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# ITER Articulated Inspection Arm (AIA): R&d progress on Vacuum and Temperature technology for remote handling.

Y. Perrot [a,*], J.J. Cordier [b], J.P. Friconneau [a], L. Gargiulo[b], E. Martin [d], J.D. Palmer [c], A. Tesini [e]

[a] Robotics and Interactive Systems Unit – CEA/LIST. BP6 F-92265 Fontenay aux Roses Cedex France
[b] Association Euratom-CEA, CEA/DSM/DRFC, CEA-Cadarache, 13108 ST PAUL LEZ DURANCE (France)
[c] EFDA CSU Garching, Boltzmannstrasse 2, 85748, Garching, Germany
[d] ITER International Team, Boltzmannstrasse 2, 85748, Garching, Germany
[e] ITER International Team, ITER Naka Joint Work Site, 801-1, Muouyama, Naka-machi, Naka-gun, Iberaki-ken 311-0193, Japan

* Corresponding author. Tel. : +33-146-54-95-44; fax: +33-1 46-54-75-80.
*E-mail address:* yann.perrot@cea.fr

This paper is part of the Remote Handling (RH) activities for the future fusion reactor ITER. The aim of the R&D program performed under the European Fusion Development Agreement (EFDA) work program is to demonstrate the feasibility of close inspection tasks such as viewing or leak testing of the Divertor cassettes and the Vacuum Vessel (VV) first wall of ITER.

It is assumed that a long reach, limited payload carrier penetrates the ITER chamber through the openings evenly distributed around the machine such as In-Vessel Viewing System (IVVS) access or through upper port plugs.

To perform an intervention a short time after plasma shut down, the operation of the robot should be realised under ITER conditioning i.e. under high vacuum and temperature conditions (120°C).

The feasibility analysis drove the design of the so called Articulated Inspection Arm (AIA) which is a 8.2 meter long robot made of 5 modules with a 11 actuated joints kinematics. A single module prototype was designed in detail and manufactured to be tested under ITER realistic conditions at CEA-Cadarache test facility.

As well as demonstrating the potential for the application of an AIA type device in ITER, this program is also dedicated to explore the necessary robotic technologies required to ITER's IVVS deployment system.

This paper presents the whole AIA robot concept, the first results of the test campaign on the prototype vacuum and temperature demonstrator module.

*Keywords:* ITER, Remote Handling, AIA, Vacuum and temperature technologies

## 1. Introduction

During the design phase of ITER, technical requirements became identified in terms of inspection tasks and maintenance of the facility. One of the needs identified concerns close inspection and helium leak detection inside the Vacuum Vessel (VV) (see Fig.1).

Figure 1

The main scope of this R&D program is to demonstrate the feasibility of an in-vessel Remote Handling inspection using a long reach, limited payload carrier (10 kg) that penetrates the ITER chamber through the openings evenly distributed around the machine. The possible ports taken into account are the In-Vessel Viewing System (IVVS) access and upper port access. This device is dedicated to close inspection processes of the Plasma Facing Components (PFCs).

The work performed under the EFDA-CSU Workprogramme includes the design, manufacture and testing of an articulated device demonstrator called Articulated Inspection Arm (AIA).

The first phase of the project concerned the analysis to define a realistic conceptual design of the equipment that fit the requirements of inspection operation inside the Vacuum Vessel.

A scale one mock up was manufactured, focusing on the electro mechanical test in air and at room temperature of a single module. The test campaign of a 2 degrees of freedom module was finally successfully performed and gave confidence of structural resistance of the system which was the first essential design driver to verify.

In parallel, a feasibility study of operation under vacuum and temperature was performed to select the possible applicable technologies. At this step it has been identified the need for developments of specific new technologies in particular for bearings, actuators and electronics.

This development required proof of principle test phase. Therefore a scale one full module with 2 degrees of freedom was manufactured and tested under vacuum and temperature conditions at Tore Supra facilities.

This paper presents in a first part the AIA robot, with its conceptual design, the kinematics of the robot and the relevant technologies. Then, the presentation focuses on the results of the test campaign performed on the CEA-Cadarache test facility.

## 2. Articulated Inspection Arm (AIA) conceptual design

A challenging design issue is being addressed to improve significantly the operational range of inspection tools. A long reach multi link carrier, like the AIA, is characterized by its large workspace and reduced mass. Unfortunately, increasing the number of joints with reduction of mass increases significantly structural compliance. When considering the ITER requirements for AIA, the limited access, the large operational range, the ultra high vacuum and pollution avoidance and the temperature ambiance at 120°C, a great improvement in the technology is required.

Due to the kinematics (a lot of actuated joints), with respect to the small outer diameter of the carrier (160mm diameter), integration of actuators, sensors, electronics and wires is a major issue. Strong reduction of size and weight is required to successfully achieve the design. ITER in Vessel operational conditions have as well a strong impact on the design. The control of the system should also be able to provide easy driving. Full remote control under blind conditions requires on line collision avoidance and monitoring

The AIA is a 8 meter long multi link carrier with 5 identical modules of diameter of 160 mm and with two electrical joints. Each module includes pitch (+-45° in the vertical plane) and yaw (+-90° in the horizontal plane) joints linked with a parallelogram structure (four bar mechanism) that keep yaw joints axis always vertical [1, 2].

The robot is moved along its support with an additional linear joint called the deployment system.

A dedicated hardened electronic networked system is on board of each AIA module [3].

## 3. Vacuum and temperature selected technologies

A feasibility assessment of suitable technologies to operate the AIA under the ITER conditions of vacuum and temperature was performed. Robotics components should sustain 120 °C during VV inspection and a temperature between 200 and 240°C during the baking phase for AIA conditioning prior to enter the VV. Limits on out-gassing inside the VV impose serious constraints for the design (e.g. on material, on joints design …). This assessment was carried out through close collaboration and knowledge sharing involving robotics designers and operational Tokamak maintenance team.

The tests of these suitable technologies were focused on both mechanical issues and electronics hardening (lubricant free joints, structural materials, tightness, actuator, sensors, on board electronics).

First design of lubricant free joints is based on thermal treatment with Teflon coating: functional tests are good and lifetime has to be verified.

AIA electronics is based on HCMOS military components with ceramic housing. The wide list of HCMOS components enables to design embedded electronics which is strongly required to limit wiring inside the robot.

After several hundred hours of test, HCMOS electronics components show good reliability both for in service temperature: 120°C and baking at 240°C.

The limit of performances of standard DC motors (135 °C) required to launch the development of a specific motor and reducer. This motor was tested with success at in service and baking conditions. The motor is tightened in a sealed box to overcome pollution issues.

After this single component test phase, a full prototype module was manufactured for integrated tests (see Fig.2).

Figure 2

## 4. Integrated test campaign

The objectives of the tests are proof of principle of design options of the AIA. Especially to evaluate performances under in service and baking conditions in terms of functioning, lifetime and outgassing. Main parameters involved are loading capabilities, speed, accuracy and ability to sustain ITER VV conditions

The module was set-up in a specific vacuum vessel (ME60) at CEA Tore Supra facility that can be baked up to 230°C under high vacuum conditions. Representative loading was applied (see Fig.3).

Figure 3

First test performed on the module was the leak detection which has proved the tightness of the boxes in which the electronics, the actuators and the sensors are embedded.

Functioning of the system under vacuum and at working temperature of 120°C was verified. The efficiency of the actuators was the same than in air at room temperature, the speed was slightly lower.

The survey of temperature of the motor and the power electronics component showed an increasing of 40°C during 3 full range pitch movements. This good result shows that despite vacuum conditions, thermal exchange is working properly through the AIA structure and this gives confidence on the in service capabilities of the system.

During all the test campaign, monitoring of vacuum and the outgassing rate of the module were recorded. The baking was performed during one week at 200°C. The final spectrum was compared to the initial one and shows a good conditioning of the module (see Fig.4).

Figure 4

At the end of the baking, the pressure of the vessel reached a good level and was $9.7\ 10^{-6}$ Pa at 120°C. Most of the greases were outgassed except mass 149 which comes from an organic material. The component using this material should be identified are removed from the design for the future AIA robot.

A first partial endurance test series was performed and gives first results. A new series is planned in the following of the program.

## 5. Conclusions and further developments

R&D Results on this multipurpose robotic device give new perspectives on maintenance and operating activities for a reactor like ITER and aim to enhance operator perception of in-Vessel situation.

Following promising first results obtained on the prototype segment, the complete AIA robot is foreseen to be manufactured.

Demonstration of the AIA behaviour and reliability in real temperature and vacuum tokamak environment is planned on Tore Supra for the next years [4]. Several processes are foreseen to be developed and demonstrated on the AIA robot carrier that could be considered very useful for ITER maintenance.

6. Acknowledgement:

This work, supported by European Communities under the contract of Association between EURATOM/CEA, was carried out within the framework of the European Fusion Development Agreement. This views and opinions expressed herein do not necessarily reflect those of the European Commission

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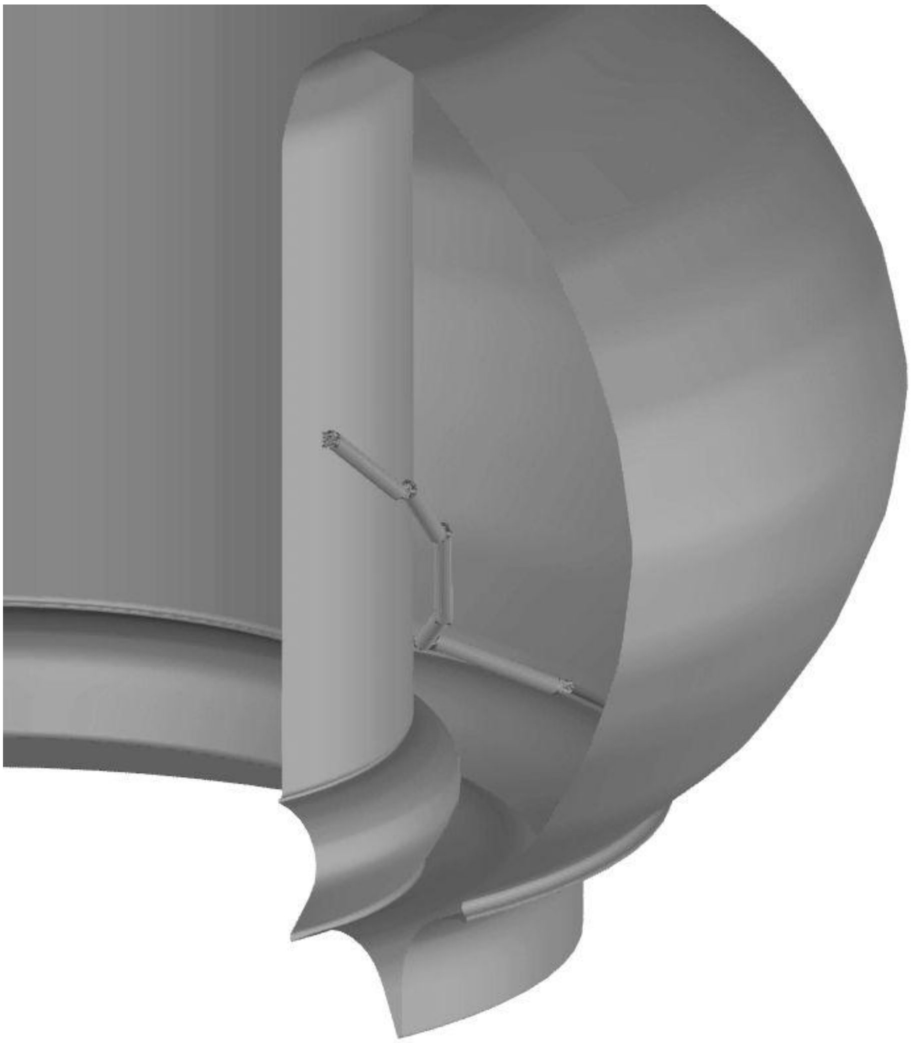

**Figure 1: AIA concept in ITER design**

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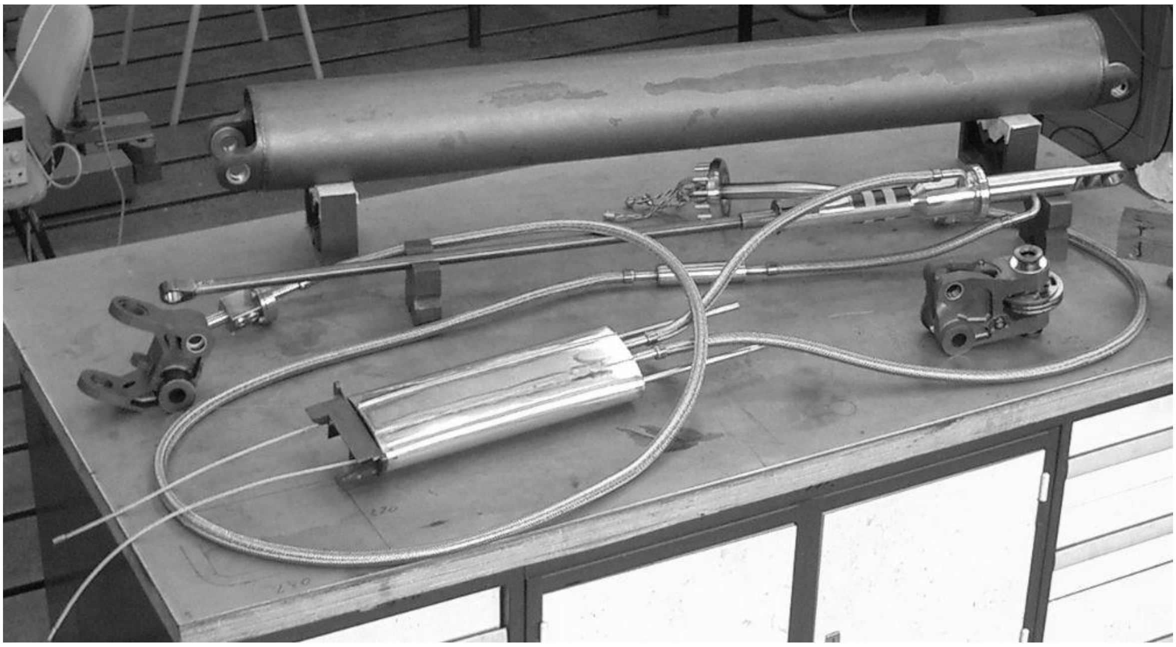

**Figure 2: AIA components during the assembly**

(1/4 pp)

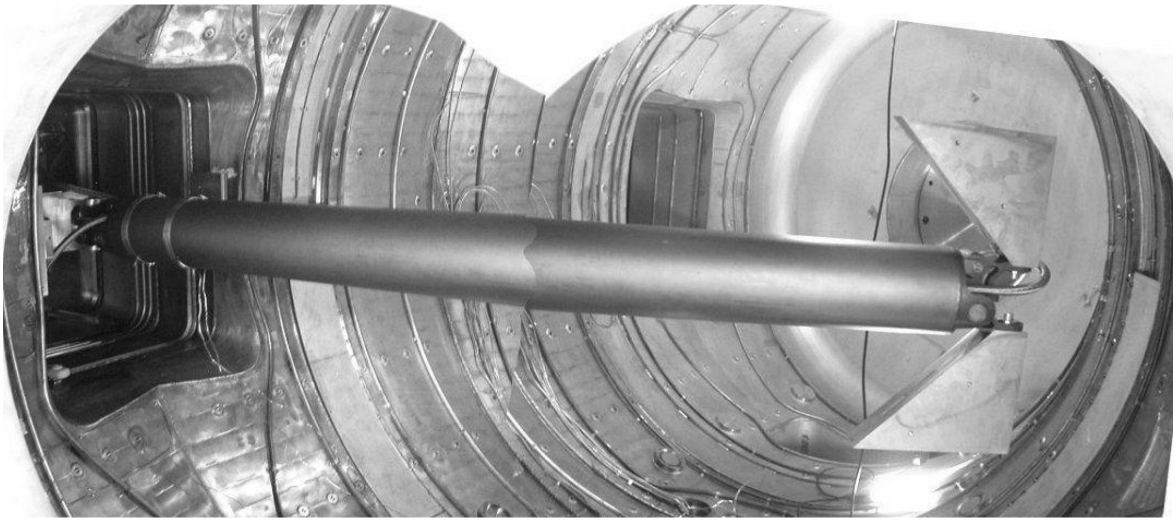

**Figure 3: AIA prototype module in the ME60 vacuum facility**

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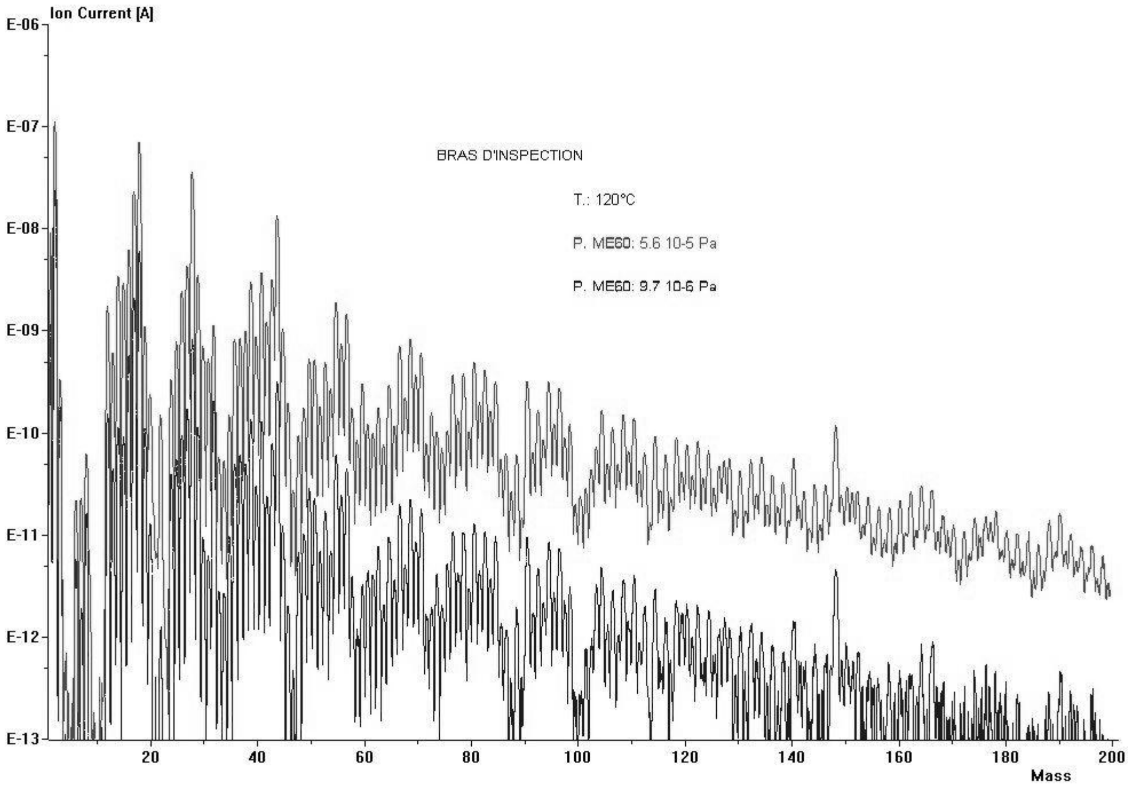


**Figure 4: spectrums of segment before and after baking**

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