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DESIGN OF LONGITUDINAL FEEDBACK SYSTEM KICKER FOR THE PLS STORAGE RING*

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Abstract

The higher order modes (HOMs) of RF cavities at the Pohang Light Source (PLS) storage ring cause longitudinal coupled bunch mode instabilities (CBMIs). To cure these instabilities, a longitudinal feedback system (LFS) is introduced. As a key component of the LFS, there is a single-ridged waveguide-overloaded cavity as a longitudinal bunch-by-bunch LFS kicker for the PLS storage ring. To damp any coupled bunch modes, the bandwidth of this kicker should be wider than 250 MHz. Also, the higher shunt impedance of the kicker is selected to use lower power amplifier. One aluminum kicker is fabricated and the bandwidth, HOMs, and shunt impedance of the kicker are measured with a network analyzer. This kicker has several different features from LFS kicker for DAΦNE. First of all, there are 4 input/output ports to obtain a wider bandwidth. Secondly, there is a nose cone to obtain higher shunt impedance. Finally, the symmetric frequency response of the shunt impedance around central frequency is provided. According to the simulation result done by HFSS code, high shunt impedance of 620 Ω (transit time factor considered value) and the wide bandwidth of 255 MHz are obtained. These are compared with the measured result.

1 INTRODUCTION

The PLS is the 3rd generation synchrotron light source. Originally, the PLS storage ring is designed to store the beam current up to 400 mA at 2 GeV and 250 mA at 2.5 GeV. By adding one RF cavity in 1996, there are four RF cavities with 60 kW CW klystron amplifier operating at the PLS storage ring to store the desired beam current [1]. But owing to HOMs of RF cavities that make the CBMIs such as dipole, quadrupole, sextupole modes, the current of PLS storage ring is possible up to 200 mA at 2.0 GeV without CBMI. By analyzing the reverse signal of RF cavities and the sidebands of the BPM spectrum, it is found that the most dangerous HOMs of RF cavities are longitudinal TM_{011} (758 MHz) and TM_{013} (1707 MHz) modes. To avoid these HOMs, the precession temperature control system for the RF cavities has been installed during 1997 Summer maintenance period. This system can regulate the cooling water to better than 0.2°C. With this system, the stored beam current without CBMIs has been increased from 120 mA to 200 mA. It means that the cooling system is not enough to avoid such dangerous HOMs fully. So, an active feedback system for CBMIs is necessary for the PLS. The typical LFS consists of a signal pickup, digital signal processing units, and a kicker. There are various types of LFS developed at several accelerator laboratories such as SLAC, LBL, Frascati, KEK, etc. In the PLS case, it is decided that the digital signal processing unit is purchased from SLAC and the kicker is fabricated by the PLS and domestic manufacturer. By considering these design, the PLS has decided to design the kicker following DAΦNE design [2] that is a single-ridged waveguide-overloaded cavity with HFSS and SUPERFISH codes.

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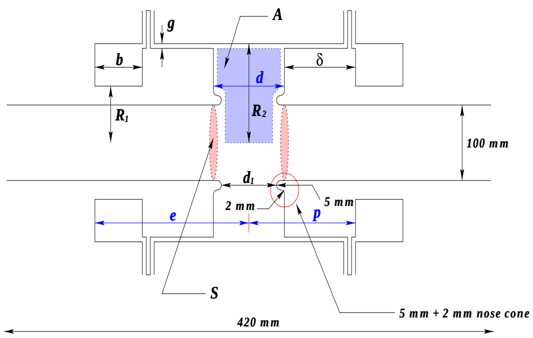
2 DESIGN OF LFS KICKER

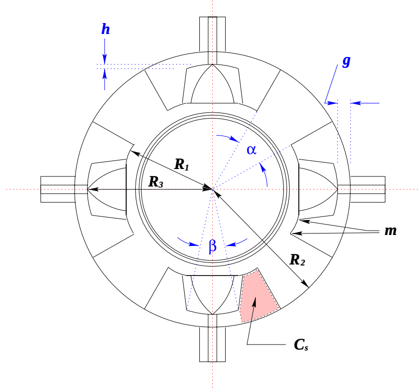
There are many things to be considered in order to design the LFS kicker for the PLS storage ring such as kicker length, working central frequency, bandwidth, shunt impedance, kicker filling time, contents of HOMs, kicker input power or kicker amplifier power. The LFS kicker will be installed at the straight section for RF cavities where there is a space of 42 cm reserved for future fifth cavity. Thus, the kicker length is determined to be 42 cm. According to CBMI theory, coupled bunch modes are characterized by a definite phase relation between the oscillations from one bunch to the next. Since all CBMIs are located within the frequency range of $p \cdot f_{RF} \sim (p+1/2) \cdot f_{RF}$ where p is any integer, the minimum bandwidth of kicker to cure all CBMIs is $f_{RF}/2$, and the central frequency of the kicker f_c is the average of the frequency range, $(p+1/4) \cdot f_{RF}$. Next is the selection of central frequency which is determined by choosing an integer p. By considering commercially available amplifiers and the operating frequency of PLS RF system of 500 MHz, the possible choice of p for the PLS LFS is either 2 or 3, which corresponds the central frequency of 1125 MHz or 1625 MHz, respectively, and $p = 2$ is selected. The selected RF amplifier is a solid state type model AS0820-250R from MILMEGA. Its operation frequency range is 800 MHz ∼ 2000 MHz and maximum output is 250 W. Even though the PLS LFS is designed to operate at $p = 2$ mode with bandwidth of 250 MHz and the central frequency of 1125 MHz, this amplifier will also be used at $p = 3$ mode in the future for more efficient kicking with lower RF power. Because the maximum power of amplifier is limited, the amplitude of the correction kick will be saturated easily in damping the phase oscillation with very high amplitude (i.e., very fast instability growth rate). One way to lower the required power of the amplifier in damping the CBMIs is to design the kicker with high shunt impedance. Since the RF frequency of the PLS storage ring is 500 MHz and the harmonic number is 468, the bunch spacing in fully filled case is 2 nsec. To perform the bunch-by-bunch kicking properly, the filling time of LFS kicker must be shorter than 2

Table 1: f_c vs. other parameters

Integer p	2	3
Central frequency f_c [MHz]	1125	1625
Loaded Q factor Q_L	4.5	6.5
Max. shunt impedance R_s [Ω]	450	650
Filling time τ [nsec]	1.27	1.27



(a) Side view



(b) Axial view

Figure 1: Side view and axial view of the PLS LFS kicker.

nsec. The relation between the central frequency and other parameters are summarized in Table 1.

3 TUNING OF KICKER DIMENSION

The DAΦNE type kicker can be simulated with Ansoft 3D high frequency structure simulator (HFSS). Unlike the original DAΦNE kicker, the PLS kicker is designed with a nose cone attached and 4 input/output ports. The profile of the PLS LFS kicker is shown in Fig. 1.

3.1 Tuning of Basic Pill-Box Cavity

It is well known that the electrical equivalence of a RF cavity is a series RLC circuit. Its resonance frequency f_r is given by $f_r = 1/2\pi\sqrt{LC}$. The central frequency f_c of RF cavity is equivalent to the resonance frequency f_r of the RLC circuit. By adjusting dimensions of the kicker geometry that are equivalent counterparts of inductance L and capacitance C, one can tune the central frequency of the kicker such as $f_c \sim 1/R_2$ where R_2 is the outer radius of pill-box cavity. From the fact that the shunt impedance R_s is proportional to R/Q, one must adjust the gap size (plate separation) d and the outer radius of the kicker to obtain maximum R/Q. Since the central frequency f_c is independent on the gap size d, f_c is not changed by adjusting the gap size with constant R_2. But the shunt impedance is inversely proportional to bandwidth, too high shunt impedance will lead to too narrow bandwidth. Therefore, one must reduce the R_s properly to have sufficient bandwidth. The cross section area of a waveguide covers about 11% of available surface of the pill-box side. If one attach the waveguide more, one can increase wall loss area, which means the increase (decrease) of total wall loss power (quality factor). To obtain a sufficient bandwidth (> 250 MHz), four waveguides are attached per pill-box side, so total waveguides are 8 (4 input/output ports). When the gap voltage or the shunt impedance of the kicker is considered, the transit time factor must be considered to correct the particle acceleration due to the time variation of the field while the particles traverse the kicker. In the case of constant frequency, the transit time factor T increases as the gap size d decreases and higher shunt impedance is possible by decreasing the gap size. When d is fixed, the transit time factor will decrease as the frequency f. Therefore, at high frequency region, the shunt impedance will be lower than that of low frequency region around the central frequency. This problem of anti-symmetry is cured by changing the structure of ports from flat to round bases with $h = 1$ mm, as shown in Fig. 1. After changing the geometry of port bases, anti-symmetry S_{21} parameters around the central frequency are obtained. The S_{21} values of $f > f_c$ region are higher than those of $f < f_c$ region. Because the transit time factor of $f > f_c$ region decreases as the frequency increases, one can obtain the frequency response symmetry in the shunt impedance. To reduce the power reflection at the transition between coaxial ports and waveguides, one must match the impedance at the transition. While there is a certain TE_{10} mode cutoff frequency at general rectangular waveguide, there is no cutoff frequency at the coaxial input port. Therefore, to match the impedance at the transition, one must lower the TE_{10} mode cutoff frequency. To do this, a single ridge is attached at the bottom of general waveguide because of the capacitive effect between the ridge and the outer cavity. The cutoff frequency of a single-ridged waveguide can be lowered further by decreasing the gap g as shown in Fig. 1.

3.2 Nose Cone Cavity

For the PLS storage ring with the beam stay-clear aperture of 100 mm, the value of R/Q is less than 50 Ω. Since the shunt impedance is directly proportional to the value

Table 2: PLS LFS kicker dimensions

Parameter	Dimension [mm or °]
Inner cavity radius R_1	67.5
Outer cavity radius R_2	101.5
Port base radius R_3	95.1
Cavity gap d	74.0
Gap between cones d_1	64.0
Barrier angle α	24.0
Port base angle β	16.9
Back cavity size b	35.8
Port base gap g	6.4
Ridge length δ	50.2
Ridge distance p	87.2
Back cavity distance e	123.0
Port round radius m	2.0
Port base round h	1.0

Table 3: HOMs of the kicker

Mode	f [MHz]	R/Q [Ω]	Q factor
TM_{010}	1130.5	49.0	21557.2
TM_{011}	2322.4	17.5	26524.4
TE_{211}	2503.0	17.3	40126.6
$TM_{111}(TE_{011})$	2749.4	5.6	44380.9
TM_{211}	3130.0	20.5	44898.5

of R/Q, it is important to increase the value of R/Q for higher shunt impedance, which depends on the geometry of pill-box. Therefore, it is possible to increase this value by change the geometry of the pill-box with help of SUPERFISH simulation. From the facts that the radius of beam chamber is fixed as 50 mm and that the central frequency of the kicker f_c depends on the radius of outer cavity R_2, only the gap size d can be adjustable to increase R/Q. Since the transit time factor T and R/Q are increased as the gap size d is decreased, the shunt impedance (the transit time factor considered) will be increased by attaching a nose cone between a gap of pill-box cavity. The final pill-box cavity with nose cone attached has 255 MHz of bandwidth and 1130.5 MHz of central frequency which is near 1125 MHz. The final dimensions of the PLS LFS kicker are summarized in Table 2.

3.3 *Global performance of the kicker*

Investigation into the dangerous HOMs of the nose cone attached cavity is performed with the SUPERFISH and the result is summarized in Table 3. Frequencies of all dangerous HOMs are higher than the cutoff frequency of beam pipe (∼ 2295 MHz). By considering the fact that the single-ridge of the waveguide widens the frequency separations between the HOMs, their frequencies are increased further beyond 2295 MHz. Therefore, they do not generate any undesirable CBMIs within the cutoff frequency of vacuum chamber. Thus, the kicker is free of dangerous HOMs. With 3D HFSS, the maximum value of gap voltage is 35.25 V for 1 W input power and its maximum shunt impedance is about 620 Ω (transit time factor considered). The central frequency of the shunt impedance is about 1131 MHz that is only 6 MHz higher than the desired value of 1125 MHz.

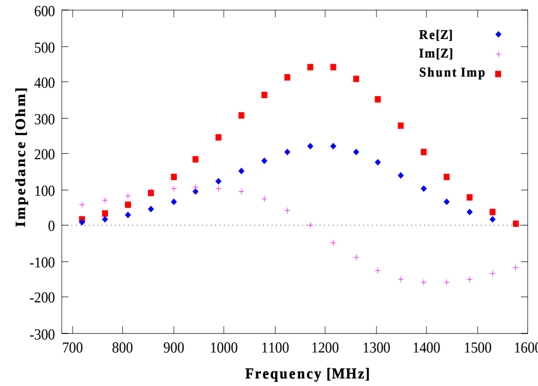


Figure 2: Measured R_s and its frequency response

4 CURRENT STATUS

With the LFS kicker design as described above, an aluminum kicker was fabricated by local manufacturer. After cleaning and assembly work was done, a series of performance test were followed with WILTRON 360B network analyzer. Measured central frequency and the bandwidth are 1115.6 MHz, and 344.4 MHz, respectively. The frequency response of the shunt impedance is shown in Fig. 2 with its maximum value of about 470 Ω. The R/Q of measured HOMs within the cutoff frequency is lower than 3.3. So, they will not generate any dangerous CBMIs to the beam. This kicker will be installed to the PLS storage ring in April 1999 [3].

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