

Development of the High-Intensity Proton Linac for the JHP

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Abstract

For a 1 GeV high-intensity proton linac for the Japanese Hadron Project (JHP), various accelerator components have been developed at KEK; a volume-production type negative ion source, a long 432MHz RFQ, a drift tube linac (DTL) with permanent quadrupole magnets and post couplers, an axially symmetric annular-coupled structure (ACS) with four slots, and a high-power RF source with 600 μ s pulse-duration. The present status of these developments is described.

INTRODUCTION

A 1 GeV high-intensity proton linac for the JHP was required to inject proton beams to the ring accelerators. The requirements for the JHP linac as an injector are summarized in Table 1.

A working group for the JHP linac was formed in June, 1987. This group proposed that the linac developed should be operated with extreme stability and reliability and the JHP linac should be composed of a volume-production type negative ion source with a low emittance, a 432MHz RFQ linac (50keV to 3MeV), a 432MHz DTL (to 148MeV) with permanent quadrupole magnets and a 1296MHz high- β linac (to 1GeV). In Table 2 and Fig.1, basic parameters of the JHP linac are given[1, 2].

In the designing stage, the following was discussed; at first, radioactivity caused by the beam loss would become the serious problem in the long-term operation of the linac and sometimes might limit the beam current accelerated. So, sufficiently large beam acceptances should be secured transversely and longitudinally, respectively. Therefore, the relatively high transition energies of 3MeV and 150MeV were chosen for the RFQ to the DTL and for the DTL to the high- β linac. The frequency of the RFQ and the DTL was chosen to be one-third of the frequency of the high- β linac. In order to suppress the beam losses due to the transient effect, it is

preferable to operate the linac with the long beam pulse (400 μ s) and the low repetition rate (50Hz). In order to ensure the large transverse acceptance, a large bore radius of 1.5cm was chosen for the high- β linac. Of course, it is very important for all accelerator components to work with the high stability. So, at first, the high-power RF station (several MW) with a long pulse length of 600 μ s was constructed to test the accelerator components with the higher power level[3, 4, 5, 6, 7].

The technical developments of the linac components have been done since 1987. In September, 1993, the RFQ linac will be excited with the high power and then proton beams will be accelerated up to 3MeV to measure beam characteristics and to compare the results measured with the designed values. The DTL also will accelerate the 3MeV beams up to the 5.4MeV after the RF field measurements.

In the following sections, the present status of the developments is presented.

TABLE 1

Requirements for the JHP Linac

Beam	H ⁻
Energy	1 GeV
Repetition rate	50 Hz
Average current	>200 μ A
Normalized emittance (90%)	2 π mm \cdot mrad

TABLE 2

Basic Parameters of the 1 GeV Linac

Energy	1 GeV
Total length	500 m
Beam pulse length	400 μ s
RF pulse length	600 μ s
Repetition	50 Hz
Peak current	20 mA

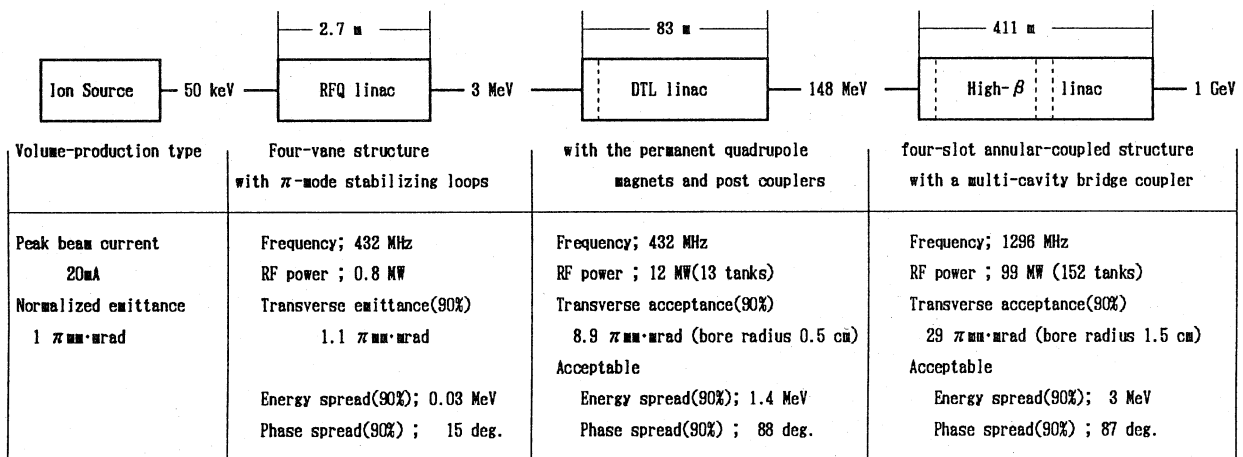


Figure 1. Structure and parameters of the 1GeV high-intensity proton linac for the JHP

High Power RF Sources

The JHP linac requires 36 L-band klystron amplifiers for the high- β linac and 14 UHF klystron amplifiers for the RFQ linac and the DTL. For the extremely stable operation of the proton linac, it is very important not only to construct the RF source with the high reliability but also to test the accelerator components up to the higher power level. So, an output RF power of 2 MW for the UHF and 6 MW for the L-band have been prepared.

At first, a line-type modulator with a peak power of 15MW (average power of 450kW) had been designed and was constructed for the L-band klystron (THOMSON TH2104A). In this modulator, the main switch used for discharging a 50 stage PFN is the most important device for the highly operational reliability and maintainability. So, finally, we chose the solid state switch of SCR as a main switch. In the test and long term operation with the full power, we have no problem against this modulator. The L-band amplifier is composed of a high power pulsed klystron, this modulator, a pulse transformer (step-up ratio of 7) and a low power circuits. Test of the entire system has been successfully accomplished up to a full power of 5.6 MW with a repetition rate of 50Hz and a pulse length of 600 μ s [8, 9, 10, 11]. Now, this L-band RF source has been used for the high power test of the ACS cavities with a multi-cavity bridge coupler [12] and the RF components.

A high duty UHF (432MHz) RF system consists of two klystrons (THOMSON-CSF, TH2134), which can produce a 2MW peak power at the saturation with a nominal duty, two individual modulating anode controls, a dc-power supply (maximum -110kV with 46Ax2 beam current) and a low level circuit. The scheme of the klystron power is shown in Fig.2. At present, the RF system with only one klystron was accomplished and tested with a nominal duty. In Fig.3, the result measured at saturation is shown as a function of the cathode voltage. The UHF RF source sufficiently supplies the RF power of about 1MW with about 3% duty into the RFQ linac and the DTL. In FY 1993, the tank to install another klystron will be constructed and then the entire system of the UHF RF source will be completed with a low level circuit, which can be used to control the amplitude and the phase of the klystron output during the pulse length and to generate the feedforward signal to compensate the beam loading [13].

Ion Source

At first, we consider that the cesium vapor, which is essentially utilized in a surface-plasma H⁺ ion source, might cause easily a break-down in an accelerator using the higher electric field like the RFQ linac. So, a cesium-free or small consuming H⁺ ion source is a very useful as an ion source for the JHP. Therefore, the volume-production type H⁺ ion source was adopted and has been developed at KEK [14, 15].

Recently, by introducing a small amount of the cesium vapor in the plasma chamber, H⁺ beam intensity was drastically increased. The extracted H⁺ beam current of 20mA was obtained in this cesium-mode operation. The measured 90% normalized emittance was about 1 π mm \cdot mrad for 12mA beam and the current density at the anode hole reached to about 70mA/cm². It is noted that the total drain current which contains mainly electrons from the ion

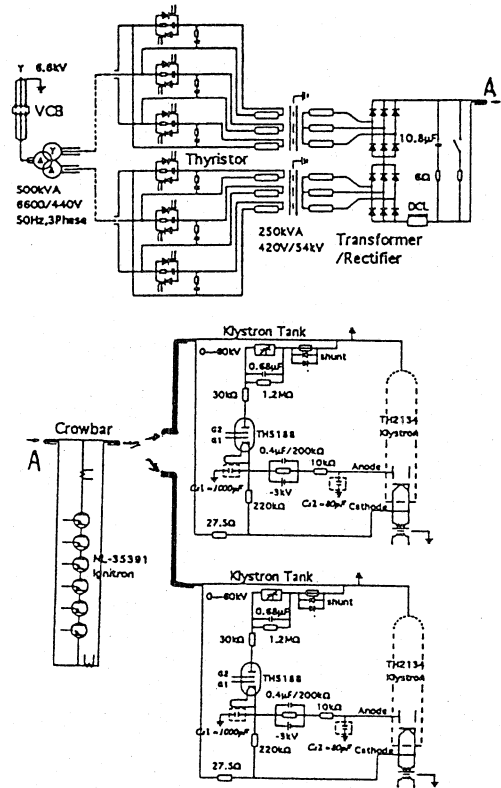


Figure 2. DC-power supply and modulating anode controls for the UHF klystrons.

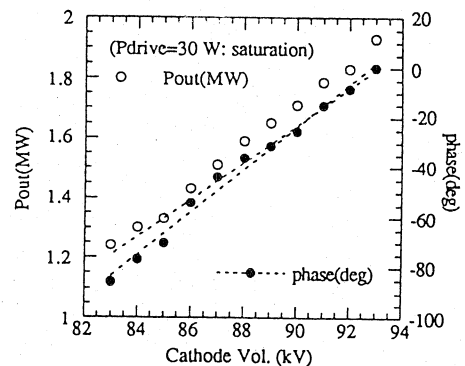


Figure 3. Output power and phase shift measured at saturation as a function of the cathode voltage.

The phase shift per 1kV is about 8deg/kV. source is dropped from 350mA to less than 100mA. Details of the explanation of this cesium effects are presented on Ref.16. At present, in order to accelerate the high intensity H⁺ beam with the RFQ linac, assembling of the ion source is in progress and the power supplies are prepared.

RFQ Linac

The RFQ linac accelerates the H⁺ beams from 50keV to 3MeV. So, the length of the RFQ cavity is about 2.7m which is about four times as long as the wavelength [17]. Therefore, in order to avoid the admixture of dipole modes to the accelerating mode, which reduces the beam acceptance of the RFQ linac, a new field stabilization method was proposed by Dr.A.Ueno. The method is

called as a π -mode stabilizing loop (PISL) [18, 19]. In the RFQ cavity with PISLs, the resonant frequencies of all the dipole modes were increased much more than that of the accelerating mode as seen in Fig.4. Details concerning to the PISL are presented on the Ref.18. After the studies of the RF property on a cold model (without a vane modulation) with or without PISLs, the RFQ linac with PISLs was designed and has been constructed as a preinjector for the JHP. In this RFQ, it was possible to tune the frequency of the accelerating mode to the operational frequency of 432MHz and the field uniformity within $\pm 1\%$ was achieved. So, we could emphasize that the admixture of dipole modes is drastically suppressed (less than 0.5% of the accelerating mode) [20, 21].

At present, the RFQ linac has been installed in the area for the acceleration test and kept at a high vacuum.

DTL

At first, a cold model (from 3MeV to 8MeV, 35cells, 2.6m in length with post couplers) made of aluminium was fabricated in order to obtain the necessary data for the hot model (3MeV to 5.4MeV); for example, an accuracy of machining and assembling of the drift tubes and the field stabilization using the post couplers [22]. Next, based upon data measured, the hot model was designed and has been fabricated. On the other side, the most important specification for the permanent quadrupole magnets (PQM) required from the beam dynamics was that the deviation of the field center from the beam axis must be less than $27\mu\text{m}$. So, we chose the following procedures; 1) to manufacture the magnet pieces with a high accuracy (for magnetization direction and dimension), 2) to assemble the PQM in the inner shell of a drift tube and 3) to weld the inner shell to the outer shell with a stem by the electron beams seen in Fig. 5. After the electron-beam welding, the difference between the field center and the mechanical center of the inner shell has been measured and the results have been within $20\mu\text{m}$ [23, 24].

Now, the alignment of the drift tubes in the unit tank and connecting the adjacent unit tanks are in progress.

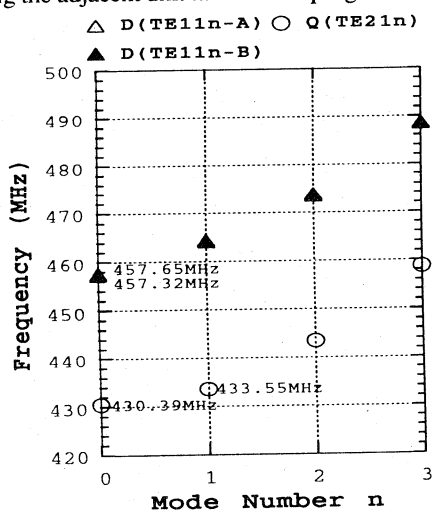


Figure 4. Measured dispersion curves of the TE21n and the TE11n-A and TE11n-B before tuning. The frequency of the accelerating mode was tuned to 432MHz with the dummy tuners.

High- β Linac

A high- β linac is the standing wave coupled-cell linac (CCL) operated at the $\pi/2$ mode. As the candidates of the coupled-cell cavities, a side-coupled structure (SCS), an alternating-periodic structure (APS) and an annular-coupled structure (ACS) have been developed. Considering the problems in the mechanical structure and the fabrication process and studying the RF property of the various type cold models, we adopted the ACS with the four coupling slots as a cavity for the CCL.

We have fabricated the several ACS cavities with the four-slots with the different β and the high power test has been carried out up to 1.5 times of the designed power [25, 26, 27, 28].

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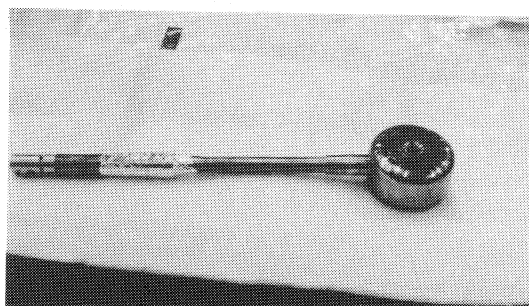


Figure 5. The drift tube after the EBW of the inner shell to the outer shell.