STATUS AND BEAM COMMISSIONING PLAN OF PEFP 100-MeV PROTON LINAC*

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Abstract

The proton engineering frontier project (PEFP) is developing a 100-MeV proton linac which consists of a 50-keV injector, a 3-MeV RFQ (radio frequency quadrupole), and a 100-MeV DTL (drift tube linac). The installation of the linac was finished on March this year. The beam line magnets were also installed in the experimental halls. The utilities will be prepared at the end of October 2012 and accelerator commissioning will start in this winter. The beam commissioning is scheduled in February 2013 with the goal to deliver 100-MeV proton beam into a 100-MeV target room. This work summarized the status of the PEFP linac development and the beam commissioning plan.

INTRODUCTION

Proton Engineering Frontier Project is the 100-MeV proton linac development project which was launched at 2002 as a 21st century frontier R&D program of Korean government [1,2]. The final goals of the project are constructing a proton linear accelerator with the final energy of 100 MeV and the peak beam current of 20 mA, developing technologies for the proton beam utilizations and the accelerator applications, and promoting industrial applications with the developed technologies.

The PEFP proton linear accelerator consists of two parts. The low energy part includes an 50-keV ion source, a low energy beam transport (LEBT), a 3-MeV radio frequency quadrupole (RFQ), and a 20-MeV drift tube linac (DTL) . The high energy part consists of seven DTL tanks which accelerator proton beams from 20 MeV to 100 MeV. A medium energy beam transport (MEBT) system will be installed after the 20-MeV DTL. It includes a 45-degree bending magnet for 20-MeV beam extraction and 2 DTL-type tanks with 3 cells for both transverse and longitudinal beam matching. The basic parameters of the linac are summarized in Table 1.

The PEFP experiment hall includes 10 beam lines, 5 for 20-MeV beams and 5 for 100-MeV beams. One of the main characteristics of PEFP beam lines is using AC magnet to distribute proton beams into 3 target rooms in both 20-MeV and 100-MeV beam lines. Each target room was assigned to special purposes as shown in Table 2 and Table 3. The main application fields are the bio-medical application, the material science, the energy and environmental application, the semiconductor production and research, the space science, and the isotope production.

The 20-MeV linac system has been successfully installed and tested at the Daejeon site of KAERI. In this operation of the linac from 2007 to 2011, we studied the characteristics of the low energy part of the linac and also supplied 20-MeV proton beams to users. The fabrication of the remaining DTL tanks was finished in 2010. The linac was installed into the accelerator tunnel in March 2012. In the process, we disintegrate and moved the 20-MeV linac into the project site at Gyeongju city. After completing utility test, the accelerator and beam commissioning will start. The proton beam will be provided to users from spring 2013.

Table 1: Basic Parameters of PEFP Linac

Parameter	Value
Frequency	350 MHz
Beam Energy	100 MeV
Operation Mode	Pulsed
Max. Peak Current	20 mA
Pulse Width	<1.33 ms (< 2.0 ms for 20 MeV)
Max. Beam Duty	8% (24% for 20 MeV)
Max. Beam Power	160 kW (96 kW for 20 MeV)

Table 2: Specification of 20-MeV Beam Lines

Target Room	Application Field	Average Current	Irradiation Condition
TR21	Semiconductor	600 μA	Hor. Ext. 300 mmΦ
TR22	Bio-Medical Appl.	60 μA	Hor. Ext. 300 mmΦ
TR23	Materials, Energy & Environment	600 μA	Hor. Ext. 300 mmΦ
TR24	Basic Science	60 μA	Hor. Ext. 100 mmΦ
TR25	Radio Isotopes	1200 μA	Hor. Vac. 100 mmΦ

Table 3: Specification of 100-MeV Beam Lines

Target Room	Application Field	Average Current	Irradiation Condition
TR101	Radio Isotopes	600 μA	Hor. Ext. 100 mmΦ
TR102	Medical Research (Proton therapy)	10μA	Hor. Ext. 300 mmΦ
TR103	Materials, Energy & Environment	300 μA	Hor. Ext. 300 mmΦ
TR104	Basic Science Aero-Space tech.	10 μA	Hor. Ext. 100 mmΦ
TR105	Neutron Source Irradiation Test	1600 μA	Hor. Vac. 100 mmΦ

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ACCELERATOR DEVELOPMENT

The 20-MeV part of the linac was installed at Daejeon site in 2005 in order to study the characteristics of the linac and proton beams [3]. In 2007, the operation license was obtained from the government and began to provide 20-MeV proton beams to users. In this process, we developed important technologies for linac and beam line operation, and for measuring beam properties.

One of the main upgrade in the operation period is developing a microwave ion source. The original ion source was a duoplasmatron whose filament had to be replaced after 40-hour operation. However the linac should supply proton beams for more than 100 hours without maintenance according to the operation scenario of the facilities. A microwave ion source was developed in 2010 and successfully tested the 100-hour operation. The duoplasmatron was replaced with the new ion source in 2011 operation of the 20-MeV linac (see Fig. 1). The total operation time was 243 hours without maintenance [4,5].

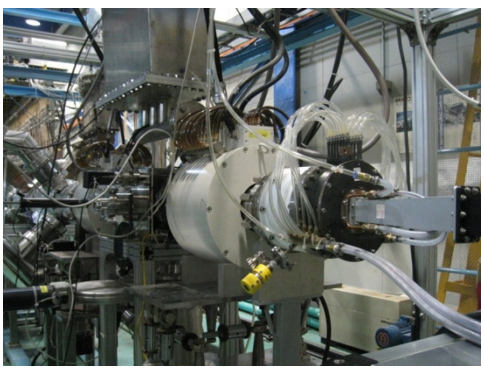

Figure 1: The microwave ion source for PEFP linac.

The beam parameters, energy and emittance were measured in the operation. The beam energy was determined by using the conventional time of flight method by using two BPMs installed downstream of the 20-MeV linac. It was 20.2 MeV which was confirmed by the range measurement with aluminium foils. The beam emittance in LEBT was measured by using the electric sweep scanner. The measured value was 0.35 π mm mrad in normalized rms unit. It is higher than the design value of 0.2 π mm mrad. The emittance of 20-MeV beams was measured by a quad scan method. It was 0.22 π mm mrad which was very similar to the PARMILA simulation.

For the beam position measurement of linac after MEBT and beam lines, we developed a stripline BPM. The prototype BPM was tested in a beam line which was designed and installed for 20-MeV beam irradiation. The BPM signal was consistent with the expectation [6].

The LLRF system was upgraded into the digital system with a commercial board equipped with FPGA. The PI control logic was developed and tested by PEFP. The high power test showed that the RF amplitude and phase were controlled within 1% and 1°, respectively [7,8]. We also developed a control system based on EPICS which was used and tested in the 20-MeV linac operation. The control system for 100-MeV linac was designed based on the experience [9].

One of important experience in the operation was supplying proton beams to users. We prepared the test beam line for proton irradiation on target. We also developed the procedure from the sample preparation to beam irradiation based on the internet communication. The safety was most important point in the procedure development. The number of samples was increased every year and reached to 687 in 2011 operation. The total number of samples is 1603 in the 5-year operation from 2007 to 2011.

The fabrication of the DTL tanks for acceleration between 20 MeV and 100 MeV was finished in December 2010 (see Fig. 2). The DTL consists of 7 tanks with the average length of 6.8 m. Each tank separated into 3 sections for easy assembly. The beam duty is 8% in this part of DTL and a 1.6 MW pulsed klystron drives one tank. The lattice structure is FFDD and the integrated field is 1.75 T for a quadrupole magnet in the tanks. The hollow conductor is used for the quadrupole magnets. In order to align drift tubes into DTL tanks, two laser trackers were used and environment temperature was controlled. The allowed value of the alignment errors is 50 μm in transverse direction and achieved the requirement in all DTL tanks.

Figure 2: The last DTL tank of the PEFP linac.

All dipole and quadrupole magnets were fabricated for the 20-MeV and 100-MeV beam lines. We also finished the field measurement and the geometrical fiducialization of the magnets. Another important component in the beam lines is the AC magnet which can distribute proton beams into the 3 target rooms. The fabrication of the AC magnets was finished. They will be derived by the programmable power supplies with operation frequency of 15 Hz for 20 MeV and 7.5 Hz for 100 MeV. We also developed a beam window with the diameter of 300 mm. The concave AlBeMat widow has the thickness of 0.5 mm. The energy loss is 0.6 MeV for 100-MeV extraction. The beam window was designed to be cooled by an air blower.

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INSTALLATION STATUS

The operation of 20-MeV linac and beam line was finished on November 2011. The accelerator and beam line components were disintegrated and moved to the project site in Gyeongju city in February 2012 (see Fig. 3) [10]. We measured the field profile of the tanks before and after the movement and found that the difference is less than 3% .

One important step in the accelerator building construction is the installation of waveguides into the concrete wall of 2.5 m thickness. The penetration section of the waveguide has a bending shape for radiation shielding as shown in Figure 4 [8]. The waveguides were fabricated as a piece of WR2300 half height and tested the leakage carefully before installation.

The accelerator building consists of 3 stories. The 1st floor is accelerator tunnel, the 2nd floor is the klystron gallery, and the 3rd floor is the modulator room. The experimental hall is located beside the tunnel. Because there is no crane in the 1st floor, the accelerator components and beam line magnets were transported into their positions by using moving carts. A vehicle is available for moving klystrons into the 2nd floor. The modulator components can be moved into the 3rd floor by using a crane.

Figure 3: Movement of the 20-MeV DTL tanks to the project site in Gyeongju city.

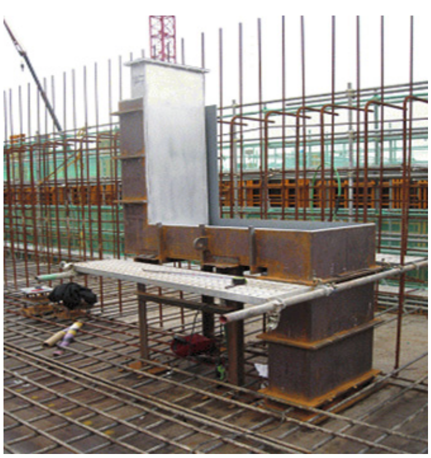

Figure 4: The penetration waveguide installed into the concrete wall.

Figure 5: The target holder for alignment network in the accelerator tunnel.

The first step of the installation was making an alignment network in the accelerator tunnel and the experimental halls. We installed 42 target holders in the tunnel and 29 holders in each hall (see Fig. 5). The thickness of the basement plate for each component was adjusted to compensate the level difference of floor which was obtained by the position measurement based on the network [11].

The installation of the linac was finished in March 2012 (see Fig. 6) [10]. The beam line magnets were installed in May 2012 (see Fig. 7) [10]. The alignment of the linac and beam line will start after finishing utility test and stabilizing the environment temperature. The installation of klystron and modulator started in September 2012.

Figure 6: PEFP 100-MeV linac installed into the accelerator tunnel.

Figure 7: The beam line magnets installed for 20-MeV beam line.

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BEAM COMMISSIONING PLAN

The beam commissioning of PEFP linac and beam lines is a two-staged process. One is testing up to the 20-MeV linac and the MEBT. A beam stop will be used for the 20-MeV beam commissioning. The other is the beam commissioning of 100-MeV linac and beam delivery to a target room. The 1-kW beam bump was installed at the end of the 100-MeV linac. The commissioning goal is the beam power of 1kW with the beam energy of 100 MeV and the peak beam current of 20 mA. The Layout of beam diagnostics for the commissioning are summarized in Figure 8.

The commissioning of the 50-keV injector including a microwave ion source and LEBT will start from the operating condition of the machine at Daejeon site. The RFQ commissioning is the process to find the RF operation amplitude by comparing the calculation with the experimental results of beam transmission. A 1-MW klystron drives 4 DTL tanks which accelerate proton beams up to 20-MeV. The RF set point of tanks can be determined by the same procedure as that for a typical DTL tank [12].

RF Set-point Determination of DTL Tanks

An important step of the beam commissioning process is to determine the RF amplitude and phase of each DTL tank. We adopted the well-known phase scan method [13] for this purpose [14]. We developed a program for the RF set-point determination based on MATLAB with the nonlinear optimization algorithm LEVMAR [15]. In the first step, we calculated beam phase as a function of RF phase by using PARMILA code as shown Figure 9. In the process we assumed that the input energy becomes the designed value after adjusting the previous tank. An experimental data of the beam phase as a function of RF phase with the fixed relative amplitude A/A_0 is compared with the simulation results to generate a χ-value for each case of A/A_0 (see Fig. 10). The quadratic fitting of the χ-values determined the RF amplitude and phase (see Fig. 11). We tested the program by using an artificial experimental data set of a DTL tank (DTL101) with $A/A_0 = 1$ and RF phase shift of 135.4°. The data were generated by PARMILA code with random Gaussian errors with σ=0.5° in the beam phase. The resulting values of the program are 1.001 and 135.2° for the amplitude and phase, respectively.

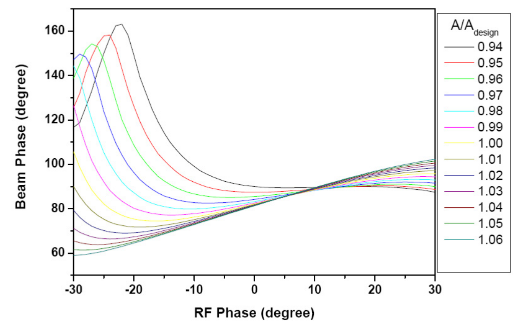

Figure 9: Beam phase as a function of RF phase with different relative amplitudes (DTL101).

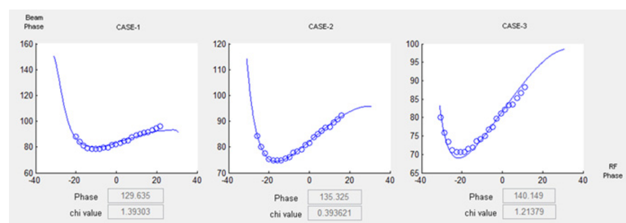

Figure 10: Comparison the artificial experimental data to the simulation results with different relative amplitudes (A/A_0 = 0.98, 1.0, 1.02).

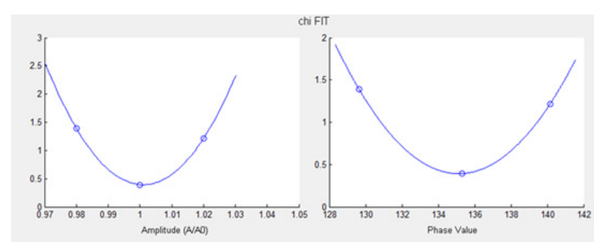

Figure 11: Determination of the RF amplitude (left) and phase (right) by using a quadratic fitting.

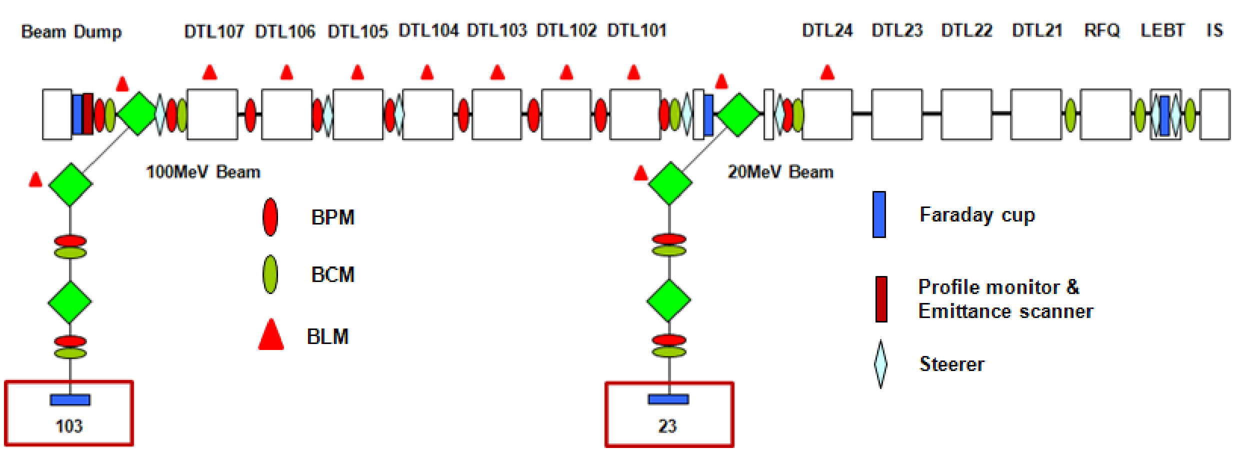

Figure 8: Layout of beam diagnostics in PEFP linac and beam lines.

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R&D FOR FUTURE EXTENSION

An superconducting linac (SCL) should be an optimal solution for extension of the PEFP linac energy to 1 GeV for spallation neutron source. The elliptical cavities with β_g=0.50 and 0.74 can be used to accelerate proton beam from 100 MeV to 1 GeV. The prototype Nb cavity with operating frequency of 700 MHz was fabricated and successfully tested below 5K (see Fig. 12). The maximum accelerating gradient was 4.2 MV/m with the RF power of 330 W, which was limited by the available RF power in the experiment [16].

Figure 12: Experiment of the PEFP SRF cavity.

CONSTRUCTION STATUS

Gyeongju city which is located in the south-eastern part of Korea hosted the project in January 2006. The geological surveys of the site and the site-dependent plan such as the facility layout and access road have been completed for the civil construction. The construction of the accelerator and beam utilization building, and utility buildings are almost finished. Figure 13 shows the present status of the PEFP accelerator research center. The construction and utility commissioning will be completed in October 2012.

Figure 13: The accelerator building at the project site in Geyongju city.

CONCLUSION

PEFP has successfully developed a 100 MeV proton linac which consists of an injector, RFQ, and DTL. The installation of the linac and beam line magnets was finished. The installation of HPRF components started in September 2012. The commissioning scheduled in this winter and beam service will start in spring 2013.

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