STATUS OF ACCELERATORS IN KOREA

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Abstract

The Pohang Light Source (PLS), the first large-scale accelerator complex in Korea, is a national users' facility for basic and applied science research using synchrotron radiation. It consists of a 2-GeV linac as a full-energy injector and a low-emittance, third generation storage ring. It has been serving users since September of 1995. The beamlines has been increased from two to eight units as the increased number of users. With the success of this facility, 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, and others. This paper summarizes the recent operational status of PLS along with 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 constructed by graduate students and 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 this period, all the necessary components were made in student workshops and/or cannibalized from used medical or military surplus equipment.

While basic science research suffered from shortages of funding and professional manpower, Korea had advanced in a great speed to a newly industrialized country during the last three decades. There are many imported facilities and equipment related to the particle accelerator technology mainly for medical and industrial applications. In the late 1970's, however, a team led by Prof. K. Chung at SNU constructed a 1.5-MeV Tandem Van de Graaff which has been using for materials research. 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 Korean government joined the project in 1989. When the accelerator construction was officially completed at the end of 1994, the total project cost was 144.7 billion Won (about 180M U$). The facility was opened to users in September of 1995 with two beamlines initially, and it is now operating eight beamlines. A commercial company, LG-Semiconductor, built its own beamline for lithography research, and the Kwangju Korea Institute of Science and Technology (KJIST) built another one 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, a FEL driver, and a 13-MeV cyclotron for medical radioisotope production, and others. We describe briefly recent activities for these accelerators along with the PLS status in the following sections.

Table 1: Survey of accelerators in Korea.

Research Accelerator			
Ion	0.4 - 2.0 MeV 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 Accelerator			
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

2 STATUS OF POHANG LIGHT SOURCE

2.1 Machine Operations

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. Recently, we installed another module with 2 accelerating sections to improve the machine availability. Each module also has an 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 vacuum chambers consist of two sectors of 10- and 7-m long in each period. 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 have demonstrated beam energy ramping to 2.5 GeV from 2.0 GeV, and we are going to provide 2.5 GeV beams routinely from the second half of 1998. We have also achieved a stored current of 373 mA, but the beam showed various instabilities in this high-current regime. The lifetime was normally more than 15 hours at 100 mA in 1997.

There are three modes in accelerator operations: user service, machine study, and beam alignment. 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. The user service time is 3,600 hours with the machine availability of 91.4% in 1997. The machine fault statistics are shown in Table 3 for both the injector linac and the storage ring. The most frequent failure in the injector linac was the modulators, and in the storage ring, the most frequent failure was the injection system. We have experienced various beam instabilities, especially the coupled-bunch instability in high-current operations. Therefore, we are going to improve the precision temperature-control system of the RF cavities and to install transverse and longitudinal feedback control systems in 1998. The longitudinal feedback system is being developed in collaboration with SLAC.

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

Machine operation (hours)			
	’95 (2nd half)	‘96	‘97
Linac	1,870	4,810	5,480
SR	1,820	4,680	4,840
User service (hours)			
Plan	1,275	3,236	3,960
Actual	1,142	3,034	3,618
Availability	89.6 %	93.8 %	91.4 %

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**

2.2 Beamlines and insertion-devices

There are 32-beamports in PLS, 22 for bending magnets and 10 for insertion devices. In 1995, we started the user service initially with two beamlines: photo-emission (VUV) and X-ray scattering. In 1996 and 1997, we added 6 beamlines: NIM for gas-phase and also photo-emission, EXAFS, White-beam/microprobe, SAXS, KJIST-XRD, and LG-lithography. There are now 6 beamlines under construction: protein, slitless, U7, LIGA, Electo-chemistry, and EPU6. There will be 11 operational beamlines including the U7 beamline by the end of 1998. Our future plan is to construct three beamlines every year so that we will have about 40 beamlines by 2008.

We have been preparing three insertion devices: U7-undulator, Elliptically Polarized Undulator (EPU), and superconducting wiggler. The U7 undulator was constructed in-house with help from a domestic company. It will provide users intense photons by more than a thousand times in the photon energy range of 40-2000 eV. It is already installed in a straight section of the storage ring. The EPU6 is now in the field measurement stage. The parameters for the U7 and EPU6 undulators are listed in Table 4. A superconducting wiggler of 7.5 Tesla was constructed in collaboration with the Budker Institute of Nuclear Physics (BINP), Russia.

Table 4: Parameters for U7 and EPU6 undulators

	U7	EPU6
Period length	7 cm	6 cm
No. of periods	59	25
Overall length	4.3 m	1.57 m
Peak magnetic field	1.01 T	0.85 T (H) 0.63 T (V)
Min. magnetic gap	16 mm	14 mm
Total weight	20 ton	2.5 ton
Status	Installed	Under field measurement

2.3 Experiments and users

Users are getting familiar with experimental techniques and instrumentation, and we have had some encouraging initial results, such as the magnetic moment measurement of Gadolinium on the Gd/Fe super-lattice and the lithography of a 0.13-μ line width. There were 18 experiments conducted in 1995 and 64 in 1996 with two beamlines. It becomes 139 experiments in 1997. Table 5 shows the statistics for the experimental proposals. The number of members in the Korean Synchrotron Users Association has increased from 77 in 1991 to 423 in 1997, as shown in Table 6. We have already experienced more competition to obtain beam-time for certain beamlines. As more beamlines become available yearly, we expect a rapid increase of users and more foreign collaboration.

Table 5: Research proposals for experiments.

	1995 (2^{nd} half)	1996	1997
Proposals applied	58	124	173
Proposals approved	53	93	135
Experiments performed	28	69	139

Table 6: Members in the Korean Synchrotron Users Association.

Year	1991	1992	1993	1994	1995	1996	1997
No.	77	92	146	218	353	400	423

Briefly, the Pohang Light Source was constructed during 1988-1994 with joint support from POSCO and the Korean government. It was opened to users in September 1995, and it is now under normal operation with a total of 4,800 hours, of which 4,000 hours are allocated to users in 1998. The machine availability to users is about 91.4%. There are machine shutdowns twice a year, in the winter and the summer, for preventive maintenance and beamline installation. Eight beamlines are now in service and six are now under construction. The number of users and beamlines is increasing rapidly, and one may expect 40 beamlines and more than 1,500 users in ten years.

3 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 treatments. As an option among several concepts, the Korea Atomic Energy Research Institute (KAERI) proposed an accelerator-based transmutation and energy production project called the KOMAC; Korea Multi-purpose Accelerator Complex [2]. It adopts a 1 GeV, 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 radioisotope production. The KOMAC basic parameters of the KOMAC system are listed in Table 7.

Table 7: 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 / Superconducting 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

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 meters. The operating frequency of CCDTL is 700 MHz, and the length for 20 MeV is 30 meters. The participating institutes in this R&D program are KAIST, PAL/POSTECH, and SNU: KAIST for ion sources, PAL/POSTECH for RFQ, and PAL/POSTECH/SNU for RF sources.

The main linac is suggested to use superconducting structures for reducing operating costs and large apertures. Since the superconducting 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.

4 OTHER ACCELERATORS

An electron linac with a beam energy of 100 MeV has also been constructed in the PLS linac tunnel for new R&D activities, such as experiments for development of special electron guns, a free electron laser (FEL), neutron generation, and a slow positron source. On the other hand, a 13 MeV cyclotron project is started jointly at KCCH and POSTECH for radioisotope production for PETs.

4.1 PAL Test-linac and Nuclear Data Center

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 40 MeV, 30 mA beams at 3 μs and 12 Hz. The machine parameters and achieved values are shown in Table 8.

Table 8: Machine parameters of Test-linac.

Beam Energy	100 MeV (40 MeV*)
Beam Current	100 mA (30 mA*)
Pulse Width	6 μs (3 μs*)
Energy Spread	< 1 % (3 %*)
Repetition Rate	60 Hz max. (12 Hz*)
Norm. Emittance	< 30 π mm-mrad

* Achieved values

As an application for the PAL Test-linac, we propose a neutron facility for nuclear data production. In order to support the active 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 radioisotopic 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 utilized for this Nuclear Data Center.

For the nuclear data center, the machine is upgraded to operate 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 - 1,000 ns, and the repetition rate is 30 – 300 Hz. The target system uses a water-cooled Tungsten. The average neutron yield is approximately 10^{13} n/sec. There will be three time-of-flight beamlines of 10 – 100 meters.

4.2 Medical Cyclotrons

In the mid-1980, KCCH introduced a 50 MeV cyclotron from Scanditronix for neutron therapy. It is also used for radioisotope production. Recently, hospitals at SNU and Samsung introduced the Positron Emission Tomography (PET) facilities including low-energy cyclotrons. They are operated at 13 MeV with capabilities of operating at 16 and 18 MeV, respectively.

Expecting more PET facilities in the near future, it is required to develop a domestic mini-cyclotron for easy maintenance and better after-service. Therefore, a new R&D project is recently initiated jointly by KCCH and POSTECH to develop a 13-MeV medical cyclotron for production of ^{18}F-isotope in the PET application [4]. It is to use negative hydrogen with internal negative PIG ion source. The major parameters of this machine are listed in Table 9.

Table 9: 13-MeV medical cyclotron.

Particle species	Negative hydrogen
Ion source	Internal, negative PIG source
Max. energy	13 MeV (fixed)
Dimensions	R = 1 m, h = 1 m
Beam current	20 μA
RF frequency	71.49674 MHz (4th harmonic)
Dee voltage	50 kV

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 and for enhancing the quality of life in Korea.

6 ACKNOWLEDGMENTS

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