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R&D Status on the High Intensity Proton Accelerator in JAERI

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Abstract

The R&D for the high intensity and high duty factor proton linear accelerator has been carried out since 1991. A hydrogen ion source, an RFQ and an RF power source have been developed and 2 MeV proton beam test has been conducted to study the front end of the accelerator. To demonstrate the high duty operation of the DTL, a hot test model was fabricated and high power test has been carried out. In this report, present status of the R&D is described.

Introduction

A high intensity proton linear accelerator with an energy of 1.5 GeV and an average current of 10 mA has been proposed to perform the various engineering tests for the nuclear waste transmutation system and to apply for the basic researches[1,2]. In the R&D for the accelerator development, low energy accelerator components have been developed, since the beam current and the quality are mainly determined by the low energy portion. Heat removal problem of the accelerator structures is an important issue because of the high duty factor operation.

To study the front end of the accelerator, the ion source, the RFQ, and the RF source were fabricated and 2 MeV beam tests have been performed. In the beam test, acceleration current of 50 mA with a duty factor of 6 % was achieved. To demonstrate the high power and high duty factor operation of the DTL, a hot test model was fabricated and a high power test has been carried out by feeding an RF power.

Beam Test of the 2 MeV RFQ

The RFQ is a four-vane type and designed to accelerate 100 mA (peak) of protons to 2 MeV with a duty factor of 10 %[3]. The low power tuning, the high power conditioning and the first beam test were carried out at the test shop of Sumitomo Heavy Industries, Ltd. and the basic performance of the RFQ was obtained[4]. To study further properties, the beam test has been made at JAERI since November, 1994.

The layout of the RFQ beam test is illustrated in Fig.1. A multicusp type ion source has been developed to obtain a high brightness proton beam. The ion source has been operated successfully at the designed current of 140 mA at 100 keV[5]. The proton beam from the ion source was focused by the two solenoids to match to the RFQ acceptance. The input and the output beam currents of the RFQ were measured by the Faraday cups of FC2 and FC3, respectively, and the RFQ transmission was deduced. The energy of the proton beam from the RFQ was measured by the compact magnetic energy analyzer (MEA) installed in the medium energy beam transport (MEBT). Figure 2 shows the beam energy spectra for five relative intervane voltages as well as the PARMTEQ simulated results. As the vane voltage is reduced, the energy spectrum shifts to the lower energy and many peaks are observed, which are in good agreement with the simulated results.

The maximum RFQ output current was 70 mA at the ion source extraction current of 155 mA. The ordinary RFQ operation current, however, was 50 - 60 mA at the ion source current of 125 - 135 mA to prevent an overheat to the ion source electrodes. The estimated transmission rate through the RFQ was around 70 %, although the precise proton fraction in the input beam was not clear due to the mass separation effects of the solenoids. There are several reasons to be considered for lower transmission than that of the designed value of 95 %. To reveal the reason for the lower transmission rate, re-alignment of the components, proton fraction and emittance measurements of the injected beam are being prepared.

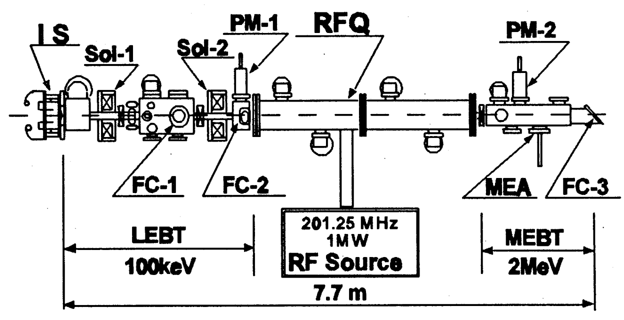

Fig.1 Layout of the RFQ beam test
FC: Faraday cup
PM: Beam profile monitor
MEA: Magnetic energy analyzer

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*** Mitsubishi Electric Corp.

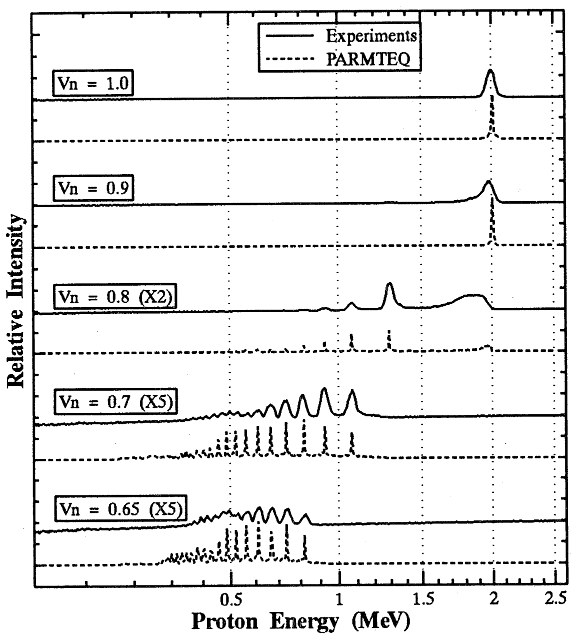

Fig. 2 Measured and simulated RFQ beam energy spectra

At the beginning of the beam test in JAERI, the maximum duty factor was limited less than 2 % due to the partial burn out of the RF contact at the RFQ. The silver plated spiral type RF contact, which is made of beryllium copper alloy, was used between the tank and the vane. To improve the heat transfer properties, it was replaced by a thicker silver plated type. In addition to the contact replacement, a copper block was installed to cover the open space between the vane and the tank to reduce the heat dissipation at the vane end region. As a result of these modification, a duty factor of 6 % at the beam current of 50 mA was achieved. The further study is in progress to achieve the designed duty factor of 10 %.

Development of the 1 MW RF Source

The RF source was designed and manufactured for the RFQ beam test and the DTL high power test. The tetrode tube, 4CM2500KG (EIMAC), is used with three-stage amplifier configuration[6].

The dummy load tests have been made successfully. The RF power output of 1 MW was achieved at the duty factor of 0.6 %, whereas the measured gain of the final stage amplifier is lower than the designed value. The power efficiency was 60 % which is in good agreement with the designed value of 62 %. At the high duty operation of 12 %, RF power of 830 kW was generated, which satisfied the requirement for the tests in the R&D.

The low level controller of the RF system includes feedback circuits to compensate power loss and phase shift due to the beam loading. The performance of the feedback system was examined in the RFQ beam test. Waveforms of the forward and reflected power from the RF source to the RFQ, RF pickup level in the tank and accelerated beam are shown in Fig. 3. The amplitude change was remarkably small to be within 0.5 % when the beam loading was 110 kW. On the other hand, the phase error was relatively large to be > 5 deg. The feedforward control system will be examined to improve the phase error.

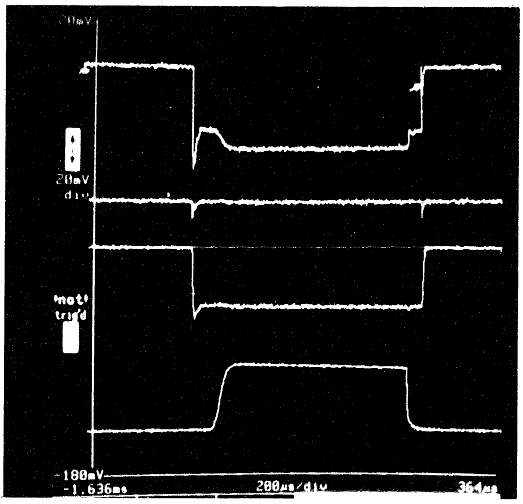

Fig. 3 RF characteristics of the RFQ operation. Waveforms of the forward power to the RFQ (top), reflected power (2-nd), pickup level at the RFQ tank (3-rd) and accelerated beam (bottom).

High Power Test of the DTL Model

A DTL hot test model with 9 cells, which is a mockup of the low energy portion of the DTL, has been fabricated to study the RF characteristics and the cooling capabilities[7]. An electromagnetic quadrupole using a hollow conductor (5mmx5mm) was chosen for the focusing magnet, of which field is 80 T/m with 5.5 turns of 780 amperes. Two quadrupole magnets have been fabricated and installed in the test model.

The high power test was carried out with the RF power source. Figure 4 shows the schematic layout of the test. Prior to the cooling capability test, high power conditioning was made with monitoring the vacuum pressure and the RF signals from the pickup loop and the directional coupler. In the conditioning, the input RF power of 128 kW with a duty factor of 20 % was fed to the model. Bremsstrahlung X-ray spectra from the gap were measured to estimate the gap voltage. The measured gap voltage was 195 kV at the RF power of 128 kW, which was in good agreement with the calculated value of 197 kV by the SUPERFISH code.

The measured RF heat dissipation power in the each drift tube and end plate was in good agreement with the SUPERFISH results. The frequency shift as a function of the

#8 drift tube temperature also agrees well with the calculated values as shown in Fig. 5. These high power test results confirm the heat dissipation calculation and the cooling design of the DTL.

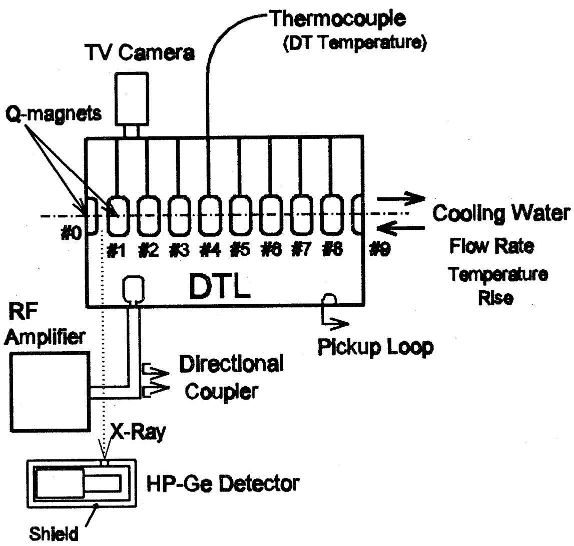

Fig. 4 Schematic layout of the DTL high power test

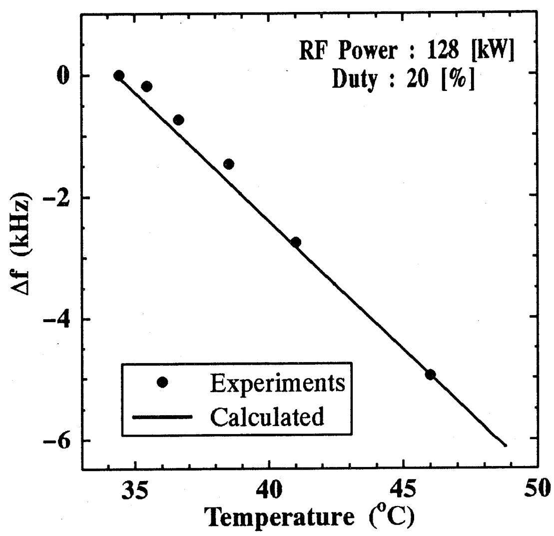

Fig .5 Frequency shift of the DTL model tank as a function of the #8 drift tube temperature

Summary and Plan

The R&D with the design and the fabrication of the prototype accelerator structures (ion source, RFQ, DTL and RF source) have been carried out. The good performance of the components has been confirmed, while some problems are remaining. For the RFQ, it is necessary to increase the duty factor and the transmission. For the DTL, erosion and corrosion in the hollow conductor will be examined to establish a reliable operation. These further R&D will be performed in FY-1995.

To inject the beam into the storage ring for the application of the basic researches, negative ion beam is required. The development of the negative ion source has been started and the R&D is continued[8].

For construction of the high intensity accelerator facilities, beam dump is one of the important issues to stop the accelerated beam effectively and safely. To investigate a beam stopper fabrication method and its thermal performance, preliminary mock-up experiment using 2 MeV proton beam has been started[9].

The superconducting (SC) cavity is one of the feasible candidates for the high-β structures and its design work is about to be started. For the injector of the SC cavities, continuous-beam or much longer duty operation will be required. Design work on the RFQ and DTL as well as SC cavities for the CW operation are being performed.

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