DEVELOPMENT OF AN INSPECTION ROBOT UNDER ITER RELEVANT VACUUM AND TEMPERATURE CONDITIONS

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Abstract. Robotic operations are one of the major maintenance challenges for ITER and future fusion reactors. In vessel inspection operations without loss of conditioning could be very mandatory. Within this framework, the aim of the Articulated Inspection Arm (AIA) project is to demonstrate the feasibility of a multi-purpose in-vessel Remote Handling inspection system. It is a long reach, composed of 5 segments with all 8 degrees of freedom, limited payload carrier (up to 10kg) and a total range of 8m. The project is currently developed by the CEA within the European work program. Some tests will validate chosen concepts for operations under ITER relevant vacuum and temperature conditions. The presence of magnetic fields, radiation and neutron beams will not be considered. This paper deals with the choices of the materials to minimize the out-gassing under vacuum and high temperature during conditioning, the implantation of the electronics which are enclosed in boxes with special gaskets, the design of the first embedded process which is a viewing system.

1. Introduction
The aim of this R&D program is to demonstrate the feasibility of in-vessel tokamak inspection tasks for the future fusion reactor ITER [1]. An Articulated Inspection Arm (AIA) is being developed to satisfy requirements in terms of maintenance and components inspection. The ultra high vacuum $10^{-6}$ Pa and the temperature ambiance at 120°C are the mean retained technical requirements for this program. Interventions under magnetic field and nuclear ambiance are not yet considered in the implemented technology for this demonstrator. The preliminary tests of the AIA capabilities are scheduled on the tokamak TORE SUPRA at CEA/Cadarache by the end of 2007. This facility is equipped with actively cooled components and operates with similar vacuum and temperature conditions as ITER (120°C in operation and 200°C during baking phase). Integration of the AIA, associated with development of inspection processes will validate in-vessel operating capabilities (viewing, leak detection on water loops, deposited layer laser ablation as well as chemical characterisation, abnormal events diagnostic…).

2. The AIA robot
The AIA is a multi linked carrier, composed with 5 modules of Ø160mm. Its length of 8m is consistent with ITER requirement. Eight degrees of freedom are distributed between the modules with pitch $(\pm 40^\circ$ in the vertical plane) and yaw $(\pm 90^\circ$ in the horizontal plane) joints with a parallelogram structure that always keeps yaw joints axis vertical [2, 3]. The weight of the AIA is about 150kg and its payload carrier up to 10kg. It is moved along its support with a linear trolley named Deployer.
Each module embedded its electronic networked system. These components should sustain a temperature of 200°C during the baking phase (for out-gassing) and 120°C for operations during in-vessel tokamak deployments. An endurance testing was also performed at room temperature condition to qualify the 5 modules performances under representative loading (figure 1).

3. Integration on TORE SUPRA tokamak
A scale one demonstration of the AIA under ITER requirements is foreseen on TORE SUPRA which required a long storage cask to be realized for conditioning (in vacuum and temperature) and guiding accurately the robot during in-vessel tokamak deployment. This stainless steel large cask (11m long, 3m height and 5t weight) is carried by 2 rolling wagons and should be connected or fold up in about 1 hour on a dedicated port of the torus. For this purpose, the cask is equipped with a couple of valves that allows (dis)connection of the vessel without loss of the vacuum conditions. Moreover, all electro-technical equipments are embedded to realize an autonomous system (figure 2).
A first deployment of the AIA robot is planned on the Tore Supra fusion facility at CEA/Cadarache by end of 2007. Robustness, reliability and flexibility will be tested and improved between successive plasma operating campaigns.

4. Vacuum and temperature selected technologies
A feasibility assessment of suitable technologies to operate the AIA under the vacuum and temperature ITER conditions was performed. Robotics components shall sustain 120°C during vessel inspection and a temperature of 200°C during the baking phase for AIA conditioning prior to enter the torus. Limits on out-gassing inside the vessel impose serious constraints for the design (e.g. on material, on joints design …). This material selection was carried out in close collaboration between robotics designers and operational tokamak maintenance team.
The choices of these suitable technologies were focused on both mechanical issues and electronics hardening. Thus, Titanium and Stainless Steel were retained for the materials under vacuum.
All electronic components were inserted in sealed boxes under $10^5$Pa nitrogen pressure to prevent contamination. The high temperature issue was solved by using High-speed Complementary Metal Oxide Silicon (HCMOS) electronic components and also the possibility of actively cooling by nitrogen-gas circulating in a flexible umbilical.

A vacuum and temperature test campaign on a prototype module was performed in 2005 at CEA/Cadarache test facility. Twenty five cycles, each included 48 hours baking at 200°C and motion operation at 120°C, showed good functioning of the equipments and a right final conditioning spectrum. These first results give confidence in the technologies developed for the AIA project.

Technical features:

- The design of lubricant free joints was based on thermal treatment with Teflon coating: functional tests were conclusive.
- To sustain the high temperature, metallic gaskets were used. Helicoflex joints were retained for standards flanges. However the shape of some boxes has required the use of Al strand hand made seals.
- Performances limit of standard DC motors (135°C) has required launching the development of a specific motor with high temperature bearings and reducer. This motor was tested with success at nominal conditions. It is tightened in a sealed box to overcome pollution issues.
- Each module had its own position detection which was based on magnetic coupling principle. The sensor is also introduced in a sealed box.
- AIA electronics is based on HCMOS military components with ceramic housing. The wide list of HCMOS components enabled to design limited wiring electronics inside the modules. After several hundred hours of test, HCMOS electronics components has shown good reliability both for in service temperature 120°C and baking at 200°C.
- Gold connectors specified for high temperature were used to avoid oxidation and provide a better contact.

5. Development of embedded processes for inspection tasks

The AIA is designed to allow accurate displacements of the head, close to the first wall. Several processes to be implemented at the front end of the robot arm are considered for maintenance and inspection tasks.

5.1. Vision process

A viewing system will be first installed to make close visual inspection of Plasma Facing Components. The camera is made up of a CCD sensor introduced in a gold coated SS tight box.
This box is linked to the head of the robot through a vertical joint actuated from inside with the same system as the yaw joint of the module (Figure 5). All the electronic components inside are actively cooled by nitrogen-gas circulating in a flexible umbilical to keep the operating temperature below 60°C. This system is currently being tested and will be used on TORE SUPRA under operational conditions by the end of 2007.

![Figure 5. First deployment inside TORE SUPRA vacuum vessel of the AIA equipped with the viewing inspection process under atmospheric pressure.](image)

5.2. Leak detection process
A process based on helium sniffer is under consideration to improve and facilitate maintenance operations on water loop leak tests. It will be performed under dry nitrogen atmosphere. A specific sensor able to sniff helium will be placed at the head of the AIA. Then, a 20m umbilical will connect this sensor to a helium spectrometer located outside.

5.3. Laser process
Laser based devices can be used to diagnose and operate the tokamak Plasma Facing Components.
- Deposited layer depth on the Plasma Facing Components can be measured using a repetitive laser pulse at a low fluence and modelling the temperature response.[5]
- The removing of the deposited layer, already demonstrated successfully at JET with an Ytterbium fibre laser. This technique appears to be very promising to recovery tritium trapped into ITER vacuum vessel.[5]
- The composition of deposited layer can be estimated via Laser Induced Breakdown Spectroscopy (LIBS) [5].
Integration of 2 optical fibres is foreseen on the AIA, both connected respectively to the laser source and the analysing spectrometer, in order to implement these laser techniques.

6. Conclusions
During laboratory R&D phase, suitable technologies in mechatronics have been successfully developed and/or selected to be operated under ITER relevant vacuum and temperature conditions. A first test campaign of the whole device equipped with an inspection camera is planned on TORE SUPRA by the end of 2007. This will focus vision capabilities under such constraints.
Leak detection unit and laser based devices are under development, which will constitute furthers tolls for the in-vessel robot arm of TORE SUPRA. Those developments should open new perspectives on maintenance and operating activities for fusion reactor like ITER and aim to enhance operator perception of in-vessel situation.

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