UPGRADE ISSUES OF THE TLS STORAGE RING RF SYSTEM

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Abstract

To achieve the goals in the TLS storage ring performance upgrade plan, the necessity of adding the third rf station to the storage ring for radiation loss compensation at 1.5 GeV/350 mA operation and lifetime improvement are analyzed. We estimated the rf power required to compensate the radiation losses by bending magnets and various insertion devices. Effects of the proposed passive Landau cavity on power consumption is also studied.

1 INTRODUCTION

TLS has been operating smoothly for years. Efforts have been made by SRRC staff to ramp the beam energy up to 1.5 GeV with improved beam stability at 240 mA. The W20 wiggler has also been operating routinely during during user shifts. In the near future, undulators such as U5, U9 and EPU will be installed and serve for the users. Superconducting wiggler has been proposed to push the spectrum up to X-ray regime. In order to achieve the goal of operating the storage ring at 1.5 GeV/350 mA, the necessity of adding the third 60 kW, 500 MHz rf station to the storage ring for radiation loss compensation as well as Toushcek lifetime elongation has been thoroughly discussed and studied in the light source division. In this report, we summarize the findings of our studied and hopefully would help decision making on whether the third rf station should be built in the following years.

Assuming the superconducting wiggler will be installed, the rf power required to compensate the radiation losses of electron beam due to bending magnets and various insertion devices are estimated. To ensure the stability of rf system operation under beam loading, the stored beam current cannot exceed certain limit for a given acceleration voltage. The maximum stored beam currents at different gap voltages for an rf system with two and three cavities are also estimated. The increase of lifetime by increasing rf gap voltage was experimentally tested in the multibunch mode up to 950 kV. From this simple experiment, we can have a picture of how lifetime improves by pursuing higher gap voltages. On the other hand, the passive Landau cavity project has been proposed also to improve beam Touschek lifetime. Extra power consumed by the Landau cavity should also be taken into account.

Addition of the third cavity will complicate the impedance (especially the narrow band impedance) of the storage ring. Coupled-bunch instabilities excited in the stored beam may spoil the emittance. The degradation effects due to coupled-bunch instabilities are difficult to predict and are not considered here due to the fact that consistent ongoing plans have already existed to cure these instabilities. These plans include rf cavities operated with two tuners [1], transverse and longitudinal dampers [2] and addition a third harmonics passive Landau cavity in the storage ring [3]. A Landau cavity will simultaneously increase beam lifetime if the mcahine is Tousheck effect dominated.

2 POWER CONSUMPTION AND BEAM CURRENT LIMITATION

The energy loss of the electron beam due to synchrotron radiation is compensated by the electromagnetic wave energy supplied by the rf system. It is essential to have enough power from the rf system to compensate this loss. Since the energy loss of an electron for each turn due to radiation from dipole magnets is proportional to the fourth power of electron energy, it has a 80 % increase of energy loss as electron energy increases from 1.3 to 1.5 GeV. On the other hand, we are targeting a stored beam current of more than 350 mA at 1.5 GeV in the future operation. Hence, the expected radiation power loss by the electron beam is at least 3 times more than the original value at 1.3 GeV. However, for a more precise estimation, one should consider also the radiation losses by insertion devices, the cavity parasitic mode dissipation and the transmission circuit loss.The results of these estimations are organized in Table 1.

In Table 1, the operation mode #1 indicated that the rf power required per station is 38 kW. This value is in good agreement with our operation experiences in spite of the fact that some of the insertion devices do not exist at this time. The required rf power per station in operation mode #2 is only 9% smaller. From power consumption point of view, very little benefit is gained from adding the third rf station and operating the ring at 1.3 GeV/200 mA. However, in the 1.5 GeV/350 mA operation modes, rf power required per station will be reduced by 17% for the three stations case (mode #4) in comparison with to the two stations case (mode #3). One may notice also that the power delivered to the cavity by each station in mode # 3 is very close to the station power limit that is 60 kW. Although we may still have a chance to achieve 350 mA, each rf station has to be operated at its full power. In mode #3, the rf power lost to beam is close to the rf power dissipated on the cavities. According to the beam loading theory, the beam will be unstable longitudinally or even lost. Hence, mode #3 represents a marginal operation condition. The machine will become touchy as the current approaches this limiting current which is 350 mA. Although operation at 1.5 GeV with beam current close to or beyond 350 mA is still possible by means of cavity detuning for Robinson damping or direct rf feedback, however, the available rf power from the rf system becomes another limiting factor. For operation beyond 350 mA at 1.5 GeV, the third rf station is absolutely necessary. Even in the three rf stations case (mode #4), the operational beam current is only ~20 % lower than the theoretical limit. This implies beam loading of rf system is still heavy. Further increase of gap voltage, detuning cavities for Robinson damping or rf feedback should be employed to stabilize the beam. And extra rf power is essential to implement any one of these schemes.

Operation Modes	#1	#2	#3	#4
Beam Energy (GeV)	1.3		1.5	
Beam Current (mA)	200		350	
Total Gap Voltage (kV)	800	1200	800	1200
Number of Cavities	2	3	2	3
Radiation Loss per Electron per Turn (keV):				
dipoles	72.28		128.12	
W20(1.8T)	73.15		129.18	
U5	74.39		130.51	
U9(1.25T, 4.5m)	75.09		131.11	
EPU(0.67T, 4.0m)	76.93		132.57	
SW(6.0T, 0.2m)	77.70		133.25	
Total	100.54		165.74	
Power Dissipation per Station (kW):				
Fundamental Mode	26.7		26.7	
Parasitic Modes	27.053		0.162	
Citcuit Loss (minimum)	28.5		1.5	
Total	28.25		28.36	
Total RF Power Required (kW)	76.62	104.8	114.7	143.1
RF Power Required per Station (kW)	38.31	34.96	57.37	47.70

Table 1. Estimations of Power Required from the RF System Under Various Operation Modes

It is important to note that rf power will be consumed by the passive Landau cavity to build up the necessary gap voltage at the third rf frequency harmonics. The effect will be discussed separately in section 4.

3 POSSIBILITY OF TOUSCHEK LIFETIME ELONGATION BY INCREASING GAP VOLTAGE

In order to find out whether one could expect an increase in beam lifetime by using a third rf system to increase the gap voltage V_g [9]. Assuming that the total beam lifetime is dominated by the Touschek effect [10] which is given by

$$\tau_T^{-1} = (r_e^2 cN/8\pi\gamma^5\sigma^3_{x'}\sigma_l\sigma_x\sigma_z) \{F(\delta)/\delta\} \quad (3)$$

where $\sigma_{x'}$ is the rms of the beam divergence, δ is defined as

$$\delta = \{(\Delta p/p)/\gamma\, \sigma_{x'}\}^2 \quad (4)$$

where $\Delta p/p$ is the momentum acceptance of the machine. The function $F(\delta)$ is given by

$$F(\delta) \approx -\ln (\gamma_e\delta) - 3/2 \quad (5)$$

for δ < or $\approx 10^{-2}$ and $\gamma_e \approx 1.78$ is the Euler's constant.

From the above equations, we can calculate Touschek lifetime at different gap voltages (Figure 1). Figure 1 shows a linear dependence between Touschek lifetime and total gap voltage. One might expect an increase of beam lifetime as gap voltage increases.

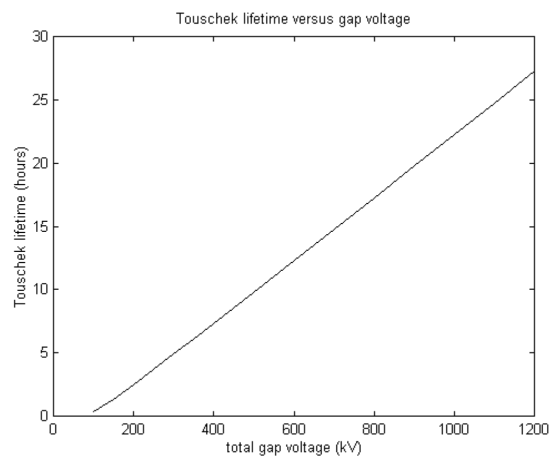

Figure 1. Calculated Touschek Lifetime vs. Gap Voltage

To check this expectation, a measurement of the lifetime was done under machine conditions typical for user operation, with wiggler gap opened, making sure that the average ring vacuum and the beam current did not vary by more than 10 %. As shown in Figure 2, the lifetime increases with gap voltage up to voltages of about 800 kV and then saturates. This means that at higher cavity voltages the lifetime is dominated by other effects than energy acceptance limited Touschek scattering. At low gap voltage, the lifetime drops dramatically because the stored beam current exceeded the beam loading current limits. These measurements were repeated, with wiggler gap closed and transverse feedback turned on, at 1.5 GeV/190 mA. The result shows the same trend.

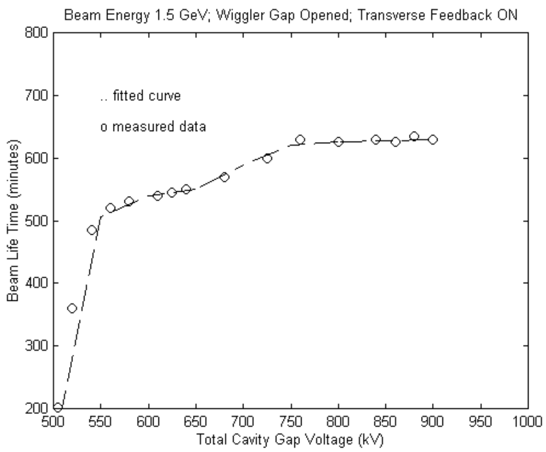

Figure 2. Lifetime vs. Gap Voltage (Wiggler Gap Opened)

4 EFFECTS OF THE PASSIVE LANDAU CAVITY

Theoretically, passive Landau cavity has no effect on bunch length at low beam current since the induced voltage across the cavity gap approaches to zero and therefore no power will be dissipated on the cavity. The gap voltage induced by the beam across the Landau cavity will depends on the tuning angle at higher beam current. The effects of the passive Landau cavity on bunch length and Touschek lifetime will therefore depend on the cavity tuning angle.

Beam Energy (GeV)	1.5	
Total Gap Voltage (kV)	800	1200
Number of Cavities	2	3
Available RF Power per Station (kW)	60	60
Total Available RF Power (kW)	120	180
Total Radiation Loss per Electron for Each Turn (keV)	165.74	
Maximum Power Loss on Passive Landau Cavity (kW)	20	
Power Dissipation per Station (kW): Fundamental Modes Circuit Loss Total	 26.7 1.5 28.2	
Maximum Beam Current (mA)	260	450

Table 2. Maximum Beam Current of TLS Storage Ring with Power Loss on Landau Cavity Included.

In analysis of power consumption, we assume the Landau cavity has a rated power of 20 kW. This loss has to be compensated by the 500 MHz rf system. Adding this power consumption to operation mode #3 of Table 1, there will be an extra power required for each station by 17.4% (i.e., 67.37 kW). This value already exceeded the norminal available power for each rf station. For operation mode #4, we need 14 % more rf power with Landau cavity than the case without. Since we have three cavities, the required rf power per station is about 51 kW that is within our capability. In Table 2, we set the available power for each station at 60 kW to deduce the maximum stored currents in the cases with two cavities and three cavities (assume the gap voltages for each cavity are set at 400 kV) at 1.5 GeV. Since the HOM parasitic loss per cavity depends on beam current and is small in comparison with other kinds of power losses, we ignored here for simplicity. The last row of the Table shows the maximum stored beam current in the two cavities case is only 260 mA. In the three cavities case is 450 mA.

5 SUMMARY

According to the above analysis, we summarize our findings for 1.5 GeV operation as follows. Based on theoretical calculations, one might expect a linear increase of Touschek lifetime at higher gap voltages. From the experiments we described in section 3 and assuming that the essence of these observations can be confirmed by further experiments, however, it is likely that a third 500 MHz rf system will not help to improve the beam lifetime for the machine status. The mechanism(s) that limits beam lifetime at higher gap voltage is still unclear and further study is needed. Without Landau cavity, the maximum beam current the storage ring can stored for an rf system with two rf stations is limited to 350 mA at 800 kV. By increasing the total gap voltage with three rf stations to 1200 kV, the storage ring has a beam current limit of about 480 mA. In operation with the passive Landau cavity, two rf stations have a current limit of 260 mA at 800 kV. The three station case has a current limit of 450 mA at 1200 kV gap voltage.

REFERENCES

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