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

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RESEARCH PROJECT SUMMARY

The MITICA experiment (Magnetar 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 reliability 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 (SSDC). 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 Nicols Island Cooling Enhancement (NICE) and able to provide a high performance cooling without exceeding the limits on the pressure drop thorough the grid. Such approach alone was still not sufficient to match the ITER structural design criteria and was then coupled with the Stress Relieving Slots (SRS) concept. Introduce suitable slots 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 milestones 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)

![Conceptual CAD of DEMO NBI](image)

DESIGN OVERVIEW

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.

**Constraints:** 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 linear velocities not significantly above 10 m/s.

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

![Design of the MITICA beam source](image)

HIGHLIGHTS

Fatigue verification of the electrodeposited copper used for the grids. The total strain range must be lower than 0.166% to have a life time 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.

![Fatigue verification curve](image)

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;
- Hypervaportron Nice Channel;
- Baffle Driven Channel
- Drap Body Channel;
- ICE Flat Channel;
- Duned Channel;
- 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.

![Present developments](image)

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 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.

![Thermo-structural analysis](image)

CONCLUSIONS

The MITICA experiments, that will be built at Consorzio RFX in the 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.

![Conclusion](image)

REFERENCES