Development of High Intensity Accelerator For Neutron Science Project

Motoharu MIZUMOTO. Joichi KUSANO. Kazuo HASEGAWA. Nobuo OUCHI. Hidetomo OGURI. Michikazu KINSHO. Yutaka TOUCHI. Yoichiro HONDA. Ken MUKUGI. Hiroshi INO. Fumiaki NODA. Nobuo AKAOKA. Hiroshi KANEKO. Etsuji Chishiro. Benjamin FECHNER

Proton Accelerator Laboratory
Japan Atomic Energy Research Institute
Tokai-mura. Naka-gun. Ibaraki-ken 319-11. Japan

Abstract

The high-intensity proton linear accelerator with an energy of 1.5GeV and an average current of 5.33mA has been proposed for the Neutron Science Project (NSP) at JAERI. The NSP is aiming at exploring nuclear technologies for nuclear waste transmutation and various basic research fields such as condensed matter physics based on a proton induced spallation neutrons. The R&D work has been carried out for the components of the front-end of the proton accelerator. For the high energy portion above 100MeV. superconducting (SC) linac has been designed and developed as a major option. A high intensity proton storage ring is also studied for basic research facility.

1. Introduction

After the partitioning and transmutation research program for high level radioactive nuclear wastes. OMEGA. was proposed by the Japan Atomic Energy Agency (AEC) in 1988. JAERI started an intensive work to study the accelerator-driven transmutation system of minor actinides. The JAERI's activities cover the development of an high intensity proton accelerator development. In recent years. there has been an additional growing interest in new intense neutron sources for basic research fileds. While previous neutron source development has been mainly concentrated in neutron data measurements for fission reactor development. new sources are largely required for applications in material sciences. In material sciences. a large number of investigations involve slow neutron scattering techniques. and many of these have been carried out at high-flux fission reactors. An alternative technology. however. started to attract the strong interest for generating neutrons based on the intense proton accelerator.

In addition to such basic neutron researches. many potential applications for applying the intense accelerator has been discussed. which include spallation RI beam (mainly for nuclear physics studies). meson/muon production and radio isotope production. A conceptual layout of the accelerator for the Neutron Science Project is shown in Fig. 1[1].

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. The design study has been intended to obtain the technical validity 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 continued on high brightness ion source. radio frequency quadrupole linac (RFQ). drift tube linac

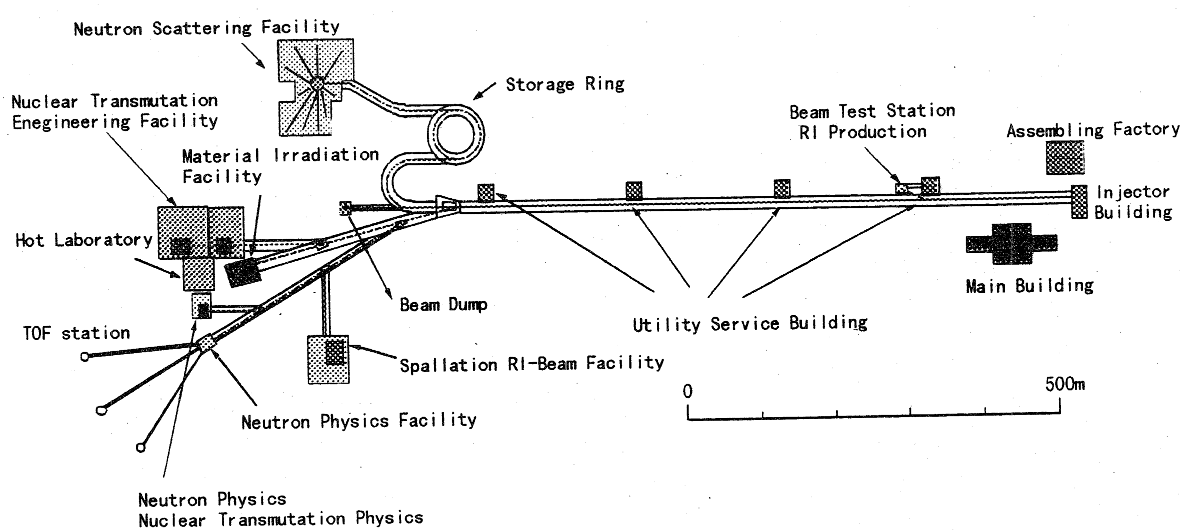

Fig. 1 Conceptual Layout for Neutron Science Project

(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[2].

JAERI has modified the original plan by proposing an option of superconducting (SC) linac to meet requirements for a variety of basic researches mentioned 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 requirement from the limited area of the 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.

Preliminary specifications for the NSP LINAC are given in Table 1. 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

2.1 Beam tests of the 2MeV R&D-RFQ

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 portion has been made as a first step in the NSP-LINAC development. The 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 first beam test were carried out. 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 70mA at the ion source extraction current of 155mA with 10% duty factor. The transmission in the low energy beam transport (LEBT) form ion source to RFQ was about 60% with the proton fraction of 80% in the ion source beam. The estimated transmission rate through the RFQ was 80%.

2.2. Low energy part for the NSP-linac

As the first R&D stage of the ion source development, a positive hydrogen source was fabricated and successfully operated at the full design values of 100keV and 140mA peak. The negative ion beam is then required for basic science researches to inject the beam into the storage ring which produces specific pulse width and repetition rate. 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 5.5mA at an arc discharge power of 18kW.

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 cavity in the range of ~30mA. Since the most important problem for the R&D-RFQ was found to be the RF contact between vane and tank, the CW-RFQ as integrated type by brazing between vane and tank in under investigation.

The parameters for the CW-DTL are also re-evaluated to match the CW operation for the new superconducting design concept. Accelerator gradient is selected 1.5MeV/m in order to reduce the RF power consumption and the RF heating. The expected maximum magnetic field gradient for the focusing magnet is about 60T/m using the hollow conductor type Q-magnet. The end point energy for the DTL is 100MeV which is determined from the beam dynamics and mechanical consideration of the high β structure. The 1/3 scale Aluminum cold model for an

Table 1 Preliminary specifications of the JAERI NSP Linac

Parameters	Operational conditions
Energy:	1.5GeV
Accelerated particle :	Negative and positive hydrogen ion
Average current: First stag:	1mA
	Maximum 5.33mA
Low energy part Second stage:	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 30mA

injection part of DTL up to 10MeV has been fabricated to evaluate conditions of the post couplers. Some basic parameters for the accelerating field stabilization has been obtained[3].

3. High Energy Accelerator Part

3.1. Layout of the superconducting linac

Superconducting cavity is selected as a main candidate for high energy portion. In the proton accelerators, 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 to be 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.

In order to determine the layout of the SC accelerating structure, a typical 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 identical with 5 cells and designed at the specific beam energy but also can be operated at slightly different beam energy with lower efficiency.

3.2. Test of superconducting cavities

The test stand for a superconducting cavity development with the cryostat 80cm dia. x 350cm long and a clean room has been constructed [4]. A single SC test cavity has 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. A first vertical test has been conducted to examine the RF and mechanical properties. The maximum field strength of 20MV/m for 4.2K and 26.6MV/m for 2.1K have been successfully obtained as first time for proton SC accelerator. This test result has satisfied the specification for the conceptual layout of the superconducting linac.

4 Proton Storage Ring

In the beam storage ring, the pulsed beam from the linac is accumulated, and high intensity pulsed beam is produced for the neutron scattering experiment. The linac beam is chopped to 670ns bunch width with 60% duty cycle at 50Hz. 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. It is important to examine reduction and localization of the beam loss with sufficient considerations of the divergence of the beam by the space charge force, the resonance phenomena by the tune shift and longitudinal instability. The design studies and beam simulation for such high intensity proton ring have been carried out and some preliminary results have been obtained [5,6]

5. Summary

The R&D work for the prototype linac structures 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 has been constructed. The design work on the RFQ and DTL as well as SC cavities for the CW operation is being performed. The vertical cavity test has been successfully conducted resulting in the satisfactory maximum electric field strength for SC proton linac.

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