Development, optimization and testing of high performance cooling systems for fusion devices

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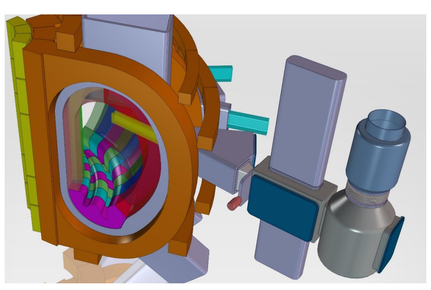
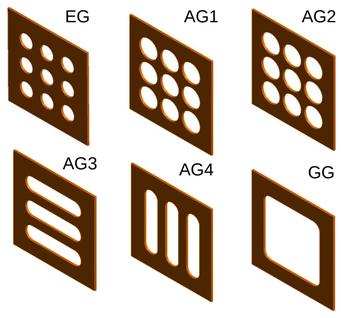
RESEARCH PROJECT SUMMARY

The MITICA experiment (Megavolt ITER Injector & Concept Advancement) is the prototype and the test bed of the Heating and Current Drive Neutral Beam Injectors, which will be necessary for the full-performance exploitation of ITER. MITICA injector experiments shall demonstrate the reliable and accurate emission of a 17 MW beam of neutral particles for duration up to 1 hour, fulfilling ITER specific requirements.

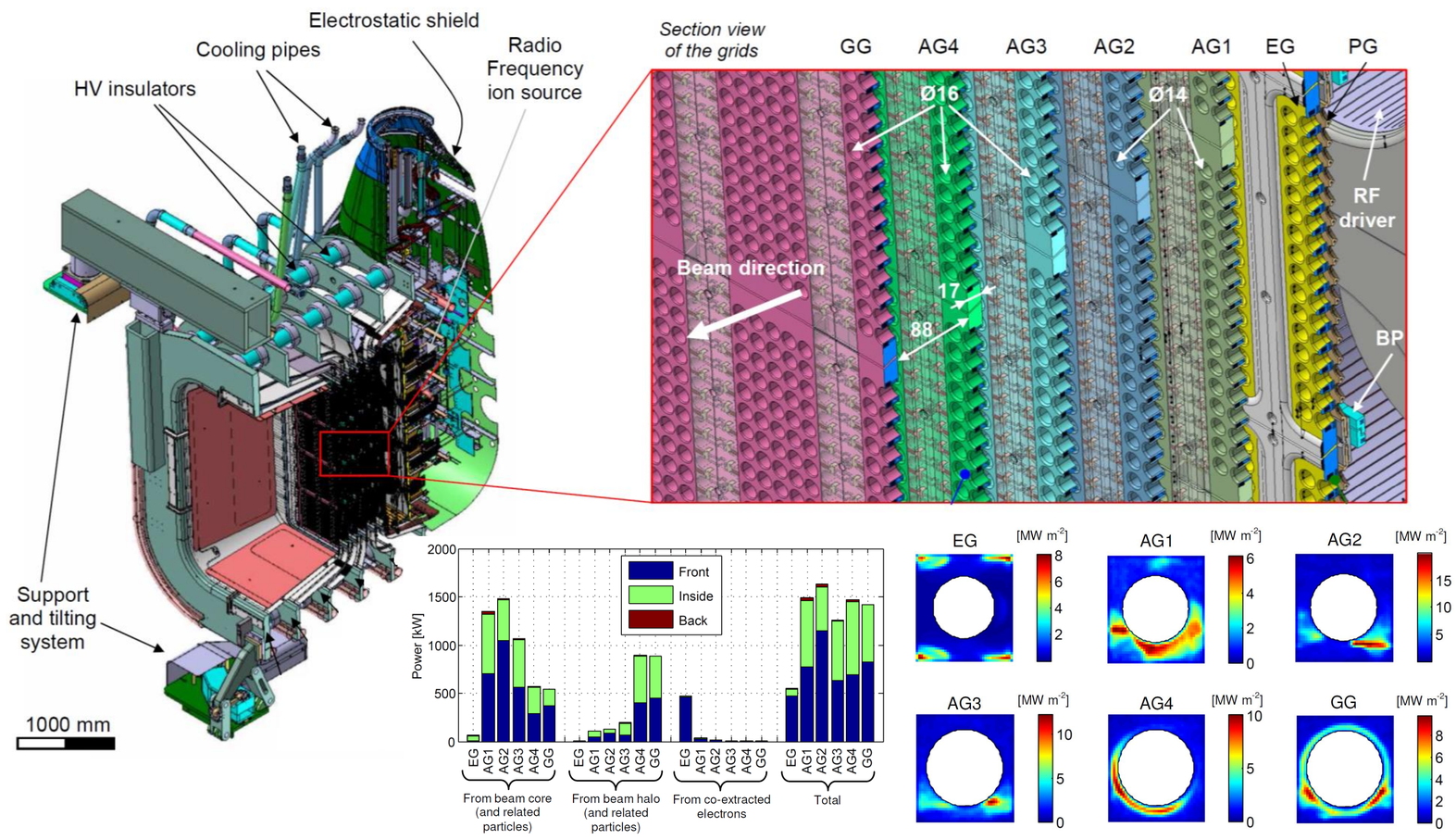
The accelerator grids are among the most critical parts of this experiment, because they must fulfill several operational requirements and at the same time satisfy the fatigue verifications according to the ITER Structural Design Criteria for In-vessel Components (SDC-IC). After an intense conceptual effort and continuous development, a cooling scheme were found to effectively increase the fatigue life of the grids up to the requested values. Such method was to adopt a novel shape of the cooling channels inside the grids, called Nozzle Island Cooling Enhancement (**NICE**) and able to provide a high performance cooling without exceeding the limits on the pressure drop through the grids. Such approach alone was still not sufficient to match the ITER structural design criteria and was then coupled with the Stress Relieving Slits (**SRS**) concept, introduce suitable slits in the grids, whose design was iteratively optimized until they were able to significantly reduce the stress/strain peaks due to thermal gradients. The approval of the project set the milestone for present research project, characterized by the further development, optimization and testing of cooling systems looking toward DEMO.





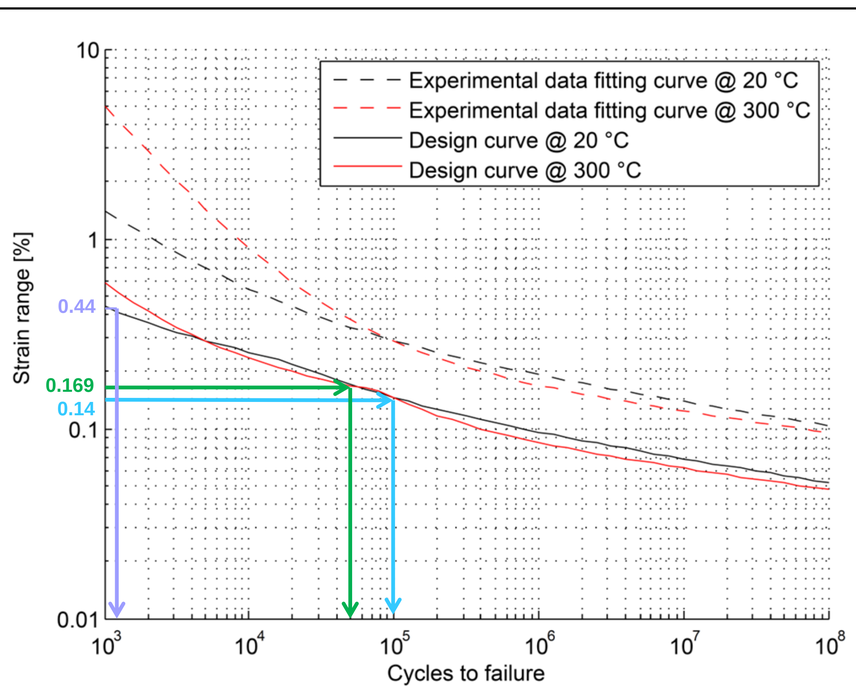
First conceptual CAD of DEMO NBI and under evaluating grids concepts (circular apertures, vertical and horizontal slots, large window)

DESIGN OVERVIEW



Design of the MITICA beam source. A vertical section of the overall beam source is shown on the left, while focus views of the grids are visible on the right. Below a quantitative and spatial estimation of the heat flux is depicted for each different grid All dimensions are in mm.

FATIGUE VERIFICATION



Fatigue verification of the electrodeposited copper used for the grids. The total strain range must be lower than 0.169% to have a fatigue life larger than 50000 beam on/off cycles. While original solution gave very poor performance, the final result of the design optimization (0.14%, giving 102000 cycles) satisfies the limit.

HIGHLIGHTS

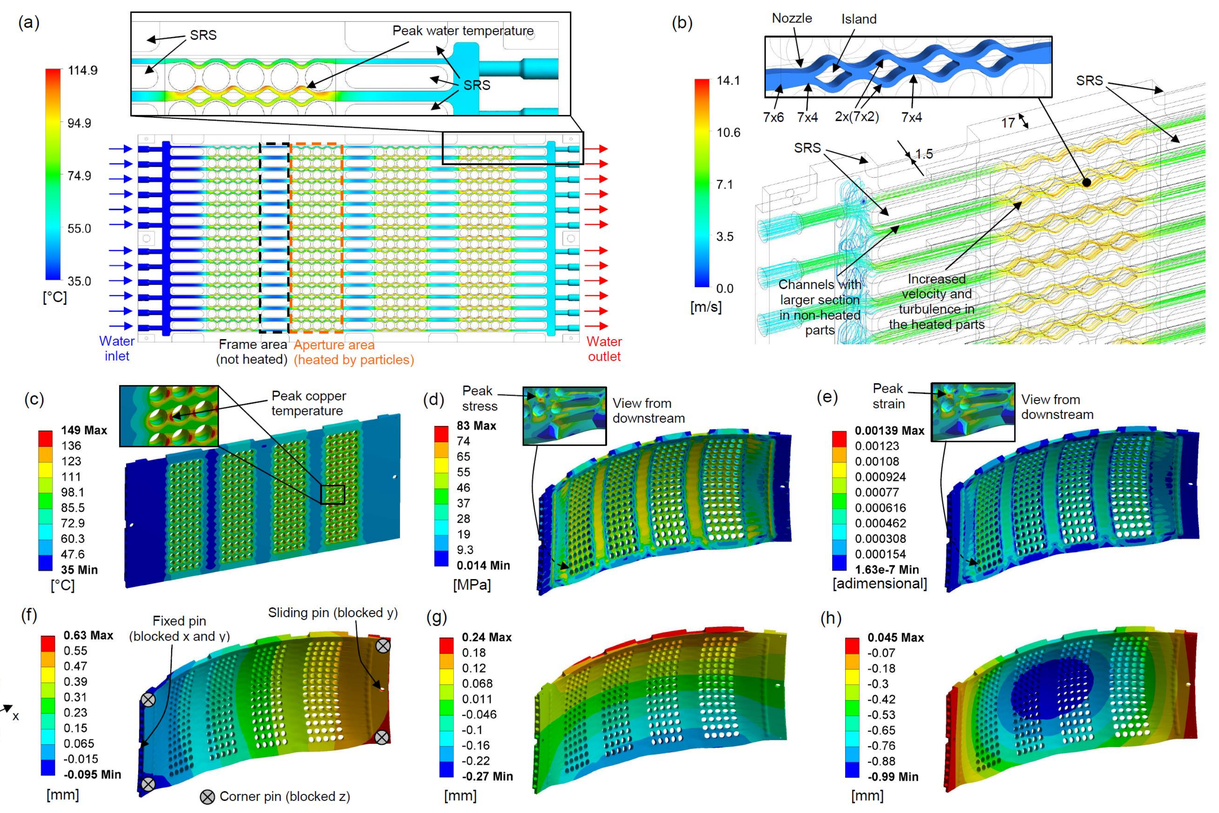
The grids for the extraction/acceleration system of the MITICA experiment (prototype of ITER NBIs) are subjected to huge heat loads (up to 1.6 MW per grid).

Problem: Using a standard design of the cooling channels and of the grid structure the **fatigue life** of these components was extremely limited, and below the ITER requirements. The main driver for such issue is the different thermal expansion throughout the grid, leading to a sharp concentration of stress and strain near the corners of the segment.

Constrains: Realize an **universal** solution for the different grids, the already commissioned cooling plant do not allow pressure drop higher than **5 bar** over each segment, furthermore structural requirements impose a minimum distance of channel wall **1.5 mm** from the upstream heated surface and **1 mm** from any other, vibration and erosion issues forbid liminar velocities not significantly above **10 m/s**.

Solution: Thanks to **NICE** (Nozzle Island Cooling Enhancement) design improvement concept for the cooling channels (and its combination with **SRS** - Stress Relieving - Slits concept for the grid structure, the fatigue life was increased significantly and the ITER requirements satisfied.

THERMO-STRUCTURAL ANALYSIS

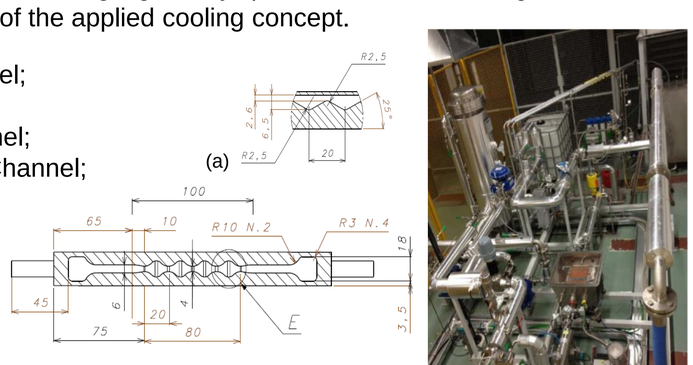


Main results of the thermo-structural analysis for AG4 with the NICE and SRS enhancement, as calculated with the fully self-consistent fluid-thermal-structural segment model: (a) water temperature at the channel wall; (b) effect of NICE concept on water turbulence; (c) copper temperature; (d) equivalent (Von Mises) stress; (e) equivalent (Von Mises) total strain; (f) displacement along x direction; (g) displacement along y direction; (f) displacement along z direction. All dimensions are in mm.

PRESENT DEVELOPMENTS

Holding on MITICA construction to be started, further developments, optimization and testing are foreseen. New promising concepts, together with the original solution, are presently under construction as SCP (Single Channel Prototype). Such activity aims on one hand to perform different code-to-code and code-to-test validation, on the other to highlight any possible manufacturing issues and consequent robustness of the applied cooling concept.

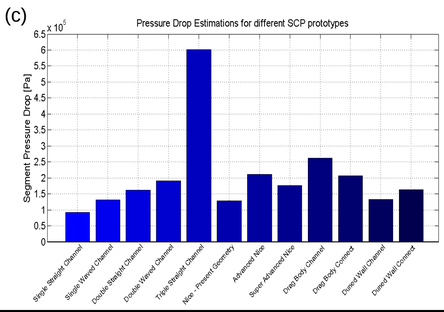
- Single Straight Channel;
- Nice Channel;
- Advanced Nice Channel;
- Hypervapotron Nice Channel;
- Baffle Driven Channel
- Drag Body Channel;
- ICE Flat Channel.
- Duned Channel;



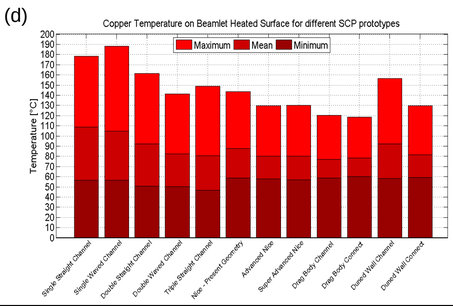
(b)

Technical drawing of Duned Channel concept (a); glimpse of ICE (Insulating and Cooling Experiment) test bed facility (b), numerical results in terms of pressure drop (c) and temperature (d) for the different proposal.

(c)



(d)



CONCLUSIONS

The MITICA experiment, that will be built at Consorzio RFX in the next future, is the full scale prototype of the ITER Heating and Current Drive Neutral Beam Injectors, whose main goals are testing, optimization and development of the ITER injectors. The accelerator represents one of the most critical parts of the MITICA experiment, because it is required to have an optimal performance in terms of optics while being subjected to high heat loads and high voltage conditions. Moreover, the efficiency of the whole injectors is largely influenced by the performance of the accelerator. The final design here proposed permits to set the basis to satisfy all the performance requirements and the fluid-dynamic (high performance cooling without exceeding pressure drop limit) and mechanical verifications (thermal gradient stress damping) set by the client.

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