Final Design of the Beam Source for the MITICA Injector

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Consorzio RFX
Consorzio RFX: what is it?

Consorzio RFX
(consortium of Padova University and main Italian public research entities)

150 employees
(40 administration, 110 scientific)
~30 students
(degree & doctorate)

Education program

Broader Approach (JT60-SA)

Activities for DEMO

Other ITER/tokamak activities

RFX experiment

ITER Neutral Beam Test Facility

MITICA beam source final design
ITER & the Heating Neutral Beam System

Two HNB Injectors at 1 MV accelerating voltage and injecting 16.5 MW each into the plasma

- 2 N-HNBs (+1)
- $P_{beam} = 16.5$ MW
- $I = 40$ A
- $V = 1$ MV
- $T_{pulse} = 3600$ s

Large scientific/technological step from existing NB systems

- Decision to establish a full scale Neutral Beam Test Facility (NBTF/PRIMA).

Agreements signed between IO and F4E (with the endorsement of Japan and India) and between F4E and Consorzio RFX
Strong international collaboration

Strong international cooperation for:
- Neutral Beam Test Facility
- ITER Heating NB
- ITER Diagnostic NB

Moreover, ITALY is contributing with the NBTF civil works and general services.
ITER Neutral Beam Test Facility
Padova Research on Injector Megavolt Accelerated (PRIMA)

Neutron shield & assembly hall
Two experiments are foreseen to be hosted in the PRIMA facility: an ion source prototype (DNB-relevant) and a full injector prototype.
The **Beam Source** for the ITER Neutral Beam Injector...

... designed (to be procured and tested first) for the **MITICA** experiment...

... based on the concept and experiments developed and running at **IPP** and **JAEA**
Negative ions generated inside the RF ion source are extracted and accelerated by the electric field generated by the system of grids at different potential.

Support and tilting system

Electrostatic shield

Radio Frequency ion source

Extractor (-1 MV) EG+PG+BP

H/D

Top connections towards Transmission Line

1000 mm

MITICA beam source final design
The functional “core”

H$_2$/D$_2$ gas in injected and ionized in each driver, then flows in the source main chamber.
Negative ions generated next to the Plasma Grid are extracted and then accelerated.
Every grid has 4 segments, with 4 groups of 16x5 apertures, for a total of 1280 beamlets of negative ions.

In the next slides:
- Interfaces
- Grid design
- Accelerator ceramic insulator
- Accelerator assembly and alignment
MITICA / HNB Beam Source - interfaces

Beam Source Vessel
- Support interfaces
- GG cooling pipes
- Tilting interface
- Actuator interface for support adjustment

Rear access (Remote Handling)
- RH

High Voltage Bushing
- Rear Lid hidden
Beam Source / HV bushing interfaces

Around 20 **ion source interfaces** within the -1 MV shield have been finalized in all details:
- DC power supply
- RF coaxial lines
- Water supply
- Gas supply
- Signal cables
- Optical fibres

**Design optimization of RF lines (ThuPE05)**
Beam Source / RH Equipment interfaces

Maintenance interventions in ITER are typically remote handled for in-vessel components. The design takes into account related procedures, specifically developed.

Source installation/removal

Example of maintenance intervention verification for the foreseen tasks

Water pipe weld/cut
Accelerator final design

Grids feature double curvature to fulfil beam aiming requirements
The power deposited on grids is very high and concentrated on the five acceleration grids, in the range $1.2 \div 1.6\ MW$, with density up to $10\ MW/m^2$.

Cu-AISI grid-pipe joint
Vacuum Tight Threaded Junction (VTTJ), conceived and patented by Consorzio RFX.

MITICA beam source final design
5 groups of 18 ceramic insulators (Al2O3, 99% purity) are part of the cantilevered accelerator structure.

The whole structure has been simulated to identify the most stressed insulators, in terms of tension, shear and bending forces.

These data were “translated” in requirements for an equivalent tensile test.

A full cylinder geometry had been first considered to maximize electrostatic performances.

Manufacture experienced difficulties in producing reliably components strong enough with such shape.

A hollow cylinder shape was then successfully produced, tested as foreseen and adopted as reference solution.
Accelerator ceramic insulators

In order to withstand the electrical test at 240 kVdc in vacuum with a background pressure in the range $10^{-5} \div 5 \cdot 10^{-2}$ Pa, the central hole had to be filled with a vespel® rod, thermally shrink fitted to eliminate gaps.

The required voltage was held for more than 20 h, with a leak current <50 µA.

The electrical tests have been successfully carried out at the High Voltage Padova Test Facility @ Padova University.
Assembly and alignment

The accelerator assembly and the alignment of corresponding apertures of different grid is one of the most challenging tasks.

- The system is very large and complex
- Many parts have difficult shape and manufacturing cycle
- Alignment requirements are very tight: maximum distance between corresponding aperture axes in the order of 0.2 mm in the extractor (between PG and EG) and 0.5 mm among AGs, at operation conditions. Offsets for each aperture were defined to deal with thermal deformation and physics requirements for optics.

Grids must be aligned for proper beamlet optics, but also pointing in the right direction to reach ITER tokamak, hence each grid (segment, aperture) shall be correctly positioned in a unique absolute coordinate system.

Not only the position of apertures is important: the orientation of the grid surfaces influences the electric field distribution, hence beamlet optics.
The accelerator will be assembled in progression starting from GG and going backwards, possibly at least initially with beam axis pointing downward for handling ease.

The source nominal configuration features the beam axis almost horizontal, cantilevered from the GG, hence gravity will likely affect the position of grids, that will need final vertical position check. Due to the “nested” shape of the accelerator frames, at the completion of assembly grids are not in sight anymore. Adjustment systems are foreseen on accelerator frames to regulate horizontal/vertical position of grids from outside.
Assembly and alignment

Criteria to handle the complex chain of tolerance in the accelerator (and meet the goal!):

• apertures will be precisely machined (in the order of few hundredths of mm tolerance) with respect to the reference holes for dowels in each grid segment
• two calibrated dowels lead the positioning of each grid segment onto the respective support plate
• once the link between each mounting flange and the adjacent one is carefully established (eighteen ceramic post-insulators), the position of grid+support frame can be adjusted in plane
• 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
Thank you for your attention!

**Monday Afternoon Poster Session – Empire (14:00-16:00)**

| MonPE01 | Simulation of beam profiles from extracted ion current distributions for mini-STRIKE | P. Agostinetti |
| MonPE02 | Multi-beamlet investigation of the deflection compensation methods of SPIDER beamlets | C. Baltador |
| MonPE07 | Analysis of diagnostic calorimeter data by the transfer function technique | R.S. Delogo |
| MonPE22 | Castellated tiles as the beam-facing components for the diagnostic calorimeter of the negative ion source SPIDER | S. Peruzzo |
| MonPE25 | Gas Flow and Density Profile in NIO1 Accelerator and Vessel | E. Sartori |
| MonPE26 | Simulation of Space Charge Compensation in a multibeamlet negative ion beam | E. Sartori |
| MonPE28 | Numerical Simulations of the First Operational Conditions of the Negative Ion Test Facility SPIDER | G. Seranni |

**Tuesday Afternoon Poster Session – Empire (14:00-16:00)**

| TuePE28 | Beam deflection applied to Neutral Beam Injection for a Fusion Devices reactor | N. Pilan |
| TuePE30 | Characterization and Optimization of NIO1 Extraction Aperture by 3D PIC Model | N. Ippolito |

**Tuesday Afternoon Poster Session – Soho (14:00-16:00)**

| TuePS24 | Preliminary Design of Electrostatic Sensors for MITICA Beam Line Components | S. Spagnolo |
| TuePS33 | Particle Transport and Heat Loads in NIO1 | P. Veltri |
| TuePS34 | Optics of the NIFS Negative ion source test stand by infrared calorimetry and numerical modeling | P. Veltri |

**Thursday Poster Session – Empire (14:00-16:00)**

| ThuPE01 | First hydrogen operation of NIO1: characterization of the source plasma by means of an optical emission spectroscopy diagnostic | M. Barbisan |
| ThuPE02 | Feasibility Study of a NBI Photoneutralizer Based on Nonlinear Gating Laser Recirculation | A. Fassina |
| ThuPE03 | Off-normal and failure condition analysis of the MITICA negative-ion Accelerator | G. Chitarin |
| ThuPE05 | Design optimization of RF lines in vacuum environment for the MITICA experiment | M. De Muri |
| ThuPE13 | Development and tests of Molybdenum armed copper components for MITICA ion source | M. Pave |
| ThuPE14 | Simulation of diatomic gas-wall interaction and accommodation coefficients for Negative Ion Sources and accelerators | E. Sartori |
| ThuPE20 | Transmission of electrons inside the cryogenic pumps of ITER Neutral Beam Injector | P. Veltri |
| ThuPE23 | Steady state thermal-hydraulic analysis of the MITICA experiment cooling circuits | M. Zaupa / D. Marcuzzi |
| ThuPE25 | Integration of RFQ Beam Coolers and Solenoidal Magnetic Field Traps | M. Cavagnago |