THE PROTON ENGINEERING FRONTIER PROJECT*

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Abstract

Since launched in 2002 to develop a high current 100 MeV, 20 mA proton linac and beam facilities, the Proton Engineering Frontier Project (PEFP) has fully developed and integrated its low energy part, consisting of a 50 keV ion source, a 3 MeV RFQ, and a 20 MeV DTL with a 24% duty factor. Successfully commissioned by achieving a designed peak beam current of 20 mA and beam energy of 20 MeV, we started user beam services in 2007. The high energy part of the linac and components of the 20 and 100 MeV beam facilities, which are designed to deliver characterized proton beams for applications in various fields, are under development. In addition, site preparation and construction works are in progress. Being completed in 2012 as planned, the proton linac facility will be utilized in core R&D projects in multi-disciplines, from nano, energy, environment, and medical, to basic science.

INTRODUCTION

Approved as a 21C Frontier R&D Program by the Korean Ministry of Education, Science and Technology, the project was launched with three primary goals. The first goal is to develop a high current 100 MeV, 20 mA proton linac and proton beam utilization facility. The second is to promote and support core R&D programs in various fields by utilizing highly characterized proton beams and in applications of accelerator technologies. Finally, the third is to transfer matured technologies to industry.

The report summarizes the progress of the project with focus on the development of the proton accelerator and proton beam utilization facility, and progress in core R&D programs through its user program, along with the remaining works to complete the project by 2012 as planned.

ACCELERATOR DEVELOPMENT

General Layout

The proton accelerator has a unique function to deliver proton beams to several users simultaneously. The key parameters of the PEFP proton linac, the proton beam energy and peak beam current of 100 MeV and 20 mA, respectively, which are essential to supply enough proton beams required to manipulate materials on a nano scale. In addition, our user survey revealed that low-energy proton beams (<20 MeV) are required to perform industry-oriented mass irradiation processing and high-energy proton beams (>20 MeV) for more fundamental research and development. Considering these conditions, we have determined the nominal beam duty of the low energy part to be 24% and high energy part to be 8%. The other key parameters of the PEFP proton linac are summarized in Table 1. A schematic of the PEFP proton linac and beamlines are shown in Fig. 1.

Table 1: Specifications of the PEFP Proton Accelerator

Parameter	DTL-I	DTL-II
Output Energy (MeV)	20	100
Max. Peak Beam Current (mA)	20	20
Max. Beam Duty (%)	24	8
Average Beam Current (mA)	4.8	1.6
Max. Pulse Length (ms)	2	1.33
Max. Repetition Rate (Hz)	120	60
Max. Avg. Beam Power (kW)	96	160

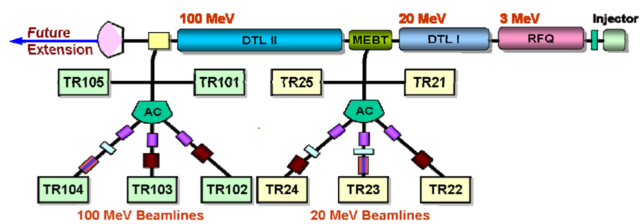

Figure 1: Schematic of the PEFP Proton Accelerator and Beamlines.

Proton Injector & LEBT

The PEFP injector consists of an ion source and a low energy beam transport (LEBT), which matches the proton beam to the RFQ. A duoplasmatron ion source has been implemented to achieve the design specifications, such as the energy, current, and emittance, as summarized in Table 2 [1]. The LEBT consists of two solenoid magnets and two steering magnets whose configurations and operating conditions are adjustable. Main functions of the two solenoid magnets are to filter out H^+_2 ions and protons with different energies, and to focus the proton beams into the RFQ entrance. The two sets of steering magnets control the beam position and angle at the RFQ entrance to match its acceptance.

Table 2: Specifications of the PEFP Injector

Extraction Energy	50 keV
Extraction Beam Current	10~50 mA
Proton Fraction	~ 80%
Normalized RMS Emittance	0.2 π-mm-mrad
Pulse Length	50 μs ~ infinity
Max. Repetition Rate	120 Hz

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RFQ

We had developed a vane-type RFQ to accelerate the proton beams from 50 keV to 3 MeV, whose parameters are summarized in Table 3. The RFQ has been fabricated, tuned, installed and commissioned successfully [2].

Table 3: Specifications of the PEFP RFQ

RF Frequency Input/Output Energy	350 MHz 50 keV / 3 MeV
Beam Current	20.2 mA
Normalized RMS Emittance	0.22 π mm - mrad
Transmission Rate	~ 70%
Peak Surface Field	1.8 Kilpatrick
Length	3.266 m
Max. Duty	24%

DTL

The DTL is largely separated into two parts with the specifications summarized in Table 4. The DTL-I consists of four tanks which had been designed for a beam duty of 24% and had been fabricated by using electroplating technology for the tanks and e-beam welding technology for drift tubes [3]. The resonant frequency has been tuned to within ±5 kHz and the field distribution to within ±2% in a tank with a tilt sensitivity against perturbations of less than 100 %/MHz. To drive four DTL tanks with a single 1 MW CW klystron, we have implemented temperature control systems and mechanical phase shifters in each tank to control the resonant frequency and phase [4].

Table 4: Specifications of the PEFP DTL

Parameters	DTL-I	DTL-II
RF Frequency	350 MHz	350 MHz
Output Energy	20 MeV	100 MeV
Max. Peak Current	20 mA	20 mA
Normalized RMS Emittance	0.2 π	0.2 π
Max. Pulse Length	2 ms	1.33 ms
Max. Repetition Rate	120 Hz	30 Hz
Max. Duty	24%	8%

The DTL-II is composed of a total of 7 tanks with design specifications slightly different from those of the DTL-I [5]. The key differences are in their beam duties and repetition rates, and each DTL-II tank is driven by a 1 MW pulse klystron. We have fabricated and assembled 6 DTL tanks, corresponding to the energy range from 20 to 91 MeV, and performed low power RF test.

Beam Extraction System & MEBT

In order to extract 20 MeV proton beams, we introduce a 45-degree bending magnet which requires a large drift space between the DTL-I and the DTL-II, and raises a beam matching issue between them. To resolve the issue, a medium energy beam transport (MEBT) system is implemented, which consists of two small buncher cavities either side of the beam extraction magnet. Each cavity is composed of three cells with four quadrupole magnets which are configured to match the proton beam transversely. An RF fed into the cavities is managed to match the beam longitudinally.

Beamlines and Targets

Fig. 2 shows a 3D drawing of the 100 MeV beamlines and targets rooms. Based on a detailed beam optics design, all required beamline components and instruments have been designed. Quadrupole magnets, beam distribution magnets, and some bending magnets have been fabricated. Other instrumentation, such as beam position monitors, beam current monitors, and beam windows, has been designed and prototyped. In addition, performance tests of the dipoles, quadrupoles, power supply, and so on, have been performed.

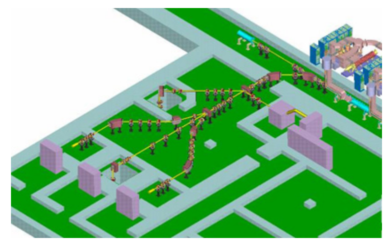

Figure 2: Schematic of 100 MeV Beamlines and Targets.

Commissioning and Operation of the 20MeV Front Accelerator

Driving four tanks of the DTL-I by using a klystron requires a delicate control of the RF system to distribute the RF power evenly into all four DTL tanks and to synchronize the RF phase in all tanks. Such complicated control has been realized by developing a digital LLRF system, which is able to control the RF amplitude to within 1% and phase to within 1 degree [6].

Since extracted the first beam from the DTL-I in 2005, commissioning operations have been performed to tune the machine parameters. With its operation license obtained in 2007 for limited conditions, a repetition rate of 0.1 Hz and 4-hour operation per week from the Korea Institute of Nuclear Safety, we have performed extensive commissioning operations and achieved its design performance at a beam energy of 20 MeV and a peak beam current of 20 mA as shown in Fig. 3.

The successful commissioning of the DTL-I has proven, for the first time, that multiple DTL tanks can be driven by a single klystron by fully satisfying the design requirements. To meet increasing user demands for intense proton beams, a target station was installed at the end of the DTL-I to supply 20 MeV proton beams to users while performing commissioning operations. Improving the radiation shielding in 2008, we revised the operation conditions and provided users with the proton beams to support hundreds of irradiation experiments annually.

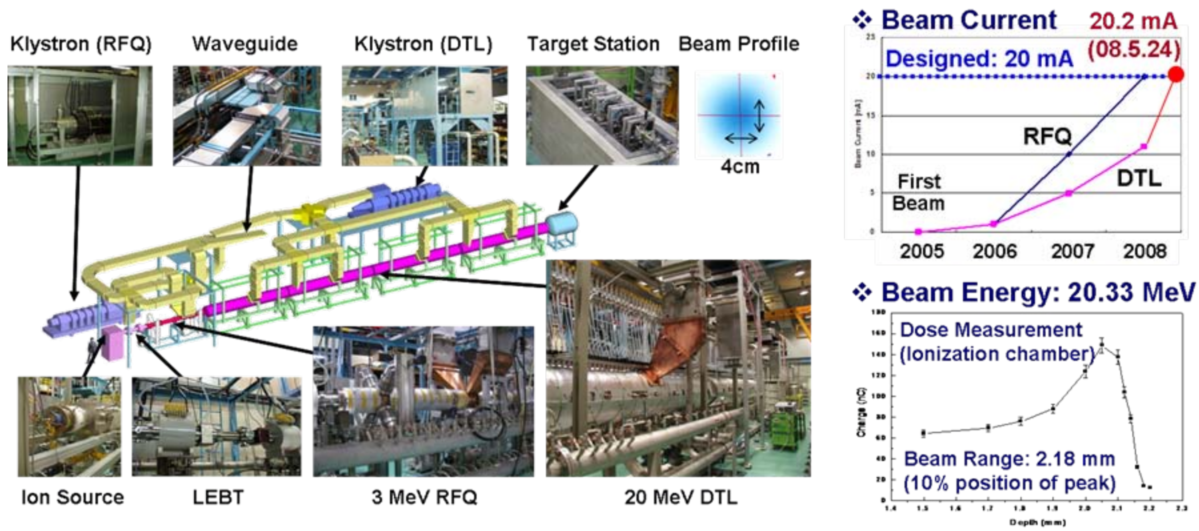

Figure 3: The PEFP 20 MeV proton linac installed at KAERI.

BEAM UTILIZATION & APPLICATION

We have developed a 45 MeV beam facility at an MC-50 cyclotron at the Korea Institute of Radiological and Medical Science, which has severed the majority of researches of the user programs. The two beam facilities supports about 1,500 irradiation experiments annually in a wide range of research fields as summarized in Fig. 4.

Completed in 2012 as planned, the unique proton accelerator facility will support state-of-art research and development in various fields requiring highly characterized proton beams. Especially, its capability of supplying high current proton beams may realize mass production processing, such as power semiconductor switch fabrication, metallic nano-particle fabrication, or medical radioisotope production.

SUMMARY

The PEFP 100 MeV proton linac facility is under development to provide multi-users simultaneously with intense and highly-characterized proton beams by meeting sophisticated requirements. A 20 MeV proton linac, a front part of the 100 MeV proton linac, has been developed and commissioned successfully, which has made the proton accelerator technology advanced in the following distinguished features. Firstly, a nearly-CW 3 MeV RFQ has been developed for the first time and the 20 MeV DTL can operate with the highest beam duty of 24%. Secondly, a unique RF system driving the 20 MeV proton linac has proven that multiple DTL tanks can be operated by a single klystron for the first time. Finally, the 100 MeV proton linac has a unique feature to extract 20 MeV proton beams in the middle of the accelerating system.

ACKNOWLEDGEMENT

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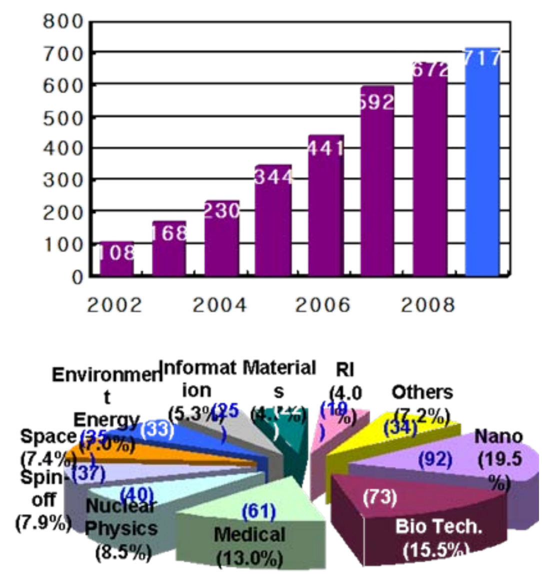

Figure 4: Statistics of the PEFP Proton Beam Users.

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