THE OPERATION EXPERIENCE AT KOMAC*

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Abstract

A 100-MeV proton linac at the KOMAC (Korea Multi-purpose Accelerator Complex) is composed of a 50-keV microwave ion source, a 3-MeV four-vane-type RFQ, a 100-MeV DTL and 10 target stations for proton irradiation on samples from many application fields. The linac was commissioned in 2013 and the user service started in July 2013 with delivering proton beam to two target stations: one for a 20-MeV beam and the other for a 100-MeV beam. In 2015, the linac has been operated more than 2,800 hours with an availability of greater than 89 %. The unscheduled downtime was about 73 hours, mainly due to troubles of ion source arcing and failures of pulsed high voltage power system. More than 2,100 samples from various fields such as materials science, bio-life, nano technology and nuclear science, were treated in 2015. Currently, a new target station for radioisotope production is under commissioning and a new target station for low flux irradiation experiments is being installed. Operational experiences of the 100-MeV linac during the past 3 years will be presented in the workshop.

INTRODUCTION

KOMAC is located in Gyeongju, which was established as a branch of KAERI (Korea Atomic Energy Research Institute) in 2013. Among the gross area of the KOMAC site is 1,100 m × 400 m which is enough to house a 1-GeV proton accelerator, only 450 m × 400 m was developed for the 100-MeV linac as a 1st stage of the KOMAC as shown in Fig. 1 and the remaining area is reserved for future extension. An accelerator building, a beam application building, a utility building, power station and water treatment building are under operation [1]. The construction of the dormitory building will be finished in October, 2016 and the construction of the administration building starts in September, 2016.

After awarding the operation license, the operation of the 100-MeV linac started in 2013. Since then, two target stations have been opened for users. The operation statistics is reported in the following section. To meet the various and dedicated users' needs, a radioisotope production beam line was developed in 2015 and a low-flux beam line is under construction in 2016, which are described in detail. Finally the operational issues related to the accelerator components and user services are discussed in the paper.

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Figure 1: KOMAC site.

100-MeV LINAC OPERATIONS

Accelerator

The main specifications of the 100-MeV linac depending on the energy of the beam line are summarized in Table 1. The characteristic of the linac is that it has two beam extraction points, one is at 20-MeV and the other is at 100-MeV. The designed beam duty up to 20-MeV is 24% and the other section up to 100-MeV is 8%. The accelerator layout is shown in Fig. 2. The ion source is a microwave ion source and magnetic LEBT (Low Energy Beam Transport) is used to match the beam to RFQ. A four-vane-type RFQ is used to accelerate the beam from 50-keV to 3-MeV. Total 11 DTL tanks are used to accelerate the beam from 3-MeV to 100-MeV. The operating frequency of RFQ and DTL is 350 MHz. There are total 9 klystrons to drive the 100-MeV linac. And total 4 modulators are used to drive 2 or 3 klystrons simultaneously. The 4 independent DTL tanks at 20-MeV section are driven by 1 klystron. The resonant frequencies of all the cavities such as RFQ, DTL and MEBT tanks are controlled by independent RCCS (Resonant frequency Control Cooling System).

Table 1: Specifications of the KOMAC Linac

Parameters	20-MeV	100-MeV
Output energy [MeV]	20-MeV	100-MeV
Peak beam current [mA]	20	20
Max. beam duty [%]	24	8
Avg. beam current [mA]	0.1~4.8	0.1~1.6
Pulse length [ms]	0.1~2	0.1~1.3
Max. repetition rate [Hz]	120	60
Max. avg. beam power [kW]	96	160

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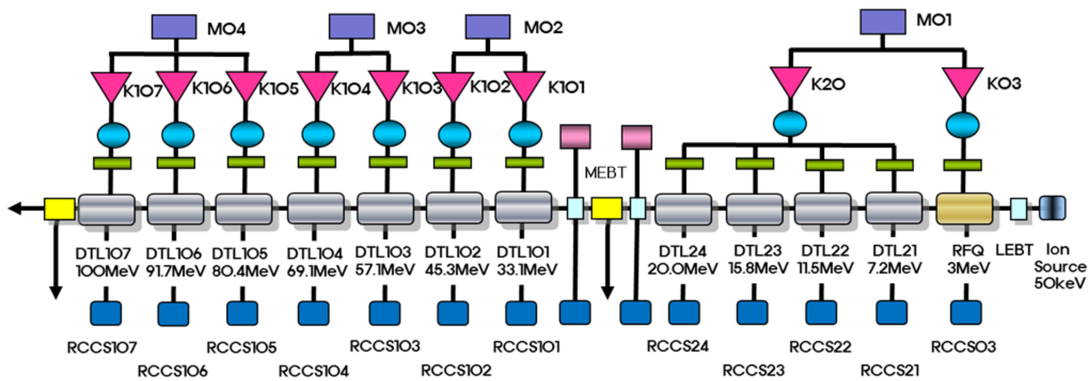

Figure 2: KOMAC linac layout.

The commissioning of the linac was carried out in 2013 and obtained an operation license of 1 kW beam on target. Then the beam power was ramped up to 10 kW with a revised operation license in 2014. The total operation time from 2013 to 2015 was 8,101 hours with accumulated availability was 86.8%. In 2015, the unexpected down time was 73.5 hours, of which the most frequent time consuming failures were modulator interlocks, DTL drift tube failures and the ion source interlocks as shown in Fig. 3.

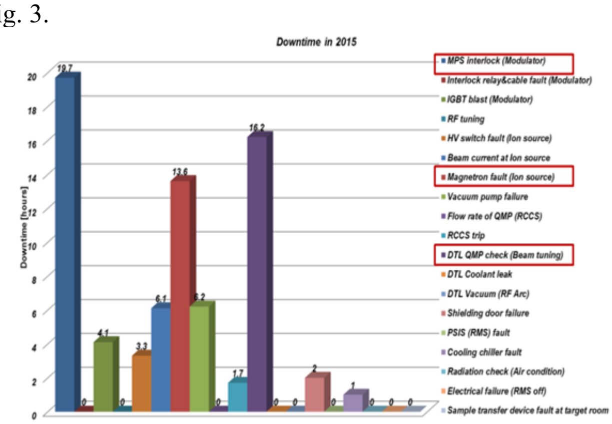

Figure 3: Downtime statistics in 2015.

Beam Service

A total 330 of research projects were proposed from the users during the past 3 years (2013~2015) and the KOMAC could support only 261 projects among them as summarized in Table 2. The numbers of R&D projects proposed are increasing year by year as shown in the Table 2.

Table 2: Service Statistics of the KOMAC Linac

Year	Proposed	Served	Ratio [%]
2013	56	39	69.6
2014	121	103	85.1
2015	153	124	81.0
Total	330	261	79.1

In beam time wise, a total of 768 days were requested, but the KOMAC could supply 460 days which are about 60% for 3 years of operation. A total of 5,058 samples were treated during the same period. The main fields of users are such that 26.4% for bio-life researches, 26.4% for nano/materials science and 22.6% for space and basic science.

BEAM LINE DEVELOPMENT

The 100-MeV beam line layout is shown in Fig. 4. A total of 5 target stations are designed and target rooms were already constructed. A general purpose beam line, which is in operation, is the straight one. Another two beam lines have been developed over the past two years, one is the radioisotope (RI) production beam line and the other is a low-flux beam line. The construction of the RI production beam line was completed in 2015 and the commissioning is underway. The radiation safety inspection will be performed in October, 2016 and the operation starts after obtaining its operation license in 2016. Construction of the low-flux beam line is completed in 2016, and is to be commissioned in 2017.

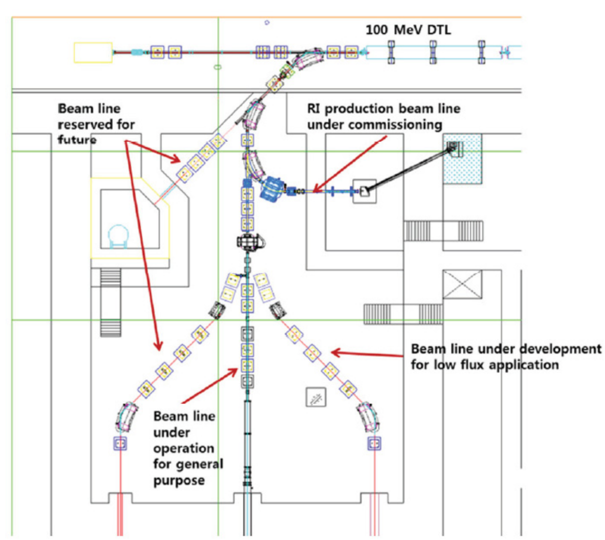

Figure 4: 100-MeV beam line layout.

RI Production Beam Line

The specification of the beam line is summarized in Table 3. The RI beamline is first to produce Sr-82 and Cu-67 by using 100-MeV proton beam. The Sr-82 is used to monitor the blood flow in the cardiac tissue and can be

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produced by using RbCl as a target material. The Cu-67 is used for cancer therapy and can be produced by using ZnO as a target. The separation and purification of the produced RI's are to performed at either HANARO research reactor facilities or Advance Radiation Technology Institute (ARTI), which are also facilities of KAERI [2].

Table 3: Specification of RI Production Beam Line

Parameters	Values
Energy	100 MeV
Peak current	20 mA
Max. duty	3 %
Average beam power	Max. 60 kW
Energy per pulse	1,000 J/pulse
Target diameter	100 mm
Scanning method	Wobbling

The beam line is composed of a beam transport system, a target transport system, a target cooling system and a hot cell. The beam transport line mainly consists of two 45° bending magnets, of which the pole tip field was 1.5 T considering the limited space. The beam window of AlBeMet was installed at the end of the beam transport line. The thickness of the beam window is 0.5 mm and the estimated energy loss in the beam window is less than 1%, which generates maximum heat of 360 W, which is dissipated by a forced air convection cooling system [3].

The target transport system is used to transport target carrier from the hot-cell located outside the target room to the irradiation chamber in the target room. The target carrier is driven by an AC servo motor with chain. The target transport system is full of circulating deionized water, which is used not only to cool the target but also to shield the neutron during beam irradiation.

The hot-cell is divided into two regions, one is used for loading or unloading the target from the target carrier, the other is used to handle the target into the shielding chamber for transportation. The hot-cell is shielded with 150 mm thick lead plate and with 375 mm thick lead glass windows. Two sets of master slave manipulators are installed to handle the target.

An independent cooling skid was installed to cool the target. The cooling capacity is 30 kW, which is considered a maximum power at first stage, and the flow rate is 180 l/min. An air-cooled chiller is used to remove the heat from the skid. The radioactivity monitor and the conductivity meter were installed in the skid to monitor the possible leakage of the radioisotopes from the target. The skid is also located outside of the target room and pipe line is installed from the skid to the target transport system through hot-cell. The pipe line is shielded 5 mm thick lead plate. The target system inside the target room is shown in Fig. 5 and the cooling skid and hot cell are shown in Fig. 6.

Figure 5: Target transport system in the target room.

Figure 6: Cooling system and hot-cell.

We performed a beam test to check the radio isotope production with during commissioning stage. A 100-MeV beam was irradiated to Zn target to produce Cu-67. Peak current during the irradiation was 0.4 mA. The radiation level was 5.5 uSv/hr at the target right after the irradiation. We measured gamma ray spectrum by using HPGe detector and found peaks around 91 keV, 93 keV and 184 keV, which showed the production of Cu-67 as shown in Fig. 7. From the spectrum measurement, we concluded that the overall system is functioning without any major fault [4].

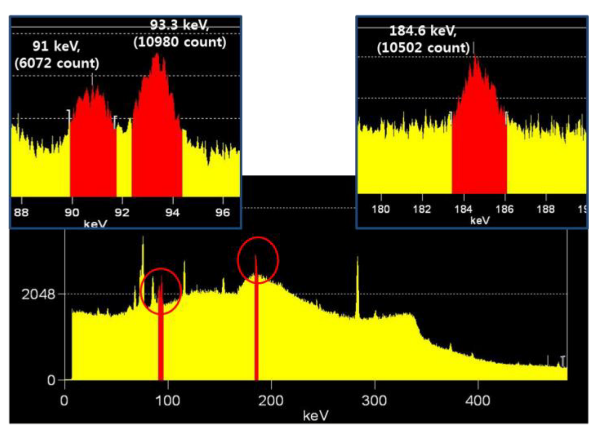

Figure 7: Gamma-ray spectrum from the Zn target.

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Low-Flux Beam Line

The low-flux beam line is designed to deliver low-flux beams to users from simulation of the space radiation, detector development and so on. The users in this field demand a beam with a low-flux and a high-duty cycle because CW-like low-flux is most suitable for such applications. To meet these requirements, we are going to use a high-power collimator to reduce the beam flux to the target while maintaining the reasonable peak current. The design specification of the beam line is summarized in Table. 4 and the beam transport system under installation is shown in Fig. 8 [5].

Table 4: Specification of Low Flux Beam Line

Parameters	Values
Energy	20 ~ 100 MeV
Peak current at accelerator	0.1 mA
Max. duty	8 %
Max. power at collimator	800 W
Beam current at target	10 nA in average
Max. beam power at target	1 W
Target size	100 mm X 100 mm
Uniformity at target	± 5%

Figure 8: Low-flux beam line installation.

A high-power collimator was designed, which has a 15° sloped-corn shape of graphite, which was chosen to minimize neutron production and to have high melting temperature. A hole of 10 mm in diameter is located in the center of the collimator and the beam is guided to the collimator in off-axis direction, then only part of the off-centered beam is transmitted to the downstream through the hole. If the beam center is diverted 40 mm from the center of the collimator, the beam current reduces to 1/1,000 assuming a Gaussian beam profile. The collimator is located downstream of the 25° bending magnet, therefore we are able to control the direction of the beam center into off-axis direction. The collimator was designed to be cooled by water with a cooling channel located at the copper, which is back-plate material of the graphite.

Two sets of octupole magnets are used to produce spatially uniform beam at the target. Two octupole magnets are installed in the beam waist position of each transverse direction to facilitate the beam size adjustment in each direction respectively.

An AlBeMet is used as a beam window. In this beam line the cooling of the window is not necessary, but the size of the window is 300 mm in diameter, which is 3 times larger than that was used in RI production beam line.

OPERATION ISSUES

Several issues found for 3 year operation periods are reported.

Ion Source

The microwave ion source is driven by a 2.45 GHz microwave power. The operation parameters are such that the extraction energy is 50 keV with 20 mA peak current and the duty is 30% (2.5 ms, 120 Hz), which means the ion source is almost in CW operation. Thus we always turn on the plasma and extract a pulsed beam by switching the extraction power supply. 80 stacks of IGBT (Insulated Gate Bipolar Transistor) are used as a high voltage switch [6]. After 1,000 hours of plasma operation, we experienced frequent sparks at the bias electrode which destroyed the switches. It was found that the BN (Boron Nitride) which was used as a microwave window was deposited on the tip of electrodes as shown in Fig. 9, which made the part insulator. And we believed this was the main source for the frequent sparking after several hundred hour operation. To cope with the above issues, we installed a ion source test bench to improve the ion source and also are going to do the preventive maintenance to replace all parts of the ion source at every 6 months.

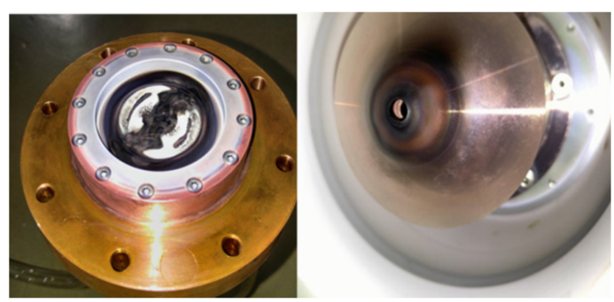

Figure 9: BN window (left) and BN coating on tip of the extraction electrode.

Quadrupole Magnet inside Drift Tube

Two types of DTQs (Drift tube quadrupole magnets) are used. One is a pool-type electromagnet which used an enamelled wire with nickel coated yoke and was immerged in the cooling water. The pool-type magnets were used for DTL from 3-MeV to 20-MeV to save the space inside the drift tube. The other is a magnet which used a hollow conductor which was used for DTL from 20-MeV to 100-MeV [7]. There were failures among the pool-type

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DTQs and eight DTQs were replaced. The inside of the failed DTQs was investigated and we found that enamel coating was separated from the wire and the yoke was covered with rust as shown in Fig. 10. Low resistivity of the cooling water which was supplied by accident for few days and high radiation during beam commissioning seems to be the factors to affect the degradation of the pool type DTQs. We consider changing the pool type magnet into permanent magnet or adding liquid type insulator.

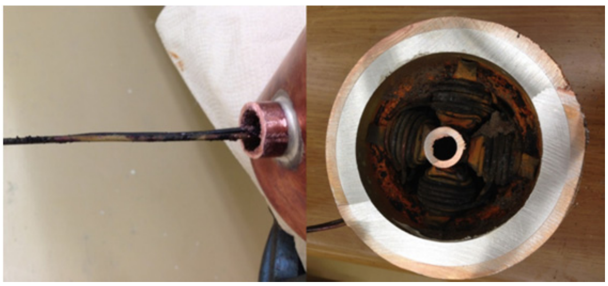

Figure 10: Enamel coating separation from the wire (left) and the yoke covered with rust (right).

Vacuum Pump

One TMP (Turbo Molecular Pump) and three IPs (Ion Pump) are installed per DTL tank. A TMP is used for initial evacuation and after the operation of the IPs, it is turned off and the vacuum of the DTL is maintained with only IPs. The normal vacuum level was from 5E-8 to 10E-8 Torr. After 3-year operation, we observed vacuum-bursts phenomena in the DTL tank as shown in Fig. 11. We suspected the argon instability of the ion pump and operated the TMP during operation which removed the vacuum bursts. Up to now, 3 IPs and a TMP are operating and we are going to replace an IP with a TMP.

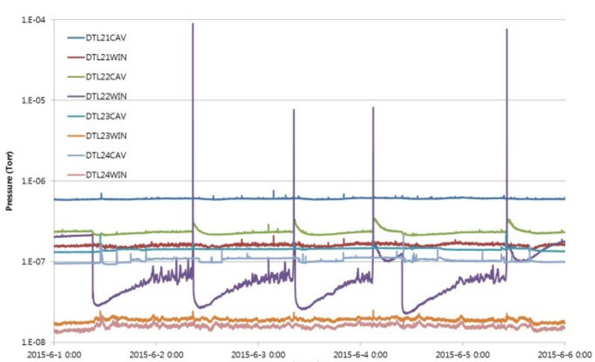

Figure 11: Vacuum burst in the DTL.

RF Network

The characteristics of the KOMAC RF system are such that 4 independent DTL tanks are driven by one klystron and 2 or 3 klystrons are driven by one klystron modulator as shown in Fig. 2. To drive 4 DTL tanks with 1 klystron, we adjusted the power balance from the design stage and installed a phase shifter at each RF transmission line. Also the resonance frequency of each DTL is controlled by an RCCS (Resonance Frequency Control Cooling System). To drive the group of klystrons with a modulator, we grouped the klystron which had the same perveance and the resonance circuit of the modulator was adjusted to the load impedance. By doing this, we could operate the RF system without problems. The normalized beam emittance was measured to be 0.23 π-mm-mrad which agrees well with the design value of 0.20 π-mm-mrad [8,9].

Shielding Door

There were frequency failures of the shielding door of the target room. The shielding door consists of 1.1 m thick concrete and 0.9 m thick steel and its mass is 26 ton. For beam service, the shielding door should be opened and closed in every irradiation. The severe case is the low flux irradiation service which needs few pulses. In this case, the shielding door needs many times of operation. This is one reason to develop a low flux beam line which will be operated without a shielding door.

History Management System of the Component

The history management system of the components was developed to operate the linac efficiently. The system used a QR code and tablet which enables us to scan the information in a distance. The possible distance is decided from the size of the QR code attached in the component. The management system includes specification, maintenance history, drawing and related document.

Diversity of the Beam Requirement from Users

Only two general purpose target rooms have been operating for 3 years, one for 20 MeV beam, the other for 100 MeV beam, and supported users from various fields such as material, bio, space and basic science. Moreover, user requirements are wildly varying in beam energy (from 20 MeV to 100 MeV), peak current, beam size, duty, number of particles (total dose), spatial uniformity of dose, timely uniformity of dose and so on. Therefore, we supply 8-discrete energy of beam to users by turning on or off each DTL tank up to 100 MeV and low-peak beam current down to 0.1 mA with some poor stability. This kind of limitations is to be resolved not only by accumulating more operation data but also operating target room more specifically. (for example high-flux beam line for RI production, low-flux beam line and general purpose.)

CONCLUSION

The operation experiences and status of the KOMAC linac are reported. Two new beam lines are under commissioning or construction in addition to the existing beam lines. Several operational issues are also summarized.

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