THE JAERI/KEK JOINT PROJECT AND ITS PERFORMANCE

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Abstract

The construction of a high-intensity proton accelerator facility, proposed by the Japan Atomic Energy Research Institute (JAERI) and the High Energy Accelerator Research Organization (KEK), has been started at Tokai campus of JAERI. The accelerator consists of a 400-MeV linac, a 3-GeV synchrotron and a 50-GeV synchrotron. The 400-MeV injection linac is comprised of a H^- ion source, an RFQ, a Drift-Tube Linac (DTL), a Separated DTL (SDTL), an Annular Coupled Structure (ACS) linac and several beam transport lines. A beam test of the Medium Energy Beam Transport (MEBT) line has been started with a 3 MeV H^- ion beam accelerated by the RFQ at the test facility at KEK. The construction of the first tank of the DTL is almost completed and the other DTL tanks are under construction. The first DTL tank will be aligned on the beam line soon. Furthermore the first two tanks of the SDTL were constructed and the high-power test has been done successfully. The newly developed techniques for linac of the project are mainly described with the overview of status of the project.

1 INTRODUCTION

The high-intensity proton accelerator facility project in Japan was formed by joining together the Neutron Science Project (NSP) of Japan Atomic Energy Research Institute (JAERI) and the Japan Hadron Facility (JHF) Project of High Energy Accelerator Research Organization (KEK). Both NSP and JHF project aimed mainly to push the study of the material science using the strong neutron beam.

The another main purpose of the NSP was to carry out the experiment of the Accelerator-Driven transmutation System (ADS) [1]. While that of the JHF project was studying the nuclear/particle physics using several secondary particle beams.

Because the construction and installation of the low energy part of the linac for the JHF ware started before the engagement of the joint project, the low energy part of the linac and RF sources will be move to JAERI from KEK in the near future.

The new project is sometimes called the JAERI/KEK Joint (JKJ) project. The facility will be constructed at the Tokai site of JAERI, about 130 km north-east of Tokyo. The schematic layout of the facility is shown in Fig. 1. The accelerator complex consists of following accelerators:

- 400-MeV normal-conducting linac,
- 600-MeV superconducting linac to increase the energy from 400 to 600 MeV,

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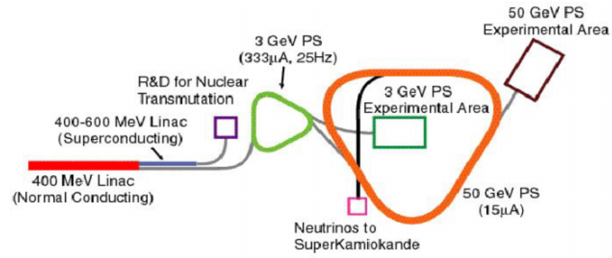

Figure 1: Configuration of the Accelerator complex.

- 3-GeV synchrotron ring, which provides proton beams at 333μA (1MW), and
- 50-GeV synchrotron ring, which provides proton beams at 15μA (0.75MW).

One half 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 a superconducting (SC) linac. The 600-MeV beam is transported to the experimental area for the ADS. The SC linac and ADS are included in the second phase of the project.

Although the 3-GeV RCS ring is used as a booster synchrotron for the 50-GeV main ring, the 3-GeV beam from the RCS is mainly used to produce pulsed spallation neutrons and muons. The muon-production target and the neutron-production target are, respectively, located in series in the Materials and Life Science Experimental Area.

A part of the beam from the RCS is injected into the 50-GeV synchrotron. The 50-GeV beam is slowly extracted in order to produce the secondary particles for the nuclear/particle physics experiment. It is also fast extracted for neutrinos experiments, which are conducted at the SUPERKAMIOKANDE detector located 300 km from the Tokai site.

2 LINAC

The linac uses normal-conducting cavities up to 400-MeV, while it uses superconducting cavities (SCC) from 400 to 600 MeV, as shown in figure 2.

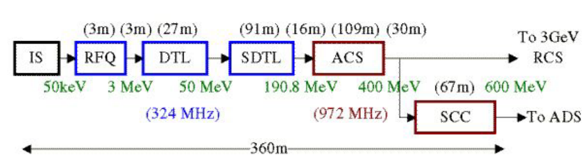

Figure 2: Layout of the proton linac.

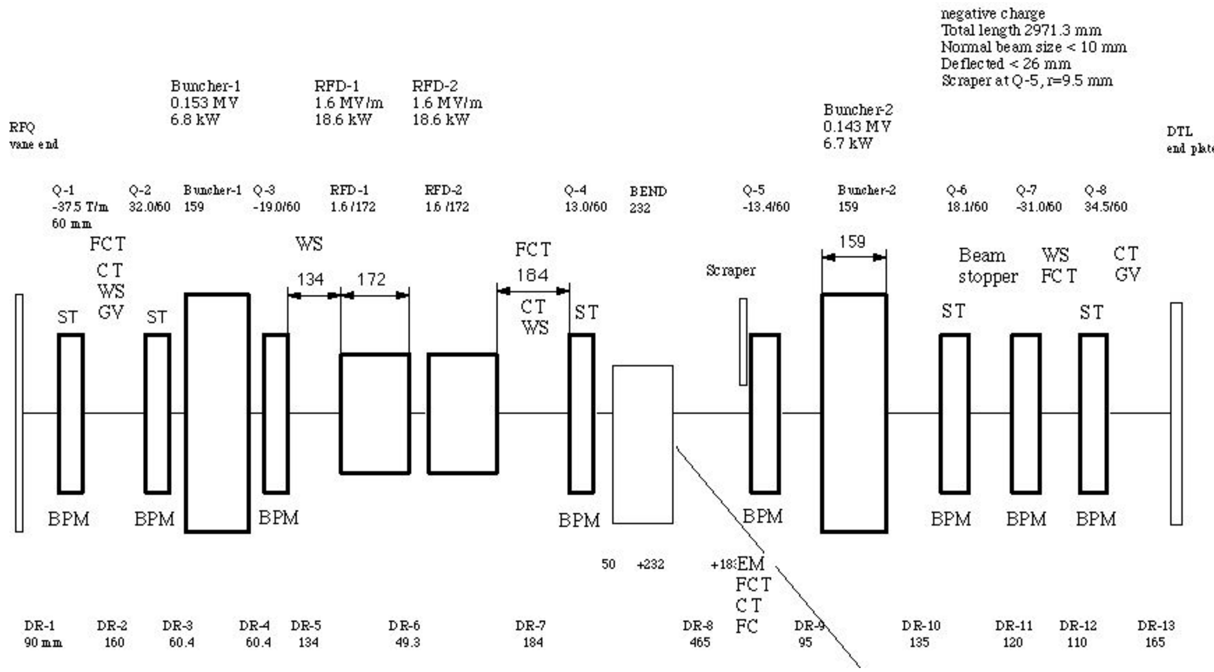

Figure 3: MEBT layout.

Requirements for the linac up to 400 MeV are summarized as follows;

Current	Average	675 μA
	Peak	50 mA
Pulse	Pulse width	500 μsec
	Chopping ratio	56 %
	RF duty (600 μsec)	3%
Beam	Momentum width	Δp/p = $\pm$0.1% (100%)
	Emittance	3$\sim$5 π mm-mrad (99%)

Because the linac system up to 60 MeV were originally developed for the Japan Hadron Facility (JHF) project of which the required beam intensity was 30 mA, it is not so easy to achieve the new requirement of the joint project (50 mA).

2.1 H^- ion source

A volume-production type of H^- ion source without cesium has been developed in KEK for JHF project to produce a peak current of 30 mA with a pulse length of 500 μsec and a repetition rate of 50 Hz. The extraction voltage of the H^- ion source is 50 kV. The H^- ion source in KEK has achieved approximately 25 mA in maximum with 100$\sim$200 μsec in pulse length and 25 Hz in repetition rate. Because the achieved values are not small but less than designed one (30 mA x 500 μsec x 50 Hz), the modification of the H^- ion source is still on going. Furthermore the H^- ion source is being used for the beam experiment for the RFQ and the medium-energy beam transport (MEBT) line located just before the DTL.

The H^- ion source in JAERI has achieved the maximum output current of 70 mA with cesium. Thus the peak current has exceeded the design value. The next step is to extend the life of filament and evaluates the effect of cesium flows into RFQ from the H^- ion source since the contamination of cesium probably make the sparking in the extraction/acceleration gaps of the H^- ion source and the intervane gaps of the RFQ.

2.2 LEBT

The low-energy beam transport (LEBT) line between the H^- ion source and the RFQ comprises with two solenoid magnets and pre-chopper cavity which decelerates the beam energy lower than the energy limit which the RFQ can accept. The pre-chopper at the LEBT and the chopper at the MEBT described in the next section are used to chop the beam of about 56% of initial value. The installation of the pre-chopper is being done.

2.3 RFQ

The RFQ was designed to accelerate 30 mA with a transmission of more than 90% by minimizing the beam emittance, especially in the longitudinal phase-space. The contamination of the dipole mode which deforms the accelerating field is minimized by the pi-mode stabilizing loop. Designed performance has been confirmed by the basic beam study [2].

2.4 MEBT

The beam, accelerated up to 3MeV by the RFQ, is transferred to the following DTL through the MEBT for the matching and diagnostics of the beam [3].

The MEBT consists of the following components: (1) eight focusing quadrupole magnets for the straight line; (2) two buncher cavities; (3) a chopper cavity with two gaps; (4) a bending magnet for beam analysis; (5) several beam position monitors in the Q-magnets and current transformers. Schematic layout of the components are shown in figure 3.

The beam study for the test and the tuning of the component is being carried out from this spring. During the study the performance of the chopper was confirmed at first. The chopper is a rf kicker cavity with two gaps. Schematic view of the chopper is shown in figure 4.

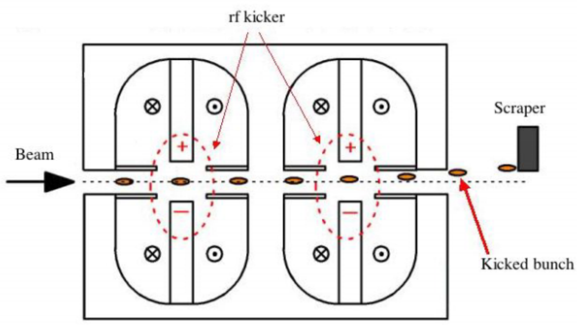

Figure 4: Schematic view of the Chopper cavity.

The example of the chopped beam is shown in figure 5. It is the measured chopped beam signal from a beam position monitor (BPM) positioned at the exit of the MEBT.The transient durations for both rising and falling times are about 10 nsec, corresponding to three micro bunches at a frequency of 324 MHz. Here, the chopped pulse beam width is minimized for studying details of the transient parts. [4].

2.5 DTL

The Alvarez type DTL, which accelerates the H^- ion beam from 3MeV to 50 MeV, consists of the three independent tanks of which the length is about 9 m.

The resonance frequency is 324 MHz. It is the highest-possible frequency, for which the 3MeV drift tubes can accommodate electromagnetic quadrupoles. The higher frequency is more preferable for suppressing the space-charge effects. The electromagnetic-quadrupole system obviously keeps much more knobs than the permanent magnet system. This frequency is nearly the lowest-possible one for the use with klystrons, practically speaking.

The DTL has been designed for the acceleration of the 30 mA beam as mentioned before. However the DTL may be able to handle the increment of the beam current to be accelerated since both focusing power of the quadrupole magnet and cooling power of the tank can be increased.

The tank cylinders have been made with the newly established copper electroforming method on the steel. The

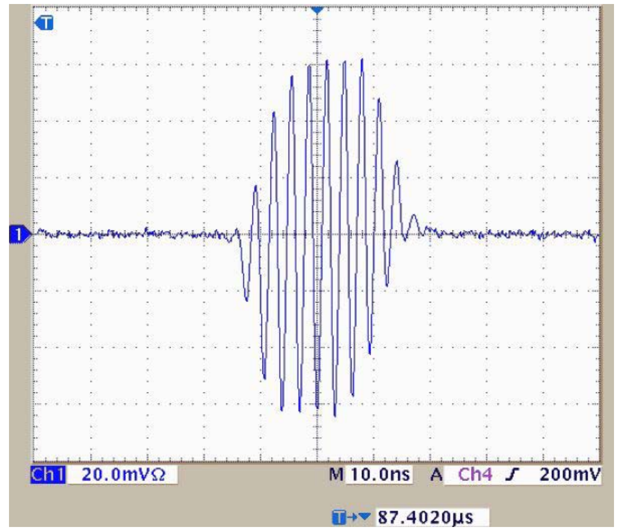

Figure 5: Chopper beam signal. A peak current is 24 mA. A repetition frequency of the chopped beam is 2 MHz. A driving power of the chopper is 36 kW.

electroforming method has been also applied to the fabrication of the SDTL tank, the coil of the electromagnet in the drift tube and the ceramic duct of the 3-GeV synchrotron [5].

The first tank of the DTL has been constructed by assembling the drift tubes precisely, in which the electro-quadrupole magnet has been installed. Measured position of the bore center of the each DTs from beam axis is plotted in the figure 6. Maximum deviation of the distribution is less than $\pm 50\mu$m for both x- and y-direction [6].

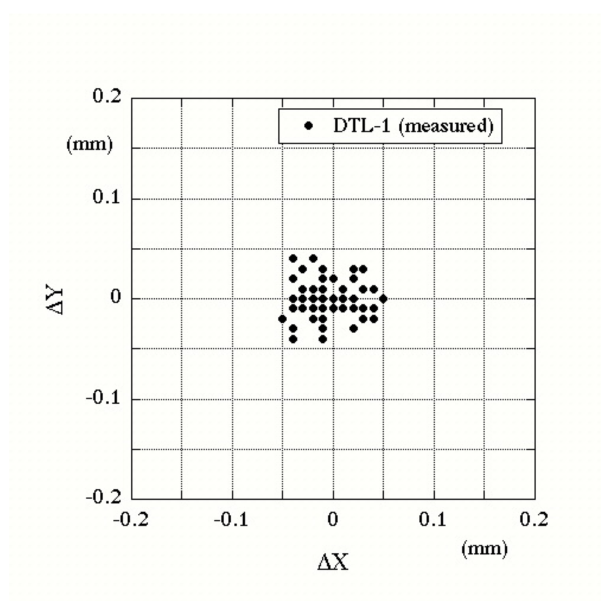

Figure 6: Measured position of the DT.

The tuning of the post-couplers is being done in order to stabilize the accelerating field. The post-couplers are also used for the fine adjustment of the accelerating field distribution on the beam axis. Figure 7 shows the preliminary result for the effect of the post-coupler. The ordinate of the figure shows the normalized average field for each cell of the DTL first tank, which includes 76 gaps. The field has been measured by a bead-pull method. The inclined distribution in the figure is the initial field distribution perturbed by the tuner and the flat one is the stabilized field by the post coupler against the tuner perturbation. The post-couplers are inserted every other DT. The fine tuning of the post-coupler is still going on.

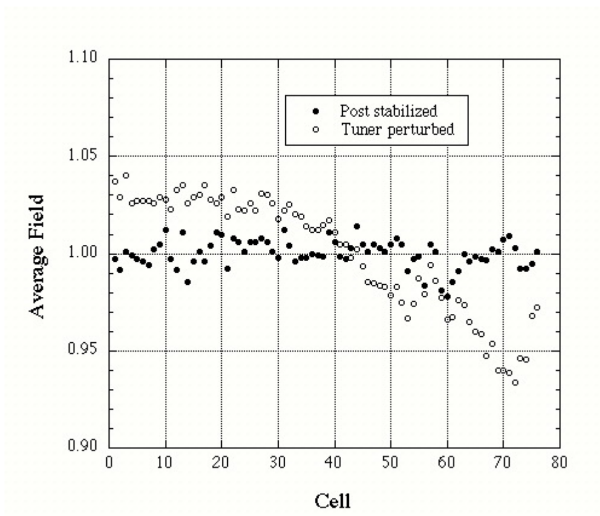

Figure 7: Chopper beam signal.

2.6 SDTL

The separated DTL (SDTL) has been designed as the accelerator following the Alvarez DTL. The SDTL has no focusing quadrupole in the drift tube. The doublet quadrupole magnet is set between the adjacent tanks of the SDTL. Thus the drift tube has much thinner shape than that of the DTL for increasing the shunt impedance. The SDTL accelerates the H^- ion beam from 50 to 190 MeV. The resonance frequency is 324 MHz. It consists of the 32 independent tanks.

The first two tanks of the SDTL were constructed and the high power conditioning has been completed. The conditioning history of the SDTL first tank is shown in figure 8.

The maximum input peak-power was about 500 kW, which is approximately three times of the required power [7]. The result shows the high performance of the SDTL cavity based upon the PR copper electroforming method described before.

2.7 ACS

The normal conducting coupled-cavity linac with the Annular Coupled Structure (ACS), which is the most preferable owing to its axial symmetry, is adopted for

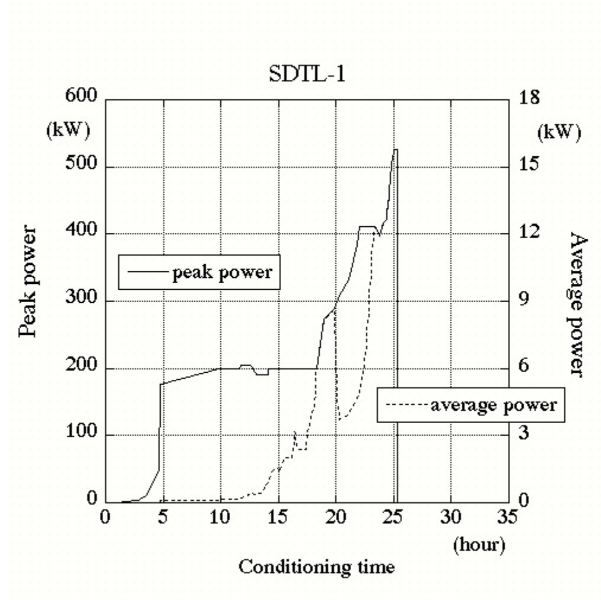

Figure 8: Conditioning history of SDTL-1.

190-400 MeV part of high intensity proton linac for the JAERI/KEK Joint Project. The operating frequency is 972 MHz and the 23 modules will be constructed [8].

The basic configuration is based on that investigated for L-band (1296 MHz) in the previous Japan Hadron Project research. However, the structure design is revised and optimized in order to meet requirements of reliability, operation efficiency and cost reduction for the Joint Project [9].

As the results of development, the transverse dimensions of the ACS tank are reduced sufficiently with the improvement in RF characteristics [10, 11, 12]. Test of the machining and the brazing of the 972-MHz version of the ACS is now in progress [13].

2.8 RF system

The rf system for the linac includes a high-power klystron, a klystron modulator, a DC high-power system, waveguide system, an rf drive system, a low-level rf control and monitor system and a chopper driving system [14].

The stability of an accelerating field in the cavity depend deeply on performance of the low-level rf control and the monitor system. At the joint project, the electric field accuracy of $\pm 1\%$ in amplitude and ± 1 degree in phase are required for the RF system [15]. In order to accomplish this requirement, the digital feedback system is adopted for the flexibility of the feedback algorism. Practical examination of the digital feedback system has been started using the SDTL tank [16].

The 324 MHz high-power pulsed klystron with a modulating anode has been developed as the rf source of 190-MeV linac. Maximum power of 3 MW and working power of 2.5 MW is required to feed the power to RFQ, DTL and SDTL structures. This klystron is pulse-operated with the rf pulse width of 600 μsec and 50 Hz repetition rate. Seven klystrons have been manufactured up to the April in 2002.

At the first stage of the development, undesirable oscillation due to the back-streaming electrons from the collector and some instabilities were observed. After the intense investigations and modifications of the critical parts, we could obtain the klystrons with the requirement [17].

The development of the 972-MHz modulating-anode klystron has also been started. The required power for driving the ACS accelerator is 2.5 MW. The rf characteristics of the first prototype klystron was evaluated at the test stand in the JAERI [18].

Because the rf input coupler has the coaxial waveguide structure for the RFQ, DTL and SDTL, the rectangular waveguide connected to the klystron converted to the coaxial waveguide (WX203D) near the cavity. Usually, it is very troublesome for connecting/disconnecting the coaxial waveguide and adjusting the length of it. Hence, the L-type 203D waveguide has been developed with an easy connecting/disconnecting structure. Furthermore the flexible straight waveguide also has been developed. Both components of the coaxial waveguide have been used for the SDTL high-power conditioning without any trouble [19].

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