FIVE YEAR OPERATION OF THE 20-MeV PROTON ACCELERATOR AT KAERI*

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Abstract

A 20-MeV proton linear accelerator was operated since 2007 by Proton Engineering Frontier Project (PEFP) at Korea Atomic Energy Research Institute (KAERI), Daejeon site. The performance test of the accelerator itself has been done with limited operation conditions. In addition, the 20-MeV accelerator was used as a test bench of the 100-MeV accelerator components. Besides the machine study itself, it supplied proton beams to more than 1600 samples for users. The 20-MeV accelerator was disassembled at Nov. 2011 and installed at Gyeongju site as an injector for the 100-MeV linac in March 2012. In this paper, five year operation experiences of the 20-MeV linac at Daejeon site are summarized and the technical issues are discussed.

INTRODUCTION

One of the goals of the PEFP is to develop a 100-MeV, 20mA proton linear accelerator. As a front end of the whole linac, a 20-MeV linac was developed, installed and operated since 2007 at KAERI Daejeon site waiting for the PEFP site preparation at Gyeongju [1,2].

The purposes of the PEFP 20-MeV linac operation at Daejeon site were machine study, 100-MeV accelerator component test and user beam service. Machine study and beam study as well as several upgrades were performed to satisfy the above purposes. In addition, the proton beam has been provided to the users for five years since PEFP got operation license of the 20-MeV linac at 2007.

In November 2011, the 20-MeV linac operation at Daejeon site was finished. Since then, the machine was disassembled and delivered to Gyeongju site at February 2012 when the accelerator tunnel was prepared. After the survey in the accelerator tunnel was completed, the 20-MeV linac was installed following the 100-MeV linac which was already prepared and ready for installation at Gyeongju [3,4]. The commissioning of the whole 100-MeV linac will be started at the end of 2012, after the klystron gallery, modulator room and utility are ready.

MACHINE TEST AND UPGRADE

20-MeV Linac Upgrade

When the 20-MeV linac got an operation license in 2007, the allowable average current was limited below 0.1uA due to the insufficient radiation shielding. Since then several upgrades were made based on the study of the machine itself and the requirement for testing the 100-MeV accelerator components.

First of all, the LLRF system was upgraded from the analogue system to digital system in 2007. The digital LLRF system utilized a commercially available control board with FPGA. The high power test results showed that the amplitude and phase were maintained within 1%, 1degree respectively. By using the digital LLRF system, the beam current could be stabilized during operation [5].

The target room operation capability was increased from 0.1uA to 1uA in 2008. Additional radiation shielding including 15cm thick concrete brick and 10cm thick lead brick were installed at the target room. Also the quadrupole triplet, beam diagnostics box and the movable target holder were installed in the beam line, which resulted in more flexible operation [6].

In 2009, the communication system between machine operator and target room operator was incorporated into the EPICS control system. The main purpose of this work was to establish the operation scenario of the ten target rooms in 100-MeV linac. Several interlock and double check points were prepared in the scenario and the new communication system was tested and debugged during the 20-MeV beam user service [7].

Also the klystron power supply was changed from DC high voltage power supply to the high voltage converter modulator (HVCM) in 2009. The design duty of the 20-MeV machine is 24%. At first, a CW klystron and DC high voltage power supply were used. During the operation, the electron beam of the klystron was operated in DC mode and only the RF operation was in pulse mode. Therefore the operation efficiency was very low because the machine could not be operated at high duty due to the insufficient radiation shielding, whereas the power consumption was 4MW to drive two CW klystrons. To increase the efficiency, the high voltage converter modulator was developed as a klystron power supply for 100-MeV linac. When the modulator was delivered, it was installed in 20-MeV linac RF system with the purpose of testing the modulator itself and driving the 20-MeV linac. The system efficiency of the 20-MeV linac could be increased by driving the klystron electron beam in pulse mode. In addition, several problems of the first modulator were identified and fixed. The debugging of the first delivered modulator was reflected on the successive procurements of the modulator [8].

The control board and OPI interface of the LLRF system were upgraded in 2010. The new board could produce synchronized NCO output, therefore the analogue parts were also modified to remove the analogue IQ modulator and install mixers at input and output section. With this new configuration, the LLRF system

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was made more stable against the external reference signal perturbation. The delay of the system was reduced from 3us to 1us by using new board. The OPI interface of the LLRF system was also modified from the text mode to GUI mode. From the upgraded OPI screen, various waveforms, such as RF forward power, RF reflected power and cavity field level could be monitored as well as the resonant frequency error detection capability [7,9].

The ion source was changed from duoplasmatron type to microwave type in 2011. The main purpose of this change was to meet the ion source requirement of more than 100 hours continuous operation without maintenance. The former duoplasmatron type ion source satisfied all the requirements such as beam current, beam emittance and so on except the life time. Due to the filament, its life time was limited to 40 hours. But the life time of the ion source should be more than 100 hours based on the operation scenario of the 100-MeV linac. Therefore microwave ion source was developed because one of its advantages was long life time. The developed microwave ion source was tested for 100 hours at the test bench and it showed no degradation of the performance. After the test at the test bench, it was installed at 20-MeV linac and used as a proton injector. The microwave ion source had been operated for 243 hours without maintenance until the November, 2011 [10,11].

For beam diagnostic devices, the beam position monitors (BPM) for 100-MeV linac and the beam transfer line were developed and tested at the 20-MeV beam line in 2011. The beam test results showed that the output signal was as expected and good enough to be used for the beam phase measurement [12].

Machine Study

As mentioned above, the 20-MeV linac was operated with limited duty at Daejeon; therefore the machine study was also limited.

The long-time operation was tried to check the pulse loss statistics. The total number of pulses was 14,400 and the total pulse loss rate was 0.56%. Among them, 0.01% was due to the spark at the ion source and 0.55% was due to the spark at the RFQ. For the long-pulse operation test, it was not difficult to increase the beam pulse width up to 500us. But the spark at the RFQ was the main cause of the beam pulse loss [13]. The high repetition rate test was also carried out. The RF system was operated at 20Hz and the repetition rate of the beam from the ion source was increased from 1Hz to 15Hz. The beam pulse at 15Hz is shown in Fig. 1. All the system including low level RF and data acquisition system was operated without any problems. The radiation dose was measured at the target room fence (1m apart from the radiation shielding block) and the neutron dose rate was shown in Fig. 2. The neutron dose rate was 500uSv/hr at 15Hz and gamma ray dose rate was 150uSv/hr.

Beam Study

The beam parameters such as beam energy, beam profile, beam emittance and beam phase were measured in parallel with the machine study. The beam energy was measured with the time-of-flight method by using two BPMs installed at the 20-MeV beam line. The result was 20.2MeV and this was compared with other two methods; dose measurement and range measurement with the aluminium foil and both results showed a good agreement. To measure the beam profile, we used the wire scanner. The beam profiles depending on various operating conditions of the quadrupole triplet were measured and the beam radius was compared with the PARMILA results.

The beam emittance at the upstream of the RFQ was measured by using the electric sweep scanner. The measured emittance was 0.35 π mm mrad in normalized rms value which showed higher than the design value of 0.2 π mm mrad. It is necessary to optimize the operation parameters of the ion source and LEBT. The beam emittance at the downstream of the 20-MeV DTL was also measured by using quad scan method. The last magnet in the triplet was used to change the transfer matrix. The measured emittance was 0.22 π mm mrad, which was well agreed with the design value [11].

The BPM signals were utilized for the beam phase measurement, which is important at the commissioning stage of the 100-MeV linac because a phase scan method is considered as a tuning method of the RF amplitude and phase. The beam phase was measured at various amplitude and phase of the RFQ and DTL and the results were compared with the PARMILA results. Finally, we could establish the phase scan algorithm based on the measurement data [14].

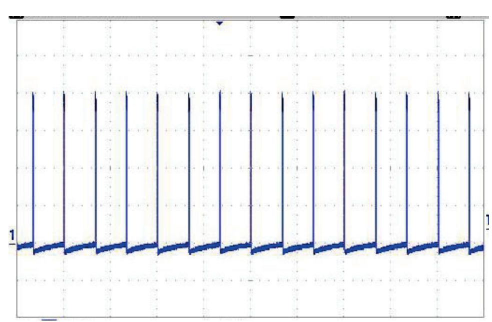

Figure 1: Beam pulse at 15Hz operation (time span: 1s).

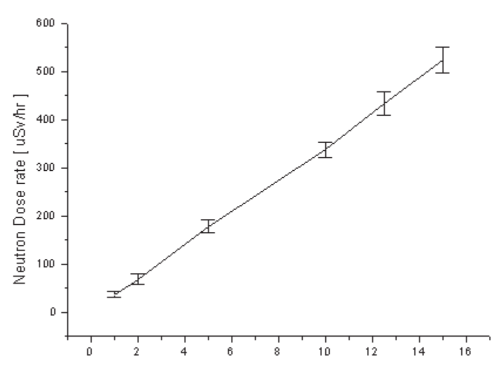

Figure 2: Neutron dose rate depending on repetition rate at the target room fence.

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BEAM SERVICE TO USERS

A 20-MeV beam was supplied to the users during the 20-MeV machine operation in Daejeon site. The users who want a beam service submit an application form through the Internet and the beam line operator contacts the users and discusses the irradiation conditions. After that, the beam line operator does the beam service by using the sample prepared by the users. During beam irradiation to the specimen, the beam line operator communicates with the linac operator through the control system which includes personal protection logics.

The beam conditions were adjusted to the specific user demand, however; the typical operation conditions were 5mA peak current with 50us pulse width, 1Hz repetition rate during beam service. There were total 1603 samples irradiated by using 20-MeV linac for five years. The number of sample treatment increased from about 100 samples in 2007 to more than 680 in 2011 as shown in Fig. 3. For five year beam service, most of the users (66%) come from the Research Institute, and the others come from the University (22%) and Industry (12%). The most frequent application field was Bio-Technology (60%) including the cancer cell irradiation and mutation study. The research and application field related to the Nano-Technology (17%) which included a nano-particle synthesis was next to Bio-Technology.

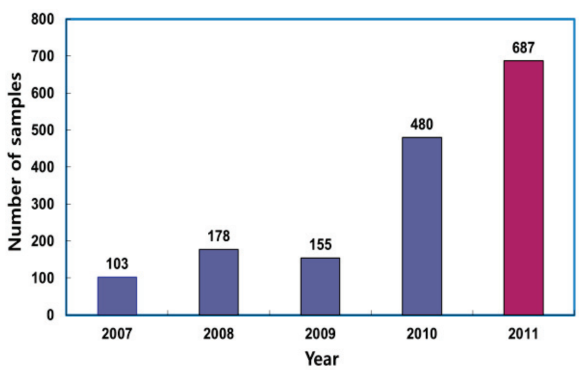

Figure 3: Number of samples depending on fiscal year.

CONCLUSION

A 20-MeV proton linear accelerator which would be used as a front-end part of the PEFP 100-MeV linac was operated for five years at Daejeon site waiting for 100-MeV linac site preparation.

There were several machine upgrades both for 20-MeV linac itself and the 100-MeV linac component tests. The machine study was done to check the machine characteristics including the long-time operation, the long-pulse operation and the high repetition rate operation. In addition, the beam study was performed in parallel with the machine study. The beam energy, the beam profile, the beam emittance and the beam phase were measured and compared with the simulation results.

Total 1603 samples were treated for five years by using 20-MeV linac. During the beam service, an algorithm for the communication between beam line operator and linac operator was established.

These kinds of experience on machine and beam study as well as beam service would be valuable information for us to do the commissioning and operation of the 100-MeV linac at Gyeongju.

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