OVERVIEW OF ACCELERATOR ACTIVITIES IN KOREA*

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Abstract

In this report, we introduce research activities for particle accelerators in Korea. There are approximately ninety small and medium energy particle accelerators currently operating in Korea. While most of these accelerators are small energy ones (6 - 15 MeV) based on hospital, there are two major institutes currently carrying out accelerator related researches, Pohang Accelerator Laboratory (PAL) and Korea Atomic Energy Research Institute (KAERI). We focus on these two laboratories to present synoptic overview of accelerator activities in Korea.

1 INTRODUCTION

As of 2001, there are about ninety particle accelerators in Korea. Among them approximately 75 accelerators are hospital based RF linear accelerators mainly for tumor treatment using x-rays generated by electron beam impinging on target. One 22 MeV microtron located in Korea Cancer Center Hospital (KCCH) of Korea Atomic Energy Research Institute (KAERI) has also been used for the same purpose. In addition, there are four hospita-based cyclotrons are to produce radio-isotope to be used for Positron Emission Tomography (PET). A 13 MeV cyclotron construction has been going on at the KCCH in collaboration with the Pohang University of Science and Technology (POSTECH). This project, to be completed by March 2002, is to produce ^{18}F isotope ($\tau_{1/2} \sim 110$ min) for the PET purpose.

In the late 1980s, The Pohang University of Science of Technology (POSTECH) launched a construction project to build a third generation synchrotron radiation source. This project started in 1988, completed in 1994, funded by Pohang Iron and Steel Company (POSCO) and Ministry of Science and Technology (MOST) of Korean government. As of September 2001, a total of 14 beamlines provide photon beams to users, one beamline under commissioning, and nine beamlines under construction. By the end of 2008, about 40 beamlines will be installed. Being a third-generation machine, the slow orbit drift in the PLS storage ring becomes troublesome for stable machine operation. Approximately 140 μm rms orbit drift has been observed during a ten-day run. Systematic studies have been going on to identify and cure such drift of orbit. During August 2001, the storage ring air control and ventilation system has been improved in such a way that the tunnel temperature is stabilized within ±0.2°C from ±1.0°C and the air is circulating around the ring tunnel. This has a significant reduction of the orbit drift, as will be described in section 2.

At KAERI, the Korea Multi-purpose Accelerator Complex(KOMAC) project has been going on to build a 1 GeV proton linear accelerator system. This accelerator will mainly be used for nuclear transmutation as well as other purpose such as proton therapy. The accelerator system consists of a 3 MeV RFQ, a 100 MeV CCDTL and a 1 GeV superconducting linear accelerator. At present, a 450 keV test RFQ has been fabricated and a 20 MeV test CCDTL is under construction. A brief overview of this project is described in section 3. Another group at KAERI has been operating and constructing electron accelerators for FEL research as well as for industrial applications. Their activities are described in Section 3. Finally, section 4 is devoted to describe medical accelerators at the KCCH.

2 POHANG LIGHT SOURCE

The Pohang Light Source (PLS) [1] is a 2.0-2.5 GeV, third-generation synchrotron radiation source which has been dedicated to users since 1995. Until 1998, PLS had been run at 2.0 GeV electron beam energy. After successful demonstration of high energy ($>$ 2.4 GeV) beam operation in 1998, the machine was fine tuned in 1999 to accommodate higher energy operation. In 2000, the operation energy was increased to 2.5 GeV with the average injection current of 170 mA exceeding the design goal. The maximum injection current is around 180 mA which is limited by total available rf power, with all the beam instabilities suppressed within this energy. At 2.0 GeV, the PLS team succeeded in storing 300 mA with a systematic control of the chromaticity and rf cavity cooling temperature in May 2000, which was the design goal of PLS storage ring. Further, new record of the maximum beam current, 430 mA was achieved in October 2000. From early this year, the PLS maintains a reference orbit chosen as a best empirical orbit during the machine-tuning period after the winter shutdown. At present, various machine upgrade projects are on-going in PLS, such as refurbishing beam diagnostic station, development of the new control system, cure of the closed orbit drift caused by thermal effects, and installation of new low level rf control electronics.

There are 14 beam lines in operation including the first insertion device (U7) beam line. Also an EPU6 beamline for elliptically polarized beam has been under commissioning and a U10 undulator was installed in August 2001. In Table 1, total beam availability since 1995 is summarized.

2.1 Accelerator operation

Injector Linac The linear accelerator operated 5,280 hours in 2000, with a 1 ns pulse beam at 10 Hz repetition

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Table 1: Beam-time and user service statistics

Year	95	96	97	98	99	00
Beam hour provided	1142	3034	3618	3784	3831	3884
Proposals submitted	58	124	173	171	255	322
Exp. carried out	18	69	139	130	156	237
No. of users	78	283	577	646	659	833

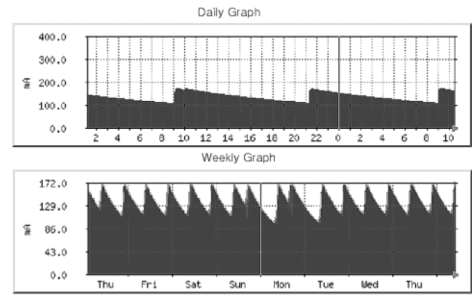

Figure 1: Beam current display for daily (top) and weekly (bottom) operation of the PLS

rate at the beam energy of 2.045 GeV. The operation time of the klystron and modulator system was 6,800 hours with the system availability of 94%. The number of modulator faults that caused injection delays has decreased from 38 in 1999 to 29 in 2000. Overall, the operation of the linear accelerator was more stable than in previous years.

Storage Ring The storage ring was operated for 4,834 hours in 2000. The beam time scheduled to users was 4,224 hours, divided into 18 ten-day periods. The actual time supplied to users was 3,834 hours with a beam availability of 90.9%. It is noteworthy that the beam energy was increased to 2.5 GeV. The average injection current was 166.9 mA, and the average beam lifetime was 40 hours in 2000. After a series of efforts for machine stabilization, the beam availability in the first half of the 2001 operation was increased to more than 93%.

Unification of the Control Room Two independent control rooms for 2 GeV Linac and the storage ring were unified into a storage ring control room beginning from March 2000. After the merging of the control room, a period of the shift-duty has become doubled for machine operators. Also injection time has been reduced by removing the need of telephone calls between two remote control operators for adjusting various injection parameters. Now the beam injection is possible by clicking the command buttons on a single console screen. Online help menus will be implemented for more secure and easier operation.

Machine Operation at 2.5 GeV PLS is now regularly run at 2.5 GeV with the stable energy ramping control system. The new energy ramping system uses independent control system based on the Windows system for synchronization of all magnet controllers. With this high energy, x-ray flux increased and the beam stability is improved. No beam instability is observed at the present operational beam current of 180 mA. Beam lifetime is also increased from 20 hours at 2.0 GeV to 40 hours at 2.5 GeV at 100 mA. Shown in Fig. 1 is a beam current display for a successful ten-day operation.

Operation of the First Insertion Device U7 From 2000, the first insertion device beamline U7 has been successfully running for the user service. The orbit change with the change of U7 gap doesn't affect user experiment seriously. The second ID in PLS, EPU6, has been installed and under commissioning now.

Access to the Experimental Hall Experimental hall has been a restricted area during the beam injection until the end of 2000. This caused much inconvenience to the users because they must escape from their experimental stations. With a five-year accumulated radiation dose data for proof of the radiation safety, PLS finally obtained permission of access to the experimental hall during the beam injection from March 2001.

Closed orbit stabilization In PLS long term orbit measurements show slow drift of the orbit up to $\pm 140 \mu$m as shown in Fig. 2. With a series of investigations, we find that there is a strong correlation between the orbit drift and the temperature changes of the magnet and air in the storage ring tunnel. Major source of the temperature change is attributed to the large change of the magnet current during the regular beam injection: dump the stored beam, degauss the magnets with the full swing of the magnet current up to saturation, fill the beam at 2.0 GeV and raise the energy again to 2.5 GeV. During this injection process, heat load changes around 200% of the normal operation. In contrary, when the machine is shutdown for several hours, it is overcooled. Once heated up or cooled down, it takes around four hours for temperature to be stabilized in the vacuum chamber and supporting structures. To reduce the temperature shock, we applied de-ramping technique of the beam energy without dump the stored beam to refill. By this process, thermal shock on the magnets reduced significantly, and the change of the orbit before and after the injection is reduced significantly now. During the summer shutdown in 2001, the air ventilation method of the storage ring tunnel has been modified so that the air now circulates around the ring clockwise direction. This has a significant effect on the orbit stabilization as shown in Fig. 3, which is to be compared with Fig. 2. Further studies are still in progress.

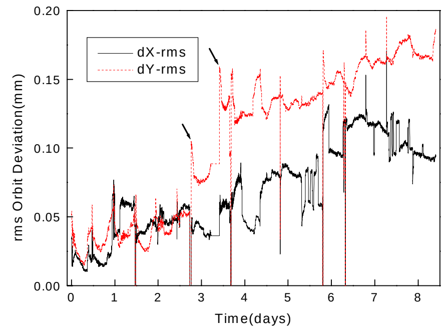

Figure 2: RMS orbit deviation with operation time before summer shut down in 2001. Arrows indicate large increase of rms values by the degaussing of magnets by unexpected beam dumps

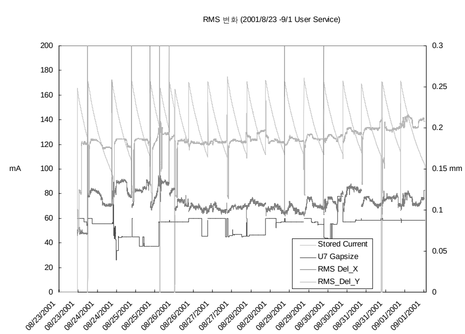

Figure 3: RMS orbit deviation with operation time after summer shutdown in 2001.

RF System upgrade RF control electronics has caused troubles for some years in PLS making frequent machine trips. All the rf control electronics have been redesigned and fabricated, with improvement of the control logic and more monitoring options. During summer shutdown in 2001, one system has been installed. So far, no sign of malfunctioning appeared. By the end of this year, the remaining three systems will be installed. Further, since the present rf power (60 kW x 4 klystrons) will become short as the number of IDs increase, plan has been made to replace 60 kW klystrons with 75 kW ones one by one and add one more cavity making total rf power 375 kW without changing the waveguide system. Then it will have a capability of operation at 200 mA with 10 IDs at 2.5 GeV energy.

Storage Ring Deformation and Realignment The settlement of the storage ring tunnel continues at about 3.0 mm (hill to valley) per year in PLS. The total deformation has reached presently 19 mm compared to the reference elevation established in June 1993. Since the accumulated deformation still increases without slowdown, the smoothing technique will not be applied any more. Thus, it was decided to realign all storage ring component toward the design orbit step by step in three years. Beamlines will also be realigned when it is necessary.

More details of the recent progress of the PLS accelerator is described in [2].

3 ACTIVITIES AT KAERI

3.1 KOMAC project

The Korea Multipurpose Accelerator Complex (KOMAC) project has been initiated by the KAERI team to develop and build a high current proton linear accelerator[3, 4]. This linear accelerator is to deliver a 1 GeV continuous proton beam with an intensity of 20 mA in the final stage.

The 350 MHZ CW RFQ accelerates the 20 mA proton beam from 50 keV to 3 MeV. The RFQ is a four-vane type consisting of 56 tuners, 16 vacuum ports, one coupling plate, four rf drive loops, 96 coupling passages, and 8 stabilizer rods. For test purpose, a 450 keV RFQ has been fabricated to verify the engineering design; cooling, control, rf system, and beam diagnostics. The RFQ is made of all-brazed OFHC copper, integrated from separated 81 cm long sections. One section is to be used for rf power feed via two 250 kW or four 125 kW coupling irises. When operational, its tuning is done by modulation of cooling system. Table 2 shows the major parameters of the KOMAC RFQ.

Table 2: The KOMAC/KTF RFQ parameters

Parameter	Value
Frequency	350 MHz
Particles	p/H^-
Input/output current	21/20 mA
Input/output energy	0.05/3.0 MeV
Input/output trans. norm. emittance	0.02/0.023 π cm mrad rms
Output long. emittance	0.246 MeV deg
Transmission efficiency	95%
Type	Four-vane
Duty factor	100%
Peak surface field	1.8 Kilpatrick
Structure power	350 kW
Beam power	67.9 kW
Total power	417.9 kW
Length	324.0 cm

The output 3 MeV beam from the RFQ is to be entered into a 700 MHz, 100 MeV CCDTL. For test purpose, the KOMAC team has been developing a 20 MeV CCDTL. Design parameters of this test CCDTL accelerator is shown in

Table 3.

Table 3: Design parameters of the test CCDTL accelerator

parameter	Value
Input/output energy	3.0/20 MeV
Frequency	700 MHz
Maximum beam current	20 mA
Input beam trans. norm. emittance	0.3 π cm mrad rms
Input long. emittance	0.4π MeV deg
Duty factor	10% (first stage)
	100% (final stage)
Surface E	$<$ 0.9 Kilpatrick
Synchronous phase	–60 $\sim$ –30 degrees
Focusing	8 $\beta\lambda$ FODO

A cold model cavities have been fabricated to verify the design, the tuning method, the coupling, and the fabrication methods. More details of the recent activities for KOMAC project can be found in [5].

3.2 Electron accelerator facility

The Korea Atomic Energy Research Institute (KAERI) has developed since 1992 three types of electron accelerators: a 0.4 MeV recirculating electrostatic accelerator for a millimeter-wave free-electron laser (FEL), a 7 MeV compact microtron for a far-infrared FEL, and a 40 MeV superconducting RF linac for the use of particle beams (e-, e+, n) and photon beams (FEL, x-ray, γ-ray).

The 0.4 MeV recirculating electrostatic accelerator consists of a 30 keV electron gun, a 400 kV high-voltage power supply, a acceleration column, a permanent-magnet helical undulator, a deceleration column, and a collector. First lasing of the MMW FEL was achieved in 1995 in the wavelength range of 3 10 mm, and the peak power of the FEL was 1 kW [6]. From 1996, KAERI has developed a compact far-infrared (FIR) FEL based on a 7 MeV magnetron-driven microtron accelerator[7]. The microtrons is very compact (70 cm in diameter) and has a simple acceleration structure. The quality of the electron beam is good enough to guarantee high FEL performance: the energy spread and the transverse emittance (ϵ_y) of the electron beam are 0.3%, and 1 mm mrad, respectively. The use of a compact low-cost magnetron (instead of an expensive klystron), makes the accelerator cheap, compact, and simple. A special technology has been developed for the stabilization of the frequency of the magnetron. A high-performance permanent-magnet-assisted electromagnet undulator has been developed for the FIR FEL[8]. The magnetic field strength of the undulator is higher by 10% than that of pure permanent-magnet undulator, and its r.m.s distribution error is as small as 0.05%, which enable high FEL gain and perfect transport of electron beam through the undulator. First lasing of the FIR FEL was achieved at the end of 1999, and now the FEL is operating stably in the wavelength range of 100-300 mm.

A new project has been launched since 1999 for the development of a 40 MeV superconducting (SC) accelerator for the use of particle beams (e-, e+, n) and photon beams (IR FEL, x-ray, γ-ray). The average current of the of the electron beam is 10 mA in energy recovery mode for photon beams, and 2.5 mA in non-recovery mode for particle beams. A 2 MeV injector for the accelerator has already been completed [9], which is composed of a 300 keV electron gun, a 176 MHz normal-conducting (NC) buncher cavity, and two 176 MHz NC acceleration cavities. Two SC accelerator modules from CERN will be used for the main acceleration section. Each SC accelerator module contains two 352 MHz four-cell SC cavities operating at 4.5 K, and can generate an acceleration gradient of 6 MV/m. The energy gain of one SC accelerator module is 20 MeV. Installation of the first SC accelerator module will be finished at the middle of 2002.

More details of the recent progress of the KAERI electron accelerators is described in [10].

4 MEDICAL ACCELERATOR

The KCCH has played a leading role in radiation medicine as well as in the treatment and research of cancer, since it was established as the Radiological Research Institute in 1963 to promote the medical application of atomic energy in Korea. For neutron therapy and radiation treatment, a 50 MeV medical cyclotron, built by Scanditronix, was installed at the hospital in 1986. The cyclotron has provided an in-house source of radio-isotopes such as ^{201}Tl, ^{123}I, ^{67}Ga, etc, and in particular, the shorter-lived radio-isotopes for diagnostic or clinical use. In addition to serving in-house duties, this cyclotron has also produced and supplied 15% of all cyclotron based radio-isotopes in Korea. This service has greatly contributed towards awareness of the potential benefits of nuclear medicine afforded by particle accelerators and evoked calls for similar services in other hospitals in Korea. So far only four hospitals have installed dedicated cyclotrons for PET (Positron Emission Tomography) applications, where the isotopes of interest are the four clinically significant positron emitters ^{15}O, ^{13}N, ^{11}C, and ^{18}F in particular.

At the KCCH, increasing desire for an uninterrupted, reliable and timely supply of the isotopes to customers has prompted obtaining a dedicated 5-13 MeV cyclotron for PET applications and pursuing the purchase of another 30 MeV medical cyclotron. A decision has been made to design the PET cyclotron in Korea. This will not only ease the problems associated with maintenance during operation but also keeps the door open for continuous upgrading of the machine in the future. The project is supported by the Ministry of Science and Technology (MOST) of the government, as a part of the 2nd phase of the mid- and long-term nuclear energy research plan. The project was started in July 1997 and is to be completed in March 2002. Table 4 shows the major parameters of the 13 MeV cyclotron.

At the time of writing this paper, the magnet systems of this cyclotron have been built and transported to the Pohang Accelerator Laboratory (PAL) to measure and correct magnetic fields. And then the whole system will be transported to the site of KCCH.

Table 4: major parameters of the 13 MeV PET cyclotron

Parameter	**Unit**	**Value**
Maximum energy	MeV	13
Beam species		H^-
Number of sectors		4
Ion source		Internal PIG
Hill angle	degrees	30 (varying)
Valley angle	degrees	60 (varying)
Average B field at 13 MeV	kG	12.98
Harmonic number		4
Radio frequency	MHz	70
Maximum average radius of a beam	cm	40.12
Maximum orbit distance	cm	41.4
Maximum B at the hill center	kG	19.16
Maximum B at the valley center	kG	8.4
Beam current	μA	50

5 ACKNOWLEDGEMENT

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