DEVELOPMENT OF A PROTON ACCELERATOR FOR THE JAERI NEUTRON SCIENCE PROJECT

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Abstract

The Japan Atomic Energy Research Institute has been proposing the Neutron Science Project (NSP). The joint project of the NSP and the JHF of KEK is under discussion. The new project makes use of the R&D results of the NSP and the JHF. The R&D activities of the proton accelerator at JAERI will be presented in this paper. The development work and characteristics measurements have been made for the low energy components of the linac; performance tests of a negative hydrogen ion source, development of an integrated type RFQ and high duty factor power tests of a DTL model tank. A superconducting linac is a main option for the high energy part of the linac. Vertical tests of a single cell superconducting cavity have been made. The maximum peak surface fields of 44 MV/m and 47 MV/m have been achieved for β=0.5 and 0.89 cavities, respectively. A 600 MHz IOT RF source has been manufactured and dummy load tests at 35 kW CW have been successfully conducted.

1 INTRODUCTION

A high intensity proton linear accelerator with an energy of 1.5 GeV has been proposed for the Neutron Science Project (NSP) at JAERI[1]. The aims of the NSP are to explore basic neutron science and nuclear energy related technologies. We have three stages to upgrade the beam power and duty factor. The operation mode in the first stage is a pulse for the neutron scattering experiments with beam power of 1.5 MW. By increasing a duty factor and peak beam current up to 20 % and 30 mA, respectively, beam power will be upgraded to 5 MW in the second pulse stage. The 8 MW CW beams will be provided for the nuclear waste transmutation experiments in the CW stage.

The joint project of the NSP and the Japan Hadron Facility (JHF) Project of KEK is under discussion to take more effective promotion of the scientific and engineering fields[2]. The new project makes use of the R&D results accomplished for the NSP. Several R&D items have been studied for high intensity accelerator development; 1) beam dynamics design and calculation, 2) a negative hydrogen ion source and fabrication of high power test models of RFQ and DTL, 3) superconducting cavities and 4) high power RF sources.

2 LINAC SYSTEM

A schematic drawing of the linac system is shown in Figure 1. The front-end part of the linac, which consists of RFQ, DTL and separated-type DTL (SDTL), uses normal conducting structures and the higher energy part uses superconducting linac (SCL). Basic parameters of the linac components are summarized in Table 1. The linac system design is described in detail in reference 3.

For the pulse mode operation, the intermediate pulsing choppers for the storage ring injection and extraction have to be installed, whereas no choppers are required for the CW operation. To obtain better beam quality by using optimized beam transport systems, injector lines for the pulse and for the CW operations are used. The two lines merge in the DTL section at 7 MeV, where the neutron generation due to the beam loss risks can be avoided.

The SDTL structure[4] is adopted for the higher energy DTL region because of some advantages such as the simpler structures and the smoother matching properties to the following section.

The superconducting linac (SCL) is a main option between 100 and 1500 MeV, because characteristics of the cavities are suitable for the high duty factor operation and less beam loss is expected due to the large bore size.

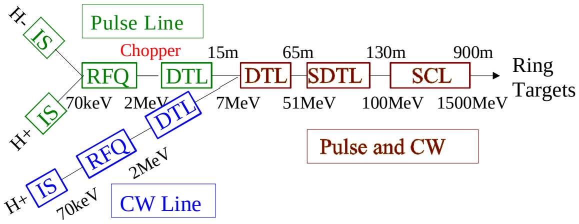

Figure 1. A schematic drawing of the linac system

3 DEVELOPMENT OF ACCELERATOR COMPONENTS

3.1 Negative Hydrogen Ion Source

Negative hydrogen beams are required to inject the beam into a storage ring. The beam extractor of the existing

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positive ion source has been modified to produce negative ion beams. The characteristics with cesium introduction of the negative ion beam have been examined at the duty factor of 5 %[5]. In the pure volume operation, the ion current has been limited to be 8 mA. In the cesium-seeded operation, the beam current has been enhanced and negative ion current and density of 21 mA and 33 mA/cm^2 have been obtained. An electron to negative ion current ratio is 4 in the cesium seeded, while 34 in the pure volume.

A new negative ion source has been fabricated to accumulate experimental data to fulfil the requirement of the NSP linac. A plasma chamber is installed outside of an insulator to change the configuration of the cusp magnet fields easily. Two differential pumping ports are equipped with the ion source. When the differential pumping system is on, the vacuum pressure in the Low Energy Beam Transport Line is improved from 7.5x10^{-5} to 1.0x10^{-5} Torr and the negative ion beam current is enhanced by 1.7 times. The experimental data have been obtained to be 11 mA without cesium. The beam test will be continued.

Table 1. Basic parameters of the linac components

Negative Hydrogen Ion Source	
Energy	70 keV
Current	50 mA

CW-RFQ	
Energy	2 MeV
Frequency	200 MHz
Peak field	1.5 Kilpatrick limit
Length	3.57 m
Duty	30 % (Pulse) , 100 % (CW)

CW-DTL/SDTL		
	DTL	SDTL
Energy	51 MeV	100 MeV
Frequency	200 MHz	200 MHz
E_0	1.5 MV/m	1.5 MV/m
Length	58 m	64 m

Superconducting Linac	
Energy	1.5 GeV
Frequency	600 MHz
Maximum Epeak	16 MV/m
No. of Cavities/ Modules	284/142
Length	690 m
Number of Cavity Group	8
Focusing Lattice	Doublet between modules

3.2 CW-RFQ

We have developed a four-vane type 2 MeV RFQ[6] based on the R&D of the OMEGA program. This RFQ has accelerated proton beams at a current of 70 mA with a duty factor of 10 % (a beam pulse length of 1 ms and a repetition of 100 Hz). At a duty factor of 1 % (a beam pulse length of 1 ms and a repetition of 10 Hz), a peak current of 100 mA has been achieved.

A new RFQ for the NSP is designed to operate at much higher duty factor (up to 30 %) pulse and CW modes. The RFQ is designed with lower electric field of 1.5 Kilpatrick limit to keep reliable operations and to reduce an RF wall loss power. The beam simulation results show that more than 95 % beam transmission is expected at the beam current up to 80 mA.

The R&D RFQ has spiral type RF contacts between a tank and vanes. The burnout problem at the contact was one of the most important issues to achieve high duty factor operations. To eliminate this problem, we have been developing an integrated type RFQ without RF contacts. A high power model with 50 cm long has been fabricated by brazing process. The 20 % duty factor operation has been achieved with an RF power of 40 kW, which is approximately 30 % beyond the normal operation power level. The duty factor has been limited by the RF source. An R&D of some metal joint processes such as electron beam welding (EBW) and laser beam welding as well as brazing is now underway.

3.3 CW-DTL and SDTL

The parameters for the CW-DTL are evaluated. Up to 7 MeV, two DTLs are prepared for the pulse and the CW lines. The lower E_0 of 1.5 MV/m is taken to reduce the heat dissipation of the structures and the RF power consumption. An equipartitioned design approach is taken to suppress the emittance growth[3,7]. The rms and the 90 % emittance growth rates are about 7 % and 10 % at the highest, respectively.

An R&D-DTL high power model with 9 cells for mock-up of the first part of the DTL was fabricated to study the RF characteristics and the cooling capabilities[8]. In 1995, the 20 % duty factor operation was achieved with an RF power of 128 kW, which corresponds to E_0=2MV/m. The high power model has been reinstalled and the 50 % duty factor operation with an RF power of 75 kW (E_0=1.5MV/m) has been achieved. The duty factor has been limited by a power supply of the RF source.

3.4 Superconducting linac

In the SC linac part, the proton velocities gradually change from 0.43 to 0.92 corresponding to the energies for 100 MeV and 1.5 GeV. Accordingly, the length of the cavity is also changed. Based on an optimization study, an SC linac with 8 groups has been designed[9]. The cavities in each group are made with identical 5 cells and two cavities are laid in one doublet focusing period. Q-magnet field gradient is determined by using the equipartitioning scheme. The transverse and the longitudinal rms emittances are nearly constant or only 1 % increase.

For the pulse beam operation, the mechanical resonant frequencies should be higher than the maximum repetition rate of 50 Hz. Analysis for the mechanical resonance has been carried out to evaluate the microphonic vibration[10]. An axial mode of 80 Hz for the β=0.499 cavity with 3 mm thick wall with stiffner is the lowest frequency mode. We have found that the stiffner is effective to increase the structural resonant frequency; in the case without stiffner, the lowest mode is transverse and the frequency is 38 Hz. We are studying better cavity from a practical point of view; stiffner type or thicker wall type.

Two sets of single SC test cavities have been fabricated for β=0.5, which corresponds to the proton energy of 145 MeV. Vertical tests have been conducted to examine the RF and mechanical properties. The maximum surface peak field strengths (E_{peak}) of 32 MV/m at 4.2 K and 44 MV/m at 2.1 K have been successfully obtained[11]. A single-cell cavity of β=0.886 has been also fabricated and tested. The peak fields have been 47 and 36 MV/m at 2 K and 4.2 K, respectively. These test results have satisfied the specification for the conceptual layout of the superconducting linac.

Two 5-cell cavities have been fabricated: one is made of copper and one is niobium. The copper model cavity is used to test a pre-tuning. Maximum deviation of the peak fields on axis at each cell center position is 37.5 % before the pre-tuning. After the pre-tuning, the deviation has improved to be 0.7 %. The pre-tuning, surface treatment and vertical test will be performed for the niobium cavity.

3.5 RF Sources

The RF sources are main components to determine the availability and reliability. They are most costly parts in the accelerator system. Two frequencies, 200 MHz and 600 MHz, have been selected in the low energy and the SC linac part, respectively. Required RF powers are 300 kW for RFQ, 9 MW for DTL/SDTL and 25 (pulse mode) or 7.5 MW (CW mode) for the SC linac, respectively. An RF system design by using a grid tube (tetrode), a Klystron and an IOT (Inductive Output Tube) has been carried out.

In the SC linac RF system, the RF source has to be operated in the high power pulse mode and low power CW mode. Klystrons are to take their maximum efficiency at the full saturation power. To keep higher efficiency in the low power range, the beam voltage reduction is effective[12].

The IOT is one of the favorable RF sources to cover the wide power range without significant degradation of the efficiency. A 600 MHz IOT system (TH760, Thomson) has been manufactured and dummy load tests have been conducted. The gain and the efficiency at 35 kW were 22 dB and 61 %, respectively. The phase and amplitude have kept within +-0.5% and +- 0.5 degree in 270 minutes duration at 35 kW CW.

4 SUMMARY

The linac design and development work has been made for the NSP. The good performances of the components such as an ion source, RFQ, DTL and RF source have been achieved. The vertical SC cavity test has been successfully conducted resulting in the satisfactory maximum surface electric field strength.

The R&D's of the accelerator components will be continued based on the new Joint Project parameters.

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