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CONSTRUCTION OF NEGATIVE-ION-BASED NEUTRAL BEAM TESTSTAND FOR LARGE HELICAL DEVICE (LHD)

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Abstract: A teststand of the negative ion besed NBI for the LHD is under construction, which has capabilities of the neutral beam 2.5 MW at the beam energy of 125 $keV(H^0)$ / 250 $keV(D^0)$ with the pulse duration of 10 sec. Components for the R&D are as follows: (1) a large and high current negative ion source which is immersed in the vacuum and composed of a compact modular ion source, (2) the beam dump to remove the high heat flux upto 1.6 kW/cm^2, (3) high pumping speed (450 m^3/s) cryopump, (4) 250 kV power supply system using GTO, and (5) the controller system to vary the beam energy within 0.5 sec. Testing will commence in the spring of 1992 at Toki new site.

1. Introduction

Neutral beam injector with the injection power of 20 MW at 125/250 keV for the super conducting Large Helical Device was conceptually designed at the National Institute for Fusion Science (NIFS)$^{1)}$. To complete the NBI for LHD by 1997, the new teststand of NBI based on the negative ions is under construction. The objectives of the teststand are as follows: (1) to develope full-scale negative ion source, (2) to test the beamline components, (3) to optimize the neutral beam transport, (4) to develop the neutralizer, and (5) to solve the technological problems of the NBI system.

Specification for the teststand is listed in Table I. One of the most important components is high current negative ion source (i.e. 45 $A(H^-)$/22.5 $A(D^-)$ for full-scale source). The component design and the fabrication except for the ion source are based on the existing technologies with a modest extraporation, which has been developed in the NBI with the positive ion source.

In this paper, the concept of the teststand for the negative ion based NBI and the design of each beamline component including the large negative ion source are described.

2. Overall design of teststand.

A schematic view of the teststand is shown in Fig.1. The testsatnd has one ion source and one beamline, while the one NBI of LHD has two ion sources and two beamlines. It has three vacuum vessels: the ion source vessel, the beam dump vessel, and the target vessel. The negative ion source is immersed in the ion source vessel and composed of 6 modular ion sources. The electrons together with the negative ions are extracted from the ion source. The electrons are eliminated by the electron beam bending magnet in the ion source vessel. They are

Table I. Specification for the Test Stand.

1. Ion source	Multifilter negative ion source immersed in the vacuum
2. Neutral beam power	2.5 MW (Ion beam power of 5.6 MW)
3. Acceleration energy	125 keV (phase I) 250 keV (phase II)
4. Pulse duration	10 s.
5. Atom species	H^0 (phase I) D^0 (phase II)

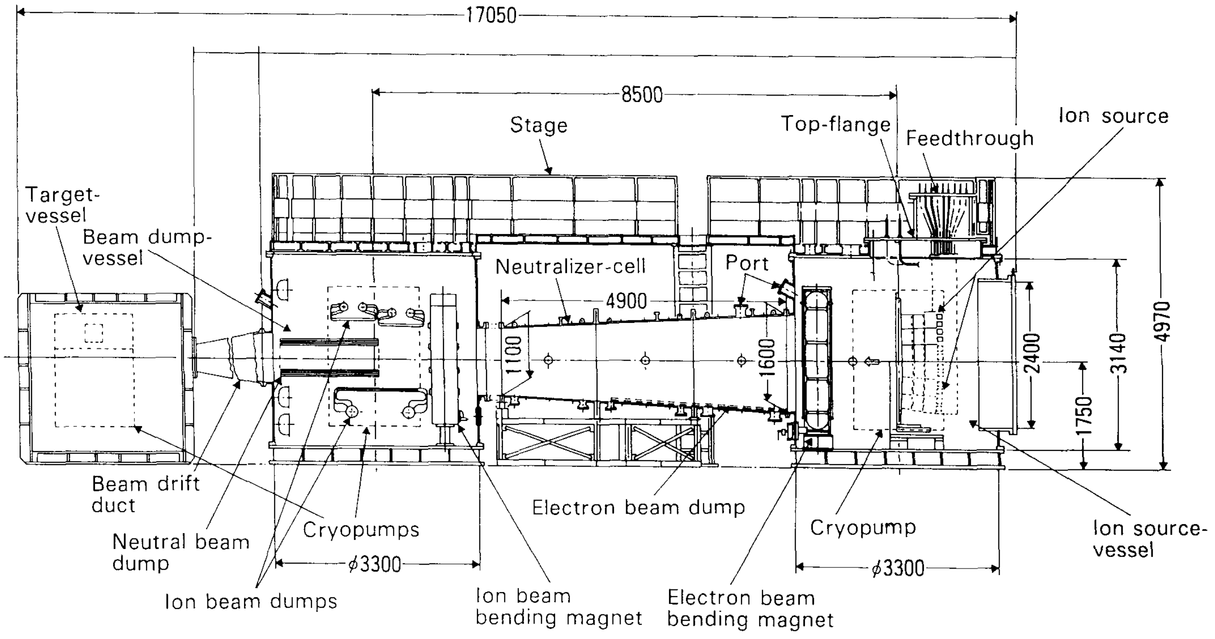


Fig.1 Elevation view of the teststand.

dumped on the electron beam dump located on the bottom of the neutralizer-cell. As the ion source is operated under a fairly high pressure (~0.93 Pa), a lot of negative ions are lost by the collisions with the neutral gases in the gap of accelerator electrodes. In order to reduce the stripping losses, a high pumping speed cryopump is installed in the ion source vessel, where the working gas pressure in the vessel is $\sim 3.6\times10^{-2}$Pa.

The ion source vessel and the beam dump vessel are connected by a long gas-neutrlizer cell, where the gas-thickness is 15.4 Pacm. The neutralization efficiency is correspondingly 0.59, and the beam power of unneutralized negative ion is equal to that of positive ion produced in the cell, as shown in Fig.2. Due to this equalization of each ion beam power, the design and fabrication of ion beam dumps are simplified. The ion beam is separated by the electromagnet from the neutral beam, and impinges on each ion beam dump.

The neutral beam power of higher than 2.5 MW is depositioned on the neutral beam dump, which is installed in the beam dump vessel. The beam power and the profile are measured by calorimetry and a thermo-couple array. The beam dump vessel has also the high pumping speed cryopump to reduce the reionization loss of the neutrals during the beam transport. The working pressure in this vessel is ~1.5x10-3 Pa.

The target vessel which is connected by the beam drift duct is provided for studying the beam transport through the narrow injection port of LHD.

Table II. Specification for the negative ion source.

1. Ion source	Multicusp negative ion source, immersed in the vacuum chamber.
2. No. of modulus	6 for full-scale / 2 for 1/3 scale source.
2. Plasma source	Pure volume / cesium-seeded Gas pressure of ~0.93 Pa (for reference design).
3. Accel. voltage	125 kV / 250 kV
4. Accel. current	45 A (H^-) / 22.5 A (D^-)
5. Beam divergence	< 0.5 deg.
6. Focal length	12 m
7. Negative ion current density	30 mA / cm^2
8. Extraction grid area	25 cm x 150 cm (full size).

3. Component description

3.1 Ion source

Specification for the negative ion source is listed in Table II. The ion source requires the large extraction area of $25\times150cm^2$ to meet the high current of 45 $A(H^-)$ at 125 keV with a low beam divergence angle (<0.5 deg.). There are a lot of technological problems, in addition to the physics research of the ion source, in the fabrication of such a large ion source; for instance, precise machining of the extraction holes, and assembling / aligning the accelerator, and fabrication of extremely large ceramics-insulator which is required to withstand both the high electric potential and an atomospheric pressure. Therefore, the ion source is composed of modular ion sources, and immersed in the vacuum. They are mounted on the frame-stand with pivoting structure, in the ion source vessel. The concept 'modular ion source' comes from the requirement to handle simply, and assemble easily the large ion source.

Ion source immersed in the vacuum has several advantages; (1) The stripping losses of the negative ions would be reduced because of a low gas pressure near the accelerator electrodes. (2) Ion source becomes compact, owing to the increase in the withstand-voltage. This requirement is important, because two ion sources will be mounted side by side in the injector for LHD, in order to inject more power through small port without impinging on the wall of LHD. (3) The chamber of the plasma source and the ceramics insulator of the accelerator can be light-weighted, because of mounting them within the vacuum vessel so that there is no pressure. (4) It is feasible for the experiment and is easy of access,

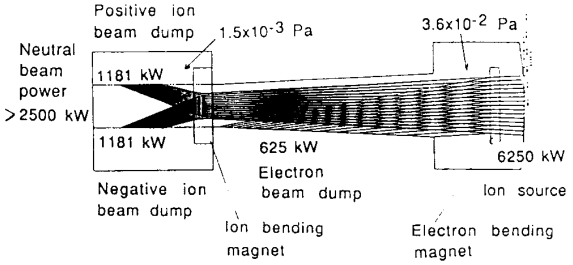
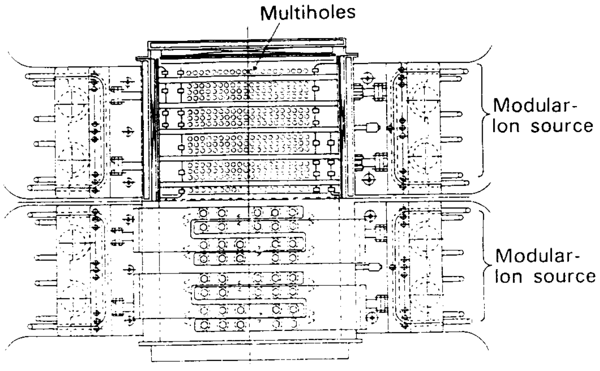
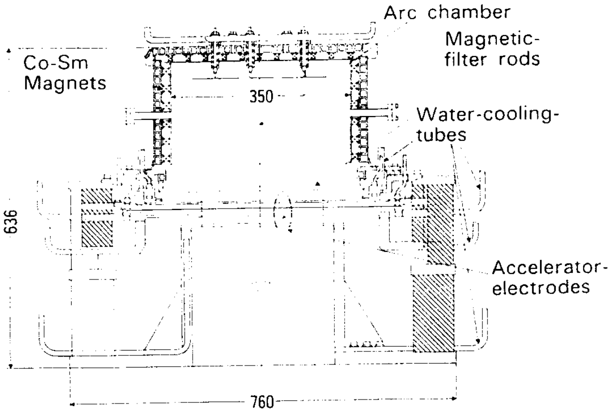


Fig.2 An example of computed beam trajectories, the power flows, and the gas pressure in the beamline. The power of 6250kW is the total of the negative ion power plus the electron power(10% assumed).



Plan view



Elevation view

Fig.3 Schematic view of the modular ion sources.

because the most parts at high voltage is sealed in the grounded vacuum vessel. Technical problems of this vacuum-immersed ion source are the vacuum interfaces. Power and cooling water connections to the modular sources are made through feedthroughs at the insulated flange. They do not need to be disconnected inside the vacuum vessel in this design. Ion source components can be taken away all in one from the ion source vessel by lifting the top flange.

Schematic views of the modular ion sources are shown in Fig.3. The plasma source uses magnetic filter rods which produce the filter field of about 200 Gcm to produce efficiently the negative ions by dissociative attachment process or volume process. Plasma grid can be heated by seeds-heater up to 400 C, and cesium/gas introduction system are attached and driven remotely from the outside of the vacuum vessel. The accelerator consists of 5 electrodes with 400 holes of 9 mm in diam. over the area of $25\times25 cm^2$ of Mo plate. Gas conductance near the accelerator electrodes is increased by using the post insulators. The same scale ion source has been already tested[2] in the another teststand.

3.2 Beamline and the design of the components

Specification for beamline components is listed in Table III.

Neutralizer: Neutralizer cell is a box of 35 cm wide, 160 cm height, and 490 cm length, and tapered off along beam axis in order to reduce the conductance. It is divided into three sub-sections to carry out easily the experiments of gas / plasma neutralizer.

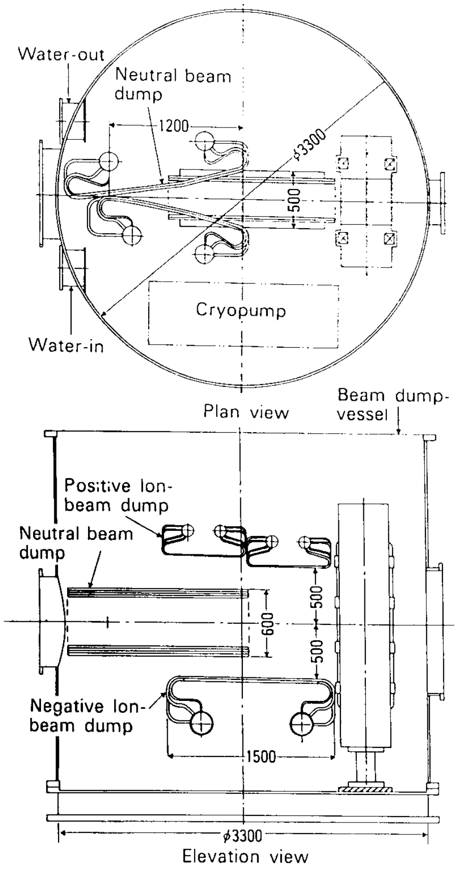


Fig.4 Neutral beam dump (upper plan view) and the ion beam dumps (lower elevation view).

Table III. Specification of the beamline.

1. Neutralizer cell	35cm wide, 160 cm heigh, 490 cm legth (tapered off) Gas thickness of 15.4Pacm.
2. Ion beam bending magnet	Pole area of 45 cm wide, 136 cm height. max. field of 700 G. Time const. of sweeping< 0.5 s.
3. Electron beam bending magnet	Race track coil of 36 cm wide, 190 cm height, max. field of 50 G, (swept periodically)
4 Ion beam dump	Active cooling by swirl tubes, 150.5 cm long, 51 cm wide. max. heat load of 1.6 kW/cm^2. Different diam. tubes are used for positive / negative ion beam dump.
5. Electron beam dump	Fixed in the neutralizer, max.heat load of 0.4kW/cm2.
6. Neutral beam dump	V-shaped plate by swirl tubes, max. heat load of 1.5 kW/cm^2.
7. Cryopump	Highly transparent parallel louvre blind panel, pumping speed of $450m^3$ / s in ion source vessel & ion beam dump vessel.
8. Volume of vacuum vessel	56 m^3.

Bending magnet: The ion beam bending magnet to bend positive and negative ion beams at a small angle of ~15 degree is used, while in the conceptual design of the injector the 180 reflection magnet was used[1]. The reason for this change is to reduce the size of the magnet, because the error magnetic field produced by big magnet core may affect the confinement characteristics of the LHD plasma. Although the heat flux into the beam dump is increased for the case of 15 bending magnet, it is not critical.

In order to fit the injection energy with the wide range of the current-less plasma parameter in LHD, it is planned that the beam energy of the NBI is varied during the injection-pulse. When the beam energy is varied, most stringent component which limits the response is the ion bending magnet due to the field delay caused by the eddy current. Eventually magnetic core is simply made of the bulk of soft ion. Both the analysis and the test result by a similar size of electromagnet gives the characteristic time of modulation of ~0.5 sec.

The electron beam bending magnet is fabricated by a pair of race-track air-core coils. The magnetic field can be swept periodically (<10Hz), if it is required to reduce the average heat flux into the electron beam dump.

Beam dumps: Heat flux into the ion beam dump was computed for various dump positions and/or the plate shapes. Maximum heat flux at the plane of the ion beam dump was about 6 kW/cm^2 for the normal incidence. Since the heat flux is high enough, the dump is inclined to make a small angle to incident beam, to reduce the heat flux. As shown in Fig.4, the planes of the positive- and negative-ion beam dump are positioned symmetrically at 50cm apart from the beam axis in parallel. The angle of incidence is 15 degree approximately, and the maximun heat flux on the plane is $\sim1.6\ kW/cm^2$ which can be removed by using the conventional swirl tubes. To develop the compact beam dump, two types of high performance heat-transfer tube will be tested.

Neutral beam dump is V-shaped to reduce the heat flux below 1.5 kW/cm^2 on the surface. They are also composed of rows of swirl tubes.

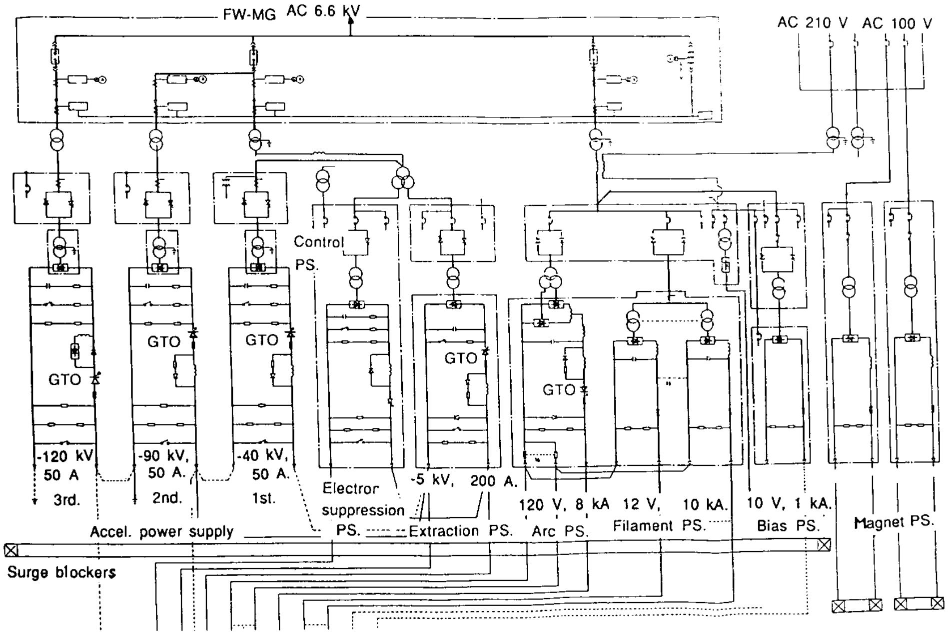


Fig.6 Schematic diagram of the power supplies.

Electron beam dump is designed to limit the heat flux of 0.4 kW/cm^2. A new functional metal, W/Cu Gradient Metal, with high melting point is applied. The dump is composed of many blocks of this metal. They are fixed in the lower plate which is water-cooled.

Cryopump: High pumping speed cryopump with the radiation shield which has parallel louvre blinds[3] is newly designed (in Fig.5). The nominal pumping speed of 450 m^3/s, and the area of effective opening is 2 m^2. The effective particle transmission probability of higher than 0.5 is achieved, based on the test result of small cryopump system as well as the Monte-Carlo simulations.

3.3 Power supply system

A schematic diagram and the specifications for the main power supplies are shown in Fig.6. All the power supplies are constituted by solid-state elements. Primary electricity will be supplied by a FW motor-generator for an exclusive use of heating system. Negative high voltage of 250 kV will be generated by the three stacks of solid-state H.V. power supply, in which the GTO's fast interrupter are applied as a switching element. GTO's power supply for NBI was originally developed by IPP-Nagoya[4]. This system is applicable for the acceleration of the negative ions.

Discharge current is delivered by an intense arc power supply in the mode of constant voltage or constant impedance. Over-current sensors with high sensitivity are utilized in each of 16 arc power supplies in parallel connection. Once the abnormal dicharge occurs uncontrollably, they protect the plasma source and the power supplies within 0.1 sec.

A small computer system controls and sets the acceleration voltage, discharge current, timing sequence, gas flow rate etc, and detects the occurrence of H.V.breakdown. Software program will be prepared for controlling the neutral beams in the mode of variable beam energy, constant beam power, and auto-conditioning runs. The control system and data acquisition system are located remotely from the beamline by optical-linkage.

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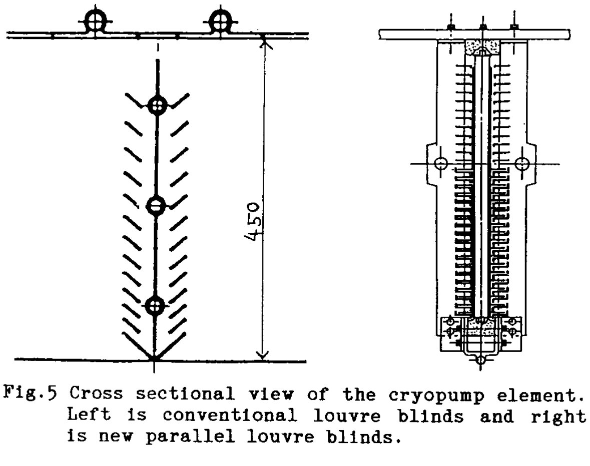

Fig.5 Cross sectional view of the cryopump element. Left is conventional louvre blinds and right is new parallel louvre blinds.