred in the lower side and in the guides of the BP

The damages occurred were caused by the sliding of the backplate on the areas in contact with the interface frame. In fact, swinging of the PFCT cannot be avoided and during the insertion of the backplate it can hit the frame on the TA.

3.4.2 RH validation of the TA replacement procedure

In total four RH replacements of the TA were performed: two manual and two automatic sequences. In the Annex 1 the procedures adopted together with the intervention times measured are reported. Also in this case the residence time of the RHE inside of the TTC has been recorded.
On the basis of the trials preliminary performed, the implemented RH procedures are well suited for the TA replacement. However the following remarks can be done:

- The TA removal can be easily performed: Opening of the three connecting flanges is the only operation to be performed, and this is considered a standard operation. For the removal the following problems were found:
  1) The compression operation of the bellow in the beam side. The compression of this bellow is obtained by maneuvering three screws , of which two are well located on the top of the beam duct (see fig. 21) and one is located in the bottom of the beam duct. Positioning of

this latter screw is not easily achievable by the bolting tool. Although the operation is feasible, the compression and the expansion system of the bellow has to be improved.

2) Interference was found between the flange on the outlet channel and the flange on the beam duct during the lift up of the TA. However, this interference was eliminated by moving forward the TA after its disconnection. This also confirms that with the present design all the TMs have to be removed prior to the starting of the TA exchange.

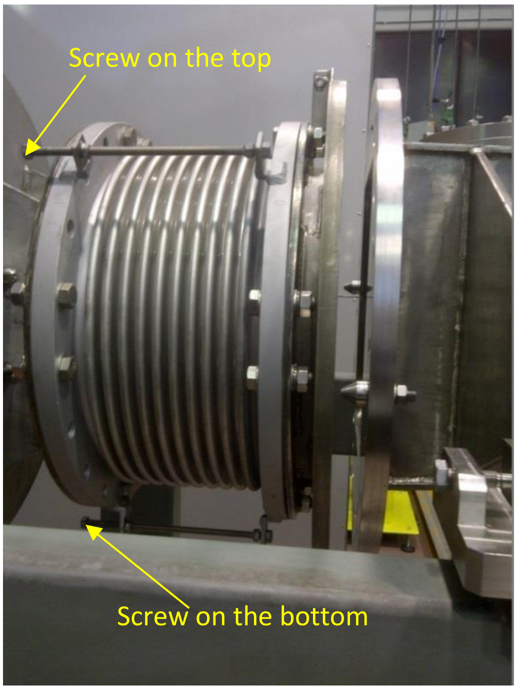

Fig. 21 Bellow on the beam side

- The installation, instead, is the most critical operation. In particular the positioning of the TA is not easily performed. The following problems were noted during the positioning of the target:
  1) The flange in the inlet side, attached to the gimbal joint, was always inclined (see Fig. 22). This inclination caused always the hitting of the flange against the structure of the FDS;
  2) The alignment of the two flanges on the outlet side was achieved with difficulties. This problem is caused by the flexion of the outlet channel, on the TA side, and in particular of the bellow, due to the weight of the flange itself (see Figs. 23,24)
  3) Alignment of four points, two FDSs and two centring pins on the TA support, is not an easy task. The alignment system of the TA and the centering system of the FDSs have to be improved.

Fig. 22. Inlet connection inclined

Fig. 23 The bellow on the outlet channel

Fig. 24 Gap between the FDS' flanges on the outlet channel

The pictures hereinafter reported illustrate some of the operations performed for the removal of the TA.

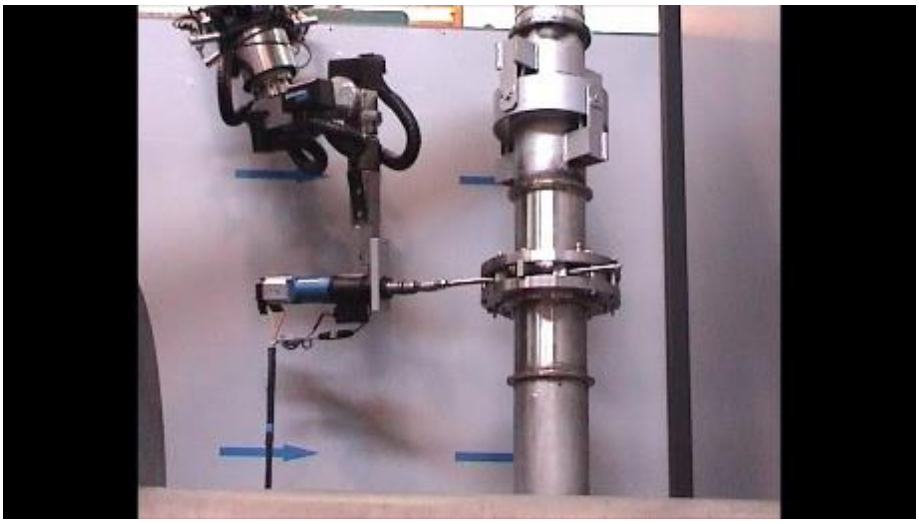

Fig. 25 Unlocking of the FDS in the inlet side

Fig.26 Unlocking of the FDS in the outlet side

Fig.27 Compression of the bellow in the beam side

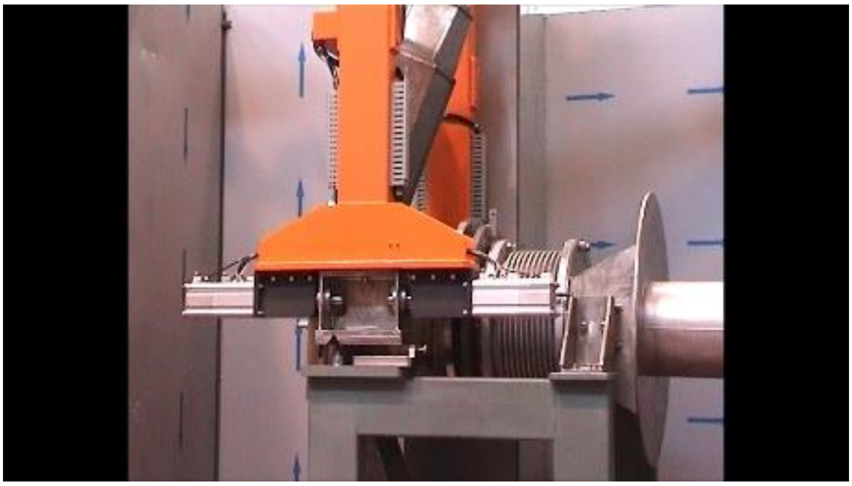

Fig. 28. Removal of the TA

Fig .29 Removal of the TA

The visual inspection of the TA before and after each installation was performed as for the backplate. The status of the three FDS systems was checked.
No damages on the TA connections were found. The only damage occurred concerns the dowel pins on the flange on the beam. The pins damaged are shown in fig. 30. While in fig. 31, the status of the flanges of the outlet TA connection is shown.

Fig. 30 Status of the dowel pins of the flange of the beam

Fig. 31 Status of the flanges of the FDS on the outlet channel

3.5 RH test results

On the basis of the test performed, the following conclusions can be done:
Both the installation and the removal of the backplate were completed successfully. The average backplate replacement time was less than expected: the entire replacement operation could be completed for 11^h 30'. This reduced replacement time leaves enough margin to complete the maintenance operation of this component within the 7 days foreseen for the refurbishment of the TA.
However it should be pointed out that:

1) The cleaning operation has been estimated on the basis of a test performed in the past and never repeated;
2) The Intervention time measured doesn't include the testing of the assembled BP prototype;
3) The average of 11^h 30' doesn't include the time between two single steps of the procedure implemented.
4) Damages occurred to the backplate and to the lift frame cannot compromise the functioning of the backplate itself.

Among the results obtained, the relevant one is the residence time of the RHE in the test cell. For the procedures implemented, the average residence time of the RHE used for the BP replacement was about 9^h 30'. As anticipated, this parameter is useful for the design of the RHE in rad-hard version.
The TA replacement tests were completed successfully despite the problems found during the trials. The interferences found between the outlet channel and the flange on the beam duct were eliminated by smoothly modifying the procedure: once the TA is released from the two FDS support, it is lifted up for a few cm, moved forwards in the direction of the TM, and lifted again up to the end of the operation.
The average of the TA replacement time was 23^h 40' and it was less than three days works. However the same considerations made for the BBP replacement can be done.
For the procedures implemented, the average residence time of the RHE used for the TA replacement was 21^h.

4 Conclusions

The preliminary tests performed have highlighted the main drawbacks of the IFMIF TA design and the improvement that are required to fit with a safer handling of the TA itself. These modifications can be implemented in the future, even on the present prototype, to move forwards with the final TA design. The RH procedures developed in this preliminary test phase will be used for the final assessment on the RH maintainability of this component.

5 References

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6 Acronyms

ABT	Angular Bolting Tool
AC	Access Cell
BBP	Bayonet Back Plate
BT	Bolting Tool
CoG	Center of Gravity
DoF	Degrees of Freedom
DRP	Divertor Refurbishment Platform
HFTM	High Flux Test Module
HMI	Human Machine Interface
IFMIF	International Fusion Materials Irradiation Facility
IT	Integral Target
LF	Lithium Facility
MFTM	Medium Flux Test Module
RAT	Robotic Arm Tool
RH	Remote Handling
RHE	Remote Handling Equipment
TA	Target Assembly
TM	Test Modules
TMS	Telescopic Manipulator System
TTC	Target &Test Cell

Annex1

Operation	**Trial n° 1** Time (min)	**Trial n° 2** Time (min)	**Trial n° 3** Time (min)	**Trial n° 4** Time (min)	**Average** Time (h:min:s)
Mode (M= manual;	**M**	**M**	**A**	**A**	
Backplate Removal					
Overhead crane in rest position (START)	0	0	0	0	0
Pick up the 7 DoF RBT	5	4	5	7	00:05:15
Take BT	4	5	4	4	00:04:45
Move the overhead crane above the TC	2	2	2	2	00:02:00
Deploy the RBT inside the TC	2	3	2	2	00:02:15
Unlock the skates	9	9	11	13	00:10:30
Unlock the bolts on the BP	38	45	55	49	00:46:45
Detach the BP	13	16	12	20	00:15:15
Extract the RBT from TC	2	3	2	2	00:02:15
Back the overhead crane to the RBT docking station	3	3	2	3	00:02:45
Release the BT	2	2	2	2	00:02:00
Release the RBT	5	4	5	6	00:05:00
Move the overhead crane to the BP gripper	1	1	1	1	0:1:00
Pick up the BP gripper	5	6	4	4	0:4:45
Move the overhead crane above the TC	3	3	2	3	0:2:45
Deploy and align the BP gripper in the TC	5	5	4	5	0:4:45
Dock the BP	5	5	5	5	0:5:00
Extract the BP up to above the interface frame	4	4	3	5	0:4:00
Extract the BP from the TC	2	2	2	2	0:2:00
Transfer the old BP in the hot cell (not included in the simulation)	4	4	4	4	0:04:00
Release the BP on its storage support (not included in the simulation)	4	4	4	4	0:04:00

Back the overhead crane from hot cell (not included in the simulation)	4	4	4	4	0:04:00
Release the BP gripper	5	8	5	5	0:05:45
Cleaning of the Frame					
Pick up the 7 DoF RBT	5	5	5	5	0:05:00
Take the cleaning tool	5	5	5	5	0:05:00
Move the overhead crane above the TC	2	2	2	2	0:02:00
Deploy the RBT inside the TC	2	2	2	2	0:02:00
Clean the interface frame of the BP	150	150	150	150	2:30:00
Extract the RBT from the TC	2	2	2	2	0:02:00
Back the overhead crane to RBT docking station	2	2	2	2	0:02:00
Release the CT	2	2	2	2	0:02:00
Release the RBT	2	2	2	2	0:02:00
Backplate Installation					
Move the overhead crane to the BP gripper station	1	1	1	1	0:01:00
Pick up the BP gripper	5	6	4	7	0:05:30
Move the overhead crane to the hot cell (not included in the simulation)	4	4	4	4	0:04:00
Grasp the BP	10	8	4	9	0:07:45
Back the overhead crane from the hot cell (not included in the simulation)	4	4	4	4	0:04:00
Deploy and align the BP gripper in the TC	15	12	8	13	0:12:00
Align and insert the BP	20	15	15	19	0:17:15
Release the BP gripper	2	2	2	2	0:02:00
Extract the BP gripper from the TC	4	4	4	3	0:03:45
Back the overhead crane to storage area	3	4	3	4	0:03:30
Release the BP gripper on its support;	7	5	4	7	0:05:45

Dock the 7 DoF RBT	7	5	3	7	0:05:30
Take the BT	6	6	4	6	0:05:30
Move the overhead crane above the TC	2	2	2	4	0:02:30
Deploy the RBT inside TC	2	2	3	4	0:02:45
Loop: tighten skates and bolts of the BP to 20% each step up to 100%	312	285	216	275	4:32:00
Extract the RBT from TC	2	2	2	3	0:02:15
Back the overhead crane to RBT docking station	3	3	3	4	0:03:15
Release the bolting tool	3	4	3	6	0:04:00
Release the RBT	6	7	7	7	0:06:45
Back the Overhead crane to rest position (START)	2	2	2	2	0:02:00
	717(11:57:00)	**697(11:37:00**	**610(10:10:00)**	**715(11:55:00)**	**11:24:45**

Operation	**Trial n° 1** Time (min)	**Trial n° 2** Time (min)	**Trial n° 3** Time (min)	**Trial n° 4** Time (min)	**Average** Time (h:min:s)
Mode (M= manual;	**M**	**M**	**A**	**A**	
Target Removal					
Overhead crane in rest position (START)	0	0	0	0	00:00:00
Dock the 7 DoF RBT	5	7	7	6	00:06:15
Take the ABT	4	4	4	4	00:04:00
Move the overhead crane above the TC	2	2	2	2	00:02:00
Deploy the RBT inside the TC	8	9	11	8	00:09:00
Release the FDS in the inlet side	20	25	18	15	00:19:30
Release the FDS in the beam side (**hands on**)	15	15	15	15	00:15:00
Compact the bellow in the beam side	95	90	88	105	01:34:30
Release the FDS in the outlet side	27	35	32	30	00:31:00

Extraction of the RBT from the TC	2	2	2	2	00:02:00
Back the overhead crane to RBT docking station	2	2	2	2	00:02:00
Release the ABT	5	5	4	3	00:04:15
Release the RBT	7	6	7	5	00:06:15
Dock the TA gripper	5	7	7	6	00:06:15
Move the overhead crane above TC	2	2	2	2	00:02:00
Deploy and align the TA gripper in the TC	25	30	20	18	00:23:15
Dock the TA	4	4	4	4	00:04:00
Lift the TA	20	25	20	30	00:23:45
Extract the TA from the TC	15	15	10	15	00:13:45
Transfer the old TA to the hot cell (not included in the simulation)	4	4	4	4	00:04:00
Release the TA on its support	20	20	20	20	00:20:00
Back the overhead crane from hot cell(not included in the simulation)	4	4	4	4	00:04:00
Release the TA gripper on its support;	10	8	11	11	00:10:00
Cleaning of the Flanges					
Dock the 7 DoF RBT	5	5	5	5	00:05:00
Take the CT	4	4	4	4	00:04:00
Move the overhead crane above the TC	2	2	2	2	00:02:00
Deployment of the CT inside TC	5	5	5	5	00:05:00
Clean the outlet FDS fixed flange	80	80	80	80	01:20:00
Clean the inlet FDS fixed flange	80	80	80	80	01:20:00
Clean the beam FDS fixed flange	30	30	30	30	00:30:00
Extract the RBT from the	2	2	2	2	00:02:00

TC					
Back the overhead crane to the RBT docking station	2	2	2	2	00:02:00
Release of the CT	2	2	2	2	00:02:00
Release of the RBT	5	5	5	5	00:05':00
TA Installation					
Dock the TA gripper	9	14	8	8	00:09:45
Move the overhead crane to hot cell (not included in the simulation)	4	4	4	4	00:04:00
Grasp the new TA	25	20	15	16	
Back overhead crane from the hot cell(not included in the simulation)	4	4	4	4	4
Deploy and align the TA gripper in the TC	25	30	20	18	00:23:15
Position of the TA onto the supporting Structure	520	840	630	435	10:06:15
Release the TA gripper	2	2	2	2	00:02:00
Extract the gripper of the TA from the TC	4	4	4	5	00:04:15
Back the overhead crane from the TC	2	2	2	2	00:02:00
Release the TA gripper on its support;	15	10	8	10	00:10:45
Dock the 7 DoF RBT	5	6	4	7	00:05:30
Take the ABT	3	5	4	4	00:04:00
Move the overhead crane above TC	3	3	2	2	00:02:30
Deploy the RBT inside the TC	15	12	12	10	00:09:45
Close the FDS in the outlet side	35	28	30	35	00:32:00
Expand the beam bellow	85	75	90	95	01:26:15
Close the FDS in the beam side (hands on)	15	15	15	15	00:15:00
Close the FDS in the inlet side	25	30	25	28	00:27:00

Extract the RBT from TC	4	6	3	3	00:04:00
Back the overhead crane to RBT docking station	2	2	2	2	00:02:00
Release the ABT	3	3	2	3	00:02:45
Release the RBT	4	7	5	6	00:05:30
Back the overhead crane to rest position (START)	2	2	2	2	00:02:00
	1338(22:18:00)	**1675(27:55:00**	**1407(23:27:00)**	**1253(20:53:00)**	**23:38:45**