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Improvement of the Proton Accelerator System

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By improvement of vacuum pressure in linac cavities to be better than 1×10^{-6} Torr and installation of a circulator between the Klystron (L5773) and the RFQ cavity to stabilize RF power level, peak RF powers up to 680kW (2.0 Kilpatrick) and 360 kW (1.4 Kilpatrick) have been applied to the RFQ and DTL cavities, respectively, while corresponding designed values are 530 kW (1.8 Kilpatrick) and 320 kW (1.3 Kilpatrick), respectively. Injected proton beam with the kinetic energy of 50 keV is proved to be accelerated up to 7 MeV with the peak RF powers for the RFQ and DTL of the designed values.

KEY WORD : Ion Source/RFQ Linac/Drift Tube Linac/Klystron/Circulator

1. INTRODUCTION

At Accelerator Laboratory, Institute for Chemical Research, 7 MeV proton linac consisting of an RFQ and a drift tube linac of Alvarez type (DTL) is constructed[1]. Its operation frequency is chosen to be 433 MHz because the cavity size becomes compact and a Klystron with high gain can be used as a power source. However such high frequency linac is not so easy to operate stably because the compact size leads to technical difficulty of evacuation and RF feed of high power without sparking. So efforts to improve the performance of the linac system have been continued in preparation for its wide spread use. The low energy (50 keV) beam transport system from the multi-cusp field ion-source to the entrance of the RFQ has been modified and beam profile monitors are added in order to study the beam characteristics in more detail. The vacuum pressure in the linac cavities has become better than 1×10^{-6} Torr by improvement of the evacuation system. A circulator has been fabricated and installed between the Klystron and the RFQ cavity after its characteristics has been measured both at low and high power levels[2]. The DTL is tuned to have the same operation frequency as the RFQ. Proton beam with the kinetic energy of 50 keV is accelerated by the RFQ and DTL up to 2 and 7 MeV, respectively. In the present paper, procedure of the improvements of the linac system is described together with the results of beam acceleration experiments.

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2. ION SOURCE AND LOW ENERGY BEAM TRANSPORT

In order to suppress the possible sparking due to extraction high voltage of 50kV, the vacuum pressure should be well conditioned near the extraction electrodes. For this purpose the diameter of the extraction aperture of the ion–source–chamber is reduced from 3mm to 2 mm and the shape of the extraction electrode is modified using a computer code AXCEL[3]. The hydrogen beam extracted with a high voltage of 50kV is focused by an Einzel lens with the potential of 30kV and a triplet of electrostatic quadrupole lenses located downstream as illustrated in Fig. 1. The extracted beam from the ion source is deflected as large as 45 degrees with a dipole magnet (Mixing Magnet) and three peaks are observed in the measured beam current at field levels of 1.40, 1.99 and 2.44kG, which correspond to H^+, H_2^+ and H_3^+ ions, respectively. Among the extracted hydrogen beam, fractions of H^+, H_2^+ and H_3^+ are measured to be 10, 70 and 20%, respectively under the present condition of the ion source with DC arc. The H^+ beam deflected by the Mixing Magnet is focused by a solenoid located between the Mixing Magnet and the RFQ.

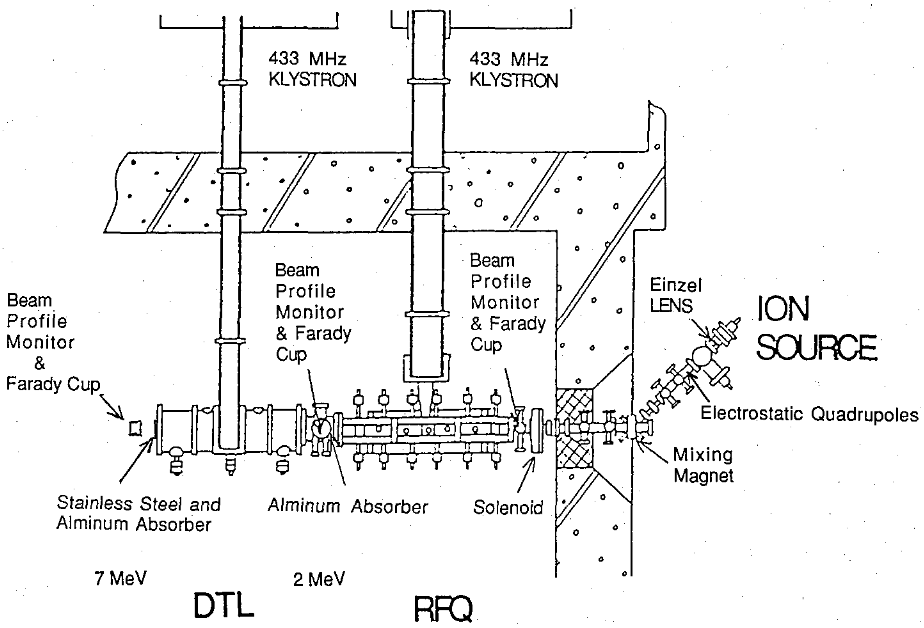

Fig. 1. Layout of the linac system. Elements of ion optics and beam monitors are also shown.

3. EVACUATION SYSTEM OF LINAC CAVITIES

From the point of view of avoiding the possible continuous sparking caused by the high power RF, it is necessary to pump out quickly the materials produced by the first discharge even if it occurs. Considering this requirement, two ion pumps with the pumping speed of 160 *l*/s used at the ports of the RF couplers of the RFQ and DTL are replaced by two turbo–

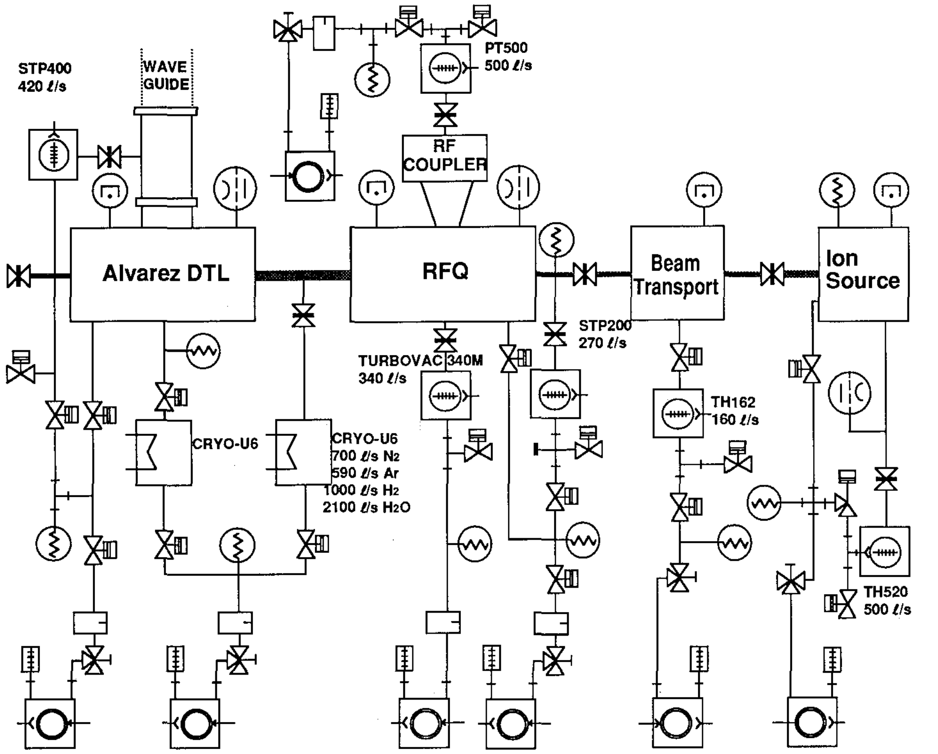

Fig. 2. Block diagram of the evacuation system for the linac.

molecular pumps with pumping speeds of 500 and 420l/s. In addition, a cryogenic pump with the specifications given in Fig. 2 and a turbo-molecular pump with the pumping speed of 340l/s are newly added to improve the end vacuum pressure. So as to reduce the partial pressure of H_2O, baking process at the relatively low temperature (~60℃) is applied. Finally the vacuum pressure has reached into the order of 10^{-7} Torr, which is proved to be enough for feeding high peak power needed for the present system.

4. HIGH POWER RF SYSTEM

So far the high RF powers had been directly fed to the cavities through wave guides (WR-2100) from the Klystrons (L5773). However it is desirable to insert an isolator in between so as to protect and stabilize the Klystron. Because of its rather high required peak power (530kW), an isolater consisting of a circulator and a dummy load is inserted between the Klystron and the RFQ cavity[2]. In Photo 1, the linac system with a circulator installed above the RFQ cavity is shown. In Table 1, main parameters of the circulator is given. The flat field distribution of the RFQ along the beam axis and field symmetry among the quadrants are realized by adjustment of 24 tuners which can be moved by stepping motors. The high RF power up to 680kW corresponding to the gap voltage of 90kV (2.0 Kilpatrick) can be applied while the designed value is 530kW corresponding to the gap voltage of 80kV (1.8

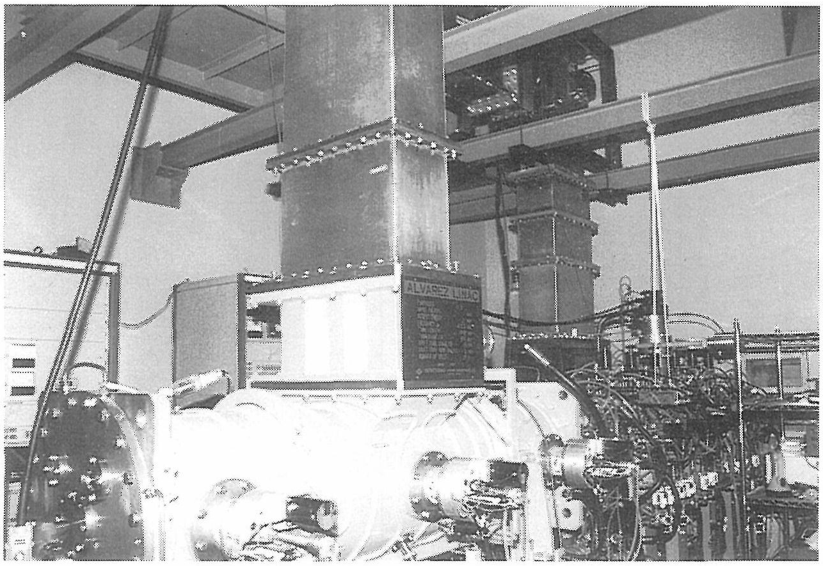

Photo. 1. Overall view of the linac system and the newly installed circulator.

Table 1. Parameters of the Circulator

Frequency	433.3 MHz
Band Width	±1 MHz
Maximum Peak Power	1 MW
Maximum Duty	1 %
VSWR	< 1.4
Insertion Loss	< 0.5 dB
Isolation	> 20 dB

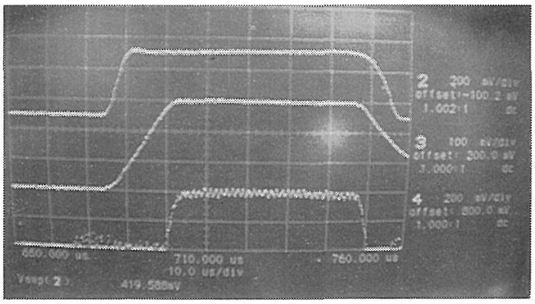

Photo. 2. Observed signals of the picked up RF power levels of the RFQ(top) and DTL (middle). The bottom signal shows the accelerated beam throughout the whole linac system.

Kilpatrick). The intervane voltage is calibrated by the measurement of the X-ray energy utilizing pure Ge detector[4]. In Fig. 3, correlation between the vane voltage and the applied peak power is shown.

The cavity of DTL should have the same frequency as the RFQ in order to accelerate the beam. As flat field distribution is realized at the resonant frequencies of 433.0MHz for the RFQ cavity, the operation frequency of the DTL is shifted to this value from 433.3MHz with use of three tuners. In this condition, the flatness of the field distribution in the DTL cavity is within ±4%. Because of the rather high Q value (40000) the filling time of RF power in the DTL cavity is rather long. So the amplitude of the RF is controled by ALC in order to enlarge the flat region of the supplied RF power in the DTL cavity. In Photo 2, the picked up RF power levels in the RFQ and DTL cavities are shown together with the accelerated beam

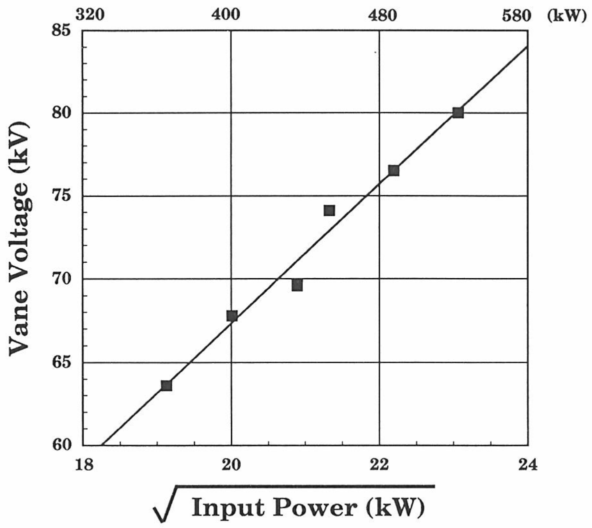

Fig. 3. Dependence of vane voltage on the input RF peak power measured by a pure Ge detector.

signal observed after the DTL. Thus a peak RF power up to 360kW (corresponds to 1.4 Kilpatrick) can be applied although the klystron is still directly connected to the RF coupler of the DTL because of its rather lower peak RF power compared with that of the RFQ. The required power for this system is calculated to be 320kW (corresponds to 1.3 Kilpatrick).

5. BEAM ACCELERATION TEST

Beam from the ion source is guided to the RFQ. In the guiding system, the currents and shapes are monitored by a Faraday cup and a profile monitor, respectively at the positions indicated in Fig. 1. Beam profile is monitored using an alminum oxide plate containing chromium oxide (Desmarquest AF995R). It should be noted that low energy beam with the kinetic energy of 50keV is visible with this alminum oxide plate.

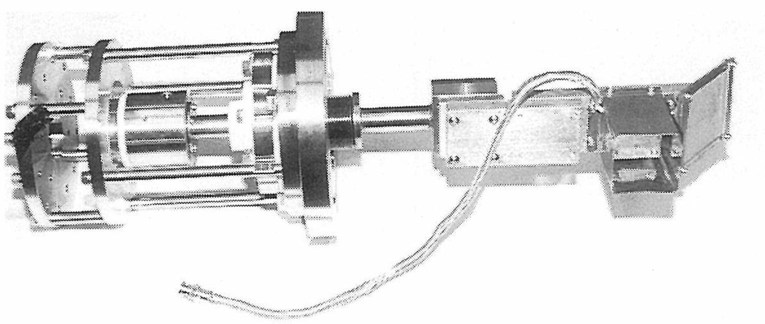

Photo. 3. The movable beam monitor utilized as a Faraday cap and a profile monitor.

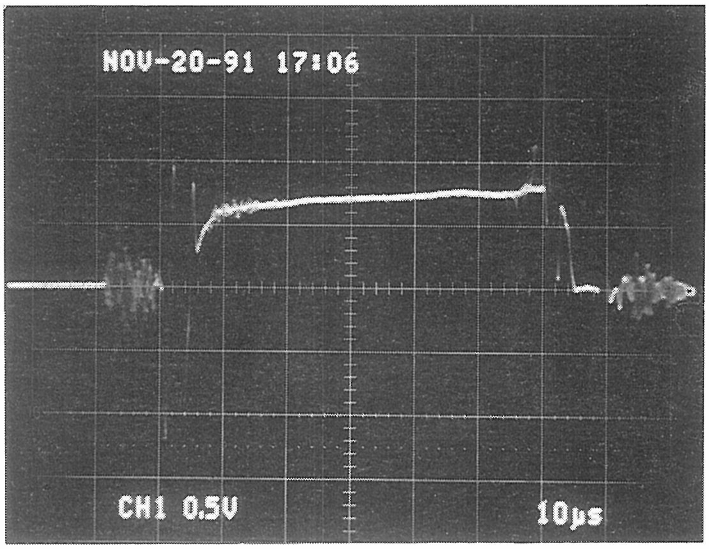

Photo. 4. Observed beam signal with use of the Faraday cup set between the RFQ and the DTL. Accelerated beam by the RFQ up to 2 MeV is detected.

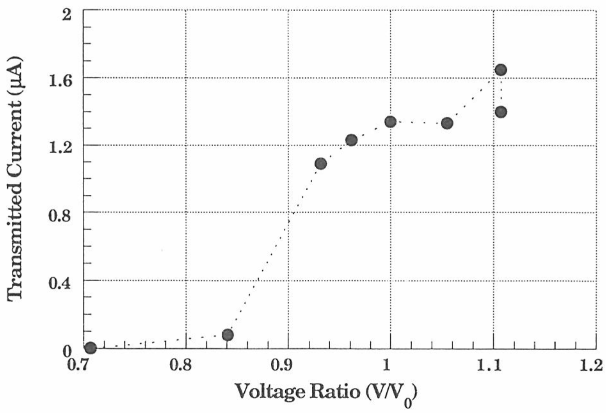

Fig. 4. Dependence of the transmission rate of the RFQ on the vane voltage normalized with the designed value.

After the RFQ, a movable beam monitor, which can be used both as a Faraday cup and a profile monitor, is installed. Its overall view is shown in Photo 3. The Faraday cup is insulated from the chamber and has a shielding made of thin copper plate so as to reject the background due to electrons emitted by a high RF peak power supplied in the cavities. The accelerated beam signal observed by the Faraday cup is shown in Photo 4. In front of the Faraday cup, we have installed an alminum foil 15μm in thickness, which corresponds to the range of 1MeV proton, in order to assure the beam acceleration. In Fig. 4, dependence of the beam current accelerated by the RFQ on the applied peak RF power is shown.

Beam acceleration by the DTL is also studied. The movable Faraday cup set just after

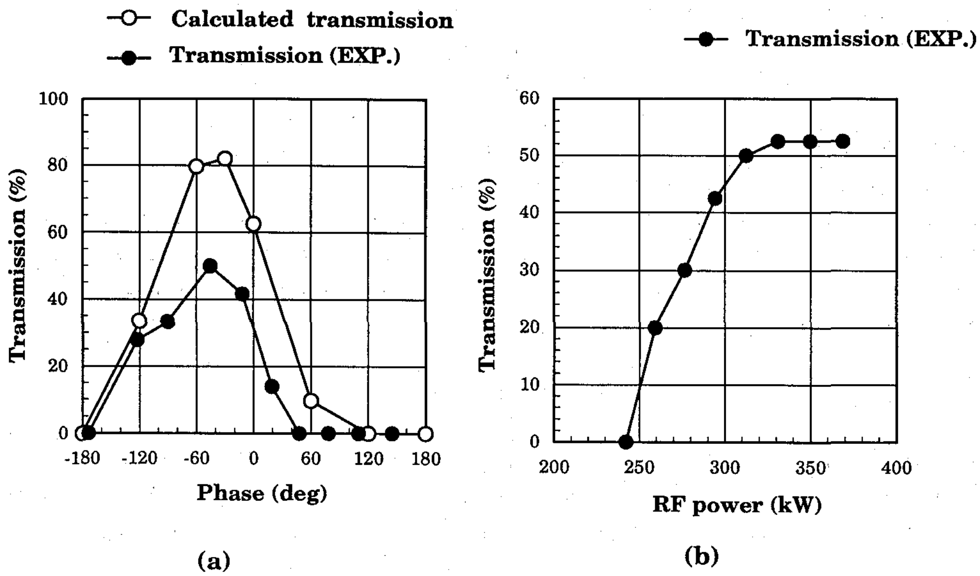

Fig. 5. Dependence of the transmission of the DTL on (a) the phase relative to the RFQ and (b) applied peak RF power.

the RFQ mentioned above was pulled out from the beam line to transfer the beam from the RFQ to DTL. Four permanent quadrupole magnets are installed to fulfill optical matching in the transverse phase spaces (both in horizontal and vertical directions)[5], while longitudinal matching is not satisfied because the space for a beam buncher is occupied by the movable Faraday cup as mentioned above in the configuration of present measurement. At the exit of DTL–tank, a window made of a stainless steel foil 0.1mm in thickness is attached and the beam profile just after the window is observed by a glass plate with ZnS coated on its surface. Clear beam shape is observed when the peak RF power of 320kW or more is applied. This glass plate is replaced by a Faraday cup when the beam current passed through the stainless steel foil is to be measured. In order to investigate the accelerated beam energy, aluminum foils with various thickness are used just after the stainless foil window. Between the stainless steel foil and the alminum foil, an air gap of 2cm exists. Another air gap of 2cm exists between the alminum foil and the Faraday cup. It is found that there is almost no change in the beam current up to 70μm of the alminum thickness while it decreases rapidly to almost zero for the thickness of 90μm. Utilizing the range data of proton in stainless steel and aluminum, the accelerated proton beam energy is estimated to be 7.0$\pm$0.2MeV, which is in good agreement with the result of the computer calculation. The correlation between transmission of the DTL and the RF phase of the DTL relative to that of the RFQ is given in Fig. 5(a). The origin of the RF phase is defined so that the peak of the measured data coincides with that of the calculation. In Fig. 5(b), beam transmissions for various input RF power levels are shown. It is found that the transmission saturates at the RF peak power level of the designed value, although it is limited at a rather low value of $\sim$50%. This somewhat lower transmission is considered to be due to the mismatch in transverse phase spaces at the low energy beam transport system, which is now in preparation for modification.

6. CONCLUSION

The RF peak powers larger than the designed values are supplied to both the RFQ and DTL cavities after the vacuum pressure of the cavities is improved better than 1×10^{-6} Torr and the circulator is installed in the RFQ power feeder. Beam acceleration experiment throughout the whole linac system is performed, which verified that the operation of the system is consistent with the calculation. The proton beam is successfully accelerated up to 7 MeV by the compact linac system with frequency of 433 MHz.

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