BEAM TEST RESULTS OF THE PEFP 20 MEV PROTON ACCELERATOR AT KAERI*

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Abstract

A 20 MeV proton accelerator, which consists of a 50 keV injector, a 3 MeV RFQ and a 20 MeV DTL, has been tested by Proton Engineering Frontier Project (PEFP) at Korea Atomic Energy Research Institute (KAERI). The operation conditions are 20 MeV, 20 mA peak current, 50 μs pulse length with a 1 Hz repetition rate due to the limited radiation shielding. The accelerator was tuned to reach to the above operating conditions. Moreover, an irradiation facility with external beam has been installed to supply the proton beam for the user and irradiation test. In this paper, we present results from tuning operation and the irradiation tests.

INTRODUCTION

The Korean Government launched the Proton Engineering Frontier Project (PEFP) in 2002 to help realize potential applications of high-power proton beams. The primary goal of the project is to develop a high-power proton linear accelerator to supply 100-MeV proton beams and to construct user beam line facilities, whose users can utilize proton beams with a wide range of energies and currents for their research and development programs [1]. In addition, the 100-MeV accelerator can be used as a proton injector for the next-stage high-power accelerators, such as a high-energy linac or rapid cycling synchrotron [2].

A 20-MeV proton linear accelerator has been developed as the front end of the 100-MeV accelerator, which consists of a 50-keV proton injector, a 3-MeV RFQ, a 20-MeV DTL, and RF systems, as shown in Fig. 1.

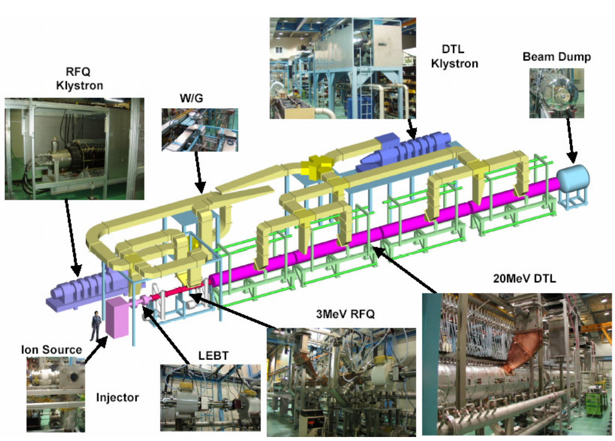

Figure 1: 20MeV proton linac at KAERI.

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THE 20-MEV PROTON LINEAR ACCELERATOR

The Proton Injector [3]

The injector includes a duoplasmatron proton source and a low-energy beam transport (LEBT). The beam current extracted from the source reached a current of 50 mA. The extracted beam has a normalized emittance of 0.2 πmm-mrad from a 90% beam current, where the proton fraction is > 80%. To achieve pulsed operation, a high-voltage switch has been installed in the high-voltage power supply, whose rise and fall times are < 50 ns. The pulse length and the repetition rate can be easily changed using this semiconductor switch. The LEBT consists of two solenoid magnets that can filter the H^{2+} ions and two steering magnets that can control the beam's position and angle at the entrance of the RFQ.

The 3 MeV RFQ [4,5]

The PEFP RFQ is designed to accelerate a 20-mA proton beam using a voltage from 50 keV to 3 MeV and has the usual four-vane-type design. The entire structure is separated into two segments that are resonantly coupled for field stabilization. The RF power is fed into the cavity through two iris couplers in the third section.

A 3-MeV, 350-MHz PEFP RFQ has been fabricated, tuned, installed, and tested. The low-power field tuning satisfied the design requirements. High-power RF conditioning experiments for the RFQ were carried out up to a peak power of 450 kW, a pulse length of 80 μs, and a repetition rate of 1 Hz. The time required for this conditioning was about 8 h. The RF signals shown in Fig. 6 are the signals detected after the conditioning, which were very stable. Beam tests were carried out by adjusting the LEBT and the RF parameters.

The 20-MeV DTL

The PEFP 20-MeV DTL consists of four tanks that accelerate the 20 mA proton beam from 3 MeV to 20 MeV. The total length of the DTL is about 20 m. The PEFP DTL structures were designed for a beam duty of 24%, and the FFDD lattice configuration has a magnetic field gradient of 5 kG/cm and an effective field length of 3.5 cm.

The DTL was fabricated using electroplating technology for the tanks and e-beam welding technology for the drift tube. A laser tracker was used to align the drift tubes in the tanks. Figure 8 shows the inside of a tank. The tuning goals for the PEFP DTL were such that the deviation in frequency was less than ±5 kHz from the design value, and the field distribution was less than ±2 %

throughout a tank with a tilt sensitivity against perturbations of less than 100%/ MHz.

For the 20-MeV DTL, a single klystron drives four DTL tanks simultaneously. For this multicavity driving concept, temperature control systems and mechanical phase shifters were installed in each tank. High-power RF tests were carried out. The peak RF power to each tank was 150 kW.

The RF System [6]

The accelerator facilities at the KAERI test stand include the 20-MeV accelerator itself, two sets of 1-MW, 350-MHz RF systems, two sets of –100-kV, 20-A DC high-voltage power supplies for the klystron, two sets of 2-MW cooling systems for the cavity, and the RF system. The design duty of the 20-MeV accelerator was 24%, and two 1-MW, 350-MHz klystrons were used to drive the 20-MeV accelerator: one was for the RFQ, and the other was for the DTL. All the other ancillary facilities, such as the klystron power supply and cooling system, were designed for an operational duty of 100%. During the low-duty operational tests at the KAERI test stand, the RF system operated such that the electron beam of the klystron was in the continuous wave (CW) mode, and only the input RF signal was modulated for low-duty pulse operation. TED Model TH2089F klystrons (350 MHz, 1 MW CW, Thales Electron Devices) were used as the RF source for the 3-MeV RFQ and for the 20-MeV DTL. Two high-voltage power supplies and two modulating anode power supplies were fabricated and tested for the klystrons. In addition, iris-type input couplers were developed and installed in the RFQ and the DTL.

The digital LLRF system was developed, and the stability requirements of the RF field were: amplitude = 1% and phase = 1°. Our digital feedback control system was based on a commercial field-programmable gate array (FPGA) card hosted on a virtual machine environment (VME) board. A control logic based on feedback and feed-forward control was implemented in the FPGA by using a very high-speed integrated circuit hardware description language (VHDL).

Target Station for 20-MeV Proton Beam Users

The operational license for the 20-MeV proton linac installed at the KAERI site was issued in 2007 by the Korea Institute of Nuclear Safety (KINS). According to our operational license, a 20-MeV beam with an average current of 1,000 nA can be supplied to users for their applications. At the exit of the 20-MeV DTL, a target station has been prepared to supply beams to the user, as shown in Fig. 2. The 20-MeV proton beams are transported with quadrupole magnets to expand the beam size and change the beam shape, for example, circular shape, and extracted into air through an aluminum beam window. Radiation is shielded with lead and concrete bricks.

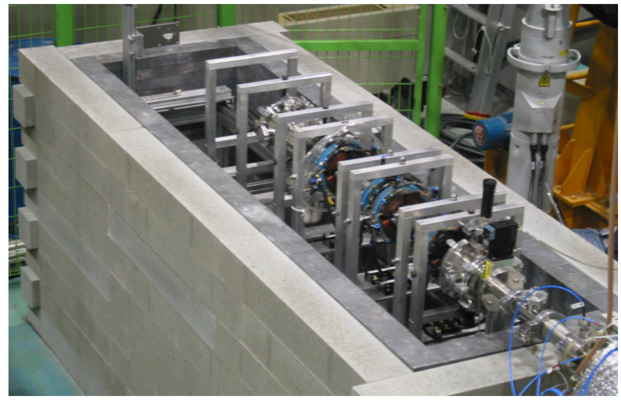

Figure 2: 20MeV proton beam target station.

BEAM TEST

The beam test of the proton injector and RFQ was done to check the operation characteristics after the slight modification of the front-end system [7]. An ACCT (AC Current Transformer) was installed to measure the input beam current to the RFQ and a Tuned-CT was installed to measure the output beam current from the RFQ. A collimator was installed not only to shield the ACCT from stray magnetic field but also to eliminate the spurious beam signal induced by the secondary electrons. Also an electron trap was installed in front of the RFQ to protect the electron flow from the LEBT. The RFQ output beam current was measured depending on the LEBT parameters – mainly solenoid magnet currents. The results showed typical characteristics of the RFQ transmission. The optimum solenoid current sets were good agreement with the TRACE-3D results within 3%. The beam transmission rate was measured as a function of the RF power. The measured value was compared with the PARMTEQ simulation results as shown in Fig. 3. We could determine the operating set point of the RF power based on the measurement. After the adjustment of the operating parameters such as LEBT steering magnet current, solenoid magnet current, RFQ RF power, we could get 20mA peak current from the RFQ.

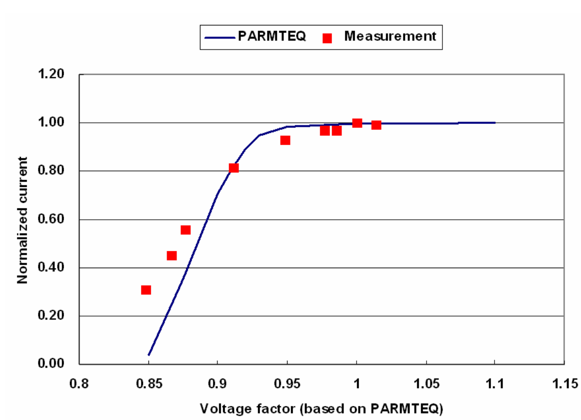

Figure 3: RFQ transmission rate depending on the vane voltage.

After the test of the RFQ, the beam test of the DTL started. The beam transmission through the DTL was about 80%. During test, the beam loss pattern was measured using pocket dosimeter (ALOKA, PDM-192) in every 20cm along the DTL. The result was such that a few numbers of noticeable localized peaks were measured as shown in Fig. 4. A beam dynamics study using PARMILA was done to investigate the cause of the localized beam loss pattern. The results showed that the cause of the first peak was estimated from the polarity reversal of the 30th electromagnet of the 2nd DTL tank. The beam loss pattern after the polarity reversal of the above quadrupole magnet is shown in Fig. 4. It could be seen that the first peak disappeared. In this case, the transmission rate through the DTL was nearly 100%. The second and third peak could not be explained from the polarity reversal of the electromagnet. And the peak could be greatly reduced by the stabilization of the tank resonance conditions. A 20mA peak proton beam could be accelerator up to 20MeV with the above conditions and the typical beam signal is shown in Fig. 5. The beam currents from the proton injector, RFQ and DTL were measured by ACCT, Tuned-CT and FCT respectively. The operating conditions were such that the RF pulse width was 50μs and the repetition rate was 1Hz.

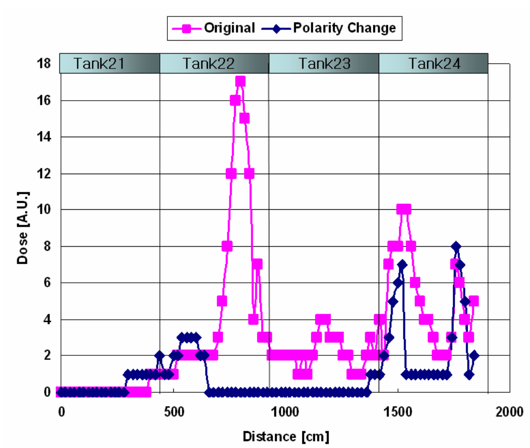

Figure 4: Beam loss distribution along the DTL (original: purple, after polarity change: blue).

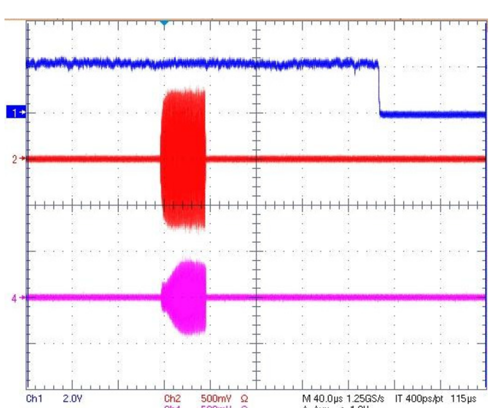

Figure 5: Beam signal of PEFP 20MeV linac (Ch 1: proton injector, Ch 2: RFQ, Ch 4: DTL).

CONCLUSIONS

We have developed the technology required for the construction of a proton linac. Using this technology, a 20-MeV proton linac was developed and installed at the KAERI site in Daejeon. 20MeV 20mA peak current was achieved at a low duty (1Hz, 50us) and has been used to supply a 20-MeV beam to users with an operational license to supply an average current of 1000 nA.

In April 2009, the ground breaking for the construction will be started and the 20MeV machine will be moved and installed in 2011. In 2012, we will perform the full 24% duty operation of the 20MeV machine. Fig. 6 shows the new site at Gyeonju.

Figure 6: Bird's-eye-view for Gyeonju site.

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