STATUS OF THE PROTON ENGINEERING FRONTIER PROJECT*

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Abstract

The Proton Engineering Frontier Project (PEFP), approved and launched by the Korean government in July 2002, includes a 100 MeV proton linear accelerator development and programs for its utilization and application. The first phase of the project, running from 2002 to 2005, was the design of a 100MeV proton linear accelerator and a part of development of a 20 MeV linac. This consists of a 50 keV proton injector, a 3 MeV radio frequency quadrupole (RFQ), and a 20 MeV drift tube linac (DTL). The 50 keV injector and 3MeV RFQ has been installed and tested, and the 20 MeV DTL is being assembled and tuned for beam tests. At the same time, the utilization programs using the proton beam have been planned, and some are now under way. The status and progress of the project are reported in detail.

INTRODUCTION

In the 21st century, science and technology will need to understand the quantum behaviour of materials on the molecular and atomic scales. Particle beams can provide manipulative and visual tools to probe and fabricate nanoscale materials. High-power proton accelerators (HPPAs) can produce high-intensity beams of protons and secondary particles, such as neutrons, radionuclei, mesons, and neutrinos. Such intense beams provide practical and efficient methods to realize quantum engineering.

Figure 1 shows various fields of interest and potential applications of proton beams with a wide range of energy, current, and power. High-current proton beams with low energy (< 10 MeV) are useful in industrial and defence applications, such as ion-cutting, power semiconductors, mine detection, boron neutron capture therapy, and neutron radiography. Low-current proton beams with medium energy (10–250 MeV) are valuable in biological and medical research, for example, in studies on mutations in plants and microorganisms, in neutron and proton therapy, and in radioisotope production. High-power proton beams with energies around 1 GeV have great potential as spallation neutron sources, radioactive nuclei beams**,** uses in high-energy physics experiments, and in accelerator-driven systems.

The Proton Engineering Frontier Project (PEFP) was launched by the Korean government in 2002 to realize potential applications from the utilization of high-intensity proton beams. Its primary goal is to develop a high-current proton linear accelerator supplying 100 MeV, 20 mA proton beams. This can be a proton driver that can be applied to various applications in the low- to medium-energy range, or can be an injector for a high-energy proton machine in the next stage of development.

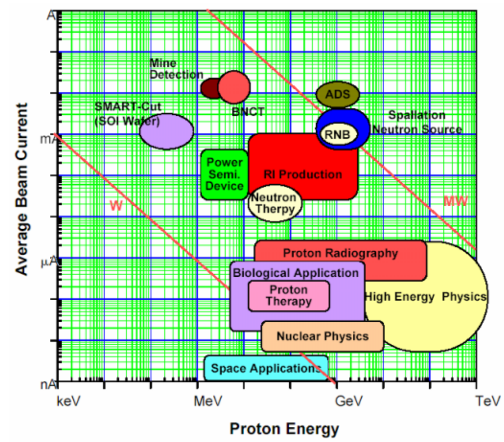

Figure 1: Utilization and applications of proton beams.

The design of the building and conventional facilities is under way with architectural engineering works in progress as shown in Figure 2.

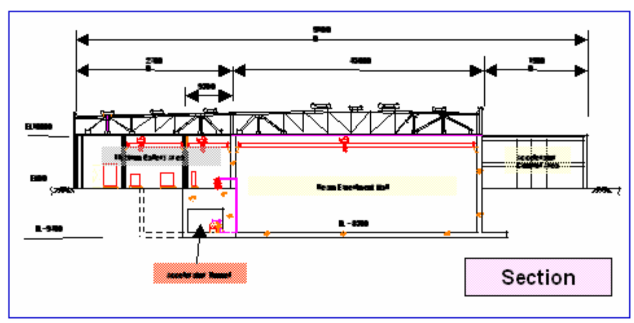

Figure 2 : Accelerator Building and Experimental Hall.

This brief report summarizes the present status of the PEFP, including the construction of the utilization facilities and the development of user programs, as well as the progress achieved in accelerator development.

ACCELERATOR DEVELOPMENT

The accelerator system for the 20 MeV proton beam is being developed in the first phase of the project, which is expected to be completed in 2005. It consists of a 50 keV proton injector, a 3 MeV RFQ, and a 20 MeV DTL. In the second phase, this will be extended to include a 100 MeV accelerator, which should be a DTL or superconducting linac. Two beam lines will be installed at the ends of the 20 MeV and 100 MeV accelerating structures to supply proton beams with low to medium energies. Figure 3 shows a schematic drawing of the PEFP linac system. The basic parameters of the accelerator are given in Table 1.

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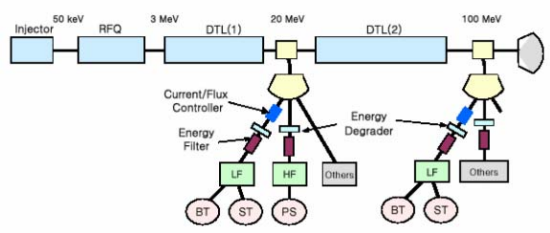

Figure 3: Schematic drawing of the PEFP linac and beam lines.

Table 1: Basic parameters of the PEFP accelerator

Parameter	Value
Particle	Proton
Beam Energy	100 MeV
Operation Mode	Pulsed
Max. Peak Current	20 mA
Repetition Rate	15 Hz
Pulse Width	<1 ms
Max. Beam Duty	24%

INJECTOR [1]

The injector part of the PEFP linac includes a duoplasmatron H^+ ion source (Fig. 4), and a low-energy beam transport (LEBT). The beam current extracted from the source reached up to 50 mA at a voltage of 50 kV using a 150 V, 10 A arc power. The extracted beam has a normalized emittance of 0.2 π mm-mrad from a 90% beam current, where the proton fraction is larger than 80%. To achieve 15 Hz pulsed operation, a high-voltage switch is installed in the LEBT system, whose rising and falling time is less than 50 ns [1]. The LEBT (Fig. 4) consists of two solenoid magnets and a 211 cm diameter beam line. The estimated transmission efficiency is 92%, with a variable beam current from 10 to 50 mA.

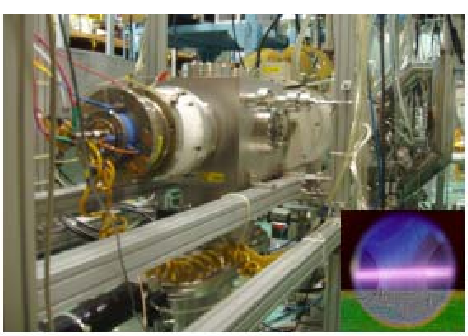

Figure 4: Injector of PEFP linac.

RFQ [2,3]

The PEFP RFQ is designed to accelerate the 20 mA proton beam from 50 keV to 3 MeV. It is the usual four-vane type. The entire structure is separated into two segments that are resonantly coupled for the field stabilization. The RF power is fed into the cavity through two iris couplers in the third section. The main design parameters of the PEFP RFQ are summarized in Table 2.

The PEFP RFQ (Fig. 5) has been fabricated and tuned. High-power RF testing is currently in progress, and the beam tests have started. Until now, the stable RF power going into the RFQ has been about 330 kW, and this will be increased up to the full power level after baking the RF window and modifying the coupler.

Table 2: PEFP RFQ parameters

Parameters	Values
Frequency	350 MHz
Input / Output Energy	21 mA / 20 mA
Input / Output Current	50 keV / 3 MeV
Peak Surface Electric Field	1.8 Kilpatrick
Power	465 kW Cu = 400 kW, Beam = 65 kW
Transmission Rate	98.3% *
Length	329 cm

We have tried to accelerate the proton beam through the machine under these RF conditions. In initial beam tests, we did not use the LEBT for matching into the RFQ. The pulsed beam current was observed using a Faraday cup located 70 cm downstream from the RFQ exit, as shown in Figure 6. We plan to measure the energy and the emittance of the output beam after full power RF testing.

Figure 5: The PEFP RFQ and its test stand.

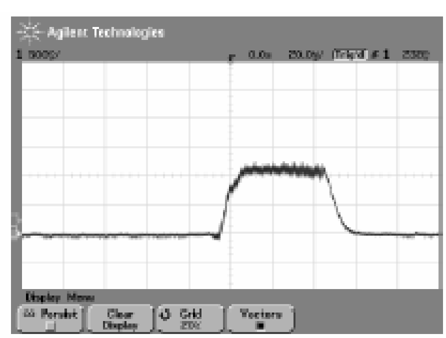

Figure 6: Faraday cup signal of the RFQ output beam.

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DTL [4-8]

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. A 1 MW klystron will supply the RF power into the four tanks. The FFDD lattice configuration has a magnetic field gradient of 5 kG/cm, and an effective field length of 3.5 cm. The DTL parameters are given in Table 3 and the general layout are shown in Figure 7.

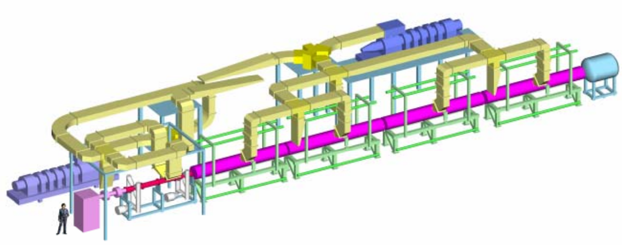

Figure 7: PEFP 20MeV Proton Linac.

Table 3: PEFP DTL parameters.

Parameter	Values
Frequency	350 MHz
Input / Output Energy	3 MeV / 20 MeV
Peak Current	20 mA
Beam Duty	1.5%
Input / Output Emittance	
Transverse	0.23 / 0.23 π mm-mrad
Longitudinal	0.11 / 0.15 deg-MeV

The drift tube installation of the third and fourth tanks is in progress (Figure 8). The field tuning of the first and second tanks is completed after installing the drift tube into the tanks (Figure 9). The klystron and circulator for the 20 MeV DTL have been installed, and the power supply system has been prepared. The klystron has been tested up to the power of 800 kW. The full power (1.3 MW) tests will be performed in near future.

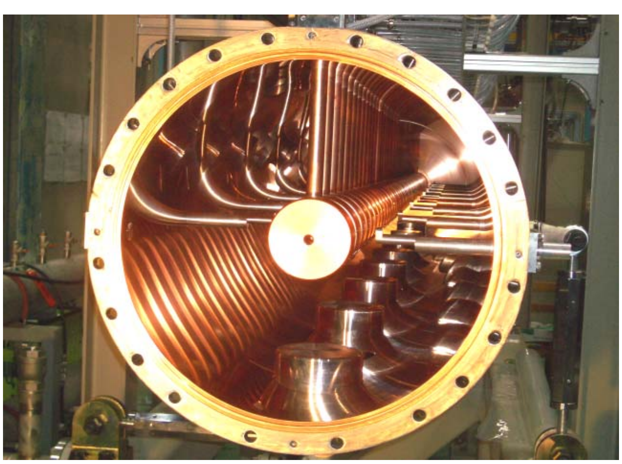

Figure 8: DTL after DT installation.

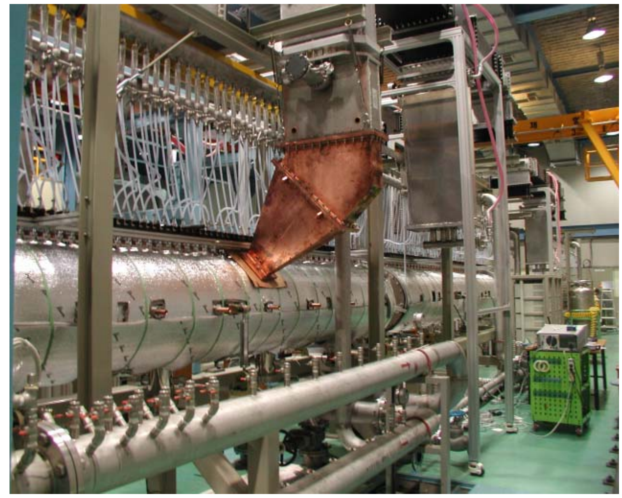

Figure 9: DTL tank1, tank2 under tuning.

The tuning goals for the PEFP DTL are achieving frequency deviation less than ±5kHz from the design value and field variation less than ±2% through the tank with the tilt sensitivity against the perturbation less than 2%/MHz. The field profile under properly tuned condition can be seen in Figure 10.

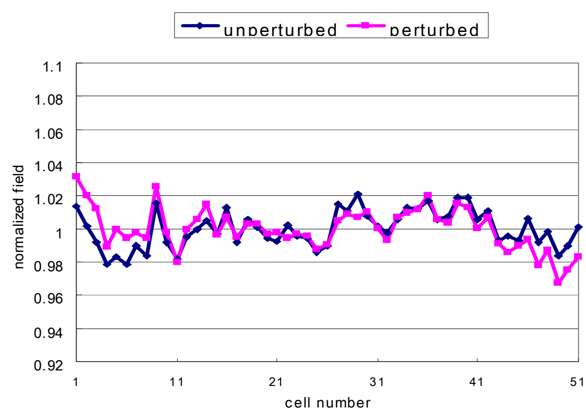

Figure 10: Tank1 field profile after tuning process.

The DTL will also be adopted for the next accelerating structure of the proton beam, from 20 MeV to 60 MeV [3]. After the 60 MeV DTL is complete, we are considering two further options. One is to extend the DTL, and the other is to adopt a superconducting linac. The latter option is related to the plan to extend the accelerator beyond 100 MeV. Design studies for each structure are now in progress.

OTHER ACTIVITIES

Several subprojects related to the development of the accelerator, such as the control system, the low-level RF system, the high-power RF source, the beam transport system, the beam diagnostics, the beam dump, and the radiation shielding are under way in collaboration with other institutions. Two subjects are introduced in some detail, as follows.

Development of the High-Power Klystron [9]

The Korea Accelerator and Plasma Research Association (KAPRA) is developing a 700 MHz, 1 MW klystron that can be used in a future accelerator project beyond 100 MeV. A test klystron has been fabricated and assembled. Several basic experiments are under way, such as cavity tuning, vacuum testing, cathode heating, and electron emission. Figure 11 shows the test klystron.

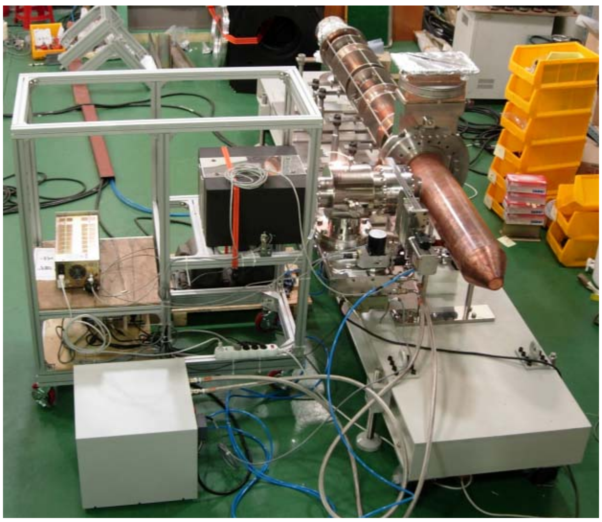

Figure 11: The test klystron developed by KAPRA.

Beam Extraction System

Since PEFP has a plan to supply a 20 MeV proton beam to the user group, the beam extraction system is an essential element after the 20 MeV DTL. This is now being designed by a team at the Pohang Accelerator Laboratory (PAL), Korea. The system includes two 45° bending magnets to extract the beam into the beam transport system, and an AC magnet to allocate the beam between several users. A schematic drawing of the system is shown in Figure 12.

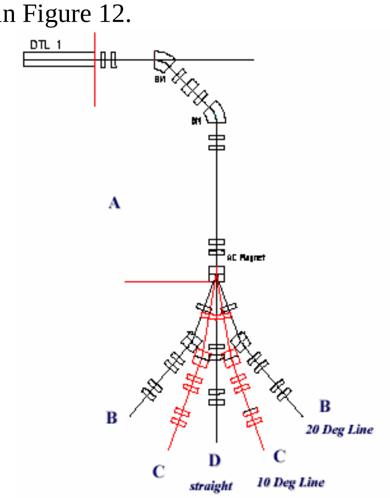

Figure 12: Schematic drawing of the beam extraction system.

PROTON BEAM APPLICATION

One of important goals of the project is extending the application area of the proton beam as well as developing the user facilities. This activity is very important for increasing the usefulness of the proton accelerator.

Development of User Facility for Proton Beam

A domestic demand survey for proton beam users shows that many users require proton beam with wide range of energy, current, and pulse width in order to control irradiation depth, dose, and temperature. To meet the requirements, beam lines in the user facility have to include a chopper and an AC magnet for pulsed beam distribution, a degrader for beam energy control, a collimator for flux control, an energy filter for fine energy selection, and scanning magnets for uniform irradiation. In order to get the practical information for the real system, a test beam line has been developed and installed in MC-50 cyclotron at KIRAMS (Fig. 13).

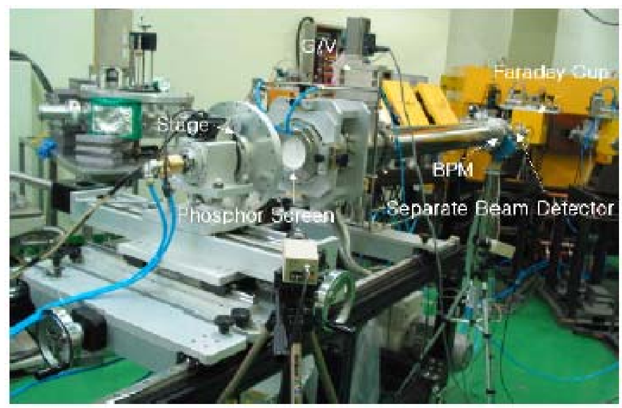

Figure 13: Test Beam Line and Irradiation System installed in MC-50 medical Cyclotron at KIRAMS.

Development of User Program

The project is developing an user program in collaboration with KAPRA in order to use the facility. The goals are developing new fields using proton beam, promoting the basic research on proton beam utilization, reflecting the user demands in the PEFP facility design, and expanding the beam user group in Korea. The project has selected and supported 23 basic research projects using proton or neutron beams since the project was launched. As a part of the program, workshops and technical meetings are held in order to exchange information about the beam utilization technology 3~4 times per year. The work also includes construction of user network, advertisement of PEFP to the foreign scientist at international conferences, and cooperation with foreign institutions in the user program development and beam utilization technologies.

Beam Utilization and Application Studies

The project is operating five subprojects to study and develop beam utilizations and applications of protons in

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low and medium energies. It is using the available proton facilities in domestic or foreign institutions.

Study on Power Semiconductor Devices

One of useful industrial applications of the low energy proton beam is to produce power semiconductors with fast switching characteristics through charge carrier lifetime control. It can be realized by irradiation of proton beam on a p-n junction of power semiconductors. After proton beam irradiation, switching speed of a fast recovery diode is improved more than about 5 times.

Study on Ion Cut Processes

Proton is useful to cut a hard material into very thin films in nano-scale. When proton beam with a constant energy is irradiated on Si wafer, the particles penetrate and stop in a certain range with a high concentration. The resulting weak layer in the material can be easily split into a very thin film. This ion cut method can be used to make Silicon-on-Insulator wafer[10].

Mutation Studies of Microorganism and Plants

The DNA structure can be changed by proton beam irradiation through energy transfer process. New genetic resources will be made by this mutation process. Two application studies are under way[11]. One is the mutation of plants like vegetables and flowers. The other is the mutation of microorganisms like E-coli to produce PHB (Polyhydroxybutyrate) plastic

Space Application Studies

The protons in space can sometimes cause fatal errors on semiconductor components and materials in a spacecraft. The environment can be reproduced by the accelerator. Single event upset (SEU) and total dose effects (TDE) are studied and simulated in this project[12].

SUMMARY

The PEFP launched by the Korean government in July 2002 includes a 100 MeV proton linear accelerator development program and its utilization and application programs. A 20 MeV proton linear accelerator is integrated as shown in Figure 14 and will be tested in 2005. Parallel developments of user facilities, user programs, and applications using the proton beam have been planned and are being developed. A test beam line and irradiation system using a 50 MeV cyclotron have been set up to support the R&D user program in the project. Five subprojects and the proton beam user program are ongoing. Fifteen small basic research projects in the user program are in progress.

Figure 14: 20MeV PEFP Proton Linac.

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