HIGH INTENSITY PROTON ACCELERATOR FOR NEUTRON SCIENCE PROJECT AT JAERI

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Abstract

The high-intensity proton accelerator with an energy of 1.5GeV and a beam power of 8MW has been proposed for the Neutron Science Project (NSP) at JAERI. The objective of the NSP is to explore technologies for nuclear waste transmutation based on proton induced spallation neutrons and various basic research fields such as material sciences in combination with a high intensity proton storage ring. The accelerator is required to operate both with pulse and CW mode. The R&D work has been carried out for the components of the low energy accelerator parts; negative ion source, RFQ, DTL/SDTL and RF source. For the high energy portion above 100MeV, superconducting (SC) accelerator linac has been designed as a major option for the high β linac. A single cell cavity of the SC linac has been fabricated and tested. The conceptual design study for storage ring is in progress. The paper will present the summary on the development plan to build the accelerator and the results of conceptual design study and the R&D work.

1 INTRODUCTION

Japan Atomic Energy Research Institute, JAERI, has been proposing the Neutron Science Project (NSP) which is composed of research facilities based on a proton accelerator with an energy of 1.5GeV and an average current of 5.3mA[1]. The conceptual layout of the accelerator for the NSP is shown in Fig. 1.

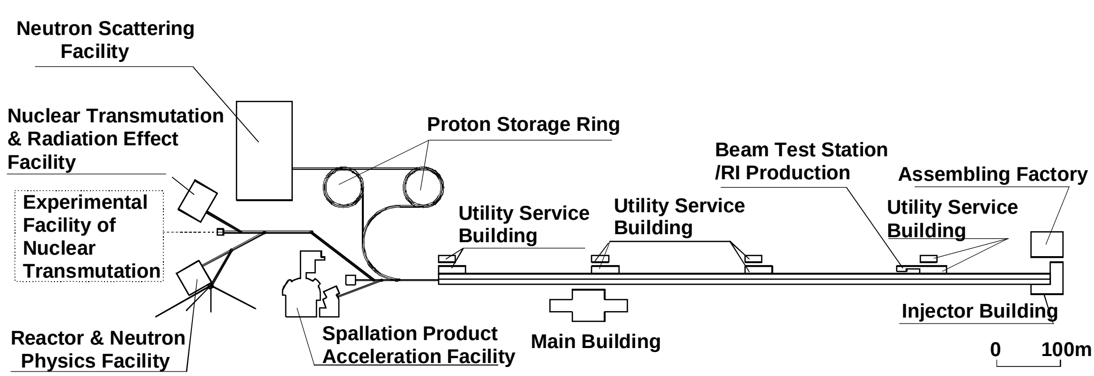
The proton accelerator will be operated in pulse as a first stage for the spallation neutron source and upgraded in CW for engineering test as a second stage. These two operational modes, pulse and CW operation, will be realized with time sharing manner, not simultaneously, and is the most challenging technical issues for the accelerator development. In the case of a high intensity accelerator, it is important to maintain good beam quality and minimize beam losses to avoid damage and activation of accelerator structures.

Several R&D items are studied for the high intensity accelerator development; 1) the beam dynamic calculation including the low energy accelerator parts and the high β linac. 2) the negative ion source and the fabrication of high power test models for CW-RFQ and CW-DTL. 3) the SC cavities, 4) the high intensity proton storage ring and 5) the high power RF sources.

A specification for the NSP LINAC is given in inlet of Fig.1. Because neutron scattering facility will require strict pulse time structure, the beam chopping capability with about 1μs intermediate pulse length will be needed to compress the beam width by the storage ring.

2 LOW ENERGY ACCELERATOR PART

Because the beam quality and maximum current are mainly determined by the low energy portion of the accelerator, the R&D work for these portions has been made as a first step in the development. In order to realize the short pulse with the proton storage ring and the final



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

Fig. 1 A Schematic Layout and Requirement of the NSP Accelerator

CW operation, R&D's are carried out including negative ion source ,CW-RFQ, CW-DTL and SDTL (separated type of DTL) at the high energy part of DTL. Table 1 summarizes the basic parameters for the low energy accelerator parts.

Table 1. Parameters of Low Energy Accelerator Part

Ion Source		
Energy Current	70keV 50mA	
CW-RFQ		
	Pulse	CW
Energy Current Frequency Peak field Length Pulse width	2MeV 20 - 40mA 200MHz 1.65Ek 3.45m 6ms	2MeV 7mA 200MHz 1.5Ek 3.57m CW
CW-DTL/SDTL		
	DTL	SDTL
Energy Current Frequency Accel. gradient Number of cells Length	50MeV 30mA 200MHz 1.5MV/m 179 58m	100MeV 30mA 200MHz 1.5MV/m 85 64m

2.1 Ion Source

The beam extractor of the existing positive ion source used for previous beam experiment was modified to produce negative ion beams. 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 with 5% duty factor and Cesium seeded[2].

2.2 RFQ for Pulse and CW operation

The low energy part should be capable for the CW mode operation with a current of 5.3mA as well as the pulse mode with 30mA 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[3].

2.3 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[4] has been adopted to obtain smooth transverse matching to the following SC linac. Relatively low accelerator gradient of 1.5MV/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 SC linac.

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[3].

3 HIGH ENERGY ACCELERATOR PART

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. Table 2 gives the basic parameters for the high energy accelerator part.

3.1 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 ($\beta<0.7$) 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.

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. 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 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[3,5].

Table 2 Parameters for SC Linac

Energy	1.5GeV
Current	30mA
Frequency	600MHz
Eacc	2.4MV/m-8.0MV/m
Number of cavities	284
Length	690m

3.2 Fabrication and test of a superconducting cavity

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.) have been performed based on the KEK experiences for 500MHz TRISTAN cavity. Vertical tests have been conducted to examine the RF and mechanical properties. The maximum surface peak field strength of 24MV/m at 4.2K and 44MV/m at 2.1K have been successfully obtained for the first time as proton SC accelerator cavity[6]. This test result has satisfied the specification for the conceptual layout of the superconducting linac.

4 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 29MW for SC linac are required for pulse operation[7]. Due to the different two mode operations and gradual upgrade path, optimization for RF configuration is one of the most important technical issues.

5 PROTON STORAGE RING

The linac beam is chopped to 670ns bunch width with 60% duty cycle. The 1.5GeV H^- linac beam is compressed by means of a multi-turn charge exchange injection. When a harmonic number of the ring is 1, a circumference and a revolution frequency are 185m and 1.49MHz, respectively. The single bunch in the ring is contained by RF resonant cavity. To achieve a beam power of 5MW with this beam structure, it is necessary to accumulate 4.17×10^{14} protons with one ring. Table 3 gives the parameters for the storage ring

Because the average current circulating in one ring scheme becomes about 100A, in such a high average current, even a very small fractional beam loss makes a very high radioactivity around the ring. It is necessary to examine reduction and localization of the beam loss with sufficient consideration of the divergence of the beam by the space charge force, the resonance phenomena by the tune shift, longitudinal instability. It is, therefore, considered to prepare two separate rings for 2.5MW and combine them to obtain the 5MW beam[8].

Table 3 Parameters for Two 2.5MW Ring Scheme

Energy	1.5GeV
Repetition frequency	50 Hz
Harmonic number	1
Circumference	185.4 m
Number of circulating protons	2.08×10^{14} protons/ring

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 SC proton accelerator. The design work on the RFQ and DTL/SDTL as well as SC cavities for the CW operation is performed. The preliminary design study for the high intensity storage ring is carried out.

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