HIGH-INTENSITY PROTON ACCELERATORS FOR THE JAERI/KEK JOINT PROJECT

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Abstract

The high-intensity proton accelerator facility project in Japan comprises a 600-MeV linac, a 3-GeV, 1-MW rapid-cycling synchrotron (RCS), and a 50-GeV synchrotron. The project was formed by joining together the NSP of JAERI and the JHF project of KEK. The 1-MW beam from the RCS is used to produce pulsed spallation neutrons and muons. The project will cover many important scientific and engineering fields which require high-intensity proton accelerators.

1 INTRODUCTION

The high-intensity proton accelerator facility project in Japan [1,2] was formed by joining together the Neutron Science Project (NSP) [3-5] of Japan Atomic Energy Research Institute (JAERI) and the Japan Hadron Facility (JHF) Project [6-12] of High Energy Accelerator Research Organization (KEK). The facility will be constructed at the JAERI/Tokai site, as shown in Fig. 1. Phase I of the project comprises a 600-MeV linac, a 3-GeV, 1-MW rapid-cycling synchrotron (RCS) and a 50-GeV main synchrotron. 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 3-GeV beam from the RCS is injected to the 50-GeV synchrotron.

The 600-MeV beam accelerated by the SC linac is transported to the experimental area for an accelerator-driven nuclear waste transmutation system (ADS). 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 Life and Materials Science Experimental Area. Ten percent of the beam is used for muon production. The 50-GeV beam is slowly extracted to the Particle and Nuclear Physics Experimental Area. It is also fast extracted for neutrino experiments, which are conducted at the SUPERKAMIOKANDE detector located 300-km from the Tokai site.

In this way, a wide variety of science and engineering fields will be intensively and efficiently promoted by the high-power proton accelerators. The Phase-I facility includes upgradability to a 5-MW neutron source, which is allocated to Phase II of the project.

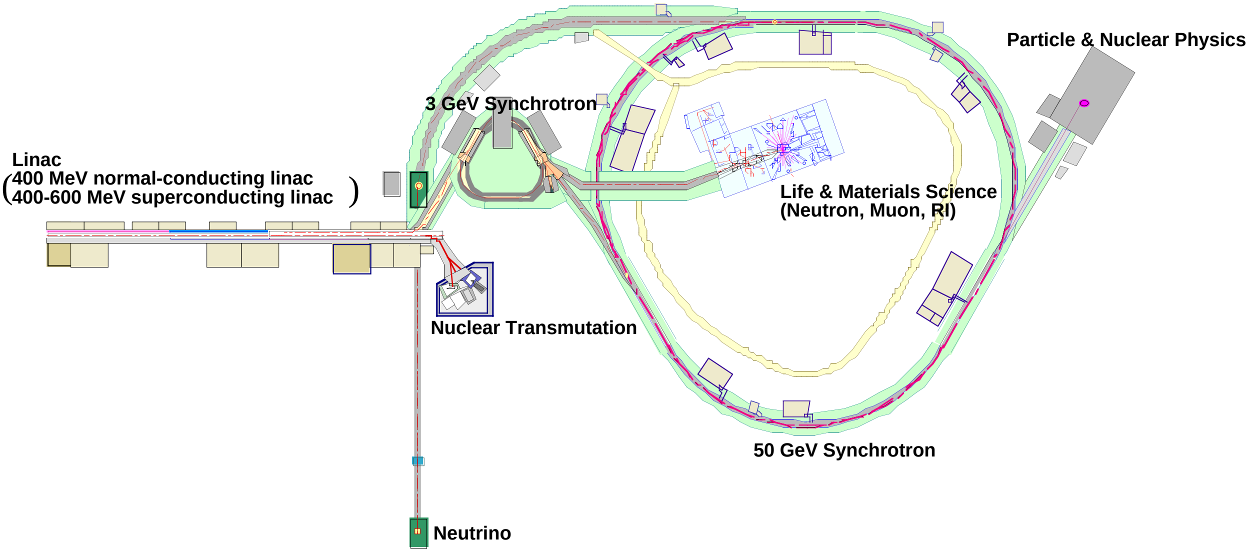

Fig. 1 Layout of the accelerator complex of the Joint Project.

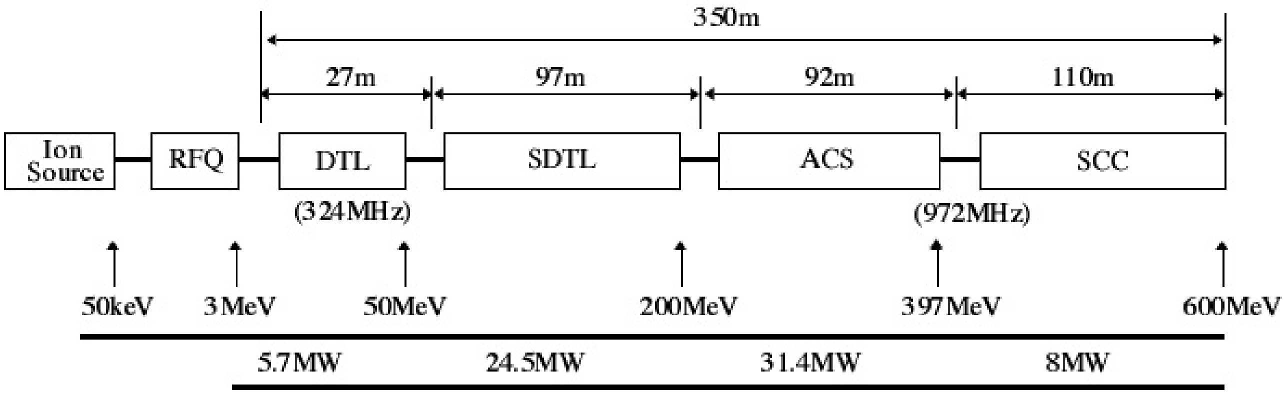

Fig. 2 The scheme of the 600-MeV linac. A 20-m long matching section will be inserted between SDTL and ACS.

2 ACCELERATOR SCHEME

In contrast to the scheme of a full-energy linac and the storage ring (SR) chosen by the Spallation Neutron Source (SNS) [13] in US and the European Spallation neutron Source (ESS) [14], the present accelerator scheme is based upon the RCS. In any case, ring injection is indispensable for obtaining pulsed neutrons with a typical pulse length of 1 μs. In the present project the high-intensity, 50-GeV synchrotron requires a several-GeV booster. This booster can be a MW-class neutron source, if it is properly made to be rapid-cycling.

The advantages and disadvantages of the above two schemes as a neutron source are discussed in Ref. [15]. It is here mentioned that the controversy is not yet settled regarding which is more promising. This can be settled only by empirical tests of the two schemes. In this sense, it will be interesting to see the real performance of the two kinds of the schemes.

The linac uses normal-conducting cavities up to 400 MeV, while it uses superconducting cavities (SCC) from 400 to 600 MeV, as shown in Fig. 2. A volume-production type of negative hydrogen source is designed to produce a peak current of 53 mA with a pulse length of 500 μs and a repetition rate of 50 Hz. About 53 percent of the beam will be accelerated after the beam is chopped at both the 50-keV low-energy beam transport (LEBT) and the 3-MeV medium-energy beam transport (MEBT). A radio-frequency quadrupole (RFQ) linac accelerates the beam up to 3 MeV, a conventional drift-tube linac (DTL) up to 50 MeV, and a separated DTL (SDTL) up to 200 MeV. An acceleration frequency of 324 MHz is the highest-possible one, for which the 3-MeV drift tubes can accommodate electromagnetic quadrupoles. The higher frequency is the more preferable for obtaining a higher peak current by more frequent focusing. 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 frequency is increased by a factor of three at 200 MeV, which is sufficiently high for acceptable adiabatic damping of the bunch length by the high-energy linac. Among the possible candidates for the coupled-cavity linac (CCL) to be used from 200 MeV to 400 MeV, the annular-ring coupled structure (ACS) is the most preferable owing to its axial symmetry. Several prototypes of the L-band ACS [16,17] have been developed and powered up to higher than the designed value for the Japanese Hadron Project (JHP). Test machining and brazing of the 972-MHz version of the ACS is now in progress.

The 400-MeV H^- beam from the linac is injected to the RCS during 500 μs, which is limited by the flat bottom of the sinusoidally varying magnetic field of the 25-Hz RCS. The beam is chopped at a rate twice as high as the ring RF frequency, 1.36 MHz (thus, two bunches per ring), in order to avoid beam loss during the injection process. The chopping system is one of the challenging development items.

The RCS thus accelerates two bunches (4 x 10^{13} protons per bunch) every 40 ms. Eight among the ten buckets of the 50-GeV ring are filled by four cycles of the RCS (it takes 40 ms x 3 + 500 μs). Then, the 50-GeV synchrotron is ramped up for 1.9 s. The beam is slowly extracted during 0.7 s. Afterwards, it takes 0.7 s for the synchrotron to become ready for the next injection. In total, the period of one beam cycle is 3.42 s, which corresponds to an average current of 15.4 μA.

The linac is operated with a repetition rate of 50 Hz. Another half of the beam is further accelerated up to 600 MeV by a superconducting linac [5,18] for the ADS experiment. The RCS (SR also) requires a linac beam with a momentum spread of $\Delta p/p \le 0.2\%$. In order to fulfill this requirement, the amplitude and the phase in each cavity should be controlled with accuracies of 1% and 1 degree, respectively, which are difficult to achieve by the SC linac with pulse-mode operation. On the other hand, the ADS experiment does not require this accuracy. The purpose of the SC linac is to develop the CW accelerator technology necessary for the ADS. If the present scheme is successful, one of the most important key technologies will be completed.

After the requirement for the amplitude and phase has been met by the future development including the beam test, the SC linac will be used as an injector for the RCS.

Construction of the 60-MeV proton linac started for the JHF at the KEK site in 1998. Beam commissioning of the ion source and the RFQ linac will start by this fall. Since these two components were designed for a peak current of 30 mA, they will be replaced in the future for the present project. However, the beam from these can be used for beam tests of the DTL and SDTL by that time. After construction and beam commissioning of the 60-MeV linac have been completed in collaboration between JAERI and KEK, the linac will be shipped to the Tokai site and used for the Joint Project.

Among the various key technologies developed for high-intensity proton synchrotrons, RF cavities loaded with magnetic alloys (MA), for example, FINEMET, should be emphasized [19-21]. The MA-loaded cavities could be powered to several ten kV/m with a constant shunt impedance for a wide range of RF magnetic fields. The design of the RF systems for both the RCS and the 50-GeV ring is only possible with this innovative work.

3 CONCLUSION AND UPGRADE PATH

The high-intensity proton accelerator facility project in Japan is ready for approval. The upgrade paths for a several-MW neutron source have been conceived, as summarized in Table 1. A beam experiment is indispensable to settle the controversial issue, which is more promising between SR and RCS. The optimum may be in between the two extreme options as shown in the last line of the table.

Table 1. Upgrade Path of Linac and Rings

RCS or SR				Linac (56 % chopping)				
Beam Power	Energy	Repetition	Number	Energy	Peak Current	Pulse Length	Repetition	Average Current a)
1.0 MW	3 GeV	25 Hz	1	400 MeV	50 mA	500 µs	25 Hz	333 µA
5.0 MW	1 GeV	50 Hz	2 or 3	1 GeV	60 mA	3 ms	50 Hz	5 mA
or 5.0 MW	4 GeV	25 Hz b)	2	600 MeV	60 mA	750 µs	50 Hz	1.26 mA c)

a) The average current is obtained by a product of the peak current, the pulse length, the repetition, and the chopping rate of 56%.
b) This repetition is for each RCS. On the neutron production target the repetition is 50 Hz.
c) The flat bottom of the RCS magnet power supply is lengthened.

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