The ITER Neutral Beam Test Facility : Design Overview

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Abstract : *In the frame an EFDA contract, the CEA, in close collaboration with the Consorzio RFX, Padua, FZK, Karlsruhe and IPP, Garching, is carrying out a design study of the ITER Neutral Beam Test Facility (NBTF) with the aim to procure in time, a dedicated test bed to optimise the performances of the first ITER neutral beam injector and to demonstrate its reliability.*

The main specifications that have to be considered for the study of the NBTF generic design and general infrastructure are first an easy maintenance of components, an easy man access and also integration of the required full set of beam diagnostics. A specific inspection tool is developed that allows remote visual inspection of the source ground grid and beam line components to be performed under vacuum. Associated safety requirements are also considered (pulses in H_2 *and* D_2*, X-ray and neutrons production)*

The current design of the dedicated beam line vessel allows mixed vertical and horizontal access to the beam line components during phase I of the operation plan (20s short pulses). The split two halves cylindrical cryopumps, developed by FZK, will be further re-assembled in the final ITER reference cylindrical configuration for phase 2 of the operation plan : long pulses at full power.

The 4.5 K cryopanels must be periodically regenerated at 90 K. Both regeneration and cool-down phases of the cryopanels are time consuming optimised. The cryosystem that supply the necessary cryogens to the cryopump is designed using existing industrial 4.5 K cold power and 80 K helium gas refrigerators.

A total power of about 50 MW will have to be removed during the two NBTF operation stages of short (20 s) and long (~ 1 hour) pulses. For both scenarios, the cooling plant is designed for cooling down the high and low voltage components, the cryoplant and the associated power supply systems.

Topic : Technology of negative ion based injector

1 Introduction

The performance of the existing NB test facilities in Europe and Japan is very limited, in particular in relation to the total current and pulse length. There is therefore a general appreciation within the NB community, in both Europe and Japan, that an ITER-scale NB test facility will be required to demonstrate high voltage acceleration at ITER-relevant currents. Such a facility would permit all elements of the ITER NB system to be tested at essentially full scale and at pulse lengths commensurate with those required for ITER (~ 1 hour).

A possible approach to achieve this aim would be to consider the required equipment and associated auxiliaries as parts of the "first ITER NB injector" to be installed initially at an ITER NB Test Facility and later at the ITER site. The test facility would be constructed on the territory of the host Party.

In the mid 2003 - end 2004 period covered by the first EU contract the design work foreseen on the ITER NB Test Facility general infrastructure, including the cryosystem, the cooling system, the dedicated beam line vessel (BLV) and buildings layout, has been completed and agreement on the designs reached with EFDA and the other EURATOM Associations involved with this work (ENEA, FZK, IPP and UKAEA).

2 Design of the dedicated beam line vessel

The beam line vessel (BLV) has to enclose the already existing ITER reference beam line components as the neutraliser, the residual ion dump and the calorimeter. The BLV has also to be connected to the beam source vessel (BSV). This last one is foreseen to be transferred to the ITER site after completion of the "first ITER NB injector" qualification at full power.

It has been agreed by EFDA and all involved EU Associations that a dedicated beam line vessel would be required for the test bed that would allow an optimised maintenance of beam line components (BLCs), an easy man access and integration of a full set of beam diagnostics. The current design of the BLV that was proposed and developed by the CEA, allows mixed vertical and horizontal maintenance of beam line components. This consists of an elliptic shape vessel that includes two (almost) semi-cylindrical cryopumps that are essentially identical to the 2 halves of the reference ITER NB cryopump.

The BLV upper large opening (9.50 m x 2.50 m) allows vertical maintenance of a single beam line component and easy man access (see figure 1 below). About two tens openings are added on the top rectangular port for beam diagnostics and BLCs survey during operation. The height of the BLV is limited to 4.4 m for transportability consideration. The BLV is connected to the BSV cylinder (ITER reference design) through a stiff 45mm thick ring (circular TIG welding). The beam line vessel volume is ≈200 m^3.

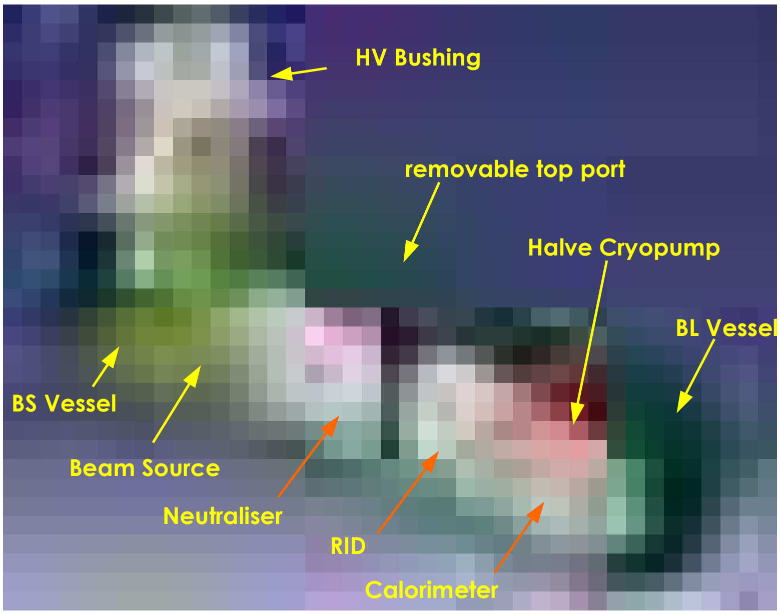

Fig. 1 : Overview of the NBTF equiped beam line vessel and beam source vessel

The proposed “Phase I operation” of the NBTF is dedicated to the qualification of the source and beam line components with short pulse operation (≈30 s). During this phase, the flexibility offered by the mixed vertical horizontal option (see figure 2.1) is considered a substantial advantage compared to using a system allowing only horizontal maintenance and limited access for diagnostics.

At the end of the Phase I operation, it is foreseen to move to Phase II, which will mainly consist of a campaign with long pulses of up to 3600 s, in H_2 and D_2. During Phase II, the beam line configuration is to be changed (figure 2.2) by linking the two semi-cylindrical cryopumps in order to reach the final geometry configuration as the ITER NB cryopumps. This will require some adaptation of the feeding pipes and cryopump support system to the wall of the BLV.

Fig. 2.1: Phase I; split cryopumps configuration

Fig. 2.2: Phase II; ITER cryopump configuration

3 Description of the experimental hall

The NBTF general infrastructure is designed taking into account activation due to neutron production and X-rays (short and long pulses of up to 3600 s, in H_2 and D_2). Man access to the hall facility will be limited as activation of the beam line vessel and components will increase. Thus, auxiliaries such as cryosystem, forepumping and water cooling system are located in an adjacent building, close to the experimental hall.

Preliminary design of the experimental hall has been performed by ENEA Consorzio RFX. The test facility would have to be located in a concrete building having the following optimised dimensions : 37m long, 15m wide and 20m high. The walls will need to be ≈1.8m thick standard concrete in order to provide shielding for the adjacent areas against neutrons produced by the beam impinging on various surfaces and X-rays from intercepted accelerated electrons. As illustrated in the figure 3 below, the beam vessels (BSV and BLV), high voltage deck, transmission lines (TL1 & TL2) are the main components to be integrated in the experimental hall. A 50 ton crane is required in the hall for the manipulation of the main components. Man access platforms (see figures 3 and 4) are designed for maintenance of the BLV upper diagnostics or maintenance of the HV bushing and Transmission lines. A pit of ≈2m depth is required below the BLV for access to lower diagnostics, lower correction coils and BLCs hydraulic connections.

Fig. 3 : Overview of the experimental hall

4 Auxiliary building description

The auxiliary systems such as cryoplant, cooling plant, forepumping are integrated in an adjacent building to the experimental hall, so called “auxiliary building”. Pipes and cables pass through a concrete chicane between these two main buildings. This allows man access in the auxiliary hall during beam operation. The auxiliary building is divided into three main areas. The first part is dedicated to the cryoplant components shown in figure 4, as cold valve box, LHe 4.5 K and GHe 80 K refrigerators, filters and gas compressors. The latter components are installed in a soundproof enclosure. The primary heat transfer system (PHTS) and heat rejection system (HRS) components are located in the second area including heat exchangers, pumps and the calorimetry measurement system. The third area contains the forepumping groups required for the initial pump down and the regeneration of the cryopump. A 60 MW cooling tower, part of the cooling plant and HRS loop, is located outside close to the auxiliary building.

Fig. 4 : Overview of the test facility and auxiliary systems (the buildings are not shown)

5 The NBTF cryosystem

5.1 Requirements

The pumping system consists of the beam line cryopump inside the beam line vessel and of an external mechanical forepumping system. The cryopump requires a dedicated cryosystem. Regeneration and cool-down phases of the cryopanels are evaluated for the NBTF operation. Optimised refrigerators for supplying 4.5 K Liquid Helium and 80K Helium gas are proposed.

The ITER cryosorption (active charcoal) cryopump is submitted to a non homogeneous gas load of H_2 or D_2 that varies from 3 $Pa.m^{-3}.s^{-1}$ to 35 $Pa.m^{-3}.s^{-1}$ [1]. The cryogenic system will have to be able to refrigerate the NBTF cryopump in representative operating conditions.

During standby and operating mode (pumping), the cryopanels are maintained at a temperature near to 4.5K by supercritical helium circulation. The shields and chevrons baffles are refrigerated at a temperature near to 80K by gaseous He circulation. The 4.5K cryopanels, must be periodically regenerated up to 100K to remove all the gas (H_2, D_2) trapped during pumping phase (2 hours pulse capacity).

5.2 Description of the dedicated NBTF cryoplant

The design proposal for the NBTF cryoplant that is described hereafter is optimised in terms of the required cooling powers at 4.5K and 80K, with very limited industrial development being required. The total heat load on the cryopanels is 150 W [1]. A standard industrial 4.5 K refrigerator cryosystem is available that will provide cooling power of 500 W at 4.5K in pure refrigerator mode, and 150 l/h of LHe in pure liquefier mode.

The total heat loads on the 80K shields and chevrons baffles in standby mode, without gas injection is about 18 kW. The added heat load by molecular viscous conduction during cryopanels regeneration at 100K is 7 kW, taking into account the BLCs temperature of 350K. The cold power at 80K is produced by a refrigeration module that operates with a 22 kW Helium Brayton cycle that includes mainly a compressor, a counter flow heat exchanger and a turbo expander as shown on figure 5. The Brayton cycle system allows a progressive cool down of the shields and baffles. Such a system must operate with a high delta T (inlet 66K, outlet 90K) corresponding to 0.240 $kg.s^{-1}$ helium gas flow rate in order to reduce electric power consumption by the compressor. It has a lower operating cost than the alternative system which uses a cold circulator to generate a helium flow thermalised by liquid nitrogen at atmospheric pressure (60000 l/week LN_2 consumption) [2].

Fig. 5 : Process flow diagram of the NBTF croysystem

5.3 Operating modes

- *Cooling down of the cryopanels at 4.5K :* It is carried out with the 1 kW cold power supplied by the two turbines of the refrigerator. The time to cool the 1000 kg cryopanels from 300 K to 4.5K is about **26 h**. The cooling down of the shields and baffles is progressively achieved in parallel, by the Brayton cycle with the cold power supplied by the expander. With 22 kW cold power the time to cool down the 4.6 tons of shields and baffles to 80K is about 10 h.
- *Cooling down after 100 K regeneration:* The cryopanels have to be cool down using the refrigerator Joule Thomson flow rate thermalised at 4.5K in the liquid helium bath. The available mass flow rate of 0.030kg.s^{-1} involves a cool down time from 100K to 4.5K of about **550 s**. During this phase a part of the cold power is supplied by the evaporation of LHe stored in the 1000 l liquid helium bath [2].

6 THE NBTF COOLING SYSTEM

6.1 NBTF water cooling Specifications

An hydraulic cooling plant is required for cooling down high voltage (HV) components (beam source, accelerator grid, transmission line, HV bushing) and low voltage (LV) components (neutraliser, residual ion dump, calorimeter). The specifications that concern the water cooling conditions are summarised in table I. The characteristics of both optimised primary heat transfer system (PHTS) and associated adaptable heat removal system (HRS) have been analysed. An optimised design of the NBTF cooling plant and water loops is proposed that can be adapted to the successive phases of short (20s) and long pulse (3600s) operation.

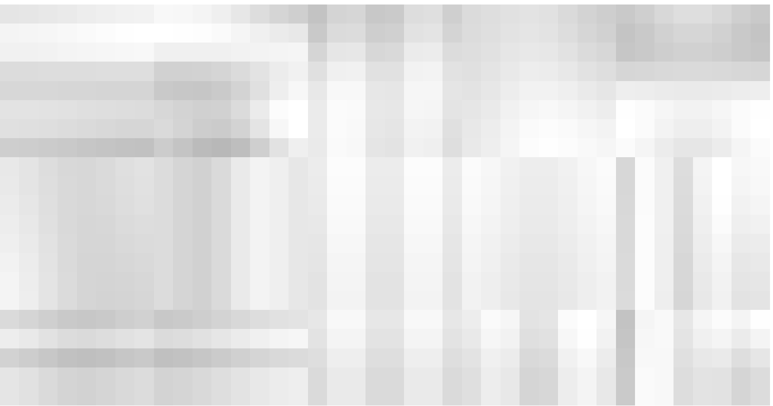

Table I : primary heat transfer system characteristics of high and low voltage components

6.2 Description of the PHTS cooling loop

The PHTS will have to exhaust the full 50 MW power during operation. To be conservative, the most pessimistic neutral beam profile in terms of heat load, has been considered for the design of the PHTS water loop. As it is shown in table I, the pump has to be designed in order to provide a water flow rate of 713 m^3/h to feed the calorimeter, which is the most loaded component. This component has to withstand a power density of 22 MW/m^2, for a maximum convected power of 20 MW. The 2.7 MPa pressure drop of the calorimeter and the required minimum low pressure at the outlet (0.5 MPa) defines the operating pressure that is required for the PHTS loop (3.3 MPa). The size of the main inlet and outlet manifolds (400 mm diameter) is optimised in terms of water velocity and pump power, respectively 3m/s and 990 kW.

The pump unit must be designed for the total mass flow rate 1250 m^3/h. As is illustrated in figure 6, flow control valves are to be inserted in the pipes of the HV and LV components (RID, neutraliser, grid, source) that are water cooled in parallel with the calorimeter. The required flow rate of each beam line component can then be optimised. A calorimetry measurement system is foreseen on the PHTS loop that consists of flowmeters and platinum temperature sensors on each individual inlet and outlet pipe. The control valves allow accurate adjustment of water flows.

Fig. 6 : Process flow diagram of the NBTF cooling system

6.3 Description of the Heat rejection System (HRS)

The main heat exchanger, HE1, is designed to provide cooling water to the Low Voltage BLCs at a maximum inlet temperature of 80°C. The two other exchangers HE2 and HE3, are designed to supply water at maximum required inlet temperatures of 20°C for the ion source and 55°C for the grid accelerators and extractor (figure 6).

The HRS has to be adaptable to take into account the successive phases of short (30 s) and long (3600 s) pulse operation, as described above. A 60 MW cooling tower can exhaust in steady state the full power of the facility. A water basin is coupled to the heat exchanger cooling tower.

7 CONCLUSIONS

A generic study of a neutral beam test facility dedicated to the first ITER NB injector qualification has been performed in 2003-2004 that is in agreement with the EFDA initial specifications in terms of maintenance optimisation and diagnostics integration. The conceptual design of the NBTF general infrastructure is completed, leading to dedicated cryoplant and cooling system that fulfils with the operation plan requirements for short and long pulses at full, 40 MW, beam power.

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