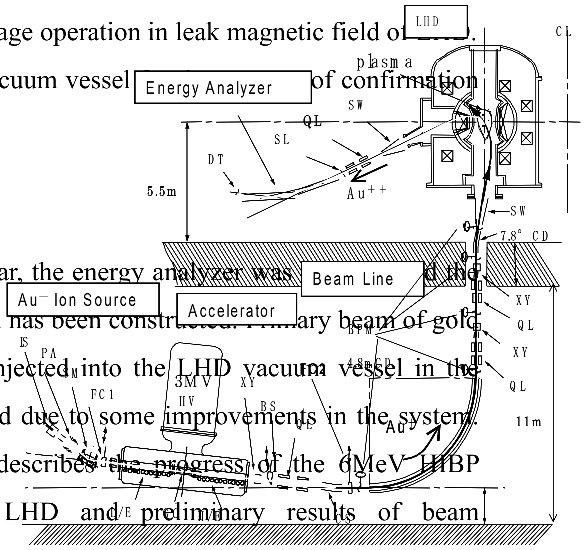
DEVELOPMENT OF 6 MEV HEAVY ION BEAM PROBE FOR LARGE HELICAL DEVICE

A. Nishizawa, T. Ido, Y. Hamada, S. Kato, Y. Kawsumi, K. Tsukada, E. Asano, M. Nishiura, A. Shimizu

National Institute for Fusion Science, Japan

6MeV heavy ion beam probe (HIBP) has been developed for the measurements of electrostatic potential and density and potential fluctuations in the Large Helical Device (LHD) plasma. The whole system has been constructed in the last campaign and some improvements of the system are achieved for high voltage operation in leak magnetic field of [illegible]. The primary beams can be observed by detectors mounted on the inner vacuum vessel [illegible] of confirmation of beam trajectories in the magnetic field of LHD.

PACS:52.70.Nc



1. INTRODUCTION

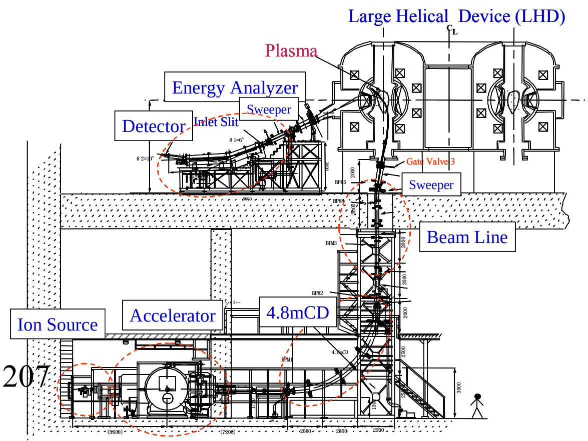
The heavy ion beam probe (HIBP) is a versatile method for direct measurements of internal plasma potential and fluctuations of potential and density in magnetically confined plasmas. The recent experimental results by the HIBP have successfully contributed for explanation of the transport mechanisms on axisymmetric and nonaxisymmetric plasma devices such as TEXT[1] and JIPP T-IIU[2] tokomak and ATF[3] and CHS[4] stellerator, respectively. The maximum beam energy in these HIBPs was 2MeV of TEXT HIBP system. The Large Helical Device (LHD) is a heliotron/torsatron device, and the maximum magnetic field, which is supplied by super conductor coils, is 3T. The major and averaged minor radii are 3.9m and 0.6m, respectively. LHD-HIBP in these dimensions requests the maximum beam energy of 5.6MeV in the case of using ion beam of mass 200. The 6MeV HIBP project for investigation of the property in helical devices plasma has been developed since 1993 and preliminary design and configuration were presented by A. Fujisawa et al. [5]. The whole 6MeV HIBP system requests essential improvements because of far higher applied voltage for the system components than 500keV system such as the JIPP T-IIU HIBP. In addition, leakage field of LHD causes unexpected phenomena in beam transport and beam adjustment components.

In the last year, the energy analyzer was [illegible]d the whole system has been constr[illegible]ary beam of gold ion can be injected into the LHD vacuum vessel in the magnetic field due to some improvements in the system. This article describes the progress of the 6MeV HIBP system for LHD and preliminary results of beam trajectory measurements in the LHD magnetic field.

2. 6 MeV HIBP SYSTEM IMPROVEMENT

2.1 OUTLIEN OF BEAM LINE

The constructed 6MeV HIBP system is shown in figure 1. The system is composed of a negative ion source, a 3MV tandem accelerator, beam-line and an energy analyzer. The gold ion beam is optimum for LHD magnetic field. The negative ion beam extracted from ion source is accelerated by a pre-accelerator tube (PA) and injected the tandem accelerator through a sector magnet (SM) for cutting light mass ions such as oxygen. Negative ion beam is accelerated by 3MeV and its charge exchanges in a gas cell at the center of the accelerator tube and is accelerated again by 6MeV. The positive primary beam in multi charged ion beam extracted from the accelerator is separated electrostatistically in a charge separator (CS in Fig.1a). The direction of the beam is changed from horizontal direction to vertical direction by a 4.8m cylindrical deflector (4.8mCD in Fig.1a). The position and width of the beam is monitored by five beam profile monitors (BPM) in optimum places of the beam line, and adjusted by quadrupole lenses (QL in Fig.1a) and steerers (XY in Fig.1a). The octpole electrode (SW) at the injection port of the LHD vacuum vessel sweeps the beam in order to scan plasma crosses sections. Three-dimensional sweep and the active trajectory control method are accepted in order to manage complicated trajectory. The secondary beam created by charge exchange through the electron impact in the plasma is introduced into the tandem type energy analyzer.



a

b

Fig.1. 6MeV HIBP System(a). Installation of 6MeV HIBP System

2.2 IMPROVEMENT OF ACCELERATOR

The 3MV tandem accelerator is used for obtaining 6MeV ion beam. The material of the accelerator tank was changed from iron to stainless steal at the installation into LHD hall in order not to disturb the LHD magnetic field in 2000 year. Operation of the accelerator was allowed after taking a license from the administrator in 2002. In starting aging, the amount of load current of the accelerator abnormally increased at voltages larger than 1MV as shown in Fig. 2. It is found from the observation of inner tank that abnormal current is caused by corona discharge between a high voltage terminal and tank edges. The corona discharge is shown in Fig.3 that is the photograph taken to determine the position where the corona discharge occurs. In the photograph, the inner wall of the tank illuminated by a light for 4 seconds and the corona discharge with exposure time of 16 minutes are superimposed. The surface of the inner wall of the accelerator tank is so rough that the corona discharge occurs even in SF_6 gas. The lode current was recovered by polishing the tank wall near the terminal.

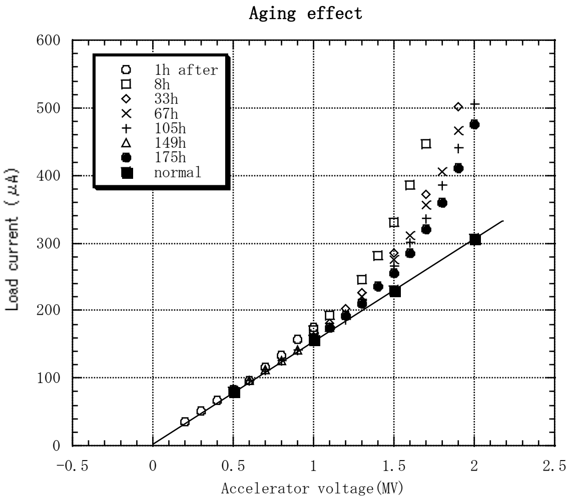


Fig.2. Load current of tandem accelerator

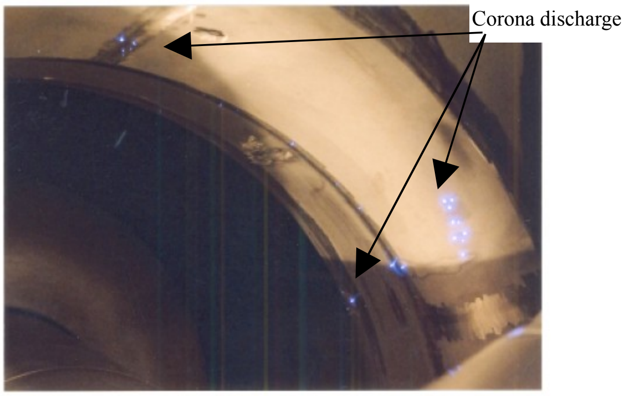


Fig.3. Corona discharge on the accelerator tank wall

2.3 PROBLEM IN THE BEAM LINE

The cylindrical electrostatic deflector with the radius of 4.8 m (4.8m CD) is divided into four sections to adjust the beam trace easily. The gap between the anode and the cathode is 30mm and curvature is large in order to treat the high voltage easily. The voltage applied to the electrodes is ±40kV for a 6MeV beam. The leakage current increases yearly because of a lot of dust. The dust may fall from upper devices such as LHD and beam line components or may be sputtered by the heavy ion beam with the energy of up to 6MeV. The cleaning of the gap dramatically reduces the leakage current as shown in the Table. The leak currents after the cleaning flow outside vacuum vessel at each electrode.

The beam adjustment to the injection port of LHD is influenced by leak filed of LHD. The displacement of the beam trajectory is compensated with the electrostatic steers.

A 7.8°cylindrical deflector (7.8°CD in Fig.1a and 4) is installed near the LHD injection port in order to bend the beam in the direction to the port. Applied voltage of 40kV requires for 6MeV beam. The magnetic field of LHD of 2 T or more causes the increase in the deflector current and the applied voltage goes down. The leakage field strength is a few hundred gauss and the direction is parallel to the electric field between the electrodes. The magnetic field line is perpendicular to the electric field between the electrodes and the grounded vacuum vessel of 7.8, and that may induce the discharge. The deflector is being developed and tested now.

Result of leak current improvement of 4.8m CD

stage	V(kV)	+plate Before cleaning (μA)	-plate	+plate After cleaning (μA)	-plate
1	40	101	113	0	0
2	40	164	166	2	27
3	40	110	114	7	0
4	40	35	16	28	3

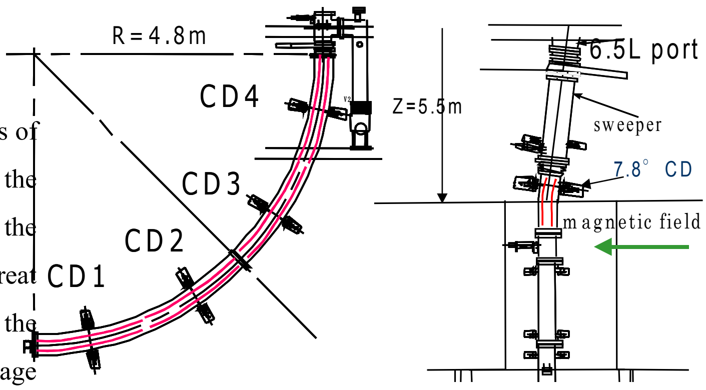


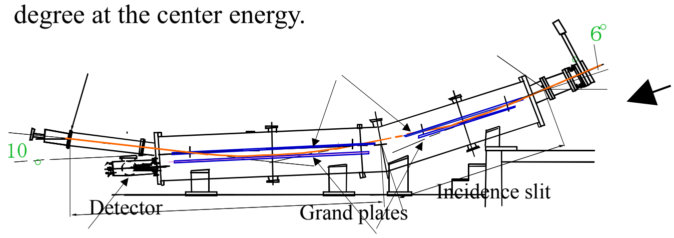
Fig.4. 4.8m and 7.8°cylindrical deflectors

2.4 ION SOURCE

The ion source with high output current and long lifetime is requested for the plasma diagnostic system. Especially, the high output current is required for the LHD plasmas because the large attenuation along the long beam path in plasma and beam line. In LHD-HIBP, ion source is a plasma sputter type of negative gold ion source, the maximum current is 12μA . A week operation under 8 hour per day is capable and depends on Cesium (Cs) quantity in the oven.

2.5 TANDEM TYPE ENERGY ANALYZER

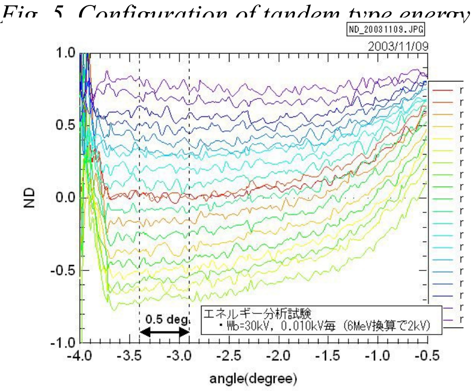
The applied voltage of an electrostatic parallel plate energy analyzer with the incidence angle of 30 degree, which is popularly used in many scientific fields, is required about 1MV for the 6MeV HIBP. That is not realistic. A new tandem type analyzer [6] is proposed for solving this problem. As shown in figure 5, this analyzer is composed of combined two set electrostatic parallel plate analyzer and has second-order focus. Accepted incidence angle of a first and second stage are 6 and 10 degree, respectively. The applied voltages of first and second stage for the secondary beam of 6MeV are 50kV and 100kV, respectively. The characters of produced instrumentation in the factory were tested with 100keV thallium ion beam on the test stand. In figure 6, measured characteristics of dependence on incidence angle of normal deference (ND), which is corresponding to potential change, is shown. Those are deferent from calculation value for wide range angle. Distance from an exit port of LHD to detector point is long and the incidence angle variation is only 0.25 degree. Calibration results show that the produced analyzer can sufficiently apply for measurement of energy deference of determined beam energy because the flat curve in the range of 0.5 degree at the center energy.



2.1m

Feed through 3.7m Positive plates

Fig. 5 Configuration of tandem type energy analyzer



Wb<30kV, 0.01kV/d (2kV/d at 6MeV)

Fig. 6. Characteristics of tandem type energy analyzer

3. BEAM TRAJECTORY MEASUREMENTS

Beam trajectory in the helical field is more complicate than in tokomak field. A slight displacement in the beam injection angle into analyzer gives a significant error to potential measurements. Secondary beam sweep system is introduced in addition to the primary sweep, and a set synchronized sweep is used for desirable observation position of the secondary ions birth. Therefore, trajectory calibration of primary beam is required to obtain precise event positions.

Primary beam is introduced to the LHD vacuum vessel in the magnetic field by the octpole sweeper and is detected by detectors installed on vacuum vessel wall. The sweeper axis is set on the direction where the beam crosses axis of the LHD vacuum vessel without applied voltage of the sweeper. As shown in figure 7, detector is composed of four stainless steel plates. V1 and V5 waveforms correspond to two dimensional sweep voltages in the injection sweeper. During the 2-D sweep the primary beam moves in the directions on the detector as shown with arrows in the fig.7. The beam is observed under the condition with the expected magnetic field strength and beam energy. The sweep voltage where the beam is observed is different from the expected value. It may be due to the error in the position of the detector or the beam line.

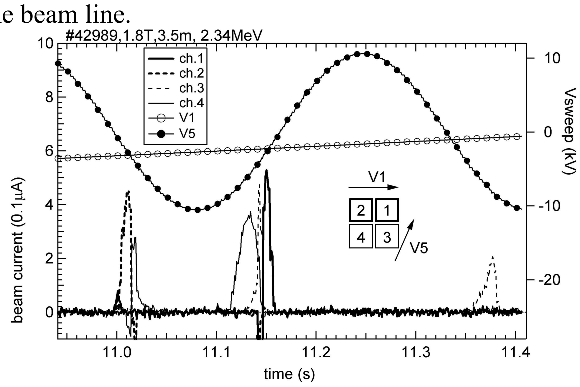


Fig. 7. Primary beam detection for trajectory check

4. CONCLUSIONS

The 6MeV HIBP, which is the biggest in HIBP systems, has been constructed for measurement of the LHD plasma. Some improvements on the large scaled HIBP have been done. Particularly, it is shown that new type tandem analyzer can be applied for analyzing energy at small incidence angle. The beam trajectory is tested with primary beam detectors in the magnetic field of LHD. The beam is observed under the condition with the expected magnetic field strength and beam energy.

One of the difficult problems is the discharge in 7.8°CD in the magnetic field. The deflector is being improved.

REFERENCES

1. R. L. Hickok and P. M. Schoch. Proposed 2MeV beam system for TEXT-upgrade// *Rev. Sci. Instrum.(32).* 1992, pp. 1295-1331.
2. Y. Hamada, A. Nishizawa, et al. Density fuluctuations in JIPP T-IIU tokomak plasmas measured by a heavy ion beam probe// *Nucl. Fusion (37).* 1997, pp. 999-1014
3. J. J. Zielinski, S. C. Aceto and K. A. Connor, et al. ATF heavy ion beam probe; installation and initial operation// *Rev. Sci. Instrum. (61)*. 1990, pp. 2961-2963
4. A. Fujisawa, S. Kubo, H. Iguch, et al. Experimental study of plasma confinement and heating efficiency through potential profile measurements with a heavy ion beam probe in the compact helical system// *Proc. of the16th IAEA Fusion Energy Conf., Oct. 7-11, 1996, Montreal, Canada.* 1996/ IAEA-CN-64/C1-5, pp. 41-54.
5. A. Fujisawa, H. Iguch, A. Tanieke, M. Sasao, and Y. Hamada. A 6MeV heavy ion beam probe for the large helical device// *IEEE Trans.Plasma Sci.* (*22).* 1994, pp.395-402
6. Y. Hamada, A. Fujisawa, H. Iguch. A tandem parallel plate analyzer// *Rev. Sci. Instrum.(68).* 1997, pp. 2020-2022

СОЗДАНИЕ ДИАГНОСТИЧЕСКОГО ПУЧКА ИОНОВ С ЭНЕРГИЕЙ 6 МЭВ ДЛЯ УСТАНОВКИ LHD

А. Нишизава, Т. Идо, Я. Хамада, С. Като, Я. Кавасуми, К. Цукадо, Е. Асано, М. Нишиура, А. Шимизу

6 МэВ-й источник ионов для измерений потенциала и плотности плазмы, а также их флуктуаций создаётся на установке LHD. За прошлый год завершено сооружение системы и улучшена работа системы при больших рассеянных магнитных полях LHD. Прохождение первичного пучка может наблюдаться с помощью детекторов, помещённых в вакуумную камеру, и тем самым подтвердить расчётные траектории в магнитном поле LHD.

СТВОРЕННЯ ДІАГНОСТИЧНОГО ПУЧКА ІОНІВ З ЕНЕРГІЄЮ 6 МЭВ ДЛЯ УСТАНОВКИ LHD

А. Нішизава, Т. Ідо, Я. Хамада, С. Като, Я. Кавасумі, К. Цукадо, Е. Асано, М. Нішиура, А. Шимізу

6 МэВ джерело іонів для вимірів потенціалу і щільності плазми, а також їхніх флуктуацій створюється на установці LHD. За минулий рік завершене спорудження системи і поліпшена робота системи при великих розсіяних магнітних полях LHD. Проходження первинного пучка може спостерігатися за допомогою детекторів, поміщених у вакуумну камеру, і тим самим підтвердити розрахункові траєкторії в магнітному полі LHD.