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Final design of the beam source for the MITICA injector

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The megavolt ITER injector and concept advancement experiment is the prototype and the test bed of the ITER heating and current drive neutral beam injectors, currently in the final design phase, in view of the installation in Padova Research on Injector Megavolt Accelerated facility in Padova, Italy. The beam source is the key component of the system, as its goal is the generation of the 1 MeV accelerated beam of deuterium or hydrogen negative ions. This paper presents the highlights of the latest developments for the finalization of the MITICA beam source design, together with a description of the most recent analyses and R&D activities carried out in support of the design. [http://dx.doi.org/10.1063/1.4932615]

I. INTRODUCTION

The ITER experiment requires additional heating by two neutral beam injectors[1] [heating neutral beam (HNB)], each delivering about 17 MW for 1 h. A test facility named PRIMA[2] (Padova Research on Injector Megavolt Accelerated), located in Padova, Italy, will host the MITICA (Megavolt ITER Injector and Concept Advancement) experiment, aiming at the development of the injectors for ITER, with the goal of generating a 40 A beam of deuterium negative ions and accelerating it to 1 MV inside the beam source[3] (BS), towards the following beam line components.

The design of the BS has been finalized by Consorzio RFX, within the framework of the activities of the European Domestic Agency for ITER (F4E), in collaboration with the ITER Organization, the Japanese and the Indian Domestic Agencies, and with other European laboratories, such as IPP-Garching and CEA-Cadarache.

The ITER ion source design is mainly based on the development carried out over the last years at IPP Garching.[4]

The ITER accelerator design is based on the JADA development of the multi-grid configuration.[5]

In Secs. II–V, final details are presented with relation to the critical interfaces and to the mechanical aspects with the highest impact on the functional performances, in particular the assembly and alignment of the system.

II. INTERFACES

The top area of the source features the interfaces with the high voltage bushing (HVB), linking to the transmission line (TL) and then to the various auxiliary plants. A complete design revision, in synergy with the final development of the HVB and the start of its manufacturing, led to the thorough definition of the functional parameters, position, and connection details for each of the lines arriving from the TL and bringing power supply, water, gas, and signals to/from the source via the HVB (overview shown in Figure 1).

The beam source design had to take into account remote handling (RH) accessibility for first installation and later maintenance during ITER lifetime[6] (Figure 2).

In addition to that, compatibility to the beam tilting requirements for source orientation in a vertical plane (2.82° ± 0.05°) and optimization of the thermo-structural behavior, as for RF coaxial lines,[7] led to the final design shown in Figure 1.

III. GRID OPTIMIZATION

The MITICA beam source features a seven grids extraction/acceleration system: the plasma grid (PG), the extraction grid (EG), the four intermediate acceleration grids (AG1 to AG4), and the grounded grid (GG).

Despite the optimization process performed on the accelerator geometry to decrease and redistribute the heat loads

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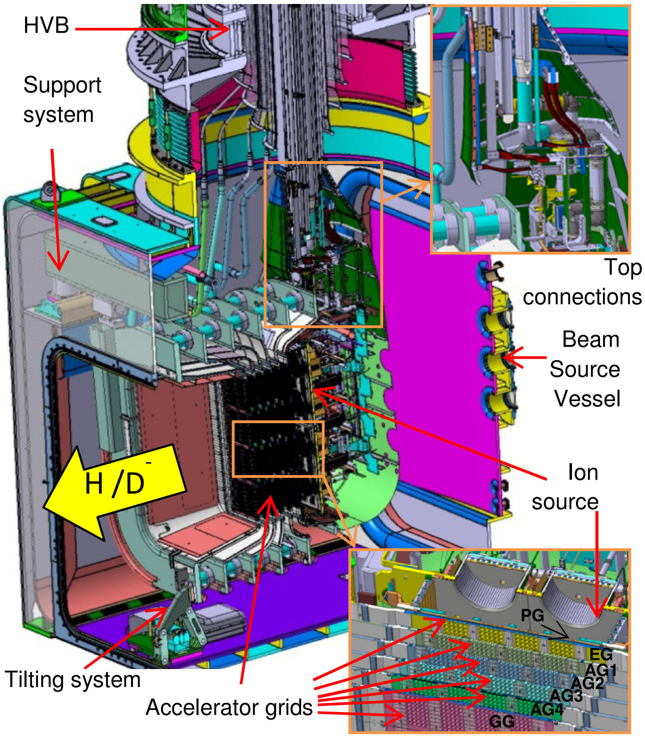

FIG. 1. MITICA beam source, main sub-systems, and interfaces.

among the grids,[8] the power deposited to be removed remains extremely high and concentrated on the five acceleration grids (from AG1 to GG), in the range 1.2-1.6 MW, with a local maximum density in the order of 10 MW/m^2.

The mechanical design of the grids has to fulfil several different requirements, including maximum temperature (200 °C), to keep acceptable mechanical properties in the copper, stress distribution and corresponding fatigue life (5×10^4 beam on-off cycles) satisfying ITER design standards, and comparable deformation among grids for aperture alignment.

The final grid design (see Figure 3) has been verified by means of a three-dimensional fully self-consistent fluid-thermal-structural model representing a whole grid segment, which uses the CFX computational fluid dynamics code to calculate the water parameters and the temperature in every point, and the ANSYS finite element code to calculate the resulting stresses, strains, and deformations in the copper.[8]

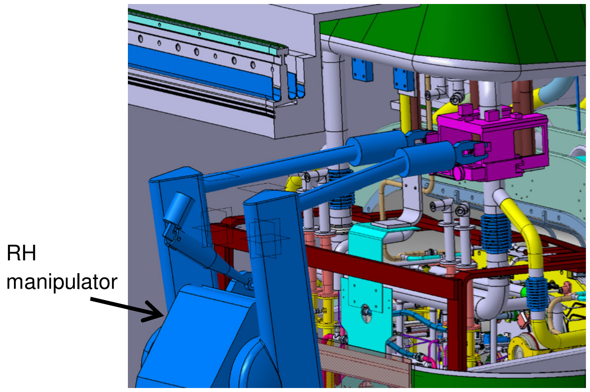

FIG. 2. Example of RH maintenance intervention in ITER, water pipe cut for source removal.

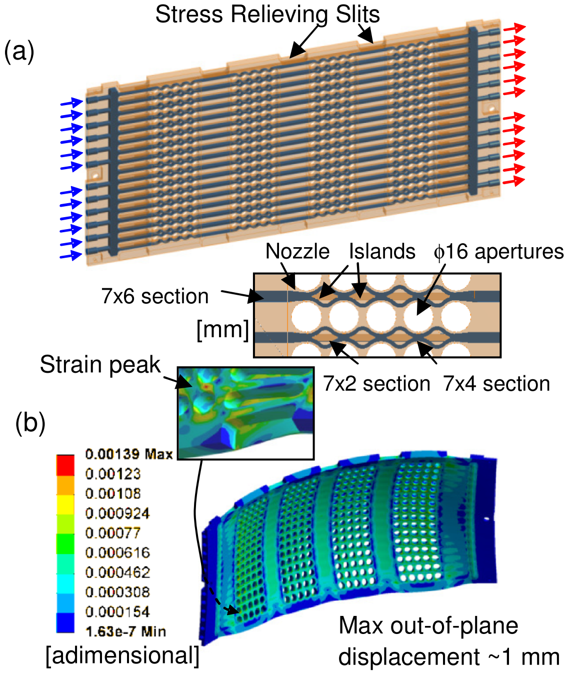

FIG. 3. Acceleration grid segment (a) design and (b) strain contour, in particular related to AG4, view from downstream.

IV. CERAMIC INSULATORS

A revised configuration for the accelerator 200 kV insulators has passed all mechanical and electrical tests.

The previous full cylinder geometry of the ceramic insulator has been replaced with a hollow cylinder configuration (Figure 4), in order to maximize the reliability of the manufacturing process. Prototypes have been tested under the combination of loads estimated for the most stressed component in the accelerator structure.[9]

In order to withstand the electrical test at 240 kV dc in vacuum with a background pressure in the range 10^{-5}–5×10^{-2} Pa, the central hole had to be filled with a vespel® rod, thermally shrink fitted to eliminate gaps. The electrical tests have been successfully carried out at the High Voltage Padova Test Facility,[10] keeping the required voltage for more than 20 h, with a leak current <50 μA.

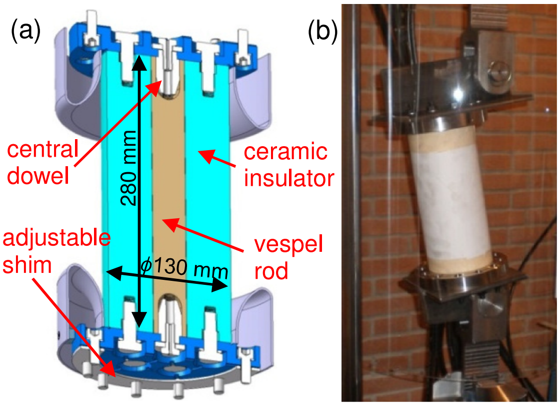

FIG. 4. Ceramic insulator for the 200 kV accelerator stage (a) and mechanical test arrangement (b).

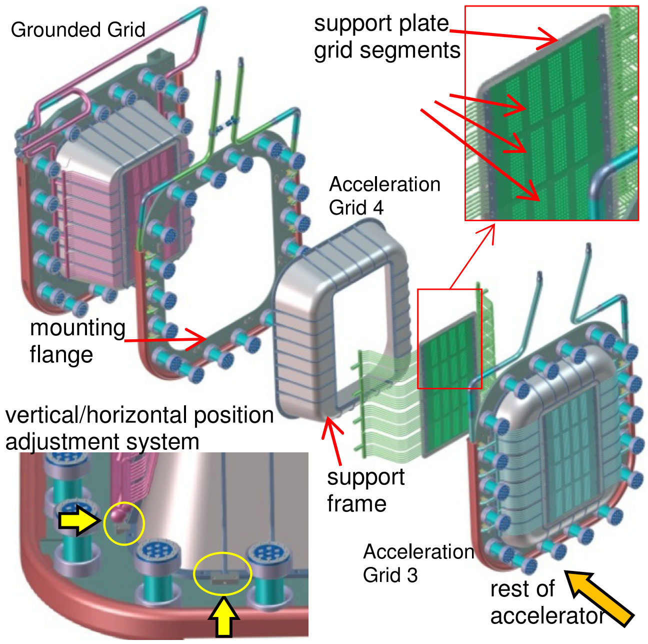

FIG. 5. Intermediate step during accelerator assembly.

V. ASSEMBLY AND ALIGNMENT

Given the beam aiming requirements[2] (vertical focusing and horizontal focusing) and the consequent source topology (curved grids), the philosophy of the assembly and positioning procedure requires that each accelerator grid, and in particular each segment of each grid, is positioned with respect to the reference coordinate system identified at the GG center, not directly with respect to the other grids previously assembled.

The accelerator and ion source shall be first assembled rotated by 90° (beam axis pointing downward) for ease of handling, but then adjusted and fixed in nominal configuration, as gravity will affect the cantilevered configuration, supported from the GG side.

The following assembly/positioning criteria and features are foreseen to fulfil the precise positioning requirements, in particular with respect to the complex chain of tolerance in the accelerator (Figure 5):

- apertures will be precisely machined (in the order of few hundredths of mm tolerance) with respect to the reference dowels in each grid segment;
- two calibrated dowels lead the positioning of each grid segment onto the respective support plate;
- the link between each mounting flange and the adjacent one is redundant (eighteen ceramic post-insulators with several bolts for each one); hence, the utmost care during the assembly procedure shall be used to minimize the stresses that might be induced on the fragile insulators;
- optical targets will be positioned on grid frames and segments, in order to allow the verification of the position of each grid at several stages throughout the assembly procedures;
- adjusting elements are foreseen on the mounting flanges and shall be used to allow the vertical adjustment while keeping fixed the lateral and in plane positions. Due to the nesting of the accelerator grids, these are no more directly accessible once assembled. Any further adjustment of grids position shall be done by acting on the support frames.

The final functional requirements and relevant acceptance criteria are the following.

- Position of grids apertures: the relative position tolerance shall be within ±0.2 mm between the axes of corresponding apertures on PG and EG at operation temperature, while AGs and EG apertures shall be positioned within ±0.5 mm with respect to their nominal positions in the the reference coordinate system identified at the GG center.
- Orientation of grid aperture planes: the orientation of each aperture plane of each segment of each grid is critical for the beam aiming, hence required tolerances (in the order of few tenths of mm) of planarity and position with respect to the nominal positions have been defined on the corresponding drawings.

VI. CONCLUSIONS

The design of the MITICA beam source has been completed, together with all the mechanical details that are relevant for the precise alignment of the grids, hence for the beam aiming.

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