A HIGH INTENSITY PROTON LINAC DEVELOPMENT FOR THE JAERI NEUTRON SCIENCE PROJECT

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Abstract

JAERI has been proposing the Neutron Science Project (NSP) which will be composed of a high intensity proton accelerator and various research facilities. The accelerator with an energy of 1.5GeV and a beam power of 8MW is required to operate both with pulse mode for basic research fields and CW mode for nuclear waste transmutation studies. A superconducting (SC) linac is a main option for the high energy portion from 100MeV to 1.5GeV. A beam test with an ion source and an RFQ has been performed with a current of 80mA and a duty factor of 10 % at the energy of 2MeV. A hot test model of DTL has been fabricated and tested with a duty factor of 20%. A test stand for SC linac cavity with equipment of cryogenics, vacuum, RF and cavity processing and cleaning system has been prepared to test the fabrication process and physics issues. The vertical test of a β=0.5 (145MeV) single cell SC cavity has been made resulting in a maximum electric field strength of 44MV/m at 2K.

1 INTRODUCTION

JAERI has been proposing the Neutron Science Project which aims at exploring the fields of basic science and nuclear technology using a high intensity proton accelerator[1]. The design studies are being carried out for a high intensity pulsed and cw spallation neutron sources for basic research fields of material science and biology and for accelerator-driven transmutation technology of long-lived radioactive nuclides from nuclear power generation The major facilities to be constructed under the project are, 1) a superconducting proton linac with a proton energy of 1.5GeV and a maximum beam power of 8MW, 2) a spallation neutron target station with input beam power of 5MW for neutron scattering, and 3) a research facility complex for accelerator-driven transmutation experiment, neutron physics, material irradiation, isotopes production, RI beam experiment for study of exotic nuclei. A conceptual layout for the NSP LINAC is given in Fig.1.

JAERI had originally planned to build a pulsed linac with an energy of 1.5GeV and a peak current of 100mA with 10% duty factor. The design study has been made to confirm technical feasibility to accelerate high peak current with high duty operation from the beam dynamics point of view. In this accelerator development, the R&D work has been performed on high brightness ion source, radio frequency quadrupole linac (RFQ), drift tube linac (DTL) and RF source, as well as the conceptual design of the whole accelerator components.

JAERI has altered the original plan by proposing an option of superconducting (SC) linac to meet requirements for a variety of basic research fields mentioned above and an ultimate goal for waste transmutation[2]. This SC linac will be operated in pulse as a first stage for the spallation neutron source and upgraded in CW for engineering test as a second stage. These two operational modes, pulse and CW operation, will be realized with time sharing manner, not simultaneously, and is the most challenging technical issues for the accelerator development.

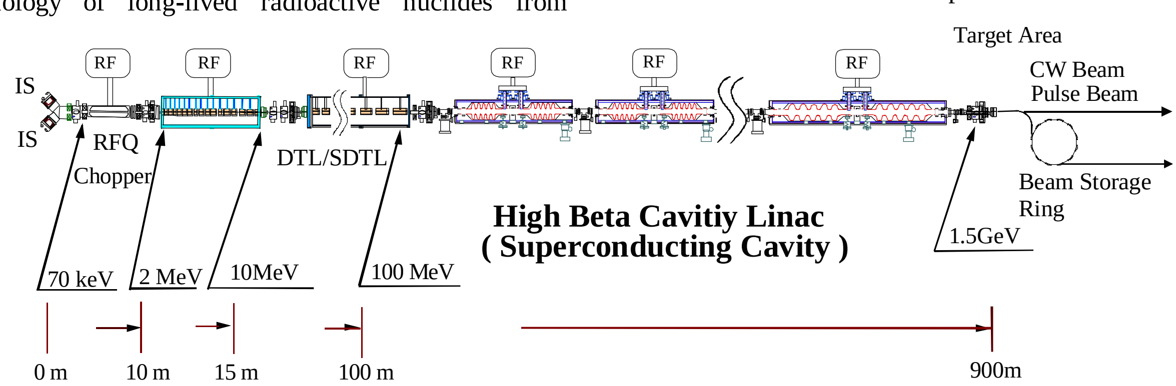

Fig. 1 A conceptual layout of the JAERI NSP-LINAC

The SC linacs have several favorable characteristics as follows; the large bore radius results in low beam loss, the length of the linac can be reduced, and high duty and CW operation can be made for engineering purposes. The possibility to inexpensive operation cost may be also expected in comparison with normal conducting (NC) option.

Several R&D items have been studied for high intensity accelerator development; 1) the beam dynamic calculation including the high β linac. 2) the development of the negative ion source and the fabrication of high power test models for CW-RFQ and CW-DTL. 3) the SC cavity development, 4) the high intensity proton storage ring and 5) high power RF source development. A specification of the JAERI NSP LINAC is given in Table 1.

Table 1 A specification of JAERI NSP LINAC

Particles	Negative and positive ion
Energy:	1.5GeV
Beam current:	
1st stage;	Pulse average 1mA, peak 16.7mA (duration 2ms, repetition rate 50Hz)
2nd stage	CW<5.33mA
	Pulsed average<5.33mA, peak 30mA
Low energy:	RFQ &DTL/SDTL Normal-
High energy:	Conducting linac: 200MHz
Chopping:	Superconducting linac: 600MHz
	60% (intermediate pulse width of 400ns)

2 2MeV RFQ BEAM TEST AND DTL HIGH POWER TEST

The R&D work for the low energy portion has been carried out as a first step in the development with a positive hydrogen ion source and a pulsed RFQ. This R&D-RFQ is a four-vane type and designed to accelerate 100mA (peak) of protons to 2MeV with a duty factor of 10%. The low power tuning, the high power conditioning and the beam tests were carried out[3]. The layout of the 2MeV RFQ and the R&D results are shown in Fig.2. The proton beam from the 100keV ion source was focused by the two solenoids to match the RFQ acceptance. The maximum RFQ output current, which was currently achieved, was 80mA at the ion source extraction current of 155mA with 10% duty factor. The transmission in the low energy beam transport (LEBT) from the ion source to the RFQ was about 65% with the proton fraction of about 80% in the ion source beam. The maximum transmission rate through the RFQ was obtained to be 90% at the most optimum ion source condition. The rms emittance values from the ion source and RFQ are minimum to be 0.15 πmm.mrad and about 0.62 – 0.76 πmm.mrad at the beam current of 170mA, respectively. These emittance values are not satisfactory and the further improvement is needed.

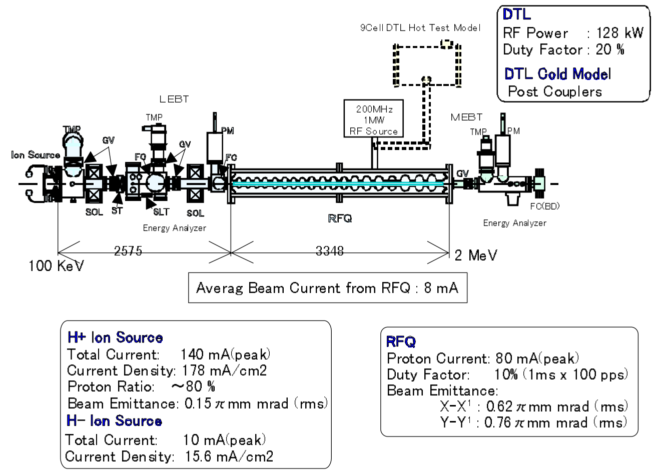

Fig.2 The R & D Results of Low Energy Accelerator Parts

An R&D-DTL hot test model with 9 cells for mock-up of the first part of the DTL has been fabricated to study the RF characteristics and the cooling capabilities. The 20% duty operation was achieved with a RF power of 128kW. The further test of CW operation with this hot model is being prepared. The 1/3 scaled DTL cold model installed with post couplers and 60 DT cells, which corresponds to the energy region of 2-10MeV, was also fabricated. The effects with post coupler such as field distribution, the detuning sensitivity and mode spacing were tested. The parameters of post coupler configurations (total numbers and positioning) has been obtained for stabilization of the accelerating fields[4].

3 LOW ENERGY PART BE LOW 100MeV FOR THE NSP LINAC

3.1 New Design for the Low Energy Part

In order to realize the short pulse for basic research with the proton storage ring and the final CW operation, new R&D's are carried out including negative ion source and CW-RFQ/CW-DTL in addition to the SC linac development. At the high energy part of DTL, the SDTL (separated type of DTL) proposed by Kato[5], KEK, has been studied. The SDTL, which has higher shunt impedance and simpler mechanical structure than DTL, is an attractive option for CW operation in the energy region of 50 - 100MeV where the SC linac can not be applicable.

3.2 Ion Source

A negative ion beam is required for basic research to inject the beam into the storage ring which produce 1 μs pulse. The beam extractor of the existing positive ion source used for previous beam experiment was modified to produce negative ion beams from source ion plasma by providing the transverse magnetic field. The characteristics of the negative ion beam have been examined with the maximum observed beam current of 21mA at an arc discharge power of 35kW[6].

A new negative ion source has been fabricated to accumulate experimental data to fulfil the requirement to the NSP linac. A schematic drawing of the ion source is shown in Fig. 3. A plasma chamber is installed outside the insulator to change easily the configuration of the cusp magnet fields. The vacuum pumping system is also improved. The preliminary data have been obtained to be 11mA beam extraction without Cesium from the test experiment.

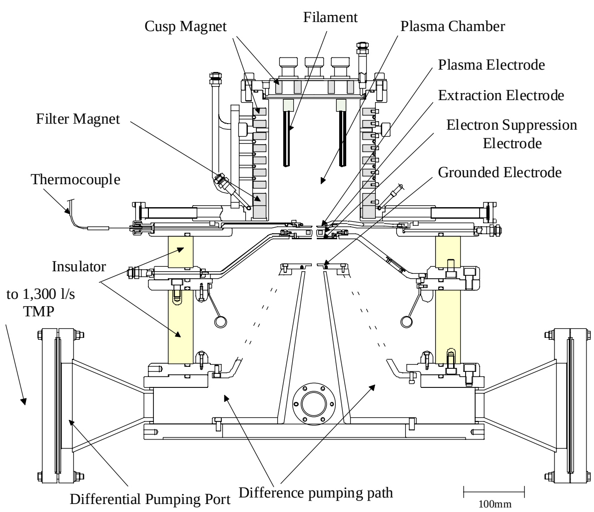

Fig.3 A schematic drawing of new negative ion source

3.3 RFQ for Pulse and CW operation

The low energy part should be capable for the CW mode operation as well as the pulse mode, because the SC linac has been operated with CW. The scheme to prepare two independent RFQs together with ion sources for pulse and CW operation is considered to meet these two different operational conditions[7]. The pulse mode RFQ is optimized at a beam current of 30mA. The maximum peak electric field of 1.65Ek is chosen. The CW mode RFQ is optimized below a current of 10mA with lower electric filed of 1.5Ek. Figure 4 shows design parameters vs length for the pulse mode and the CW mode RFQs. The beam simulation is performed with the PARMTEQ and PARMTEQM codes. The similar performance for transmission rate and transverse and longitudinal emittances were obtained with the calculations. Because the most important problem for the R&D-RFQ was found to be the RF contact between vane and tank, the RFQ will be made as integrated type by brazing between vane and tank. The high power model 50cm long was fabricated and tested with a power of 60kW and a duty factor of 20%.

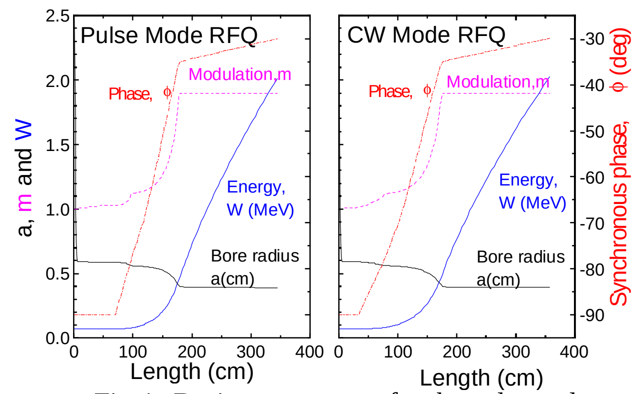

Fig.4 Design parameters for the pulse and the CW RFQs

3.4 CW-DTL/SDTL

The parameters for the CW-DTL are also re-evaluated to match the CW operation for the SC linac design concept. The SDTL concept has been also adopted to improve the performance for CW operation. Relatively low accelerator gradient of 1.5MeV/m is taken in order to reduce the RF power consumption and the RF heating. The expected maximum magnetic field gradient for the focusing magnet is about 50T/m using the hollow conductor type Q-magnet. The end point energy for the SDTL is 100MeV which is determined from the beam dynamics and mechanical consideration of the high β structure.

The beam dynamics study is conducted to obtain the optimized parameters for each accelerator structure. An equipartitioned design approach is taken for the DTL/SDTL to maintain the good beam quality and to prevent emittance growth causing beam losses. Figure 5 shows a concept of the CW-DTL and SDTL[4].

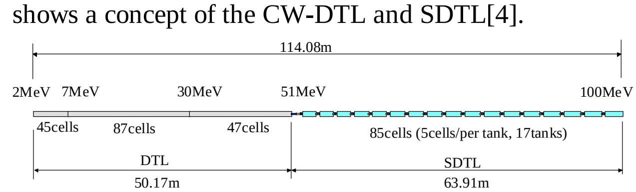

Fig. 5 A concept of DTL and SDTL

4 HIGH ENERGY ACCELERATOR PART

4.1 The layout of the superconducting linac

In the SC linac part, the proton velocities β gradually change from 0.43 to 0.92 corresponding to the energies for 100MeV and 1.5GeV. Accordingly, the length of the cavity is also changed. Main concern is the strength of the cavity under the vacuum load for the low β (β<0.7) region. The mechanical structure calculations with the ABAQUS code have been made to determine the cavity shape parameters as well as electromagnetic ones with the SUPERFISH code.

are shown in Fig.7. The equipartitioning factor of about 0.9, which is defined by $\gamma_0(\varepsilon_{nx}/\varepsilon_{nz})(z_m/a)$ where z_m and a are radius and longitudinal half length of ellipsoidal bunch, respectively, shows the design parameters nearly equipartitioned. There is only 1% increase of the transverse and the longitudinal rms emittances.

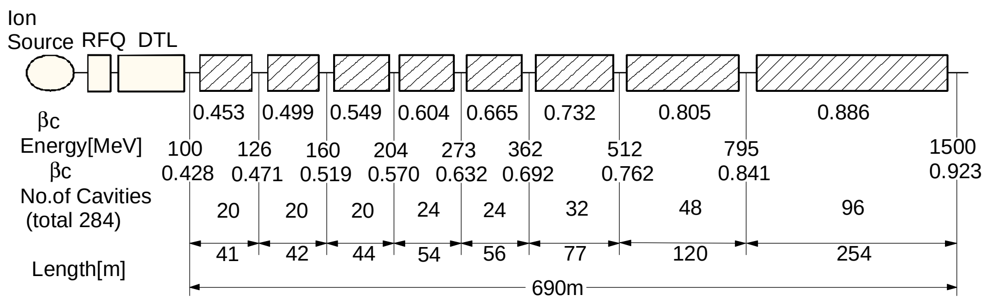

Fig. 6 Basic parameters for superconducting(SC) linac.

In order to determine the layout of the SC accelerating structure, the case of the SC linac, which is composed of 8 different β sections has been studied[8]. The cavities in each β section will be made with identical 5 cells and designed at the specific beam energy but also can be operated at slightly different beam energy with lower efficiency. The maximum peak surface field is set to be 16MV/m. Two cavities are laid in one doublet focusing period. The conceptual layout and basi parameters of the superconducting linac are shown in Fig. 6. The structure of the cryomodule, input/HOM couplers and tuning devices etc. are being designed based on the KEK-TRISTAN (high energy e+, e- colliding machine) experiences. Using these parameters, calculations for the beam dynamics have been made with the modified PARMILA code. The equipartitioned design approach is also taken for the SC linac. The design and beam simulation results of the SC sections such as wave numbers, the beam sizes and the equipartitioned factors

4.2 Fabrication and test of a superconducting cavity

The test stand for a superconducting cavity development with the cryostat 80cm dia. x 350cm long and a clean room has been constructed[9]. Two sets of single SC test cavities have been fabricated for β =0.5 which corresponds to the proton energy of 145MeV. Fabrication process such as cold rolling and press of pure Niobium metallic sheet, electron beam welding, surface treatment (barrel polishing, electro-polishing and high pressure water rinsing, etc.) has been performed based on the KEK experiences for 500MHz TRISTAN cavity. Vertical tests have been conducted to examine the RF and mechanical properties. Figure 8 shows the results of performance test for two prototype cavities. The measurements were made several times for each cavity. The maximum surface peak field strength of 24MV/m at 4.2K and 44MV/m at 2.1K have been successfully

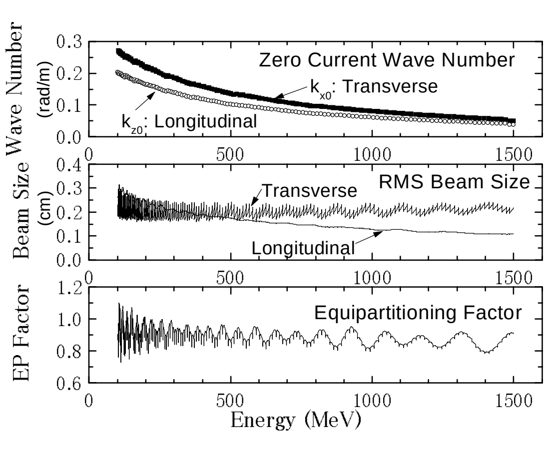

Fig.7 Design and beam simulation results of the superconducting linac section

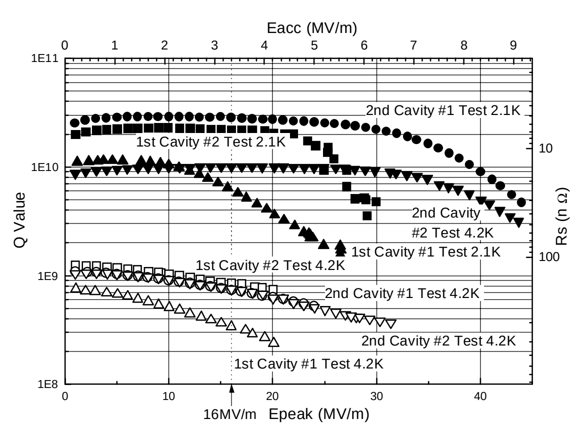

Fig.8 Results of the performance tests for two prototype cavities; Q valuses as a fuction of the surface peak electric field (Epeak)

obtained for 2nd cavity. The Q values of 2.8×10^{10} at 2K and 7.3×10^{8} at 4.2K were obtained at E_{peak}=16MV/m[10]. This result was reconfirmed at the recent 2nd experiment although the Q values this time was lower to be 1×10^{10} at 2K because some deterioration of the surface condition occurs during the intermediate period. Those test results have satisfied the specification for the conceptual layout of the superconducting linac.

5 RF SOURCES

The RF sources are main components to determine the availability and reliability, and most costly parts for the accelerator system. Two frequency choices, 200MHz and 600MHz, have been selected in the conceptual study for low energy and high energy part, respectively, where total peak RF powers of about 300kW for RFQ, 9MW for DTL/SDTL and 25MW for SC linac are required for pulse operation. Due to the different two mode operations and gradual upgrade path, optimization for RF configuration is one of the most important technical issues. An RF system based on the Grid tube (Tetrode) Klystron and IOT has been carried out[11]. As an example, Figure 9 shows RF power requirements for 8 different β sections for each operating condition in the SC linac.

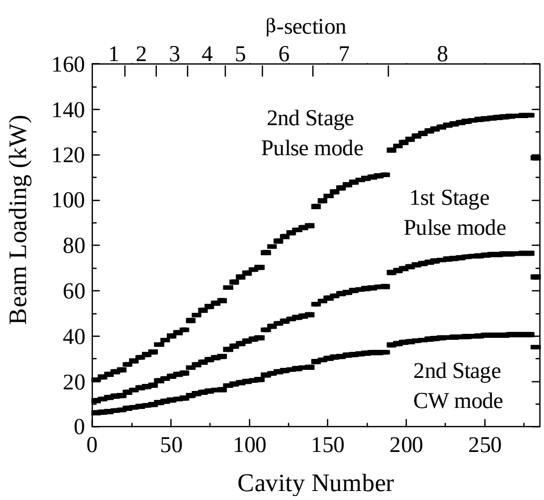

Fig.9 Beam loading for each cavity

6 SUMMARY

The R&D work for the prototype linac structures has been performed. The good performances of the components such as ion source, 2MeV-RFQ, RF-source have been achieved. The test stand for the SC cavities was constructed. The vertical SC cavity test has been successfully conducted resulting in the satisfactory maximum surface electric field strength for the SC proton accelerator. The design work on the RFQ and DTL/SDTL as well as SC cavities for the CW operation is performed.

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