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Status of 2-GeV Linac at Pohang Accelerator Laboratory*

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ABSTRACT

Pohang Accelerator Laboratory (PAL) has constructed the 2-GeV Pohang Light Source (PLS) on August, 1994. The 2-GeV electron linear accelerator is used as a full energy injector to the storage ring. There are 42 accelerator structures, 11 klystrons of 80-MW maximum which are driven by 200-MW modulators, and 10 rf-pulse compressors in the 150 meter long linac. It's construction and commissioning was completed on June 30, 1994. We present the machine scheme and parameters, the commissioning results and the present status of the 2-GeV linac.

I. INTRODUCTION

The 2-GeV linac is a full energy injector for the Pohang Light Source (PLS) which is a low-emittance synchrotron radiation source. The construction and commissioning of the PLS linac was completed by the end of June, 1994. Since then, it has been serving 2-GeV electron beams to the storage ring (SR) without any significant failure. The PLS linac consists of 42 accelerating sections, 11 klystron-modulator modules, 10 SLAC-type pulse compressors (SLED), 6 quadrupole triplet magnets, a prebuncher, a buncher, and three beam analyzing stations (2 installed currently) [1].

The storage ring and the linac are connected by 96-m long beam transport line (BTL). It consists of 5 bending magnets, 24 quadrupoles, 5 vertical correctors, and 8 horizontal correctors. The 2-GeV beam leaving the linac is bent to 20 degrees horizontally by two horizontal bending magnets toward the injection area of the storage ring. After about 65-m behind the end of the linac, the beam is bent upward to the beam plane of the storage ring which is 6-m higher than that of the linac. There are three vertical bending magnets and one Lambertson-type DC septum magnet in the vertical section. Each vertical bending magnet and the septum magnet bend the 2-GeV beam by 8 degrees.

The performances of the linac and the BTL are heavily depended on the reliability of individual components and the best beam optics including magnet settings and RF phasing. The first-year experience of the 2-GeV linac and the BTL operations is reported in the following sections.

II. GENERAL DESCRIPTION

A. Linac

The norminal beam energy of the PLS linac is 2-GeV with the operating frequency of 2,856 MHz. There are 42 SLAC type $2\pi/3$ mode accelerating sections, 11 klystron-modulator modules including those for the preinjector. The total length of the linac is 150-m. The required accelerating gradient of the main linac is at least 15.8 MV/m. If we consider one or two klystrons as stand-by, it requires an accelerating gradient of 17.8 and 19.8 MV/m, respectively. In order to achieve this accelerating gradient, we adopted high-power klystrons of 80-MW and SLAC-type pulse compressors. In addition, we required the RF pulse length at least 4 μs for a higher energy gain factor from SLED cavities [2]. The energy spread with energy 100-MeV at BAS #1 is less than 0.4 % and with energy 2-GeV at BAS #3 is less than 0.3 %. The e-gun current in the linac is 1 ~ 2 A with 10-Hz repetition rate. Major parameters of the PLS linac are summarized in Table 1.

Table 1: Major parameters of the PLS linac

Beam Energy	2 GeV
Energy Spread	+/- 0.3 % or less
RF Frequency	2,856 MHz
Emittance (Measured)	320 π.nm.rad at 2 GeV
Current Delivery Ratio	> 60 %
Repetition Rate	10 Hz (60 Hz Max.)
Accelerating Gradient	15.5 MV/m (min.)
E-gun	> 1 A/ 1.2. or 40 ns
Klystron Output Power	50 MW (80 MW Max.)
Machine Length	150 m
No. of Klystrons	11 (= 1+10)
No. of Pulse Compressors	10
No. of Accelerating Sections	42 (= 2+40)
No. of Quadrupole Triplets	6
Beam Exit	100 MeV, 1 GeV, 2 GeV

B. Beam Transport Line (BTL)

The 2-GeV electron beam from the linac is injected to the storage ring through the beam transport line. Total length of the BTL is 96-m. There are two 18-m long branches for the beam analyzing station and for the beam dump, respectively. There are 5 bending magnets to form the beam path and 24 quadrupole magnets to focus the beam in the BTL. The maximum design value for βx is 57-m, and for βy is 56-m. The maximum value for ηx is 0.6-m between 2 horizontal bending magnets,

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and for ηy is 1.2-m in the last vertical section. The inner radius of the BTL chamber is 21-mm. The maximum beam radius calculated from the operation data taken in last April is 21.9-mm in the vertical section. The beam delivery rate measured by using 3 beam current monitors in the BTL is more than 90 %. The major parameters of the BTL are summarized in Table 2.

Table 2. Major parameters of the BTL

Beam Energy	2 GeV
Energy Spread	+/- 0.3 % or less
Emittance (Measured)	320 π.nm.rad at 2 GeV
Current Delivery Ratio	> 90 %
Injection Current to SR	600 ~ 1,000 mA (Pulsed)
Machine Length	96 m
No. of Bending Magnets	5 (2 horizontal, 3 Vertical)
No. of Quadrupole Magnets	24
Maximum βx (Designed)	57 m
Maximum βy (Designed)	56 m
Maximum ηx (Designed)	0.6 m
Maximum ηy (Designed)	1.2 m
Injection Beam Size	
Horizontal	< 3.0 mm
Vertical	< 3.0 mm

III. OPERATION RESULTS

A. RF Power, Phase

The most important parameter in the linac operation is the beam energy. The RF power is a primary factor to gain the beam energy. In the PLS linac, eleven klystron-modulator modules including one preinjector module are used to supply high RF power. Each module except the preinjector supplies the RF power of 48 MW to each of four accelerating sections. Without SLAC-type pulse compressor (SLED), we can get 1.5-GeV energy with that RF power. Using 10 SLEDs, we can achieve 2-GeV beam or higher. The highest energy we achieved so far is 2.34-GeV beam on November 7, 1994. In the normal operation, the SLED efficiency to improve enegy is 150 %. During two weeks on last April, one module was stand-by, so only 10 modules were used to get 2-GeV energy. In this case, we improved the SLED efficiency to 163 % by adjusting RF phase.

The RF phase is as important as the RF power to achieve the beam energy. It influences the beam qualities such as the energy spread, the beam emittance, and the current delivery ratio. So the RF phase control is another main factor in the linac operation. As a matter of fact, in the early period of the linac operation, we sometimes deccelerated the beam because of mismatched RF phase. Adjusting the RF phase is also related to the drive power supplied by the klystron modulator modules. In the PLS linac, the isolator-phase shifter-attenuator (IPA) system controls the phase and the amplitude of the drive power for each klystron [3]. Fig.1 shows the relation of RF phase angle, modulator high voltage, and the beam energy achieved by the klystron #11. The energy is measured at the beam analyzing station #3.

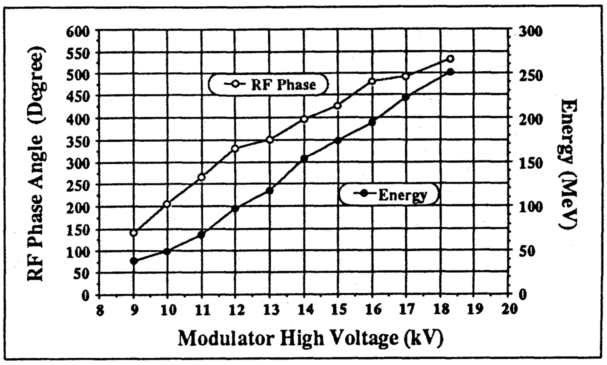

Fig. 1 Measurement of energy by optimized RF phase angle

The prebuncher and the buncher are another parts related to the RF power and phase. The electron beam is firstly bunched in the prebuncher and the buncher. They influence the beam delivery ratio in the preinjector. Table 3 shows the improvement of the delivery ratio in the preinjector by adjusting the RF power and the phase at one particular case.

Table 3. Delivery ratio in the preinjector

	Before Adjust	After Adjust
Prebuncher Input Power	31.1 kW	6.1 kW
Prebuncher Phase	334°	154°
Buncher Input Power	0.54 MW	1.1 MW
Buncher Phase	284°	296°
Delivery Rate	<50 %	> 80 %

B. Beam Analyzing

There are three beam anlayzing stations in the linac. One is located at the end of the preinjector for 100-MeV energy (BAS #1). Another is located behind the switching magnet in the BTL horizontal line for 2-GeV energy (BAS #3). The third is not installed but is preserved with its location for 1-GeV energy (BAS #2).

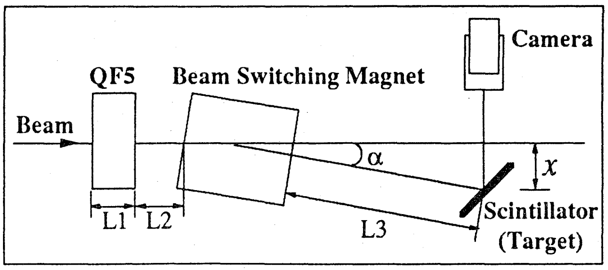

Fig.2 Schematic diagram of beam analyzing station

The schematic diagram of the beam analyzing station is shown in Fig. 2. The beam energy is measured by the controlling of the bending magnet field. The bending angle α is fixed to 24° at BAS #1, and to 10° at BAS #3, so we control the bending magnet field to locate the beam to the center of the target. From the magnet field, we can calculate the beam energy. The energy spread is obtained by the measurement of FWHM of the beam image on the target by the equation $\delta p/p=\delta x/2x$ (p is the momentum of the beam, δx is the FWHM of the beam, and x is the distance from the straight beam path to the center of the target.) [4]. In the early operation of the linac, the energy spread of 2-GeV beam was above 0.6 %. We tried to improve the beam qualities by adjusting beam optics. Now we have injected 2-GeV beam to SR with the energy spread of 0.3 % or less.

Beam emittances are measured by varying quadrupole magnet fields located in front of the bending magnet. It can be calculated from the relation of the quadrupole fields and the beam size on the target. Measured beam emittance is 320 π.nm.rad or less in both horizontal and vertical plane. In the future, we will expect to obtain more accurate values by using beam position monitors.

C. Beam Diagnosis

There are 13 beam-current-monitors (BCM) and 12 beam profile monitors (BPRM) for the diagnosis of the beam in the PLS linac and the BTL including two beam analyzing stations. The delivery rate of the beam current is affected mainly by the beam optics. In the early operation, the delivery rate is less than 20 % in the linac and less than 60 % in the BTL. We have improved the optics and now we obtained more than 60 % in the linac and 90 % in the BTL. By the TUTLE CODE simulation we expect above 96 % of the delivery rate in the BTL. The operation results show a good approach of the simulation results. The electron gun current also affects the delivey rate. Fig.3 shows the delivey rate in the linac and the BTL by in terms of e-gun current.

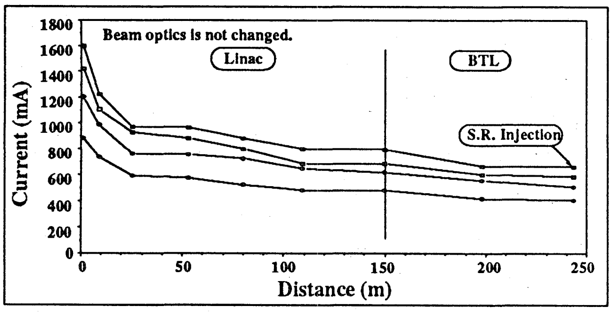

Fig. 3 Beam delivery rate by the e-gun current

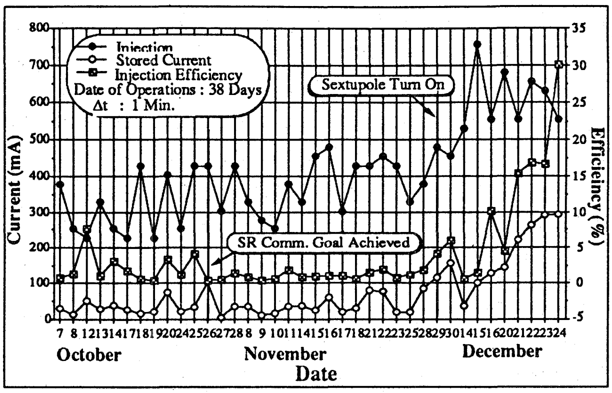

Fig. 4 Beam current and the injection efficiency during the period of October-December in 1994

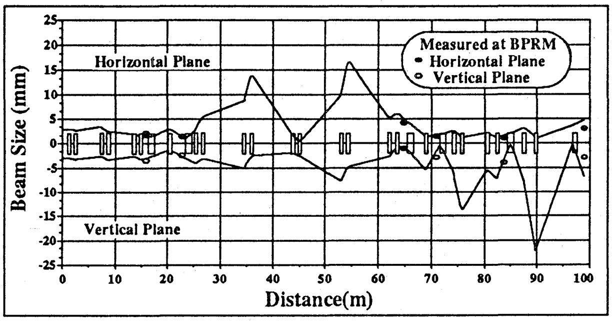

Fig. 5 Beam envelopes in the BTL

The history of the linac operations are summarized in Fig. 4 during October-December period in 1994. It shows clearly that the beam current from the linac was increased as we accumulated more experiences for the linac operation. The stored beam and the injection efficiency were also increased drastically. We measured the beam size from the image on the target of the BPRM in the BTL. It is compared with the simulation results by TRANSPORT CODE and is presented in Fig.5, which shows a good agreement.

IV. SUMMARY

The PLS 2-GeV linac has been successfully commissioned in June 1994 as scheduled, and its performance exceeds the design values. We obtain 2-GeV energy, high current, low emittance and low energy spread beam routinely. We injected the beam to SR without any significant failure. During the second maintenance period in 1995, we will install beam position monitors and beam loss monitors in the BTL, so more accurate operations will be expected.

V. REFERENCES

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