

HL-1M Neutral Beam Injection System and Preliminary NB Heating Experiments

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Abstract: This paper describes the configuration and commissioning of HL-1M neutral beam injection system. The system has one beamline with maximum neutral beam power 0.6MW, maximum beam energy 35keV and beam pulse length 150ms. The initial neutral beam injection into HL-1M Tokamak is also introduced.

1. INTRODUCTION

The HL-1M neutral beam injection system is designed to provide auxiliary heating experiment for HL-1M Tokamak plasma. Development of the system has enabled neutral beam injection experiment. With further commissioning of the system, new achievements of HL-1M Tokamak experiment are expected.

2. NEUTRAL BEAM INJECTION SYSTEM

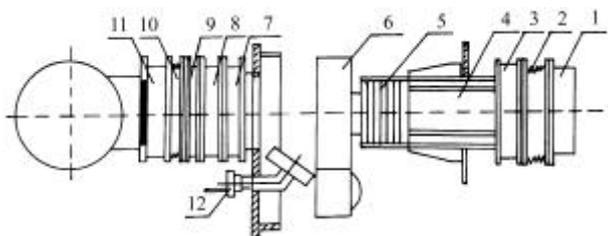


Fig. 1 HL-1M NBI beamline

1. Ion source, 2. Bellow, 3. Vacuum valve, 4. Neutralizer, 5. Magnet shield, 6. Deflecting magnet, 7. Calorimeter, 8. Vacuum valve, 9. Fast shutter, 10. Bellow, 11. Drift duct, 12. Ion dump

The HL-1M neutral beam injection system consists of one beamline, including a bucket ion source, a neutralizer, a deflecting magnet, vacuum vessel, a movable calorimeter, a ion dump, gate valves, a fast acting valve and drift duct, as well as power supply system, vacuum pumping system and diagnostic system, etc. Fig. 1 shows the

configuration of the beamline. The main technical parameters are listed as follows:

Beam energy	20-35keV	Injection direction	perpendicular
Extracted beam power	0.5-1.7MW	Beam focal length:	
Neutral beam power	0.2-0.6MW	-horizontal (curved grids)	3.5m
Beam pulse length	150ms	-vertical (grids displacements)	4.5m
Ion species	H ⁰ (D ⁰)	Beam divergence	
Injection window	15×40cm	-horizontal	±0.5°
		-vertical	±1.5°

2.1 The bucket ion source is the key component of the injector. It can be divided into two parts, the arc chamber and the accelerator system.

The arc chamber (20×33×13cm³ in dimension) is surrounded by permanent-magnet cusp field. The magnetic field on the inner surface of the arc chamber is between 4.5×10⁻²T

(between the cusp lines) and $9 \times 10^{-2} \text{T}$ (at the cusp line). The magnetic field is reduced to $1.5 \times 10^{-3} \text{T}$ 4 cm away from the wall.

The accel-decel three grids system is adopted as the accelerator system. The grids are made of molybdenum. Each grids has 5 sections in which there are 12 slots of the size $0.2 \times 12 \text{cm}^2$. The plasma grid occupies plasma surface of $12 \times 25 \text{cm}^2$ with 48% transparency. The gaps between the grids are 5.5mm and 2.5mm respectively and grids are insulated by epoxy. All the heat accumulating components are water cooled directly or indirectly. The beam is converged horizontally by curve geometry of the grids (focal length 3.5m) and vertically by slots displacement (focal length 4.5m). The gas feeding rate is $1.5 \text{Pa} \cdot \text{m}^3/\text{s}$ with gas efficiency of 50%.

Accelerated beam passes through neutralizer in which the ions collide with background gas and exchange charges. Most of the ions become neutral particles at exit of the neutralizer. The unneutralized ions are deflected by deflecting magnet and collected by ion dump.

2.2 The power supply system consists of a filament PS, an arc PS and a gas valve PS, snubber PS, accelerate PS, decelerate PS and deflecting magnet PS, as well as a programmable logic controller and control panels.

The filament PS is a DC adjustable stabilized voltage supply which is capable of delivering 15VDC with output current of 2000A for 10s every 3 minutes. Besides the over-current and overtime protection circuit, the protection system is equipped with filament blow out detector. The arc PS is a DC adjustable stabilized current supply which is capable of delivering 100VDC with an output current of 2000A for 2s every 3 minutes. The arc PS has an over-current and an over-pulse width protection circuit, which picks up signals of the load current and load voltage through a Hall sensor. When the signals exceed threshold, the circuit issues 2 block commands to the GTO and the thyristor AC regulator, respectively, so as to interrupt the power. A high power modulator tetrode TM- 904C is used as the series switch/regulating device of the accelerate power supply, output pulse voltage 35kv, pulse current 60A, pulse width 300ms, rise time and fall time of the voltage are less than 100 μs , fluctuation of the pulse flattop is less than 1%, and regulation response time of the pulse voltage is about 200 μs .

A programmable logic controller is used to control the sequence of the PS's with good accuracy. The control system is interlocked with plasma current to avoid beam injection without plasma. Pulse electrical parameters are measured by multichannel A/D converters whose outputs are transmitted via optic fibers to the control room. The operation of power supply system has proved to be reliable and stable.

2.3 The vacuum pumping system is composed of main pumping and auxiliary pumping. The main pumping is provided by a titanium pump which has an arc discharge evaporator. The evaporator consists of 4 titanium rods that are triggered in turn for a few cycles. The discharge voltage is 40V~50V with discharge current of 200A~300A. An aluminum screen that is cooled by liquid nitrogen is used as adsorption surface. The surface area of liquid nitrogen screen is about 10m^2 . Liquid nitrogen consumption rate is about 20kg/h. Calculated pumping speed is $1 \times 10^5 \text{l/s}$. The auxiliary pumping is provided by two turbomolecular pumps of pumping speed 1500l/s and two mechanical pumps of pumping speed 30l/s. After 100°C baking for 50 hours, the vacuum vessel whose volume is 5.7m^3 has reached its background vacuum $1.1 \times 10^{-5} \text{Pa}$. Total leakage and deflation rate of the vacuum system is $6.8 \times 10^{-6} \text{Pa} \cdot \text{m}^3/\text{s}$.

2.4 The diagnostic system includes electrical parameters measurement for power supply, beam power measurement and beam profile measurement.

Main station and substations which are placed at high voltage constitute the power supply

electrical parameters measurement system. Optic fibers are used to transmit digital signals between main station and substations across the high voltage. Software has been developed for data acquisition, compression, transmission, processing and storage. A calorimeter is used for beam power measurement and an array of secondary electron emission probes is used for beam profile measurement. Special measures with hardware and software have been taken to eliminate interference and to avoid damage.

2.5 Commissioning of the neutral beam injection system is focused on the commissioning of the ion source after commissioning of the sub systems such as power supply and control system, vacuum system, water cooling system, hydrogen gas feeding system and pneumatic system. Commissioning of the ion source is performed by three steps: filaments, arc discharge and accelerator.

The 18 filaments of tungsten with 1mm in diameter are installed as the cathode of the arc chamber. The filaments work in space-charge limited regime with heating power of 1200A, ~11V to improve discharge stability and plasma uniformity^[1]. To reduce current shock and to avoid gas absorption, DC preheating current of 150A~200A is normally applied to the filaments during operation.

Two discharge modes are discovered with this bucket type ion source: higher arc voltage/lower arc current and lower arc voltage/ higher arc current. Transition between the two discharge modes normally occurs. The transition area is generally between 400A and 500A in the operation depending on work gas pressure and filament current^[2].

Key steps of ion source commissioning are the accelerator system high voltage conditioning and the matching of accelerating voltage to arc current. High voltage conditioning is carried out by large number of shots without and with load while gradually increasing the high voltage without causing severe breakdown. For a specific accelerator system, there is an optimum perveance^[3], i.e. there is a matching of accelerating voltage to arc current. When the ion source operates in its optimum perveance, the best optical characteristics of beam is obtained. Therefor beam profile is detected to find the matching of accelerating voltage to arc current.

The ion beam of 20A, had been accelerated to 20kV for 150ms pulse after commissioning.

3. INITIAL NEUTRAL BEAM INJECTION EXPERIMENT

Achieved by 400kW extracted power on the ion source, the first neutral beam was injected into HL-1M Tokamak on September 1998. The vacuum system was cleaned and baked before the experiment to reduce impurities in the beamline.

The main parameters of HL-1M Tokamak during neutral beam injection were: R=102cm, a=26cm, $I_p=140kA$, $B_T=2.3T$, $\tilde{n}_e=1\sim 3.5\times 10^{13}cm^{-3}$, $T_e=700eV$. Neutral beam was injected perpendicularly into the torus port. Graphite amour tiles are installed on the inner wall for beam shine through protection. Typically, 300kW power was extracted from the ion source with energy 20keV. It is from ion source experiment data base and work pressure that H_2^+ species component was about 10%, while H_1^+ and H_3^+ were 45% each. The hydrogen gas supply was $1.1Pa\cdot m^3/s$. Calculated gas target in neutralizer was $7.5\times 10^{15}/cm^2$. Therefor all the molecular ions were disassociated and neutralization efficiency for 20keV full energy ions H_1^+ was above 80% while for one third energy ions was above 90%.

During neutral beam injection the central ion temperature in HL-1M Tokamak was monitored by neutral particle spectrometer. Significant ion temperature increases were

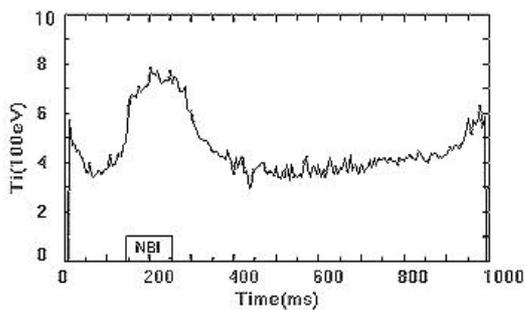


Fig. 2 Ion temperature during NB injection

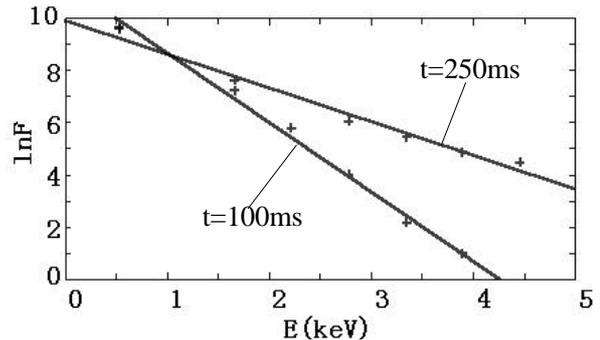


Fig.3 Neutral particle energy spectrum

observed. Fig. 2 shows the ion temperature measurement on shot 5452. The central ion temperature increased from 400eV to 750eV during neutral beam injection. Fig. 3 shows the neutral particle energy spectrum also on shot 5452 before (at 100ms) and after (at 250ms) neutral beam injection. Linear arrangement indicates that energy distributions of ions in plasma were almost Maxwellized. While the slope decrease of lines also indicates the temperature increase after neutral beam injection.

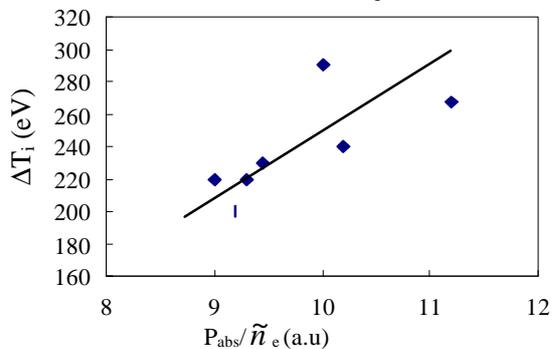


Fig. 4 Ion temperature rise with P_{abs}/\tilde{n}_e

Fig.4 shows that the ion temperature increase ΔT_i basically scales with beam power and electron density as P_{abs}/\tilde{n}_e . P_{abs} is the injected power less the power calculated to shine through the plasma^[4]. The electron density rises with the onset of NB injection was also observed. The electron heating has not been observed. The impurity radiation variation was not obvious during NB injection due to the wall conditioning of HL-1M Tokamak^[5]. The experiment is preliminary. More NB injection related experiments on HL-1M

Tokamak are scheduled. With further commissioning of the NBI system, mainly the ion source, new achievements in the experiment are expected.

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