Recent Experimental Results of HL-1M Tokamak and Progress of HL-2A Project

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ABSTRACT. Recent experimental results of HL-1M tokamak and progress of HL-2A project are presented. Strong fishbone instability was observed during off-axis ECRH. This is first observation of the fishbone instability purely driven by energetic electrons produced by ECRH. The MBI was first proposed and demonstrated on HL-1M. Recently new results of MBI experiment were obtained by increasing the pressure of gas. A stair-shape density increment was obtained with high-pressure multi-pulse MBI just like the density evolution behavior during the multi-pellet injection. It is shown that injected particles could penetrated into the core region of the plasma. HL-2A is a divertor tokamak in construction at SWIP based on original ASDEX main components. Mission of HL-2A Project is to exploring physics issues involved in advanced tokamak. For first phase, the divertor (edge plasma) and confinement researches will be emphasized. The major parameters of HL-2A are: R=1.65m, a=0.4m, Bt=2.8T, IP=0.48MA. The main parameters and characteristics of subsystems such as power supply, pumping, diagnostics and auxiliary heating are presented in the paper. The first plasma of HL-2A is expected at the end of 2002.

1. Introduction

Main objectives of the HL-1M tokamak(R=1.02m, a=0.26m) are to conduct experiments on auxiliary heating & current drive and also to explore new fueling techniques in order to develop the physics and technology basis for next tokamak, HL-2A, which is in construction with two original ASDEX main components, the vacuum vessel and the magnet coil sets. HL-1M started operation at the end of 1994[1]. Since then, HL-1M plasma performances have been improved significantly with wall conditioning and auxiliary heating and current drive[2,3]. Up to now, the maximum parameters of HL-1M are: plasma current IP=320kA, line average density ne=8×1019m-3, toroidal magnetic field B t=3T and discharge duration of up to 4 seconds. To fulfill the objective of the device, 4 different system of auxiliary heating and current drive were installed on HL-1M, which are an electron cyclotron resonance heating (ECRH) system of 0.5MW/75GHz, a lower hybrid current drive (LHCD) system of 1MW/2.45GHz, a neutral beam injection (NBI) beam line of 1MW, and a ion cyclotron resonance heating (ICRH) system of 0.8MW. At the same time, many advanced diagnostics with high time-spatial resolution were developed, including a 2mm ECE heterodyne receiver with 20 spatial points and time resolution of 2ms, a 15 channels bolometer with fast response time of 5 μ s. A high speed CCD camera with minimum exposure time of 0.1 μ s for the study of pellet ablation process and a laser blow-off for impurity transport research.

HL-2A is a divertor tokamak in construction at the new site of SWIP in Chengdu based on original ASDEX main components (vacuum vessel and magnet coils) [4]. HL-2A project is an important part of the fusion research program of China. Mission of HL-2A Project is to exploring physics issues involved in advanced tokamak. Most of the important issues of fusion physics, such as confinement improvement, divertor and scrape-off layer, wall conditioning, MHD instability and energetic particles, auxiliary heating and current drive, would be studied and explored on the HL-2A through the progressively improvement of the hardware [5]. For first phase, the divertor (edge plasma) and confinement researches will be emphasized. It is hoped that the experiment results from HL-2A will make contributions to the development of worldwide fusion research. The construction of HL-2A was approved by Chinese government in 1998 and started in early 1999. The civil construction was completed in 2001. The installations for the main machine structure including vacuum vessel, magnetic field coils have been accomplished in the end of 2001. The construction of power supply and control systems was finished at summer of 2002. The diagnostics and auxiliary heating systems are being developed and installed progressively. The first plasma is expected before the end of 2002 according to the schedule.

The experiment results obtained since last IAEA conference are presented in section 2. The progress of HL-2A project is given in section 3 of this paper.

2. Experimental Progress of HL-1M tokamak

In past years, on the HL-1M experiment progresses in many aspects were made including confinement improvement, auxiliary heating, fueling of plasma and wall conditionings[3][6]. In the off-axis ECRH, double sawtooth in soft X-ray radiation were observed, which imply that the reversed magnetic shear could be formed during ECRH. At higher ECRH power, when the resonance position is near to the q=1 surface, fishbone instability was observed and investigated. The reversed magnetic shear (RMS) configuration was obtained also in the other scenarios of experiments on HL-1M[7], including LHCD and the plasma current ramp-up control combined with supersonic molecular beam injection(SMBI). In past two years, most important experiment progress are as follows:

Fishbone instability driven by ECRH: Strong fishbone instability was observed during off-axis ECRH in the HL-1M tokamak. This is first observation of the fishbone instability purely driven by energetic electrons produced by ECRH. The fishbone appears in the middle of the sawtooth, it could be distinguished from the precursor oscillations just like one burst.

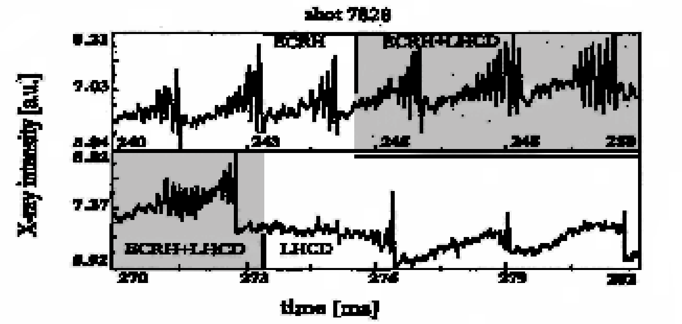

Fig.1. The behavior of the fishbone instability for ECRH, combination of ECRH and LHCD, LHCD.

Excitation of the fishbone instability was observed only when the ECR location is near the q=1 surface on the high field side. Addition of lower hybrid waves to ECRH significantly enhances the MHD excitation, but lower hybrid waves alone cannot excite or sustain the mode, as shown in Fig.1. This result is a clear demonstration of the suprathermal trapped electron effect on the instability because of the absence of energetic ions in the plasma[8] [9].

High-pressure molecular beam injection (MBI) experiments: On the fueling technique, besides pellet injection, a new fueling method, supersonic molecular beam injection was first proposed and demonstrated on HL-1M, which can significantly improve the efficiency of fueling and plasma performances[10]. The MBI Recently new results of MBI experiment were obtained by increasing the pressure of gas from 0.5 MPa to over 1.0 MPa. A stair-shaped density increment was obtained with high-pressure multi-pulse MBI just like the density evolution behavior during the multi- pellet injection. This demonstrated the effectiveness of MBI as a promising fueling tool. The penetration depth and injection speed of the high pressure MBI were measured and estimated by the contour plot of H_α emission intensity, as shown in Fig.2. It is shown that injected particles could penetrate into the core region of the plasma, which was also verified with observation by a CCD camera located at same cross-section of the plasma with H_α array. The speed of high-pressure MBI particle in the plasma was estimated as about 1200m/s[11].

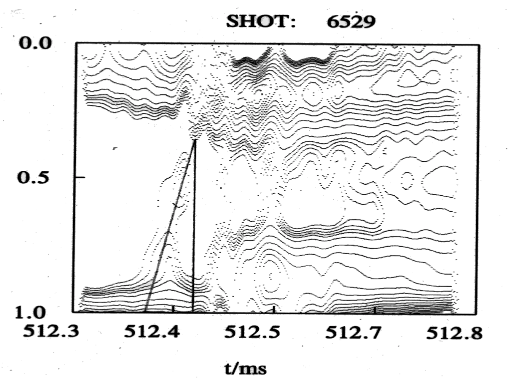

Fig.2. The contour of the evolution of radial profile of the H_α emission during MBI.

3. Progress of the HL-2A project

The major parameters of HL-2A are:R=1.65m, a=0.4m, B_t=2.8T, I_P=0.48MA. The transfer of the former ASDEX components greatly helps the construction of HL-2A project. The HL-2A tokamak is characterized with a large closed divertor chamber. This is unique in present tokamak experiments. This unique feature will make significant contributions to enhance understanding of complex divertor plasma physics and help validate divertor physics modeling. To utilize this unique feature completely, much more attention will be paid to the enrichment of diagnostics for divertor plasma. The machine can be operated in double null, upper single null and lower single null configurations with the same main plasma condition to study the physics of divertor operation and various improved confinements regimes.

The vacuum vessel, 16 toroidal field coils, poloidal field coil systems and supporting structure of the former ASDEX are adapted for HL-2A[12]. The other sub-systems of HL-2A, including pumping system, cooling system, power supply system, diagnostics system, auxiliary heating system, have been designed and have been or are being constructed, to meet the requirements of the experiment program of HL-2A.

The main pumping system of HL-2A is composed of 8 turbo molecular pumps (3500l/s each), with 2 sets of pre-stage pump. The divertor pumping system is composed of 18 titanium getter pumps installed in divertor chambers. The vacuum vessel can be baked up to 130°C -150°C for degas and a glow discharge device is installed in the vessel for cleaning the inner surface of the vessel.

The cooling system is consisted of 4 sub-system. One is for cooling to TF coils, MP coils and MPC coils, the second is for cooling (baking) for vacuum vessel, the third is for cooling for divertor protection shields and neutralizer plates during discharge, the fourth is for cooling for VF coils,OH coils.

8 sets of DC pulse power supplies have been constructed for the coil system of TF, OH, VF, MP, MPC, RF and so on. The peak power of 300MVA and the total energy release of 1200MJ per shot are required for the operation at B_t=2.8T, I_P=0.48MA. Three motor generators (MG) are used for the power supply system. Two identical existing MG were modified by replacing original flywheel of 40 ton with a new one of 90 ton. After modification, the released energy will be increased to 500MJ from 100MJ. The two MG are used to power the toroidal field coils via a 12 pulses diode rectifier. Another MG with output power of 125MVA is used to power the poloidal field system with transformers and thyristor rectifiers. In order to check the system design and optimize the parameters of feedback control system, the power supply system has been simulated with EMTP code. The current in TF coils is controlled by regulating the exciting field current of MG sets. The currents in PF coils are controlled by using a feedback control system. A digital control method has been developed to adapt to the AC frequency changes from 120Hz to 96Hz corresponding to the MG shaft rotating speed slow down from 1650rpm to 1200rpm.

HL-2A control system consists of into two parts, the machine control system and the discharge control system. The machine control system configures and operates the all subsystems of tokamak. In this system logical control and interlock protection are realized with PLC. The discharge control system is designed for controlling plasma current, plasma position and plasma shape with a real time feedback control system.

The auxiliary heating systems with total power of about 10 MW are planed, which include NBI of 4MW/60keV/2s, LHCD of 3MW/2.45GHz/1s, ICRH of 2MW/30-65MHz/2s, ECRH of 1MW/75GHz/1s. The NBI of 4MW with two beamlines will be developed with priority. According the schedule, a NBI system with 2MW and a LHCD system with 1MW will be built up for first phase experiments. Then the auxiliary heating system will be extended to the planed parameters to realize the goals of the HL-2A tokamak.

The diagnostics will be developed to meet the requirements of physics goals. some of the diagnostics are upgraded or extended from these on the HL-1M, such as Thomson scattering, ECE, Multi-channel HCN laser interferometer, SXR array, Bolometer array, visible and VUV spectrum, neutral particle charge exchange, probes array, etc. The diagnostics for the closed divertor are well considered and emphasized for the understanding of complex divertor plasma physics with the exiting unique closed divertor. Up to now, infrared camera, microwave interferometer and probe array is adopted.

A 30 shots pellet injection system will be developed with both low field side and high field side injection. For first phase, a 8 pellet system will moved from HL-1M to HL-2A for preliminary pellet injection experiments. The molecular beam injection, which was first proposed on HL-1M, as a fueling technique will be further developed on the HL-2A.

After realizing the objective for closed divertor research for a period of operation, the divertor will be modified into an open one[4]. The PF coils and vacuum vessel will be redesigned and the divertor coils will be moved out of the vessel so that larger plasma volume and more shaped configurations could be obtained. It is expected that the experiment results from HL-2A will make contributions to the development of worldwide fusion research.

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