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An Articulated Inspection Arm for fusion purposes

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HIGHLIGHTS

- Requirements for in vacuum tokamak inspection are presented.
- Development of a prototype of the Articulated Inspection Arm is described.
- The upgrade of the prototype to convert it into a fully operational device is detailed.
- Future applications of inspection robots in the new fusion reactors is discussed.

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ABSTRACT

Fusion Tokamaks are complex machines which require special conditions for their operation, in particular, high vacuum inside the vessel and high temperature of the vessel walls. During plasma phases, the first wall components are highly stressed and a control is necessary in case of doubt about their condition. To be able to make safely such an inspection in a short period of time is a great advantage. The Articulated Inspection Arm (AIA) developed by the CEA provides the capability for fast inspections of the first wall overall surface keeping the vacuum and temperature conditions of the vessel. The robot prototype was validated in Tore Supra in 2008. In the frame of a joint laboratory, CEA/IRFM and ASIPP have decided to upgrade the existing AIA prototype to use it routinely in the EAST and WEST tokamaks. The robot has followed an important upgrade program in 2013 and 2014. The document presents the various upgrades made on the mechanics, the sensors, the electronics, the control station and the integration adaptation for the operation on EAST. From the AIA experience, thoughts for future inspection robots are given.

1. The tokamak inspection problematic

Tokamaks are complex machines with very demanding operational conditions. Their internal components are hugely stressed, thermally and mechanically. The stresses are caused thermally by the high radiative and conductive power generated by the plasma and mechanically, by possible big halo current or Hall effect forces generated in case of a loss of control during the experiment.

The geometry and the mechanical integrity of the plasma facing components may be compromised after such events and a fast inspection is useful in case of doubt about their condition. In the vacuum vessel, many components are water cooled, if a water leak appears, its detection will be more effective if the investigation is done from inside the vessel kept in vacuum [1].

Fast inspection capability is already a clear demand to improve the efficiency of the experimental campaigns in existing facilities like WEST or EAST. Moreover, during the WEST experiments, regular vision controls of the components under test are required.

In ITER or DEMO, the logistics to open the vessel for the deployment of an inspection device is very heavy and will imply a full shutdown of the facility. Inspection should be possible keeping the operational conditions of the tokamak, therefore, in vacuum and temperature conditions.

At present, in ITER a vacuum compatible inspection is foreseen to be done with the IVVS, the mobility of this system is very limited and solutions for more agile equipment must be found. Already in DEMO, it is envisaged to make fast inspections of the divertor cassette and blanket module attachments on a regular basis or just after unexpected events. These inspections must be done between plasma experiments keeping the vessel in plasma compatible condition.

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Fig. 1. The AIA robot inside Tore-Supra mock-up.

Other constraints will apply on the inspection device. It concerns particularly the level of radiation inside the vessel and the temperature of the first wall:

- Radiation dose up to 3.5 kGy/h are expected inside the vessel, this dose level is hardly compatible with embedded electronics and is a major design constraint.
- The cooling of the robot will be done by radiation toward the first wall at a temperature in order of 100 °C if no external cooling source is used.

In term of inspection processes, the visual inspection is an obvious one, metrology is also highly desirable, and leak detection has been mentioned. Other complementary tasks could be performed if an in-vacuum carrier device is available like in-situ calibration of diagnostics, windows and mirror cleaning, and even material sampling.

2. The Articulated Inspection Arm (AIA) project

The project started in 2002 within CEA, merging skills in robotics and fusion activities. The aim was the demonstration for ITER of the feasibility of a multi-purpose inspection device able to operate when the vessel is kept in vacuum. The first phase of the project called "In-Vessel Penetrator" (IVP) was dedicated to the design and validation of the technology. In second phase called AIA a scale one prototype was developed and tested in real condition in the CEA tokamak Tore-Supra (Fig. 1). The project is now in its third phase called EAST–WEST AIA in collaboration with the Institute of Plasma Physics of the Chinese Academy of Sciences. It consists in the equipment of the two tokamaks EAST (ASIPP) and WEST (IRFM) with fully operational inspection devices that can be used in routine mode during the experimental campaigns.

3. Phase 1: The In-Vessel Penetrator (IVP)

For ITER, the need to access very close to the blanket and divertor had been identified when considering:

- Helium leak testing.
- Visual inspection.
- Dust and debris removal.
- Vacuum vessel sampling.

This meant that the desirable working area for the IVP was considered to be the whole in-vessel surface with a penetration in the ITER vessel through openings evenly distributed around the machine such as In-Vessel Viewing System (IVVS) access or upper ports access (Fig. 2).

The operational conditions taken into account were:

- A temperature of the first wall at 120 °C.
- A vacuum of 10–6 Pa.

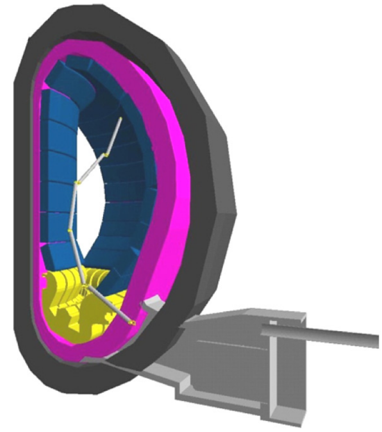

Fig. 2. Simulation of the IVP inside ITER.

A baking temperature of 200 °C was considered, and the payload was set to 10 kg.

The IVP solution developed to fulfill these requirements is an articulated boom made of five segments electrically powered. Each segment includes a pitch joint and a yaw joint linked with a parallelogram structure that keeps the yaw joint axis always vertical. The working range inside the VV from the entry point is about 8200 mm. The IVP is deployed from outside the VV by means of a dedicated mechanism that pushes the system through the existing penetrations.

An electromechanical demonstrator was made to check the feasibility of the IVP. Several actuator and sensor technologies were adapted for their use in vacuum and tested at high temperature. A mockup of the most loaded segment with its yaw and pitch joints was made and functional and loading tests proved the validity of the design [2] (Fig. 3).

4. Phase 2: The AIA prototype for Tore-Supra

To fully validate all the choices made for the IVP, a scale one prototype (AIA) was developed and tested in the IRFM tokamak Tore-Supra. The same kinematic and representative segment lengths were used.

The AIA main design features are [3]:

- Metallic alloys for the structure materials such as titanium.
- Other non organic materials like Vespel for the cable guides.
- Welding processes for the assembly of the body tubes.
- Temperature hardened DC motors for the electric actuators.

Fig. 3. The IVP demonstrator.