A HIGH INTENSITY PROTON LINAC DEVELOPMENT FOR NEUTRON SCIENCE RESEARCH PROGRAM

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Abstract

The high-intensity proton linac with a beam energy of 1.5GeV and a maximum current of 10mA has been proposed for the Neutron Science Research Program (NSRP) in JAERI. The NSRP is aiming at exploring new basic researches and nuclear waste transmutation technology based on spallation neutron. The R&D work has been carried out for the components of a low energy part of the proton accelerator and conceptual design study on superconducting accelerating cavity as a main option for a high energy part (high β linac) above 100MeV.

The proposed plan for accelerator design and construction will be composed of two consecutive stages. The first stage will be completed in about 7 years with the beam current of 1mA. As the second stage, gradual upgrading of the beam current will be made up to the final maximum value of 10mA.

Introduction

In 1980's, research activities have been made for high intensity proton linacs to be applied to the nuclear fuel breeding and high level radioactive waste transmutation. After the OMEGA (the partitioning and transmutation research) program was proposed by the Japan Atomic Energy Agency, JAERI started the work to study an accelerator-driven transmutation system of minor actinides. In addition to the development of the OMEGA program, new basic neutron researches on material science, neutron irradiation, neutron physics and many other potential applications for applying the intense linac have been also discussed. Those include meson/muon production and spallation RI beam (mainly for nuclear physics studies) and radio isotope production.

JAERI had originally planned to build the pulsed linac with an energy of 1.5GeV and a peak current of 100mA with 10% duty factor[1]. The design study has been intended to apply the accelerator to the engineering test for the transmutation system and obtain the technical validity to accelerate high peak current from the beam dynamics point of view. In this accelerator development, the R&D work has been continued 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. In the beam test, the current of 70mA with a duty factor of 10% has been accelerated from the RFQ at the energy of 2MeV. A hot test model of the DTL for the high power operation with high duty factor was fabricated and tested[2]. The conceptual layout of the NSRP-LINAC is shown in Fig. 1.

High Intensity Linac Development

General Concept

Recently, JAERI has modified the original plan by proposing an option of superconducting (SC) linac to meet requirements for a variety of basic researches mentioned

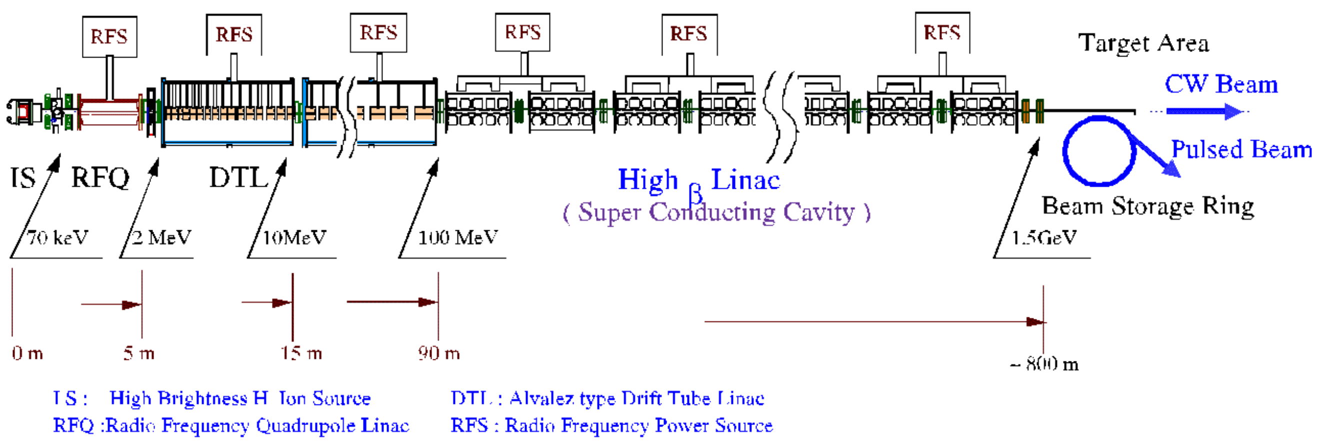

Fig. 1 A conceptual Layout of the Accelerator for the Neutron Science Research Program

above and an ultimate goal for waste transmutation. This SC linac will be operated in pulse as a first stage for the spallation neutron source and gradually upgraded toward CW by increasing duty factor. The SC linacs have several favorable characteristics as follows; the length of the linac can be reduced, which can meet the rather stringent requirement from the limited area of our laboratory site, and high duty operation can be made for simultaneous experiments. The possibility to inexpensive operation cost may be found in comparison with normal conducting (NC) option.

A preliminary specification for the NSRP LINAC is given in Table 1. The final value of the energy/current, accelerating frequency and pulse time structure etc. will be determined from further discussions based on the user requirement and the cost estimate. In particular, because the relationship between the energy and the current is complimentary, the reduction of the energy value can be compensated by increasing the beam current. Neutron scattering facility will require more strict pulse time structure. The beam chopping capability with about 400ns intermediate pulse length will be needed to compress the beam width by the storage ring. Three major R&D items are presently carried out. 1) the beam dynamic calculation including the high β linac. 2) the development of the negative ion source[3] and the fabrication of high power test models for CW-RFQ and CW-DTL. 3) the SC cavity development with the KEK electron SC group[4].

Table 1 A preliminary specification of the JAERI NSRP-LINAC

Energy	1.5GeV
Accelerated particle	Negative and positive hydrogen ion
Average current:	First stage; 1mA Second stage; Maximum 10mA
Low energy part	Normal-conducting linac: 200MHz
High energy part	Super-conducting linac: 600MHz
Pulse structure	First stage ; Pulse mode operation Second stage; CW/pulse mode operation
Repetition rate	maximum 50Hz
Macropulse width	2ms (at1mA operation) -> maximum CW
Intermediate pulse width	400ns (interval 270ns)
Chopping factor: Peak current	60%: nominal 17mA

Low Energy Accelerator Part

In the case of a high intensity accelerator, it is particularly important to maintain the good beam quality (low emittance; small beam size and divergence) and minimize beam losses to avoid damage and activation of the accelerator structures. The R&D work for the low energy portions has been made as a first step in the NSRP-LINAC development. Table2.1 gives the preliminary specification of negative ion source which will be necessary for the injection into the storage ring.

Table 2.1 Preliminary Specification of Negative Ion Source

Accelerated particle	H^-
Energy	70keV
Current	30mA
Emittance(rms)	0. 2πmm.mrad
Type	Single /multi-aperture Volume type

Because the superconducting accelerator has been selected for the high β linac, the low energy part should be capable for the CW mode operation. The design study has been started to develop the CW-RFQ (at 200MHz) cavity in the range of 20Å`30mA. From the experience of the pulse RFQ operation, the maximum electric field will be reduced to be 1.43 Ek (Kilpatric Limit) compared to the previous value of 1.63Ek. The calculated transmission for the CW-RFQ is 97% for 20mA and more than 90% expected for the wider range of 0 - 60mA. Because the most important problem for the R&D-RFQ was the RF contact between vane and tank, the CW-RFQ will be made as integrated type by brazing without any RF contact between vane and tank. In 1996, the high power test model of the CW-RFQ of 50 cm in length is fabricated and tested in order to establish the manufacturing and assembling techniques. Table 2.2 gives the preliminary specification of the CW-RFQ.

Table 2.2 Preliminary Specification of CW-RFQ

Energy	70keV - 2MeV
Current	nominal 17mA
Frequency	200MHz
Vane voltage	88kV
Length	3228mm
Number of cells	183
Bore radius	5.93mm
Synchronize phase	-30^{o}
Total power	280kW(60%Q)

The parameters for the CW-DTL are also re-evaluated to match the CW operation for the new superconducting design concept. The frequency of the CW-DTL is chosen to be

200MHz. Accelerator gradient may be lowered to be 1.5MeV/m in order to reduce the RF consumption and the RF heating. The expected maximum magnetic field gradient for the focusing magnet is about 60.1T/m using the hollow conductor type Q-magnet. The end point energy for the DTL is 100MeV which will be determined from the beam dynamics and mechanical consideration of the high β structure.

Table 2.3 Preliminary Specification of CW-DTL

Energy	2-100MeV
Current	nominal 17mA
Frequency	200MHz
Accelerating gradient	1.5MV/m
Synchronize phase	-35° - -25°
Number of cells	239
Length	90.17m
Focus gradient	60.1T/m - 26.6T/m
Total wall loss	3.16MW (100%Q)

High Energy Accelerator Part

Superconducting cavity is selected as main candidate for high energy portion. In the CW electron accelerator, technologies of SC accelerators are established. Long design and operating experiences are accumulated and routinely used for the operation such as KEK-TRISTAN and other many accelerator laboratories. In the proton accelerators, however, 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 also has change. Main concern is the strength of the cavity under the vacuum load for the low β 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[4].

In order to determine the layout of the SC accelerating structure, two typical cases of the SC linacs, which are composed of 4 different β sections and 8 different β sections, respectively, have been studied. The cavities in each β section will be made identical with 4 cells and designed at the specific beam energy but also can be operated at slightly different beam energy with lower efficiency. The structure of the cryomodule, input/HOM couplers and tuning devices etc. are being designed based on the KEK-TRISTAN experiences. Using these parameters, preliminary calculation for the beam dynamics has been made with the modified PARMILA code. Preliminary data is given in Table. 3.

The test stand for a superconducting cavity development with the cryostat 80 cm dia. x 350 cm long and a clean room is under preparation and the first SC test cavity will be fabricated and tested within 1996.

Table3. Preliminary Parameters for the SC Linac

Case	4 sections E_p=16MV/m	8 sections E_p=16MV/m
Cavity configuration	4 cells	4 cells
Average synchronize phase	-30.1°	-29.4°
Accelerating length (m)	292	276
Total length (m)	769	719
Number of cavities	408	378
Number of cells	1632	1512
Output emittance (50mA)		
x:πcm.mrad (rms)	0.11	0.11
y:πcm.mrad (rms)	0.12	0.12
z:πdeg.MeV (rms)	1.55	1.64
Total wall loss (kW)	23.3	23.3

E_p:Maximum peak field

Summary

The R&D work for the prototype linac structures (ion source, RFQ, DTL and RF source) has been performed. The good performance of the components has been achieved.

Since 1995, the basic specification for the accelerator has been changed such as negative ion acceleration, SC cavity option and storage ring. The new design modification has been started. The test stand for the SC cavities is under preparation. For the injector of the SC cavities, continuous-beam or much longer duty operation will be required. The design work on the RFQ and DTL as well as SC cavities for the CW operation is being performed.

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