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5.1 Linac Design for the KEK/JAERI Joint Project

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Abstract

The Japan Hadron Facility of KEK and the Neutron Science Project of JAERI have been merged to one project; the KEK/JAERI Joint Project for high-intensity proton accelerator facility. The accelerator for the Joint Project comprises a normal- and super-conducting linac, a 3-GeV rapid cycling synchrotron and a 50-GeV synchrotron. The linac design is described in this paper. The total length of the linac is approximately 360 m. The normal conducting linac provides a 400-MeV beam to the 3-GeV synchrotron and to the superconducting linac. The superconducting linac provides a 600-MeV beam to an accelerator-driven nuclear waste transmutation system (ADS).

1. Introduction

The Japan Atomic Energy Research Institute (JAERI) and the High Energy Accelerator Research Organization (KEK) are proposing "the Joint Project for high-intensity proton accelerator facility"[1] by merging their Neutron Science Project (NSP)[2] and the Japan Hadron Facility Project[3]. The NSP was originally proposed for the accelerator driven nuclear waste transmutation system (ADS), and the accelerator complex comprises a 1.5-GeV proton linac and storage rings. The JHF comprises a 50-GeV synchrotron, a 3-GeV rapid cycling synchrotron (RCS) and a 200-MeV linac[3]. The beam is used for fundamental particle physics, nuclear physics, materials science, life science and others. Since both projects have some common goals by a key word "high-intensity proton accelerators", the Government suggested a joint effort to one proton facility in Japan.

Figure 1 shows a plan view of the Joint Project. The facility will be constructed at the JAERI/Tokai site. The accelerator complex for the Joint Project consists of a 600-MeV linac, a 3-GeV RCS and a 50-GeV synchrotron. The 600-MeV beams are for the ADS experiment. The 3-GeV, 1-MW beam is provided to the pulsed spallation neutron experiments and muon experiments. The 50-GeV beam is used for particle and nuclear physics.

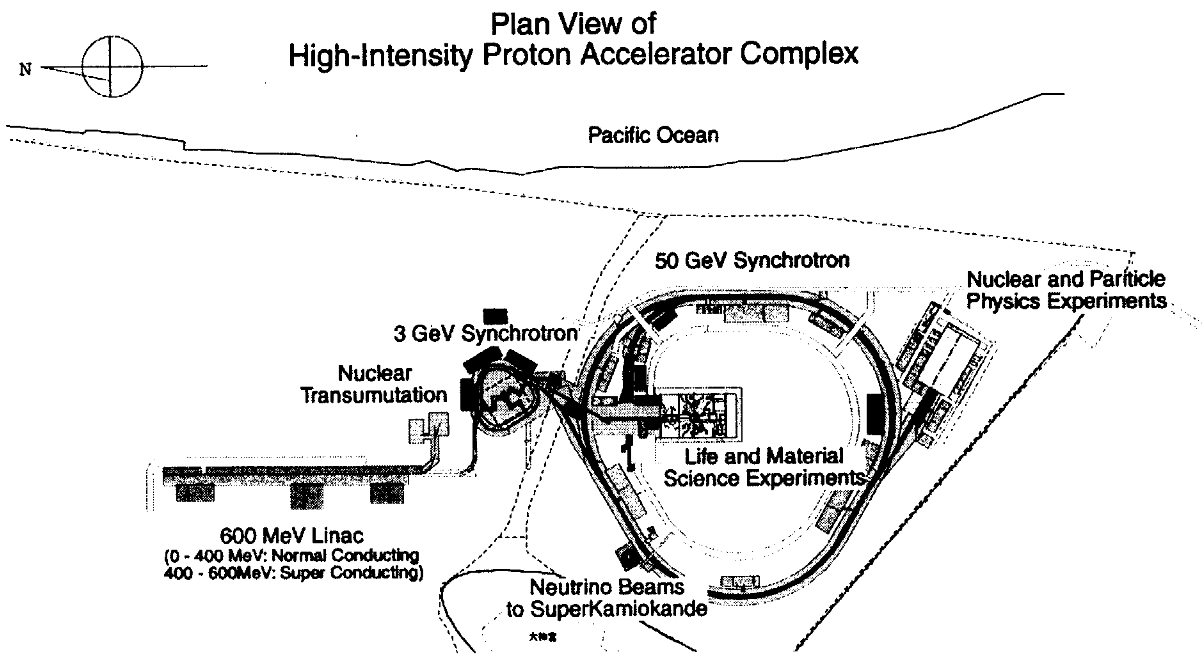

Fig.1 Plan view of the Joint Project Accelerator Complex

2. Overview of the Linac Design

Since the 50-GeV synchrotron requires several-GeV injection beams, the accelerator scheme is based on the RCS in contrast to the scheme of a full-energy linac and a storage ring option as the SNS or the ESS project. The H^- beam from the linac is injected to the RCS during 0.5 msec, which is limited by the flat bottom of the sinusoidally varying magnetic field of the 25 Hz RCS.

The block diagram and key parameters are shown in Fig. 2 and Table 1. Parameters are slightly modified after the Linac2000 Conference in Monterey[4]. The linac plays two roles; one is to inject the beam to the RCS, and the other is to provide the beam to the ADS. The high-energy part of the 600-MeV linac uses superconducting (SC) cavities, which can be a prototype of the future CW accelerator for the ADS applications. A peak current of 50 mA for H^- ion beam of 0.5 msec pulse duration is accelerated at a repetition rate of 50 Hz. The linac uses normal-conducting cavities up to 400 MeV. By using an AC switching magnet at 400 MeV, the half (25Hz) of the 400-MeV beam from the linac is injected to the RCS, while the other half is further accelerated up to 600 MeV by the SC linac. An RF frequency of 324 MHz has been chosen for low-energy structures and 972 MHz for high-energy structures.

3. Design of the Low Energy Linac Part

A negative hydrogen ion source is designed and will be examined to produce at least 60 mA peak current. An RFQ linac accelerates the beam up to 3 MeV, a DTL up to 50 MeV, and a Separated type DTL (SDTL) up to 190 MeV. The frequency of 324 MHz is the highest-possible choice, for which an electromagnetic quadrupole magnet can be embedded in a drift tube at 3 MeV. The electromagnetic quadrupole system has much more tuning knobs against beam current and emittance variations than those of the permanent magnet system.

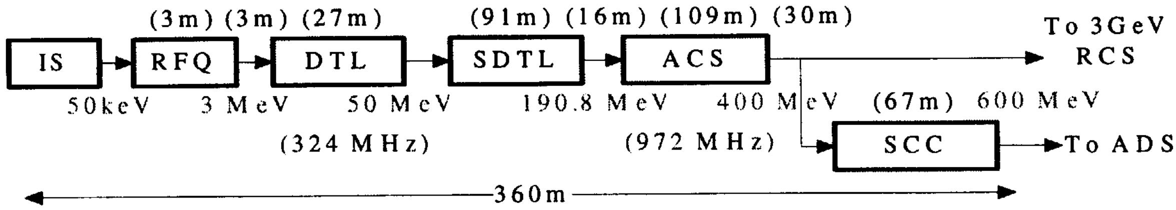

Fig.2 Block diagram of the linac

A 3-MeV, 324-MHz RFQ with PISLs is under construction at KEK[5]. Since the RFQ is designed for the original JHF project, the peak current is limited to 30 mA. Design of a new RFQ for 50 mA acceleration is underway.

The RFQ is followed by a medium energy beam transport (MEBT). The 3-m long MEBT consists of 8 quadrupole magnets and two bunchers[6]. In order to reduce beam losses after injection into the RCS, a fast beam chopper is required. The bunch length is 396 nsec in a period of 733 nsec. The chopping system is one of the most difficult items to be developed. A newly devised RF deflecting chopper[7] is used in the MEBT and the test will be carried out.

The DTL accelerates the beam from 3 to 50 MeV. Each tank is stabilized with post couplers. The maximum electric field on the surface of drift tubes is less than the Kilpatrick limit (17.8MV/m). The coupled envelope equations and the equipartitioning theory are used for the focusing design[3]. Since the transverse beam size increases gradually along the linac, a bore radius of the drift tubes varies by three steps to take enough margin to the beam sizes; 6.5, 11 and 13 mm.

A new structure, an SDTL[8] has been chosen after 50 MeV. The SDTL has very similar principles of the conventional DTL, but it uses shorter tank with several cell structures. The SDTL has some advantages to the DTL:

(1)Geometrical shape optimization to maximize the shunt impedance with ease.
(2)A stable accelerating field without post couplers.
(3)Easier alignment tolerance of drift tubes and tanks.
(4)Separation of the transition point in the transverse and the longitudinal motion to reduce a degradation of beam qualities. For this linac, the transverse transition point is at 50 MeV (before the SDTL) and the longitudinal transition point is at 190 MeV (after the SDTL).

Table 1 Key parameters of the linac

Parameter	RFQ	DTL	SDTL	ACS	SCC
Output energy (MeV)	3	50	190.8	400	600
Section length (m)	3.1	27.1	91.2	109.2	69.0
Structure length (m)	3.1	26.7	65.7	68.2	24.4
Frequency (MHz)	324	324	324	972	972
Accelerating field (MV/m),E0		2.5 ~ 2.9	2.5 ~ 3.7	4.3	13.3
Vane Voltage (kV)	82.9 (1.8Kilp)				
Number of cavities	1	3	32	46	30
Synchronous phase (deg)	-30	-30	-27	-30	-30
Copper RF power (MW)	0.34	3.3	15.1	29.4	
Total RF power (MW)@50mA	0.48	5.7	22.1	39.9	10
Number of klystrons	1	3	16	23	15
Aperture radius (mm)	3.7 (average)	6.5 ~ 13	18	20	30@Q, 45@Cav.
Number of cells	294	146	160	690	210

4. Design of the Medium Energy Linac Part

A coupled-cavity linac (CCL) is a natural choice from 190 MeV to 400 MeV, if we use normal conducting structures. Among the possible candidates in the CCLs, an annular coupled structure (ACS)[9] is a preferable choice owing to its axial symmetry, which may be important to minimize a halo formation. Figure 3 shows the schematic drawing of the ACS. The tank has 15 cells and two tanks are coupled via a bridge coupler. The bridge coupler is a disk-loaded structure and has an input iris port at the middle cell. Transverse focusing is provided with doublet quadrupole magnets. The fundamental RF issues concerning the ACS were solved and a high-power test using a 1296-MHz model cavity was successfully performed[9]. Detailed design work and brazing tests of the 972-MHz ACS cavities are underway.

In order to satisfy the requirement of the momentum spread, a debunching system is necessary in the beam transport (BT) line between the linac and the RCS. Considering the site boundary and arrangement of some target stations, there is no possibility to take optimum length from the linac to the RCS. In the current design, the length of the BT line is approximately 330 m. The BT line consists of a matching section from the previous doublet lattice to an FODO section, a transport line, an achromatic bending system with emittance and momentum scrapers and matching section to the RCS. A full energy spread of ±0.07 MeV is obtained at a debuncher voltage of 4.0 MV, located at a distance of 50 m from the ACS. Since the energy spread becomes larger again due to the space charge, another debuncher of 1.3 MV is required at 200 m. The debuncher is a similar cavity of the 324-MHz SDTL.

Another accelerating structure choice of this energy region is the SC linac. Detailed design and technology experiments are underway considering the pulse mode operation[10].

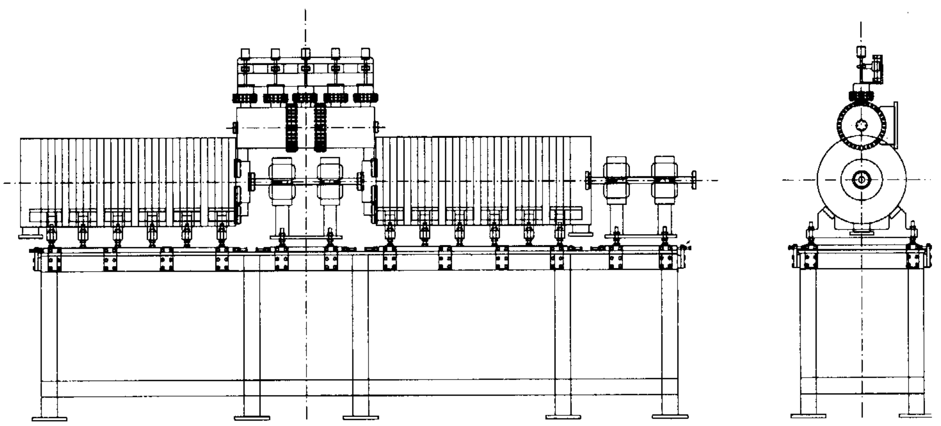

Fig. 3 Schematic drawing of the ACS

5. Design of the High Energy SC Linac Part

In the first phase of the Project, the SC linac[11] has a role to accelerate from 400 to 600 MeV for the ADS experiments. The system design is conducted as the similar manner as the NSP design[12]. The SC linac consists of cryomodules containing two 7-cell 972-MHz niobium accelerating cavities. Quadrupole magnets provide focusing with a doublet lattice located in a room temperature region between cryomodules; these regions also contain beam diagnostics and vacuum systems. From the lengths in Table 1, the cavities are occupied only 35 % in the total length (24.4/69.0)=0.35.

According to the quench condition experiments for the high-field SC cavities, the maximum accelerating field is determined by a multipacting referred to the magnetic field, not by a field emission or sparking referred to the electric field. In the current design, maximum magnetic field is set to be 525 Oe, which corresponds to the peak field of 30 MV/m. Total length and the number of the cryomodules are 69 and 15, respectively.

To reduce emittance growth, the lattice design is performed according to a nearly equipartitioned condition. Beam simulations are carried out using the PARMILA code. The 90-% emittances and RMS beam sizes along the SC linac are shown in Fig. 4. Since the equipartitioning scheme has applied in this design, emittance growth rates in the transverse and the longitudinal directions are as small as 5 % and –3 %, respectively. The beam sizes are nearly constant, because the energy range is not so wide in this SC linac. Ripples of the transverse beam sizes are due to the modulation of the doublet focusing system. The RMS beam size in transverse direction is 0.2 cm at the highest. The bore radius is 3 cm at the quadrupole magnets and 4.5 cm at the cavities. The ratio of bore radius to RMS beam size is greater than 15, which may be enough for the beam losses in the linac. One of the upgrade paths to increase 3-GeV beam power is to take the higher injection energy to the RCS. The RCS requires a linac beam with a momentum spread within ± 0.1 %, which refers to ±1MeV at 600 MeV. According to the evaluation of the effects of the RF phase and amplitude control errors, phase and amplitude errors within ±1 degree and ±1 % are required. After the momentum spread will meet the requirement, 600 MeV beam accelerated by the SC linac will be injected to the RCS to upgrade the beam power.

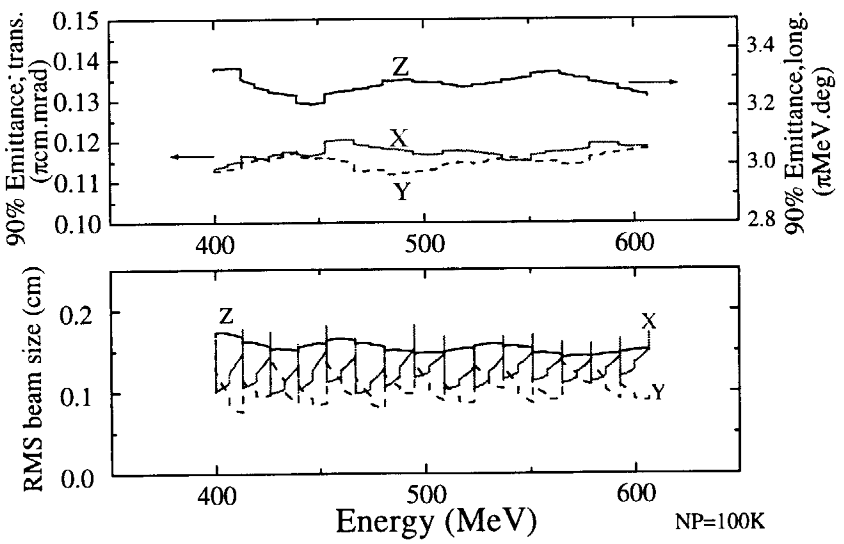

Fig. 4 90-% emittances and RMS beam sizes in the SC linac

6. Summary

The system design of the linac is almost completed. To obtain better performances, new structures such as the SDTL, the ACS and the SCC are adopted. The layout of the linac building and conventional facilities are designing.

The R&D programs have been performed in order to overcome various difficulties associated with their high-intensity characteristics. Construction of the 60-MeV linac[13-15] started for the JHF at KEK in 1998. It includes the 324-MHz RFQ, the DTL and the first two tanks of the SDTL. The beam commissioning of the ion source has been started and of the RFQ linac will be scheduled in spring, 2001. Since these two components were designed for a peak current of 30 mA, they will be replaced in the future. These components, however, will be used for beam tests of the DTL and SDTL for the time being. After construction and beam commissioning of the 60-MeV linac have been completed, the linac will be transferred to the Tokai site and used for the Joint Project.

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