OPERATION OF KOMAC 100-MEV LINAC*

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Abstract

A 100-MeV proton linear accelerator at the KOMAC (Korea Multi-purpose Accelerator Complex) was under development for past 15 years, including preliminary design study period, and was successfully commissioned in 2013. The operation of the linac for user service started in July 2013 with two beam lines: one for a 20 MeV beam and the other for a 100-MeV beam. The linac is composed of a 50 keV microwave proton source, a 3 MeV four-vane-type RFQ (radio-frequency quadrupole) and a 100 MeV DTL (drift tube linac). In 2015, the linac operating time was more than 2,800 hours with an availability of better than 89% and unscheduled downtime was about 73 hours, mainly due to the ion source and HVCM problems. More than 2,100 samples from various fields such as material science, bio and nano-technology and nuclear science, were treated in 2015. Currently, additional beam line for radioisotope production is being commissioned and a new beam line for low-flux irradiation experiments is under construction along with a continuous effort being made to increase the average beam power.

INTRODUCTION

KOMAC is a facility for hadron beam application hosting a 100 MeV proton linac and several low energy ion beam accelerator including a 3 MeV tandem machine and ion implanters. It was established as a branch of KAERI (Korea Atomic Energy Research Institute) in 2013. Gross area of the KOMAC site is 1,100 m by 400 m, which is enough to host a 1 GeV proton machine and 450 m by 400 m was developed up to now for the 100 MeV linac as a first phase as shown in Fig. 1. The remaining are is reserved for future extension [1].

Currently, buildings for a 100-MeV linac, low energy beam applications, utility systems, the electric power station and water treatment are completed and under operation. In addition, a building for guest house is under construction and will be finished at the end of this year. The construction of the administration building is supposed to start in October, 2016.

The user beam service of the linac started in 2013 after the inspection for operation license from government. At first, we started user beam service with two beam lines and target stations, even though KOMAC has design capacity of ten beam lines and target stations. To meet various and dedicated requirements from users, we developed a beam line for radio-isotope production in 2015 and demonstrated a RI production by using low current test run. The commissioning of the RI production beam line is almost completed and it is waiting for the operational license. In addition, a new beam line for low-flux beam applications such as space environment simulation and detector test is under construction. The operational experiences of a 100 MeV proton linac are given and some issues are discussed in this paper.

Figure 1: KOMAC site.

OPERATION OF 100 MEV LINAC

Accelerator

The 100 MeV proton linac is installed in an accelerator building. It consists of a 50 keV microwave ion source, a 3 MeV four-vane-type RFQ and a 100 MeV DTL. The accelerator building is a three-story building; first floor is hosting a linac, second floor is a klystron gallery and third floor is a modulator room. The layout of the accelerator building with a linac is shown in Fig. 2. The main specifications of the 100 MeV linac are summarized in Table 1. One of characteristics of the linac is that there are two beam extraction points; one is at 20 MeV and the other is at 100 MeV.

We use a microwave ion source (2.45 GHz) due to its long life time without maintenance. For the LEBT (low energy beam transport), two solenoids are used to match the beam to the RFQ. The RFQ is a four vane type and used to bunch the beam from the ion source and accelerate the beam up to 3 MeV. Total 11 DTL tanks are installed to accelerate the beam from 3 MeV to 100 MeV. First 4 tanks are used to accelerate the beam up to 20 MeV and driven by a single klystron, which is a unique feature of KOMAC RF network. The power balance is maintained through three magic Tees with 1% precision and the phase of each tank is adjusted by mechanical phase shifters installed at each branch of RF waveguide network from the klystron to each DTL tank. Under these RF environment, the measured normalized rms emittance of 20 MeV beam was 0.23 pi-mm-mrad, which agrees well with the design value of 0.20 pi-mm-mrad.

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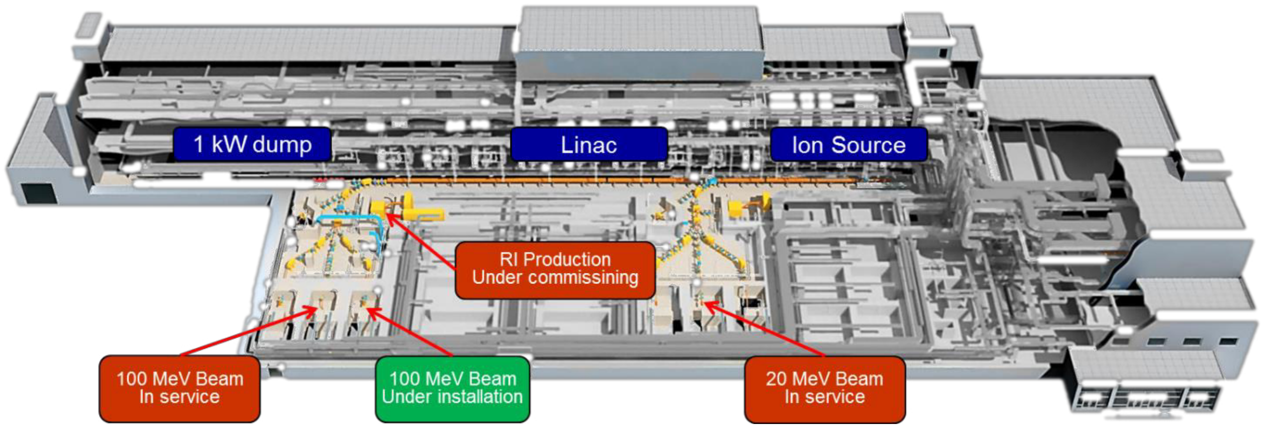

Figure 2: Layout of KOMAC Accelerator building and the 100-MeV linac along with beam lines and target stations.

Table 1: Specifications of the KOMAC Linac

Parameters	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)

The operating frequency of the linac is 350 MHz and the resonant frequency of linac machine is maintained by using an independent RCCS (resonant frequency control cooling system) dedicated for each accelerating cavity including RFQ and DTL.

The commissioning of the linac started in 2013 and obtained an operation license of 1 kW beam on target. Then we started user beam service since July, 2013. In 2014, the average beam power was increased up to 10 kW and we revised the operation license according to the corresponding beam power. Total operation time from 2013 to 2015 was 8,101 hours with the accumulated availability of 86.8%. In 2015, the unscheduled downtime was 73.5 hours and the most frequent time consuming failures were modulator interlocks, DTL drift tube failures and the ion source HV switch problems as shown in Fig. 3.

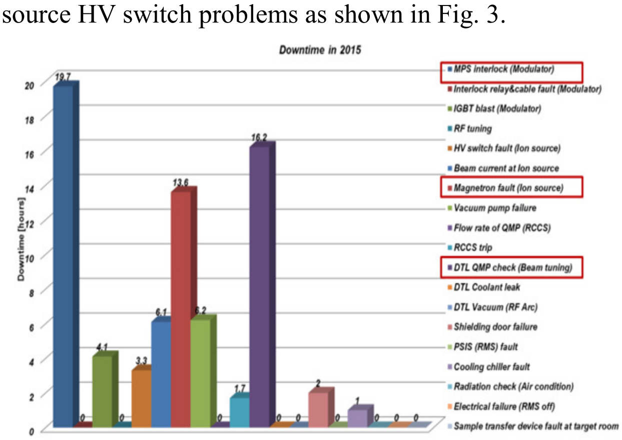

Figure 3: Unscheduled downtime statistics in 2015.

User Beam Service

In the past 3 years (2013~2015), research programs more than 300 were proposed by users from various fields and KOMAC has supported 261 programs. The number of R&D programs proposed is increasing year by year. The related statistics are shown in Table 2.

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

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

BEAM LINE DEVELOPMENT

KOMAC accelerator facility was originally designed to host up to ten beam lines; five for 20 MeV energy and the other five for 100 MeV beam utilization. Therefore, the space and target rooms for the beam lines other than the currently-operating ones are already prepared. For 100 MeV beam line, 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 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 will be started after obtaining its operation license. Construction of the low-flux beam line will be completed at the end of 2016 and is to be commissioned in 2017. The remaining two beam lines and two target stations are reserved for future. Figure 4 shows the layout of 100 MeV beam lines.

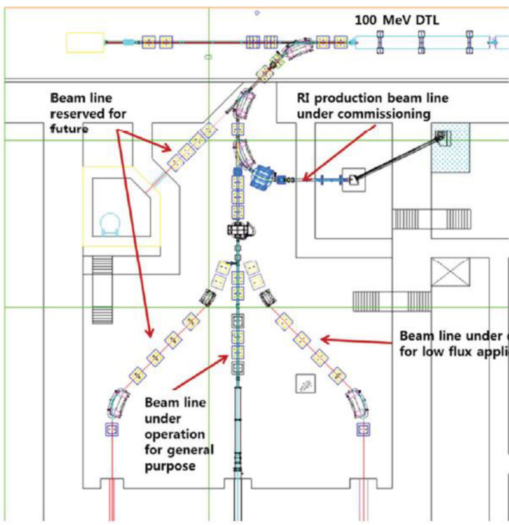

Figure 4: 100-MeV beam line layout.

RI Production Beam Line

The specification of the beam line for RI production is summarized in Table 3. The RI beam line is going to produce Sr-82 and Cu-67 at its 1st phase by using 100 MeV proton beam with average beam power of 30 kW. The Sr-82 is mainly used for monitoring the blood flow in the cardiac tissue and can be produced by using RbCl as a target material. The Cu-67 is used for cancer therapy and can be produced by irradiating proton beam on ZnO. The separation and purification of the produced RI's will be done by using facilities at either HANARO research reactor or Advance Radiation Technology Institute (ARTI). Both of them are 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	30 kW (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 as shown in Fig 5. In the RI beam line, a relatively high field magnet was required due to the limited space available. Therefore, we designed and fabricated a 1.5 T, 45-degree bending magnet with the bending radius of 1.0 m and the pole gap of 90 mm. We chose an H-type magnet with rectangular shape due to its simplicity and good field uniformity within the given space. We used POISSON code and EMStudio code to optimize the magnet and obtained good field region wider than 100 mm with uniformity better than 0.1% for a 310 mm pole width, which is enough considering the beam dynamics.

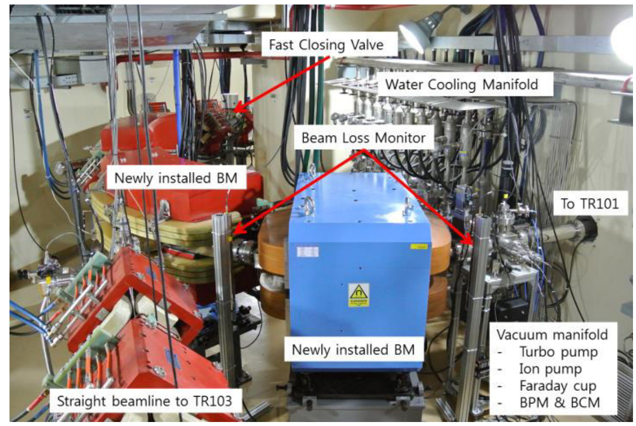

Figure 5: Newly installed RI beam line.

A beam window made 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 that can be dissipated by a forced air convection cooling system.

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. 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.

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 remotely. The target system inside the target room is shown in Fig. 6.

Figure 6: Target transport system in the target room.

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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 as expected [3].

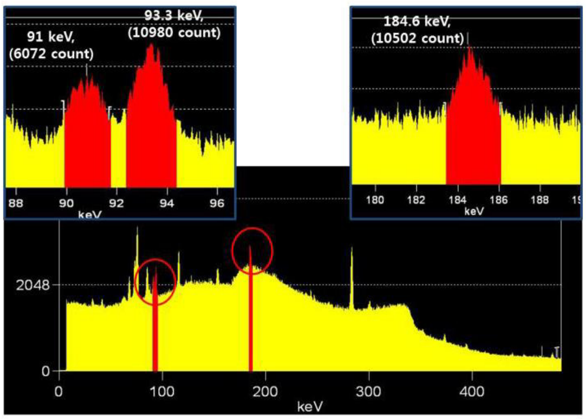

Figure 7: Gamma-ray spectrum from the Zn target.

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 [4].

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%

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 downstream. If the beam center is shifted to 40 mm from the center of the collimator, the beam current will be reduced to 1/1,000 assuming a Gaussian beam profile. The collimator is located downstream of the 25° bending magnet, therefore we are able to steer the direction of the beam center into off-axis direction.

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.

Figure 8: Low-flux beam line installation.

OPERATIONAL ISSUES

Ion Source

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). We 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. 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) used for a microwave window was deposited on the tip of electrodes as shown in Fig. 9 and this is considered as the main cause of the frequent sparking. To deal with this issue as well as to improve its performance, we installed an ion source test bench as shown in Fig. 10. In addition, the preventive maintenance will replace all parts of the ion source at every 6 months.

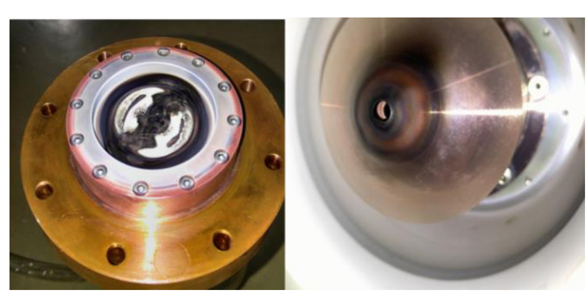

Figure 9: BN window and BN coating on the electrode.

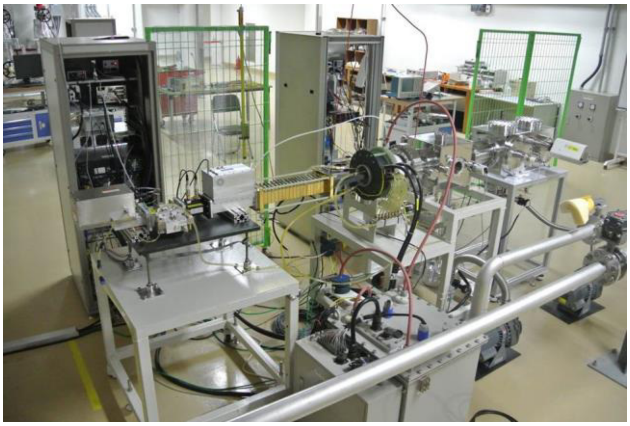

Figure 10: Ion source test bench.

Quadrupole Magnet inside Drift Tube

We used two different types of DTQs (Drift tube quadrupole magnets). One is a pool-type electromagnet which used an enamelled wire with nickel coated yoke and immerged in the cooling water. The pool-type magnets were used for DTL from 3-MeV to 20-MeV due to limited space. The other is a magnet with a hollow conductor and used for DTL from 20-MeV to 100 MeV [5]. There were failures among the pool-type 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. 11. Cooling water with low resistivity, which was supplied by accident for a few days and high radiation during beam commissioning seem to be the cause of the degradation of the pool type DTQs. We are considering changing the pool type magnet with a permanent magnet or adding liquid type insulator.

Figure 11: Enamel coating separation from the wire (left) and the yoke covered with rust (right).

Vacuum System

One TMP (Turbo Molecular Pump) and three IPs (Ion Pump) are installed at each DTL tank. A TMP is used for initial evacuation. After the operation of the IPs, TMP is turned off and the vacuum of the DTL is maintained with IPs only. The normal vacuum level is from 5E-8 to 1E-7 Torr. After 3-year operation, we observed vacuum bursts phenomena in the DTL tank as shown in Fig. 12. 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.

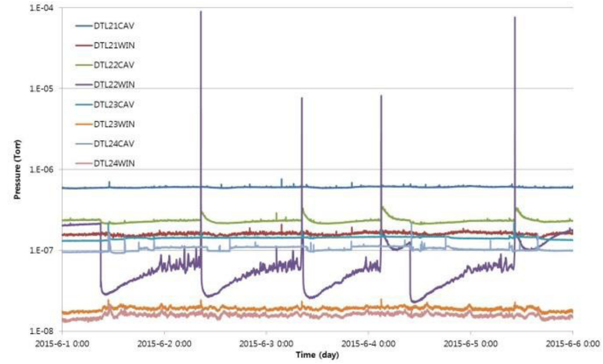

Figure 12: Vacuum burst in the DTL.

History Management System of the Component

The history management system of the components was developed to operate the linac efficiently as shown in Fig. 13. The system uses 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.

Figure 13: Component history management system.

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 related with an ion source, a drift tube and the vacuum system are also discussed.

REFERENCES

[1] Y. S. Cho, Proceedings of LINAC2014, Geneva, Switzerland, 2014, pp. 413-416

[2] H. J, Kwon, et al., Journal of the Korean Physical Society, vol. 67, no. 8, (2015, 10) pp. 1387 – 1392)

[3] S. P. Yun, et al., Proceedings of IPAC2016, Busan, Korea, 2016, pp. 1384-1386

[4] H. J. Kwon, et al., Proceedings of IPAC2016, Busan, Korea, 2016, pp. 938-940

[5] Y. S. Cho, et al., Journal of the Korean Physical Society, Vol. 52, No. 3, March 2008, pp. 721-726

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