LINAC R&D IN KOREA*

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Abstract

A 2-GeV linear accelerator is constructed as an injector to the Pohang Light Source (PLS), the first large-scale accelerator complex in Korea. It is a national synchrotron radiation users' facility for basic and applied science research. The PLS storage ring is a third generation machine with a low-emittance, and it has been serving users since September 1995. With the success of this construction project, there are strong demands on accelerator facilities for various applications, such as a neutron facility for transmutation and energy production called the KOMAC-project, a nuclear data center, a mini-cyclotron for radioisotope production. Most of linac R&D programs are subsystems in the low-energy end/or special components to improve the performance of the existing subsystems of the PLS linac. We present the current accelerator status, R&D activities related to linear accelerators at PAL, and the proposed accelerator programs in Korea.

1 INTRODUCTION

In the early 1960's, there were three particle accelerators in Korea: a 1.5-MeV cyclotron at the Seoul National University (SNU) and two Cockcroft-Walton type accelerators both at the Korea Atomic Energy Research Institute (KAERI) and at the Yonsei University. The cyclotron at SNU was used for accelerator physics studies. While the KAERI machine was used for neutron production via the D-T fusion reaction by 240-keV beams, the 300-keV machine at Yonsei produced proton and Lithium beams for various physics experiments. In the late 1970's, SNU constructed a 1.5-MV Tandem Van de Graaff for materials research.

Recently, there are many imported facilities and equipment related to the particle accelerator technology mainly for medical and industrial applications. In 1980's, the Korea Cancer Center Hospital (KCCH) imported a 50-MeV cyclotron and a 22-MeV microtron for medical treatment. A survey of research and medical accelerators in Korea is listed in Table 1.

The PLS is, therefore, the first large-scale accelerator complex in Korea. It is a national synchrotron radiation users' facility for basic and applied science research consisting of a 2-GeV linear accelerator as a full-energy injector and a low-emittance storage ring.

In 1988, the Pohang University of Science and Technology (POSTECH) initiated the PLS project with financial support from the Pohang Iron and Steel Company (POSCO), and the government joined in the project in 1989. The accelerator construction was officially completed at the end of 1994, and it was open to users in September of 1995 with two beamlines initially. There are now eight beamlines. A commercial company, LG-Semiconductor, built its own beamline for lithography, and the Kwangju Korea Institute of Science and Technology (KJIST) built its own beamline with support from the Kumho Business Group.

With the success of the PLS project, there are strong demands on accelerator facilities for various applications: the KOMAC-project for nuclear transmutation and energy production, a neutron facility for nuclear data production and evaluation, a FEL driver, industrial accelerators, and a 13-MeV cyclotron for medical radioisotope production, and others. We describe briefly recent activities for these accelerators along with R&D activities in the following sections.

Table 1: Survey of accelerators in Korea.

Research Accelerators			
Ion	0.4–3.0 MV Van de Graaff	8 Research institutes	Basic R&D
Electron	1.0 MeV Electro-Static	SHI	Environment R&D
	2.0 MeV ES	ADD	NDT
	8.0 MeV Microtron	KAERI	FEL
	0.1 GeV	PAL	Nuclear Data
	2.0 GeV	PAL	Light Source
Medical Accelerators			
Linac	5 ~ 20 MeV	~60 Hospitals	Therapy
Microtron	22 MeV	KCCH	RI production
Cyclotron	50 MeV 18/13 MeV 16/13 MeV	KCCH SNU Samsung	Therapy, PET PET PET

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2 POHANG ACCELERATOR LABORATORY

2.1 PLS Status

The 2-GeV injector linac consists of a 100-MeV preinjector and 10 SLAC-type regular modules, with 4 accelerating sections fed by each klystron [2]. Recently, we installed another module with 2 accelerating sections to improve the machine availability. Each module also has a SLAC-type Pulse Compressor with an average energy gain factor of 1.5. Since we use 80-MW-class high-power klystrons, each regular module is able to provide beam energy of 200 MeV with microwave power of 50 MW. The beam injection to the storage ring takes usually 2-5 minutes with 10-Hz and 1.5-ns pulses.

The PLS Storage Ring has a TBA-lattice structure with 12 super-periods with circumference of 280 m. There are two straight sections allocated for the RF-cavities and the injection system. Aluminum vacuum chambers are machined by an outside vendor and welded in-house. The RF system uses 4 RF klystrons of 60-kW to support a beam current of 400 mA at 2.0 GeV and 250 mA at 2.5 GeV. We demonstrated beam energy ramping to 2.5 GeV from 2.0 GeV, and we will provide 2.5 GeV beams from the second half of 1998.

Table 2 shows hours of the total machine operation and user service mode. We operated the linac for 5,480 hours and the storage ring for 4,840 hours in 1997. The user service time is 3,600 hours with the machine availability of 91.4% in 1997 and 92.4% in the first half of 1998. The machine fault statistics are shown in Table 3 for both the injector linac and the storage ring. The most frequent failure was the modulators in the linac and the injection system in the storage ring. We have experienced various beam instabilities, especially the coupled-bunch instability in high-current operations. Therefore, we are developing the longitudinal feedback system in collaboration with SLAC.

Table 2: Statistics for total machine operation and user service mode.

Machine operation (hours)				
	'95[1)]	'96	'97	'98[2)]
Linac	1,870	4,810	5,480	2,848
SR	1,820	4,680	4,840	2,657
User service				
Plan	1,275	3,236	3,960	2,400
Actual	1,142	3,034	3,618	2,222
Availability	89.6 %	93.8 %	91.4 %	92.6%

[1)] 2nd half year, [2)] 1st half year.

2.2. PAL Test-linac and Nuclear Data Center

Another electron linac, called PAL Test-linac with a beam energy of 100 MeV, was recently constructed in the PLS linac tunnel for R&D activities, such as experiments for development of special electron guns, a free electron laser (FEL), neutron generation, and a slow positron source.

The PAL Test-linac consists of a thermionic RF-gun, an alpha magnet, four quadrupole magnets, two SLAC-type accelerating sections, a quadrupole triplet, and a beam analyzing magnet [3]. With a temporary klystron-modulator, it produces 75 MeV, 30 mA beams at 3 μs and 10 Hz. The machine parameters and achieved values are shown in Table 4.

As applications of the PAL Test-linac, we proposed a pulsed neutron facility for nuclear data production and evaluation. In order to support the nuclear-power development program and the nuclear R&D applications in Korea, KAERI decided to establish the Nuclear Data Center to produce and evaluate nuclear data. Among various kinds of neutron sources (reactors, accelerators, and radio-isotopic neutron emitters), an accelerator-based neutron source is the most efficient one for high-resolution measurements of microscopic neutron cross sections. It produces short bursts of neutrons with a broad continuous energy spectrum by nuclear reactions of energetic photons or charged particles. Especially, an electron linac is a useful tool for the neutron time-of-flight (TOF) measurement as an intense pulsed source. The Test-linac will be jointly utilized for the Nuclear Data Center.

Table 3: Machine fault statistics in 1996-1997.

Storage Ring		Linac	
RF system	65	Modulator	127
MPS system	48	Control system	35
Control system	28	MPS system	30
LCW system	19	Timing system	25
Vacuum system	18	Vacuum system	8
Interlock system	13	Power failure	8
Timing system	12	Microwave system	3
Power failure	6		
Injection system	5	E-gun	1
Total	**214**	Total	**231**

Table 4: Machine parameters of Test-linac.

Beam Energy	100 MeV (75 MeV*)
Beam Current	100 mA (30 mA*)
Pulse Width	6 μs (3 μs*)
Energy Spread	< 1 % (3 %*)
Repetition Rate	60 Hz max. (10 Hz*)
Norm. Emittance	< 30 πmm-mrad

* Achieved values

For the pulsed neutron facility, the machine is to be upgraded with following parameters; The beam energy is at least 100 MeV with beam currents of 0.3 –5.0 A. The pulse width is in the range of 10-1000 ns, and the repetition rate is 30–300 Hz. The target system uses water-cooled Tantalum. The average neutron yield is approximately 10^{13} n/sec. There will be three time-of-flight beamlines of 10 – 100 meters.

2.3 Linac R&D activities at PAL

There are several R&D programs at PAL to improve the existing machine and to explore possibilities for the future facility expansion and other applications. These are described in the followings.

2.3.1 RF-gun: A one-cell S-band RF-gun is fabricated in-house with a dispenser cathode and installed to the Test-linac. It is capable to produce beams of 1.0 MeV and average 600 mA with 2.0 MW RF-power [4]. It shows the beam energy range of 0.4-1.0 MeV with the peak energy of 0.9 MeV. Therefore, one needs an alpha magnet before injection into the main accelerating section.

2.3.2 Triode RF gun: The triode RF gun is a conventional triode gun with its pulser replaced by a S-band RF power source. A preliminary experiment to investigate the feasibility of this scheme shows that electrons could be bunched at 2.856 GHz, although the extracted bunch current would be relatively low. Presently, a coaxial cavity is being prepared in order to increase the bunch current.

2.3.3 Polarized electron source (PES): The PLS 2-GeV electron linac at PAL is the only facility applicable for nuclear and high-energy experiments in Korea. However, it is very difficult to have meaningful experiments due to the lower duty-factor for nuclear experiments. One of ways to utilize the existing 2-GeV electron beams to nuclear experiments is to use a polarized electron source for studying spin dependencies in the nuclear systems.

The polarized electron source consists of a polarized electron gun with a GaAs-type photo-cathode, a laser system operated at the wavelength near the GaAs band gap, and a polarimeter. In the first stage, we designed and constructed a test stand, which consists of a photo-cathode gun, a light source, a cylindrical condenser and a Mott chamber to develop the polarized electron source.

We used a bulk GaAs as a photo-cathode and supplied a few kV high-voltage. The energy of the emitted laser light is sufficient to photo-excite electrons to just above the photo-threshold for GaAs. Thus, a diode laser with photon energy of 1.56 eV and a maximum power of 20 mW will be used for the light source. The polarized electrons are bent to 90-degrees by a cylindrical condenser and measured the polarization by the Mott polarimeter.

2.3.4 Klystron-Modulator: A new modulator is designed to improve the current PLS 200-MW modulator. It employs an inverter type switching power supply to charge high energy density PFN capacitors, a command charging method to improve the system reliability, and a computerized automatic control system with a microprocessor. This modulator is compact, highly efficient, and reliable with easy remote-control capability. On the other hand, in the electron-positron linear collider program, the modulator efficiency is one of the most important issues in the operating cost. A prototype modulator, called the smart-modulator, is developed in collaboration with the C-band group at KEK. The initial test result shows that the efficiency of the 111-MW modulator system is 47.9% in compare with the design value of 59.3%.

2.3.5 Resonant ring: An S-band traveling-wave resonant ring is constructed for high-power RF tests on microwave components, such as ceramic windows and waveguide valves. This system is capable of delivering traveling microwaves of 4 μsec and 30 Hz with more than 200 MW power level, even though the peak power from the E3712 klystron is limited by 80 MW.

2.3.6 Waveguide valve: There needs a proper waveguide valve for the 80-MW RF system. It is very useful one for easy replacement and quick maintenance of klystrons. We adopted a new concept without limitations on power transmission. The new S-band waveguide valve consists of a U-shaped waveguide section with a pushrod assembly, a vacuum chamber with two H-corner sections and a scaling plate with two viton o-rings. We achieved a power transmission of more than 65 MW at a pulse with of 3.5 μsec and a pulse repetition rate of 30 Hz. It also shows an excellent reliability of the vacuum seal.

2.3.7 Portable cooling-water system; A stand-alone cooling-water system with the precision temperature control for the use of RF tests of microwave components, such as a resonant ring, a energy-doubler, and RF loads. The system consists of a centrifugal circulating pump, electric heater, air-cooled heat exchanger, direct digital temperature controller, and auxiliary components. The capacity of the maximum thermal dissipation is 3 kW with the temperature control range of 24 - 45 ± 0.2°C.

3 KOREA ATOMIC ENERGY RESEARCH INSTITUTE: KOMAC-PROJECT

There has been a great demand on electricity along with a rapid economic growth in Korea. The national policy for constructing more nuclear power plants requires spent fuel treatment. As an optional concept, the Korea Atomic Energy Research Institute (KAERI) proposed an accelerator-based transmutation and energy production project called the KOMAC; the Korea Multi-purpose Accelerator Complex [5]. It adopts a 1 GeV and 20 mA CW proton linac for the driver of a 1000 MWth test reactor with electrical power of 300-400 MW. It is capable to handle spent fuels from 2 units of 1 GW Light Water Reactors (LWR). There are two beam extraction areas, at 100 MeV for fast neutron generation and 260 MeV for medical application. The basic parameters of the KOMAC system are listed in Table 5.

In the first R&D phase of 1997-2001, it is to develop a low-energy end of 20 MeV consisted of an ion-source, RFQ, and CCDTL(I). It requires both positive and negative ion sources for beam extractions at 100 and 260 MeV. The RFQ operates at 350 MHz CW for 3 MeV and 20 mA. The minimum aperture of the vanes is 4.6 mm, and the total length is 2.4 m. The operating frequency of CCDTL is 700 MHz, and the length for 20 MeV is 30 m. The participating institutes in this R&D program are KAIST, PAL, and SNU: KAIST for ion sources, PAL for RFQ, and PAL and SNU for RF sources.

The main linac is suggested to use super-conducting structures for large apertures and reducing operating costs. Since the super-conducting linac technology is now being developed in many places, for example, at TESLA and JAERI, it is desirable for the KOMAC team to participate in collaboration research among interested groups.

Table 5: KOMAC basic parameters

Parameter	Specification
Beam energy	1.0 GeV
Beam current / power	20 mA / 20 MW
Particle	H+ (18 mA) / H- (2 mA)
Operational mode	CW (final), Pulsed (initial)
Accelerator Type	Ion Source / RFQ / CCDTL / Super-conducting Linac
RF system	31 Klystrons (700 MHz)
Beam extractions	100 MeV / 250 MeV
Electricity	68.5 MW
Cooling water capacity	60.0 MW (excluding reactor)
Overall Length	705.4 m

3.1 Ion Sources

A duoplasmatron H^+ ion source has been built at KAERI. It has a peak current of 30 mA with a normalized 90% emittance of 0.5 mm-mrad. While the Korea Advanced Institute of Science and technology (KAIST) is developing an H^- ion source, KAERI is responsible for an injector delivering both H^+ and H^-.

3.2 Radio frequency Quadrupoles (RFQ)

PAL is developing a 350 MHz RFQ which accelerates 50 keV H^+/H^- up to 3 MeV. The total length is to be 3 m with a minimum aperture of 2.4-mm radius. Full beam current will require 68 kW. Because of RF loss on wall surface, we still need total power of 400 kW.

3.3 Phase Matching Section

A phase matching section is required after RFQ for H^- since the frequency of CCDTL becomes 700 MHz. This section will be used as an alignment steer (two beams can be aligned independently). A system of quadrupoles and bunchers for transverse matching is also required in this matching section.

3.4 Coupled-cavity drift-tube linac (CCDTL)

KAERI is developing a CCDTL with the features of conventional DTL and CCL. The CCDTL accelerates both positive and negative ions from 3 to 100 MeV. It is easy to fabricate and install it on the structure without breaking vacuum. The total length is 29.8 m with total RF power of 1.5 MW. As an option, a 5-MeV RFQ is also considered. In the first phase, the first part of CCDTL is to be fabricated to deliver 20-MeV beams. In the second phase, 94.2-m CCDTL is to accelerate beams to 100 MeV.

3.5 Beam Extraction

A partial extraction of H^- beams is planned at both 100 and 260 MeV. A magnetic-stripping study shows that the threshold field for stripping an electron at 100 MeV is 1 T and one for 260 MeV is 0.8 T. Since one expects the emittance degradation in this system, there need more studies on a special magnet with a very sharp peak-field and a laser extraction method.

3.6 Super-conducting linac

A SNU team studies on this subject due mainly to save RF power and to have a large aperture size to reduce beam loss. However, there need more detailed studies on the capital investment cost and availability for the related technologies. In the preliminary investigation, there are three cryomodules: 100-140 MeV, 140-260 MeV, and higher than 260 MeV. The cryostats contain four 4-to 6-cells of 700 MHz niobium cavities. The transverse focus requires doublet quadrupoles in the outside of cryostats.

4 SEOUL NATIONAL UNIVERSITY AND SAMSUNG HEAVY INDUSTRY

4.1 Seoul National University (SNU)

SNU constructed a 1.5 MeV cyclotron in Physics Department in the early 1960’s and a 1.5 MV Tandem Van de Graaff in Nuclear Engineering Department in the late 1970’s. These are constructed as a graduate program. The 1.5 MV Tandem is being used for Rutherford back scattering (RBS), Photon induced x-ray emission (PIXE) analysis, and various nuclear cross-section measurements.

The Users Support Center at SNU purchased a Tandetron AMS from the High Voltage Engineering Europa. The nominal terminal voltage is 2.5 MV with the maximum of 3.0 MV.

4.2 Samsung Heavy Industry (SHI)

During the last few years, many industrial processes using the electron beam irradiation have been developed. In order to meet the industrial needs for irradiation technology, Samsung Heavy Industry established the accelerator development center and employed an ELV-type industrial electron accelerator developed by the Institute of Nuclear Physics (INP) in Novosibirsk, Russia in the mid-1970s. The ELV accelerator is characterized by the high voltage generation with a cascade coreless transformer.

The main parameters for ELV-type accelerators are as follows; Electron energy is 0.4 - 2.0 MeV, and beam power is no less than 20 kW within the whole energy range. SHI began to commercially manufacture ELV-type accelerators in collaboration with INP for various industrial applications, such as waste-water treatment, flue-gas purification, cross-linking of polyethylene, hardening of coatings and paints, graft polymerization, vulcanization of rubbers, deinsectization of grain, and fabrication of fiber glass plastics.

5 SUMMARY

We believe that we have established technological basis for accelerator related sciences, especially, through experience of the PLS construction. This accelerator community is to contribute the country for advancing basic and applied science research.

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