The PLS RF System Upgrade Activities

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Abstract

The PLS RF system at the initial phase consisted of three stations, in which each station has a 60-kW CW klystron amplifier as a power source, a circulator and a single-cell cavity, all connected by 6 1/8” coaxial transmission lines. The total RF capacity could afford to store the beam current up to 300 mA with 1.2 MV of the accelerating voltage at 2 GeV. In mid-1996, one more station was added to provide enough RF power to store up to 400 mA with 1.6 MV of the accelerating voltage at 2 GeV and 200 mA at 2.5 GeV. A new control electronics were also added for enhanced performance of the phase feedback and the automatic gain control. A transient data acquisition system was installed for better analysis of the unknown beam loss. Efforts to identify the higher order modes causing the collective instabilities were made and a strategy to reduce their effects were established. The cooling water control system for the RF cavities were massively upgraded during the summer maintenance period of 1997 to shift the harmful HOMs and to regulate the operation temperatures of cavities at stable condition. A disk-type input coupler with better HOM-absorbing capability has also developed and tested.

1 INTRODUCTION

The Pohang Light Source (PLS) is a 2-GeV, third generation synchrotron radiation source, which has a full energy linac and a storage ring. The storage ring RF system should provide enough energy for compensating synchrotron radiation loss and the beam loading. During the initial phase of operation, the PLS RF system consisted of three cavities powered by three independent klystron amplifiers. A single RF station includes a 60-kW klystron amplifier, a circulator, a coaxial switch and a cavity connected by 6 1/8” coaxial transmission line. Total RF power of 180 kW can provide enough power to store 300 mA at 1.2 MV of accelerating voltage. Table 1 shows characteristics of the RF system components.

Table 1. Characteristics of the PLS RF System

Klystron amplifier	60-kW (CW)
Transmission line	6 1/8” Coaxial line
Cavities	Single-cell (PF-type)
Shunt Impedance	>8 MΩ
Unloaded Q	>35,000
Coupling Coeff.	~1.8
Gap Voltage	400 kV/cell

In 1996, one more RF station was added to the storage ring. Total available RF power increased to 240 kW enough to store 400 mA of 2-GeV electron beams and even 200 mA of 2.5 GeV beams. The accelerating voltage also increased to 1.6 MV, which was beneficial to the lifetime to increase over 40%. Figure 1 shows the available operating regime of the required RF power as a function of the beam current for different accelerating voltages and beam energies. The upper limit of the available RF power with four stations are clearly marked in the figure.

Another important motivation for the upgrade activities are the beam instabilities induced by the higher-order-modes (HOM) of cavities. As the earlier reports[1,2] presented, most harmful modes are two longitudinal modes, 758 MHz, and 1707 MHz. A correlation of the lifetime oscillation with that of the cavity cooling temperature was found. Also the cavity cooling temperature control system was open loop, and poorly regulated system. A plan for massive upgrade of this system was initiated in 1997 and completed in the summer 1997. Even before optimization, great improvement of the photon beam quality and the wide range of control capability are apparent.

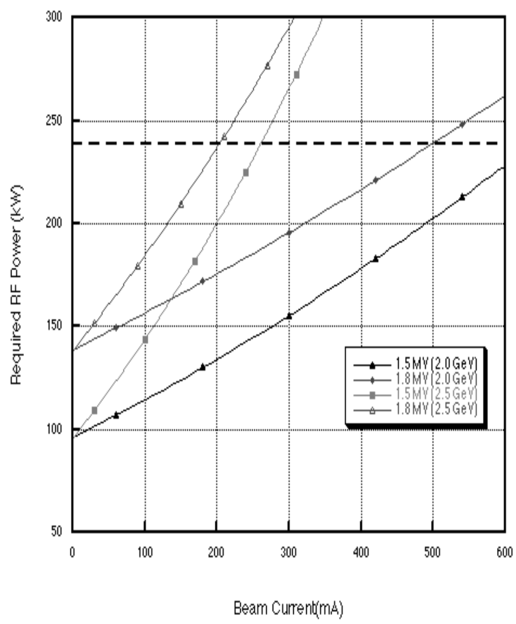


Figure 1. Operation window of the PLS in terms of the beam current and the required RF power for two cases of the accelerating voltage and the beam energy.

In 1998, the PLS goes into the fourth year of the user operation. One of the operational targets of this year is to provide 250 mA of current to users regularly. Main stumbling block is, obviously the instabilities. Optimizing the cavity temperature and adding the longitudinal feedback system will ease the pressure from beam instabilities. Some technical improvements of the low level RF system should also be followed for precise control of the phase and amplitude in that high current operation.

2 UPGRADE ACTIVITIES

2-1 Addition of the fourth station

It was decided to install the fourth RF station to the storage ring in 1996 for increasing the accelerating voltage and therefore the beam lifetime. For this station, an in-house assembled klystron amplifier was placed and a newly developed low level system was prepared. A sufficient baking and continuos beam conditioning lowered the vacuum pressure down to 0.2~0.3 nTorr quickly. By adding one more station the gap voltage increased to 1.6 MV which obviously affected the beam lifetime increasing over 40%. Because of minor problems and tuning, the first operation with all four RF stations was realized in early 1997. Table 2 lists the PLS RF system parameters with four stations.

Table 2. PLS RF System Parameters

Number of stations	4
Gap voltage(each cavity/total)	400/1,600 kV
Dissipated RF power(each/total)	20/80 kW
Synchrotron phase(Degrees)	81.9
RF acceptance(%)	2.18
Max. stored current(2.0/2.5 GeV)	480/220 mA
Over-voltage factor	7.11
Synchrotron tune(frequency)	11.01 kHz
Touschek lifetime(1mA/bunch)	18 hours

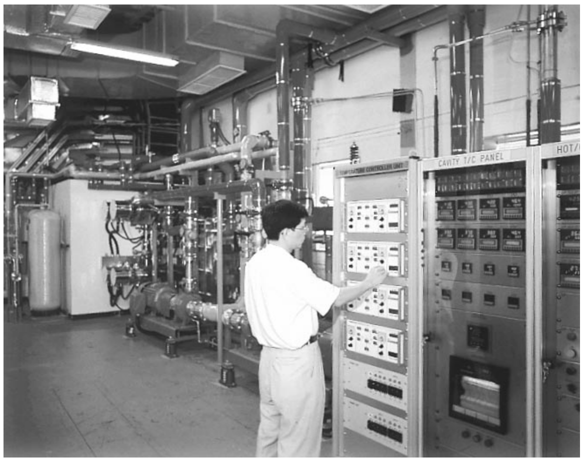
The new low level system[3] improved the isolation between modules, phase and amplitude feedback loop and the dynamic range. The phase variation with the phase feedback was less than 0.3 degrees and the amplitude variation of the input RF power into the cavity was measured to be less than 0.4%. After test and optimization of the design, the other three low level systems have been replaced. They will be fully operational after tuning and reducing noises from the direct beam signals.

The in-house assembled klystron amplifier used the Philips tube, while other subsidiary components were manufactured in domestic companies and it was finally assembled in the laboratory. The main purpose for this is for RF engineers and technicians to greatly improve the maintenance skill and the level of understanding of the power source which they have to deal with all the time, by using the spare parts and components efficiently with a minimum budget. It has been operated over 6,000 hours without major problems.

2.2 Cavity temperature control system

One of the major obstacles for prohibiting higher current and quiescent operation in PLS is the longitudinal multi-bunch instabilities. A series of studies showed that the HOMs of the cavities were the source. The Photon Factory in KEK where the same type of cavities were installed did use a fixed frequency shifter to avoid harmful HOMs for each cavity. However, it was considered not to be practical in PLS. Few strategies were, thereafter proposed to solve this problem. A damping antenna, a movable second tuner, the longitudinal feedback system and an upgrade of the cavity temperature control system were those. The longitudinal feedback system was chosen as a longterm but definite answer for this. An alternative way should be picked as a short-term but efficient plan.

Figure 2. Upgraded cavity temperature control system.



Upgrade of the cavity temperature control system[4] was strongly recommended since the original system was not a closed loop and the stability and the controllability were very poor. A clear correlation of the beam lifetime with the variation of the cavity inlet temperature were observed and it also was found that the beam quality was sensitive to the cavity cooling temperature. Another advantage for better temperature control system is to reduce the power load of the future longitudinal feedback system by lowering the HOM impedance to a considerable extent.

Upgraded temperature control system should be a closed loop system and should have larger control range(~30 degrees) and better stability within 0.2 degrees at each set value. For minimizing extra spending, the old equipments were reused as much as possible. To achieve the above requirements, the cooling line was designed to have two loops; the primary and the secondary loops. The primary loop has two circuits; cold water from the heat exchanger and hot water from the electric heaters. The temperature of cold circuit is maintained at about 27 ^{0}C and that of hot circuit is variable between 30 and 65 ^{0}C, depending on the operation temperature of the cavities after tuning. The secondary loop is connected with main utility system through the heat exchanger, and the low conductivity water (LCW) of about 25 ^{0}C should be circulated into heat exchanger to dissipate the RF power. The temperature control of the input water into the cavity is performed in two stages. The first rough control is obtained by three-way electric motor-driven control valve with a full range of linear characteristics, provided by the proportinal-integral-differential (PID) temperature controller. The fine control is carried out by regulating two-way valves installed downstream at each cold and hot circuits with computer controllers. A linear-coefficient type, quartz crystal with oscillator circuit is used as a temperature sensor. It showed excellent resolution and linearity. Figure 2 shows the upgraded cavity temperature control system.

Simultaneously the thermal shield for the cavity body and cooling channel were strengthened by ‘jackets’ and foam tubes. Cooling lines of the cavity were also rearranged better for reducing thermal stress and replaced for the stainless steel tubes.

After installing new system, maximum stored current with stable condition increased 200 mA and the designed emittance of 12 nmrad has been achieved. With optimization and tuning, it is anticipated to achieve higher current and quiescent operation soon.

2.3 Other activities

When an unexpected beam loss happens, sometimes it is very difficult to find what causes the loss. Most time the RF stations are tripped off at the beam loss. Monitoring beam signals and RF signals during this transient period could be very interesting to analyze and understand the unknown beam loss process. A fast sampling data logger was used for monitoring some signal traces during the beam loss transient utilizing pre-trigger option[5]. Figure 3 shows a case of beam loss due to the cavity arc.

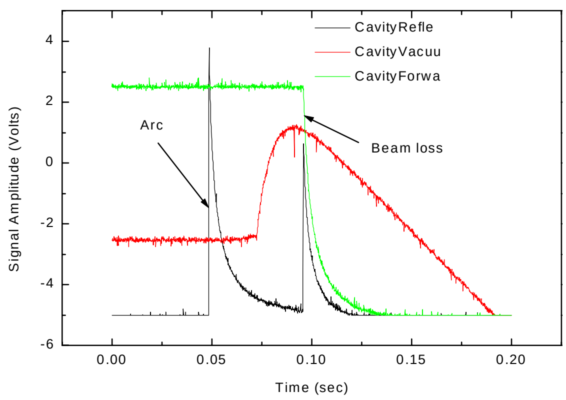


Figure 3. Cavity arc-induced beam loss recorded in the transient data logger.

Since the power transmission is carried through the coaxial line, the present cylindrical type cavity window adds unnecessary transition from coax to waveguide. A disk-type window and input coupler assembly was designed and fabricated recently in house and is ready for the high power test. In low power test[6] it shows a good characteristics on the HOM transmission, too. A specially designed HOM absorber will be designed and placed outside cavity.

Using a spare cavity and a newly assembled klystron amplifier, the high power test station is being prepared. New component tests, control electronics test and other high power test of the prototype components will be performed in this facility. Previously mentioned input coupler and a high power water load developed by a local company will be tested soon.

3 FUTURE PLAN

In 1998, there are two wish-lists to achieve in PLS operation. One is higher current operation over 250 mA for users, and the other is the 2.5-GeV operation by ramping. Both goals depend heavily on the performance of the RF system. With more subtle tuning of the cavity temperature control system and possibly with help from the longitudinal feedback system, the first goal will be approached. More stable and reliable control of the RF system is a key factor for both. Then the current record of 171 hours of uninterupted operation will also be further extended.

4 ACKNOWLEDGMENTS

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5 REFERENCES

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