DETERMINATION OF THE OPTIMAL OPERATING CONDITIONS OF THE ADDITIONAL RF CAVITY IN PLS WITH THE COMPUTER SIMULATIONS

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Abstract

Pohang Light Source has operated 2.5GeV storage ring with four RF cavities, of which the power is 60 kW each. As the number of insertion device increases storage ring needs more accelerating power to meet the requirements of beamline users. So PLS decided to extend the supplying capability of RF power as much as another 60 kW in the summer maintenance period in 2005. The new cavity will be twin sister as the existing ones. To find the optimal operation conditions of the new cavity, we simulated the thermo-structural interaction.

Keywords: HOM, beam instability, cavity

1 Introduction

Pohang Light Source (PLS) with beam energy of 2.5 GeV has provided stable photon beam to the users during 10 years. The primary parameters of PLS are shown Table 1. Although the principal components of PLS were designed optimally at 2.0 GeV, they had sufficient design margins for future upgrade to 2.5 GeV. The electron beam was stored at 2.0 GeV during 6 years after first commission, and then at 2.5GeV after improving LINAC and beam transfer line since 2000. The storage ring was operating with 3 RF cavities during the first 3 years, which was warm up period for our operating experience and preparing beamlines. In summer shutdown period of 1997 the forth cavity was installed to provide sufficient power for serial installation of insertion devices, simultaneously cooling water system of RF cavities was also reconstructed to control the temperature of cavities more fine. Now, PLS operates 24 beamlines from bending magnets and 5 insertion devices and 5 beamlines are under construction with 4 RF cavities of which power is 60 kW each. We plan to install another 5 insertion devices including a superconducting multipole wiggler for medical research for 5 years. According to calculation of RF power required to our-mid term plan the RF power with 4 cavities are estimated to be not enough. Table 2 shows required RF power with insertion devices. The improved beam quality by steadily efforts for it reduces beam lifetime. That also requires more RF power. With these considerations we decided to install another RF cavity with 60 kW in summer of 2005.

In this paper we report the simulation results about the thermal-structure of RF cavity surface to find the optimal operation conditions of the 5th cavity and cooling water system.

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Table 1 The machine parameters of the PLS storage ring

Beam energy	E (GeV)	2.0	2.5
Design current	I (mA)	400	150
Accelerating frequency	f_{RF} (MHz)	500.066	500.066
Revolution Frequency	f_0 (kHz)	1.068517	1.068517
Synchrotron oscillation frequency	f_s	11.4	10.05
Harmonic number	h	468	468
Momentum compaction factor	α	0.001809	0.001809
Horizontal tune	ν_x	14.28	14.28
Vertical tune	ν_y	8.18	8.18
Natural emittance	ε_n (nm rad)	12.1	18.9
Damping time (transverse)	ms	16.62	8.5
Damping time (longitudinal)	ms	8.34	4.2
Number of RF cavities		4	4
Gap voltage / cavity	kV	400	400
Shunt impedance od cavity	MΩ	8.5	8.5
Synchronous phase		171.3°	159.3°

Table 2 Required RF power with insertion devices (2.5GeV/250mA, 5cavity, 5klystron)

Year	Required RF Power [kW]	Available RF Power [kW]	Power Margin (%)	Klystron
2003	220	204	93	75kW(1), 60kW(3)
2004	228	240	105	75kW(4)
2005	234	240	103	75kW(4)
2006	242	240	99	75kW(4)
2007	268	300	112	75kW(5)
2008	284.5	300	105	75kW(5)
2009	317	300	95	75kW(5)

2 Characteristics of RF cavity and RF cooling system

RF cavities in PLS are a re-entrant single cell type with coaxial coupling as shown Fig. 1. The higher order modes are controlled by one tuning plunger. The two blank flanges are to avoid the conditions for all coupled-bunch instabilities. The cavities have a small diameter of beam pipe, 100 mm and a nose cone structure to increase the shunt impedance.

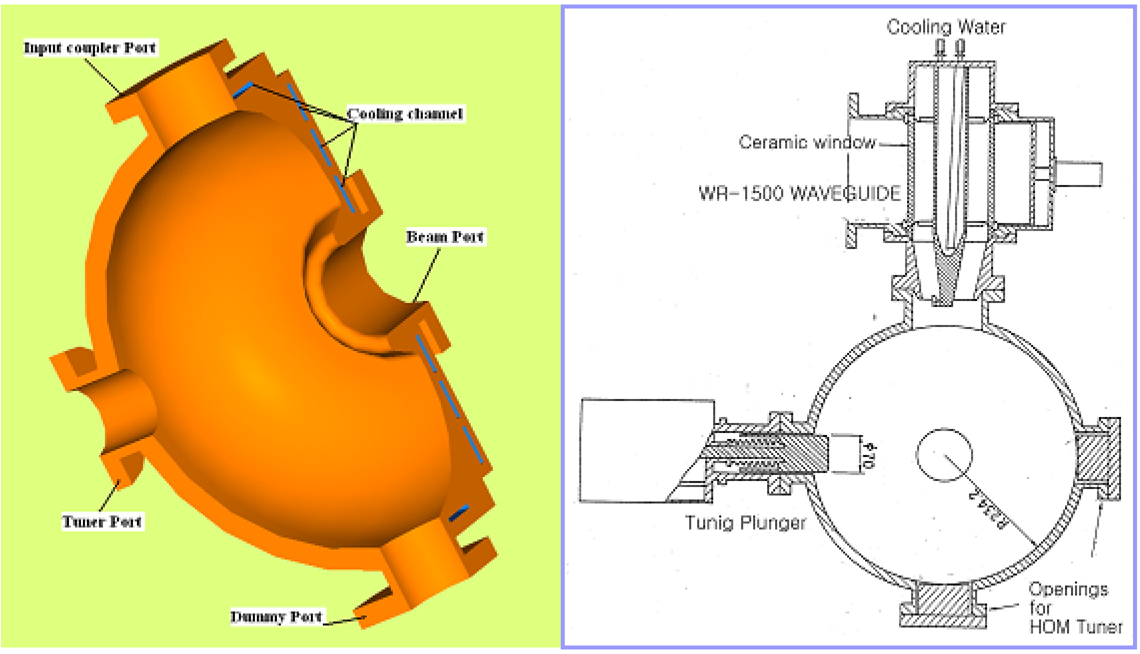


Fig. 1 shows a 3D modelling and a cross-sectional view of the RF cavity

The cooling water system should carry away about 20 kW of dissipated power each, so the temperatures of cavity surface are maintained steadily at particular points between 37-48 ^{o}C. The temperature of cooling water at upstream of the cavity is controlled in two stages. The first rough tuning of water temperature is obtained by adjusting flow rates of hat and cold water with three-way motor-driven valves, showed linear characteristics in full range of valve stroke, controlled with PID controller. The temperature resolution of 1st stage is within ±0.5°C. At the second step the fine adjustment of input water temperature, within ±0.1°C of resolution, is carried out by regulating two-way motor control valves installed at upstream of water entrance in cavity with cold and hot water adjusted at 1st stage.

3 HOM characteristics and its behavior to cooling water temperature

The some parts of RF power gotten by electron beam are lost in form of synchrotron radiation. During this process beam instabilities such as beam oscillation are generated, which is induced cavity higher-order mode (HOM). A multi-bunch-filling mode in storage ring also gives electron beam instability if a parasitic HOM is coupled to a multi-bunch oscillation mode. The coupled bunch instability is a big concern in storing the high current beam for the 3rd generation light source. The stored beam current is generally limited to a certain value because of the coupled bunch instabilities driven by HOMs of RF cavities. So the frequency turning of HOM in cavities is indispensable. Basically, HOMs should not be generated or be as low as possible in cavities. This can be practiced by cavity cooling system. The alternative measure is HOM removal by filter or to control HOM frequency by tuner.

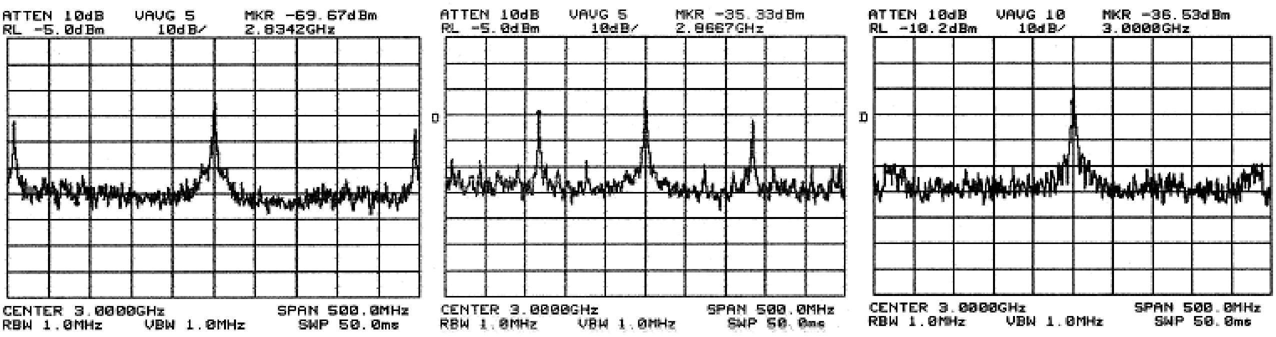
Table 3 summarizes the dangerous longitudinal and transverse HOMs of the PLS RF Cavity. The important cavity parameters are loaded-Q and R/Q. The excited amplitudes of HOMs in cavities depend on R/Q. The measured resonant frequencies of HOM are different for each cavity because of machining errors of the cavity bodies and dummy blocks.

Table 3 Resonant frequencies and loaded Q-values of longitudinal and transverse HOMs

(Q_0, R and $R_\perp$ are calculated by the MAFIA code)

Frequency(MHz)	Mode	Q_L	Q_0	R or $R_\perp$	R/Q	Instability
500.1	TM010	12000	41765	9.37	224.0	
758.6	TM011	21000	34741	2.89	83.2	Longitudinal
1052.7	TM012		36171	0.011	0.3	Longitudinal
1301.1	TM020		90964	1.04	11.4	Longitudinal
1326.6	TM021		35830	0.355	9.9	Longitudinal
1658.2	TM022		37626	0.29	7.7	Longitudinal
1707.0	TM013	45000	79991	0.738	9.2	Longitudinal
1870.1	TM030		108636	0.002	0.018	Longitudinal
1967.8	TM023		38592	0.085	2.2	Longitudinal
2125.9	TM015		73210	0.389	5.3	Longitudinal
826.4	TM110V	1700				Vertical
833.5	TM110H	40000		12		Horizontal
1071.4	TM111H	14000		27		Horizontal
1073.0	TM111V	13000				Vertical

The measurement with beam position monitors gave that the very severe beam instabilities were generated at frequencies, 758.6, 1301.1, 1326.6, 1707. These HOMs are all longitudinal. Fig.2 shows the HOM behaviors of cavity # 2 of PLS with change of temperature. In Fig. 2(a) the mode at 758 MHz at 43.92 °C is shown, this is the most severe mode for beam stability. At 47.25 °C of water temperature the mode from 758 MHz disappeared and other mode at 2866.7 MHz, which its effect to beam stability is negligible, appeared as shown in Fig. 2(b). Fig.s 3(a) and (b) is for 2.0 GeV. When the SR was operated at 2.5 GeV at with same condition with (b), all modes included mode at 2866.7 MHz disappeared as shown in Fig. 2(c).



(a) (b) (c)

Fig. 2 HOM mode in the cavity #2

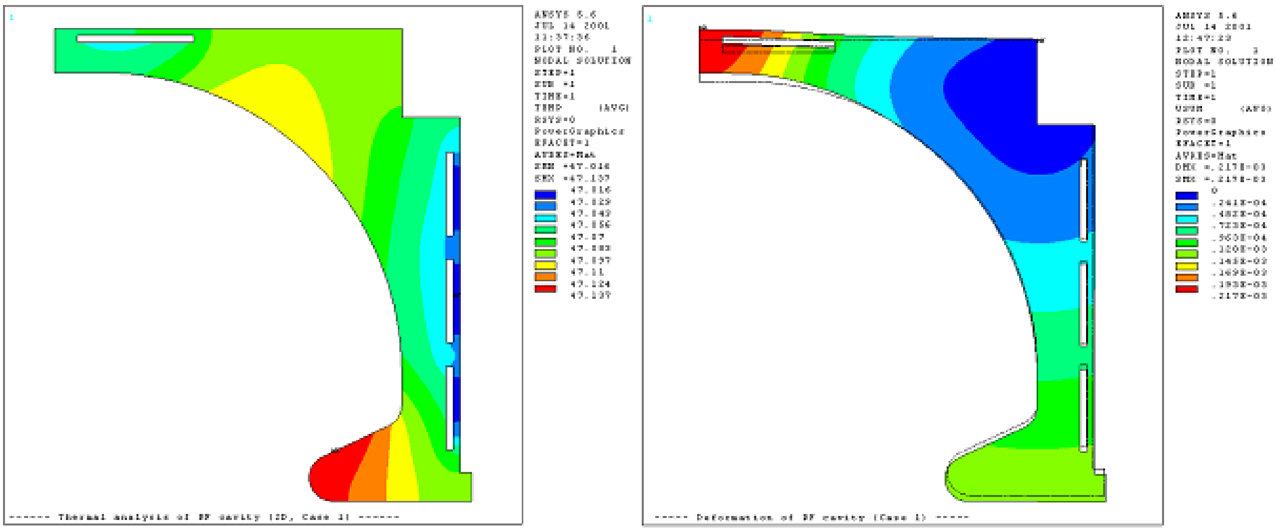
(a) 2.0GeV/758MHz at 43.92℃ (b) 2.0GeV/2866.7MHz at 47.25℃ (c) 2.5GeV/170mA

As shown in Fig2, the higher order modes which of induce beam instability can be controlled by adjusting temperature of cooling water and by change of beam energy. So the control-ability of cavity cooling system is one of excellent tool to maintain stable beam.

4 Thermal analysis of RF cavity

The thermal dissipation in a cavity is about 20 kW of full power, 60 kW with 400 kV of gap voltage. The heat dissipated in cavity body is transported to environment by cooling water. The surface temperatures of cavities increase slightly depending on each cavity due to its own condition. In a cavity temperature is distributed unevenly over the surface due to the uneven distributions of cooling pipes. They induce structural deformation, resulted in generation of HOMs. To analysis thermally-induced HOMs in quality and quantity the thermal behavior of cavity surface was simulated with FEM code, ANSYS. The distribution of heat dissipated was calculated with MAFIA. Only a quarter of cavity was modelled in simulation due to the symmetricity with respect to two axes .

The temperature distribution and deformation in cavity are shown in Fig. 3(a) and 3(b). The temperature difference is about 0.25 ^{o}C, maximum is on the nose cone as seen in Fig. 3(a). While maximum deflection was occurred at cavity equator as about 215 μm. The cavity is deformed primary in vertical direction, that is due to the clamping condition of cavity to confirm cavity length, which is major factor to resonant frequency, and horizontal position. Near nose cone the deflection is about 145 μm in vertically but horizontal deflection is negligible small as shown in Fig. 3(b). From simulation the deformation shape is thought to be ok, but the level of HOMs must be estimated by using a computer code like MAFIA.



(a) (b)

Fig. 3 Thermal Analysis of RF cavity: (a) Temperature distribution in a RF cavity during beam operations, (b) Deformation of RF cavity due to the heat dissipation

The maximum temperature, 0.25 ^{o}C seems to be underestimated compared to measured value, about 1.0 ^{o}C, so same situation in deformation. That is thought that the efficiency of heat transfer coefficient at cooling channel wall was not counted and that constant heat transfer coefficient was assumed over the channel wall in simulation.

The deformed shape of cavity in Fig. 3(b) is exaggerated in scale for showing, anyway that kind of deformation and volume change induce higher order modes. With 2 dimensional model like Fig. 3 major qualitatic characteristics can be shown, however it is difficult to interpret them in quantity. Therefore to get more exact condition for cavity operation, 3 dimensional analysis must be practiced in coupled way between thermal structure and high frequency electromagnetics. That will be done as our next step of project. In 3D simulation, measured data such water temperatures, and power dissipation for input information will be used, and heat, structure, and high frequency electromagnetics will be calculated coupled each other with "Multi-physics of ANSYS 7.0". With these simulation the optimal operation conditions about new cavity, #5 will be determined.

5 Conclusion

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6 References

[1] H.S. Kang, "Exact determination of HOM frequency in storage ring RF cavity" Nuclear Instruments and Methods on Physics Research A 483 (2002) 629-640

[2] I.S. Park, "Design of cooling water system for PLS storage ring RF cavity" Asian Particle Accelerator Conference 1998,