§2. Archival Studies on Plasma Heating Devices and Related Technologies

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The technological evolution of plasma heating in Japan up to around 1985 have been surveyed on the basis of documents and materials of the heating devices for fusion research collected during this collaboration work, and summarized as follows.

1) 1956 - 1964: Fusion researches in Japan began around 1956 with the pinch experiment in Osaka University, the torus experiment in Nagoya University and Scylla type experiment in Electrotechnical Laboratory. Until 1958, the high temperature plasma devices based on the three confinement approaches - pinch, mirror and stellarator concepts - were built to confirm and extend the works published in the world. Heating methods such as Joule heating and wave heating were provided in these devices, but the major efforts in the early experiments were focused on producing refined plasma and controlling the devices reliably by the improvement of device and the development of technologies.

The preliminary ion cyclotron heating experiments were carried out on Heliotron B in Kyoto University and on QP machine in IPP Nagoya U., both with the power of less than 50kw. In order to understand the plasma behavior in a magnetic field, small scale experiments were carried out for wave excitation, diffusion and radiation in the cold plasma produced in the glass tube devices.

2) 1965 - 1970: By advances of technologies of fusion plasma devices and plasma experiments, the production of good quality plasma became feasible and Joule heating plasma studies were progressed and auxiliary heating such as ion cyclotron heating (ICH), turbulent heating and adiabatic heating were investigated. In small size experiments, the glass tube was replaced by metal tube to produce higher density plasma by the intense discharge, and the excitation and the propagation of waves were studied in the wide range of frequency. The beam- plasma interaction was also studied for plasma heating and stabilities. Since the confinement time in T-3 tokamak showed progress, laboratories around the world built tokamaks. A new generation of torus experiments started on JIPP T-I stellarator in IPP Nagoya U., and on toroidal hexapole device, JFT-1 in JAERI.

3) 1971 - 1975: The confinement study proceeded in the experiments on JFT-2 and JIPP T-II stellarator/tokamak. The developments of NBI heating devices began in the test-benches, and for RF heating, the technological and engineering studies of power supply, antenna and transmission system were carried out both in JEARI and IPP Nagoya U. Small tokamak devices and medium size machines were built in universities and not only for heating studies (turbulent heating, adiabatic compression heating and electron heating in pinch etc.) but also for physical studies of plasma heating-related problems (heating mechanism and the excitation and propagation of waves), and utilized for investigating the warm plasma to provide alternative heating and the basis for RF heating. The physical and technical studies of ion source were carried out actively in universities also and the cluster particle source was investigated as an alternative to conventional ion source.

4) 1976 - 1980: In 1976, the first experiment of NBI heating in Japan was carried out successfully with perpendicular injection of the power of 100 kW level and the 30keV beam on JFT-2. In 1977, the effectiveness of simultaneous heating with lower hybrid wave and tangential injection NBI was demonstrated with the power of 100kW level each in JIPP T-II. On the basis of the research and development of components for heating device (ion sources for NBI, and launcher and antenna for RF heating) in universities and institutes, the heating devices for fusion-oriented experiment, JFT-2, JIPP T-II, Heliotron and GAMMA, were constructed by industries. After the performance test of the devices and confirming usefulness of the heating method, higher performance systems were developed further. NBI (~100keV, <20MW) development was started for JT-60 that was decided to build in JEARI in 1974. RF heating was aggressively studied on various types of plasma waves. The fundamental studies for physical and technological problems were promoted for ion source, ion cyclotron wave and lower hybrid wave, and also for the plasma heating with them. Prototype gyrotron (17.5 GHz, 9 kW, 1 ms) was developed in Kyoto University and ECH experiment was carried out using the gyrotron in small tokamak, WT-3. The development of high power gyrotron continued under the collaboration research with industries.

5) 1981 - 1985: The plasma heating technology was progressed steadily. The research and development of high power heating devices capable of longer pules operation for next large fusion project (MW level / a devices) and the components of heating device - negative ion source, high power microwave sources (klystron and gyrotron), etc. - were initiated in universities and institutes. In order to determine the most promising heating method for next fusion program, the efficiency of each heating method and the accessibility to plasma were investigated on high temperature plasma devices-JIPP T-IIU, JFT-2, etc. The technical bases for high power heating devices had been provided and studies of alternative heating were continued.

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