SECTION IX

HIGH INTENSITY BEAMS
(continued)

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PRESENT STATUS OF THE JAPANESE HADRON PROJECT

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Abstract Description of the Japanese Hadron Project will be given, and the present status of an R&D program on accelerator components will be reported.

INTRODUCTION TO THE JAPANESE HADRON PROJECT

Unstable beams, such as mesons, mouns, neutrons and short-lived nuclei have been fundamental tools for research in a wide range of science; not only nuclear and particle physics but also condensed-matter physics, atomic physics, chemistry, life science and so forth. The Japanese Hadron Project (JHP), which was proposed in 1987, aims to build a next-generation research center for such fields of science.[1]

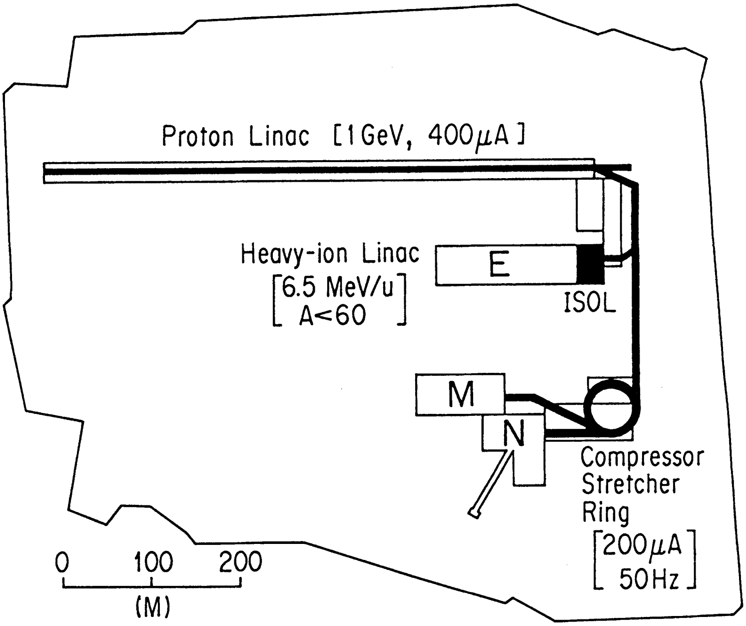

FIGURE 1 Proposed layout of the Japanese Hadron Project.

The proposed layout of the JHP is shown in Figure 1. Major research facilities which will be built in the JHP are:

(1) Meson science facility (M-arena)
(2) Neutron scattering facility (N-arena)
(3) Exotic nucleus beam facility (E-arena)

In the M-arena, a pulsed or dc, ultra-slow to fast muon beam, a high-intensity pion beam and a time-separated neutrino beam will be provided. The N-arena will be the most powerful pulsed spallation neutron source by cooperating with an elaborate target design. The E-arena is a unique facility of producing various unstable nucleus beams.

The proposal of the Japanese Hadron Project was endorsed by the Japan Science Council in January 1988, and submitted to the Ministry of Education, Science and Culture of the Government. Research and development works have been continued.

GENERAL DESCRIPTION OF THE ACCELERATOR SYSTEM

The primary requirement to the accelerator system is a high-intensity proton beam at a medium energy to produce secondary beams mentioned. Among others, a proton linac has been considered as relevant to the present requirement, and a proton linac of an energy of 1 GeV has been proposed in the JHP. Therefore, the accelerator system of the JHP will consist of:

(1) 1-GeV proton linac
(2) Compressor/stretcher ring (CSR)
(3) Heavy-ion linac

The proton linac is the key facility of the JHP, and will supply a proton beam to both the CSR and the Isotope-Separator-On-Line (ISOL) for a generation of unstable nuclei.

The CSR is a storage ring which has a function of tailoring the time structure of the proton beam, ranging from a several-tens-ns long pulsed beam to a continuous beam. In the standard mode, a 400 μs long macro-pulse of the linac will be compressed into two short bunches of 200 ns in length. One bunch is extracted to the neutron facility and another bunch is to the meson facility. The time-averaged beam current of the CSR will be 200 μA. In the short-bunch mode, the bunch which is alloted to going to the meson facility, after extracting one bunch to the neutron facility, will be compressed down to as short as 50 ns or less by the non-adiabatic bunch rotation technique. In the continuous-beam mode, slow extraction of high efficiency will be employed.

In order to reserve a kicker gap in the CSR, the macro-pulse of the linac is chopped into a train of 200 ns long pulses with a frequency of 3 MHz, the same as the CSR rf frequency. Therefore, specifications for the proton linac call for an average beam current of 400 μA, which implies a peak current of 20 mA, a beam duration of 400 μs and a repetition rate of 50 Hz.

Radioactive nuclei will be produced via spallation, multi-fragmentation and/or fission processes, by irradiating a thick target with a 10 μA proton beam. These ions will be pre-accelerated to 1 keV/u and, after mass-analyzed with the ISOL, accelerated in a chain of heavy-ion linacs to an energy of 6.5 MeV/u. The high-energy proton beam is a powerful means for producing various nuclides over a wide range of the N-Z plane in the nuclear chart.

1-GeV PROTON LINAC

The JHP proton linac is composed of an ion source (50-keV), a four-vane RFQ (3-GeV), a drift-tube linac (150-MeV) and a coupled-cell linac.[2] The feature of this linac is that rf frequencies are higher than those commonly used in the currently operating linacs. The RFQ and the DTL operate at 432 MHz and the CCL operates at 1296 MHz. By this selection, many advantages arise. Shunt impedance and Kilpatrick limit become high. Overall size of accelerator structure become small, which leads to ease of material handling in every fabrication process, and klystrons will be available in these frequency ranges. Disadvantages could be, however, small acceptance and severe mechanical tolerance.

The followings are the research targets on the proton linac during the R&D stage:

(1) Construction of the front-end of the linac
(from the ion source to the first tank of the DTL)
(2) RF structure development of the CCL
(3) Development of rf sources at both frequencies

RFQ

An energy of 3 MeV is a somewhat aggressive number, but will surely ease the design and fabrication of the very beginning of the drift-tube linac. So a research target has been set to develop a 3 MeV RFQ. The cavity length (2.7 m) is 3.9 times the rf wavelength, which means that severe tolelance will be required and that proper tuning procedure should be developed.

A cold model has been fabricated since last year in order to disclose problems inherent to fabrication and rf properties such as field tilt, mixing of dipole mode and effects of couplers, tuners and vacuum ports. Figure 2 shows a conceptual drawing of the RFQ. This is a model with unmodulated vanes and made of blocks of vacuum-melted copper. It was delivered to the Laboratory in August 1989. A dimensional

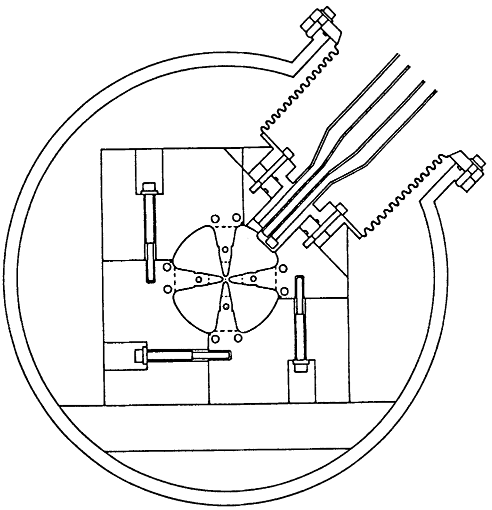

FIGURE 2 Conceptual drawing of the RFQ.

precision achieved in the finished vanes was within ±10 μm after assembled.

Drift-tube linac

The drift-tube linac will be post-stabilized and provided with permanent magnet quadrupoles as focusing elements. As a result of choosing a frequency twice as high as conventional 200 MHz, a presicion as high as 30 μm(rms) is required in drift-tube and permanent magnet alignment.

Technique of sealing a drift-tube with a permanent magnet inside has been investigated, and both electroforming and electron-beam welding will be applicable to the present case.

Study on the permanent magnet (both Nd-Fe and Sm-Co) continues to investigate a fabrication technique that meets the above requirement. As a result of measurement on three assembled magnets, the magnetic center has turned out to deviate from 7 to 70 μm with respect to the mechanical center.

A cold model of the first tank was fabricated in order to confirm the design and to study the effect of post-couplers.[3] Results of rf measurements have been quite satisfactory. We now proceed with the final design of the first tank of the DTL. The fabrication will start this year.

Coupled-cell linac

An rf structure development strated in 1987. The main effort has been paid to the annular-coupled structure (AGS).[4] Parallel to this, a preliminary fabrication test on the side-coupled structure (SCS) has been done.

The symmetric structure of the ACS should be highly appreciable, since it will ease fabrication with high precision. The eventual goal of the study is to find a procedure in which no tuning will be necessary after brazing.

The present design of the ACS, as shown in Figure 3, has four coupling slots with each opening angle of 30 degree, and has a coupling factor of 5 %. A reduction of Q-value due to introduction of coupling slots is 20 % at present. However, it will be reduced to 15 %, by adjusting slot shape and web thickness, which is comparable with 10 % in the SCS. The dipole and quadrupole modes in the coupling cell are well above the accelerating mode passband (higher order modes still exist, though). Disadvantages of the ACS will be its bigger overall size and harder cooling of web and nose cone.

By combining the design of the bridge cavity, we now proceed with the design of a high-power model which will comprise two 5-cell ACS cavities coupled with each other via a bridge cavity .

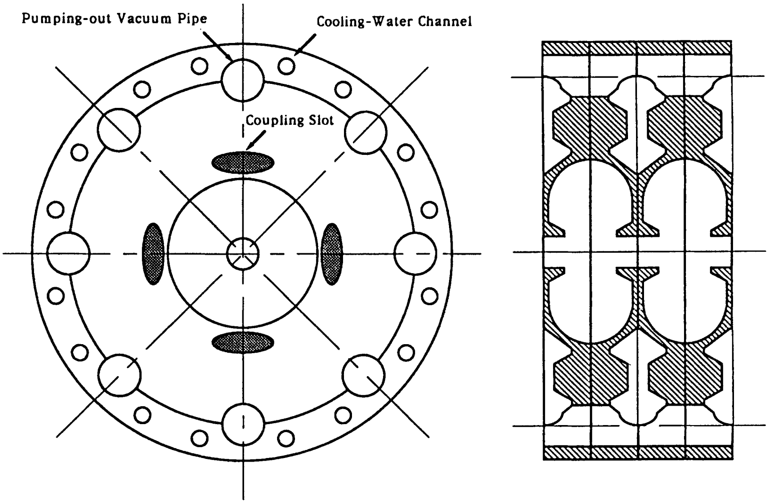

FIGURE 3 Schematic drawing of the ACS cavity.

Microwave sources

Construction of a prototype model of the 1296-MHz source completed and is under test with a dummy load (Varian).[5,6] The final amplifier is a Thomson TH 2104A klystron (5 MW peak, 600 μs, 50 Hz). Pulsed power of high voltage is supplied to the klystron by a line-type modulator and a pulse transformer (step-up ratio of 7). The modulator has a capability of a peak power of 15 MW, a pulse duration of 600 μs (400 μs at present) and a repetition rate of 50 Hz. A hydrogen thyratron ITT F-259 is used as the switching tube. Up to now, operation of the klystron at an output power of 5 MW, a pulse duration of 400 μs and a repetition rate of 30 Hz has been achieved.

The 432 MHz source will use a modulating anode/hard-tube modulator, since a peak power required per klystron is 1.5 MW with a pulse duration of 650 μs and a pulse repetition rate of 50 Hz. Construction of a prototype modulator begins this year. A high voltage power supply (110 kV output voltage, 92 A peak, 3 A average current) supplies cathode voltage to two klystrons (assuming a peak power of 2 MW and an efficiency of 40 %). This modulator will be used as the power sources of the front-end accelerator system to be developed in the R&D.

COMPRESSOR/STRETCHER RING (CSR)

The present design of the CSR uses a simple FODB lattice of high periodicity (16).[7] Main parameters of the CSR is listed in Table I. The CSR injection will use an H^0-injection,[8] which will be suitable for the FODO lattice. Owing to enough acceptance relative to beam emittance, a lost beam will be managed properly by the beam collimation system.

The bunch rotation will require an rf voltage more than 200 kV. An rf frequency during the bunch rotation is 1.5 MHz, instead of 3 MHz during capture. A computer simulation on the bunch rotation[9] has shown that a bunch length as long as 50 ns will be achieved for an intensity of 1.2×10^{13} ppb, and a bunch length of 30 ns will be attained for a reduced intensity.

An R&D on the rf system has been initiated by fabricating a new rf system with beam loading compensation for the KEK-PS.[10] This will be a pilot plant of the ultimate design for the CSR.

The fast extraction, which will be done in the vertical plane, applies a conventional method. The slow extraction will use the rf frequency sweep to move the beam to resonance, since the extraction period is less than 20 ms and too short to move the betatron tune by a magnetic means.

TABLE I Main parameters of the compressor/stretcher ring.

Circumference	175	m	RF frequency	3	MHz
Number of bunches	2		Number of cavities	2	(for capture)
Particles	2.5×10^{13}	ppp		16	(bunch rotation)
Emittance	30	π mm·mrad	RF voltage	15	kV/cav.
Acceptance	120	π mm·mrad	Momentum acceptance	± 1.5	%

HEAVY-ION LINAC

Figure 4 shows a proposed scheme of the heavy-ion linac. Radioactive beam produced in the ISOL ion source[11] will be injected in the linac at an energy of 1 keV/u. A front-end of the linac will be a split-coaxial RFQ which is suitable for acceleration of very slow ions. The duty factor of the linac is as high as 10 %, in order to get effective capture of produced nuclei.

Construction of a 2-m long prototype of the SCREQ continues at INS.[12] Table II is a list of main parameters of the prototype model as well as those of the final design. It operates at the same intervane voltage as the final design in order to check thermal and breakdown problems to be encountered in the real machine. The basic problems have been investigated in the 50 MHz proton model for a couple of years and it has been turned out that transmission agrees quite well with prediction.[13]

TABLE II Main parameters of the prototype SCREQ in comparison with those of the final design of the JHP.

	prototype	final design	
Frequency	25.5	25.5	MHz
Charge-to-mass ratio	1/30	1/60	
Input energy	1	1	keV/u
Output energy	45.4	170.2	keV/u
Vane length	2.135	22.3	m
Kilpatrik factor	2.2	2.2	
Intervane voltage	109.3	109.3	kV
Mean bore radius	9.46	9.46	mm

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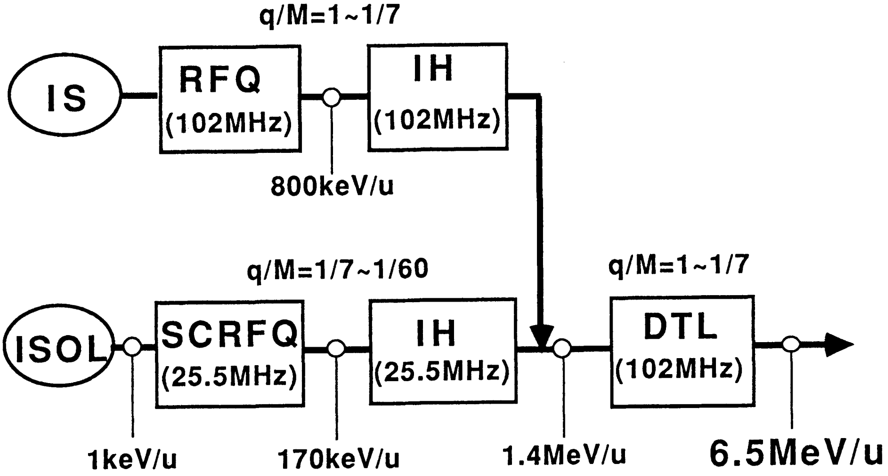

FIGURE 4 Proposed scheme of the heavy-ion linac.