COLLECTIVE EFFECTS IN THE TLS STORAGE RING AFTER THE INSTALLATION OF SUPERCONDUCTING RF CAVITY

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Abstract

A superconducting (SC) rf cavity designed by Cornell University [1] was installed in the storage ring at Taiwan Light Source (TLS) in December of 2004. The purpose of rf system upgrade is to increase the stored beam current without collective instabilities caused by higher-order-modes (HOM) of rf cavity. Beam measurements related to collective effects are performed. Results are compared with those measured prior to the rf system upgrade. Theoretical studies on collective effects after the rf upgrade are also presented.

INTRODUCTION

The original design of TLS storage ring employed two Doris cavities for particle acceleration. The nominal beam current is 200 mA. The TLS storage ring suffered from the longitudinal coupled bunch instability caused by the HOMs of Doris cavities for some time [2]. Eventually the problem was alleviated by applying the technique of rf voltage modulation at an expense of stringent control of accelerator parameters [3]. In order to increase the stored beam current without collective instabilities caused by HOMs of rf cavity, the SC rf cavity developed by Cornell University was chosen for the upgrade. One SC rf cavity of CESR type was installed and successfully commissioned before the Christmas of 2004. A major upgrade of vacuum chambers took place subsequently. The injection section of storage ring was completely replaced by new vacuum chambers. There were transverse instabilities in the early stage of user operation after replacement of vacuum chambers. The major cause of the transverse instability is believed to be beam-ion effects. The transverse instability was suppressed when the transverse fast feedback was finally employed in user operation. There is no sign of collective instability observed at 200 mA in present operation. At present the stored beam current is limited by the available rf power of klystron. The upgrade of klystron system is under way.

OBSERVATION AND ANALYSIS

The basic parameters of the SC rf cavity are: operating frequency= 499.654 MHz, total gap voltage= 1.6 MV, and the loaded Q-factor Q_{load}= 2.5µ10^5. The harmonic number of the storage ring is 200. The horizontal and vertical tune is 7.304 and 4.160 respectively.

Longitudinal Collective Effects

The spectra of the BPM sum signal were measured before and after the installation of SC rf cavity. Figure 1 shows the difference of longitudinal beam spectra between the operation with Doris cavities and the one with SC rf cavity. The longitudinal HOMs of the SC rf cavity is well damped compared with Doris cavities as shown in Fig. 1. Measurements of the first upper synchrotron sideband across one rf frequency band shows that there are longitudinal modes around 657 MHz and 762 MHz respectively. Fig. 2 shows the dependence of the amplitude of synchrotron sideband on the total beam current for longitudinal modes at 657 MHz and 762 MHz. Results of measurements by a streak camera reveal a longitudinal beam oscillation with steady amplitude. Figure 3 shows the measured longitudinal bunch motion over a period of 100 ms.

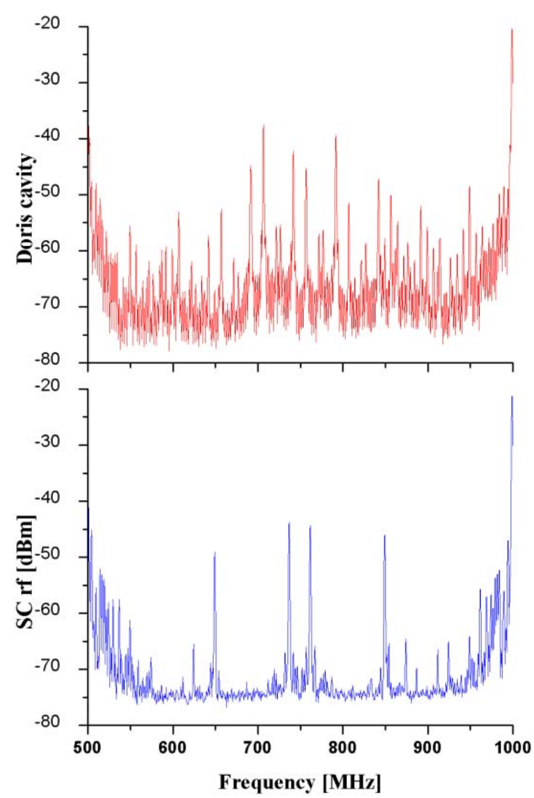

Figure 1: The spectra of BPM sum signal measured before and after the installation of SC rf cavity. The red line depicts the longitudinal beam spectrum measured when Doris cavities were used for particle acceleration. The blue line depicts the spectrum after the SC rf cavity was installed to replace the Doris cavities. The storage ring was uniformly filled and the total beam current was 200 mA.

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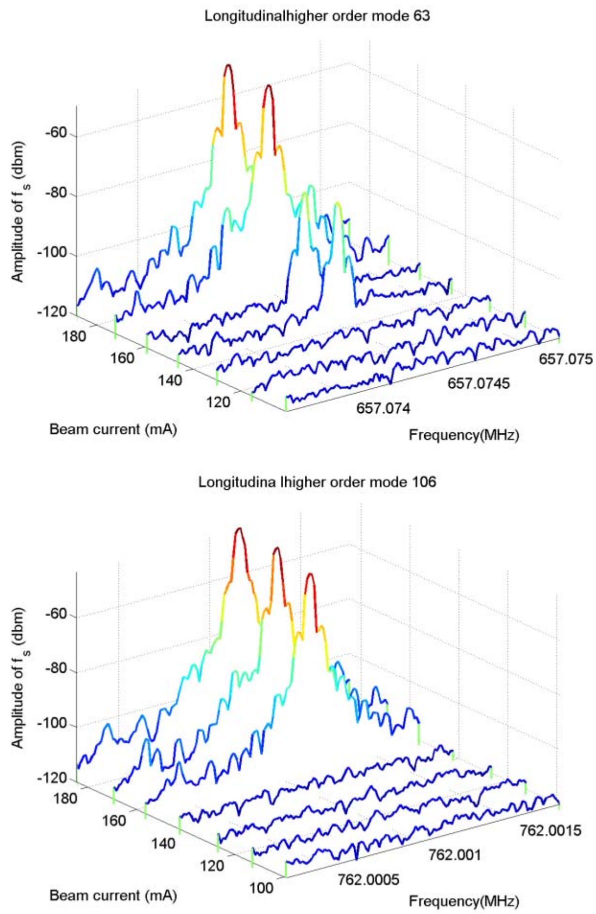

Figure 2: The dependence of the amplitude of synchrotron sideband on the total beam current. The top graph is the measurement for the longitudinal mode at 657 MHz, and the bottom is for the mode at 762 MHz. The threshold current is 130 mA for the longitudinal mode at 657 MHz and 140 mA for the mode at 762 MHz respectively.

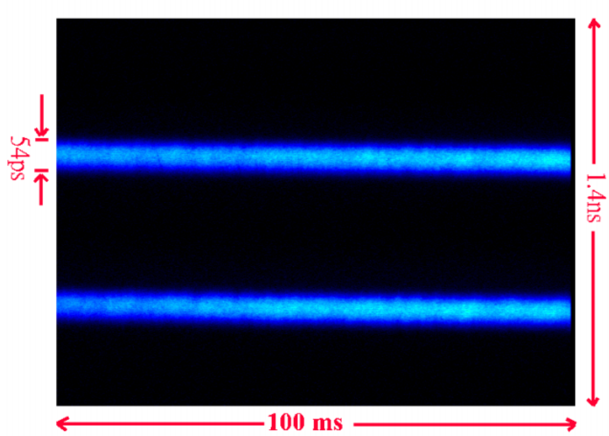

Figure 3: The longitudinal bunch motion measured by a streak camera. The total beam current is 200 mA and the fill pattern is uniform. The measured rms bunch length is 22 ps. The revolution period of TLS storage ring is 400 ns.

The growth time of longitudinal coupled instability has been estimated for each HOM of SC rf cavity[4]. The results suggest that there should be no longitudinal instability due to the HOMs of SC rf cavity at 400 mA. We could not find any HOM of SC rf cavity corresponding to the longitudinal mode we have observed at 200 mA. There are some cavity-like vacuum components in the storage ring. The rf simulations of those cavity-like vacuum components are under way. Preliminary results of rf simulations for those cavity-like structures suggest that they might pose a problem for beam stability at 400 mA.

Transverse Collective Effects

There were transverse instabilities in the early stage of user operation after the replacement of vacuum chambers of the whole injection section. It is believed that the major cause is the beam-ion effects based on various measurements. The transverse motion is stabilized after the transverse fast feedback is applied. A typical spectrum of transverse BPM signal measured in user operation is shown in Fig. 4.

The transverse coupled bunch instability due to the resistive wall is estimated for the case of zero chromaticity and a total beam current of 400 mA. The contribution of all insertion devices is included in the model of resistive wall impedance. The growth rate of the most prominent vertical mode is 330 s^{-1} for mode 195 in the baseband. The nominal radiation damping rate is 107 s^{-1} in the vertical direction. A transverse feedback system is imperative for a stable operation of storage ring at 400 mA.

The vertical impedance of SC rf cavity simulated by using the rf code GdfidL is shown in Fig. 5. The growth rate estimated for each vertical HOM of SC rf cavity indicates that there should be no transverse instability caused by the SC rf cavity at 400 mA. Numerical simulations with refined models to improve the accuracy of transverse HOMs of SC rf cavity is in progress.

CONCLUSION

The performance of TLS storage ring after the SC rf upgrade has been satisfactory. In present operation the accelerator is mainly affected by the vertical instability that can be effectively suppressed by a bunch-by-bunch feedback system at 200 mA. The SC rf cavity is not expected to cause collective instabilities at 400 mA according to theoretical estimate. The longitudinal spectrum we observed at 200 mA is probably caused by other cavity-like vacuum components. The impedance of those cavity-like vacuum components might not be negligible at 400 mA. Proper measures are needed to mitigate effects caused by those cavity-like vacuum components at 400 mA. At present the maximum stored beam current is limited by the available rf power of klystron.

The resistive wall impedance is expected to cause transverse instabilities at 400 mA according to theoretical analysis. A transverse feedback system is required for intensity upgrade to 400 mA.

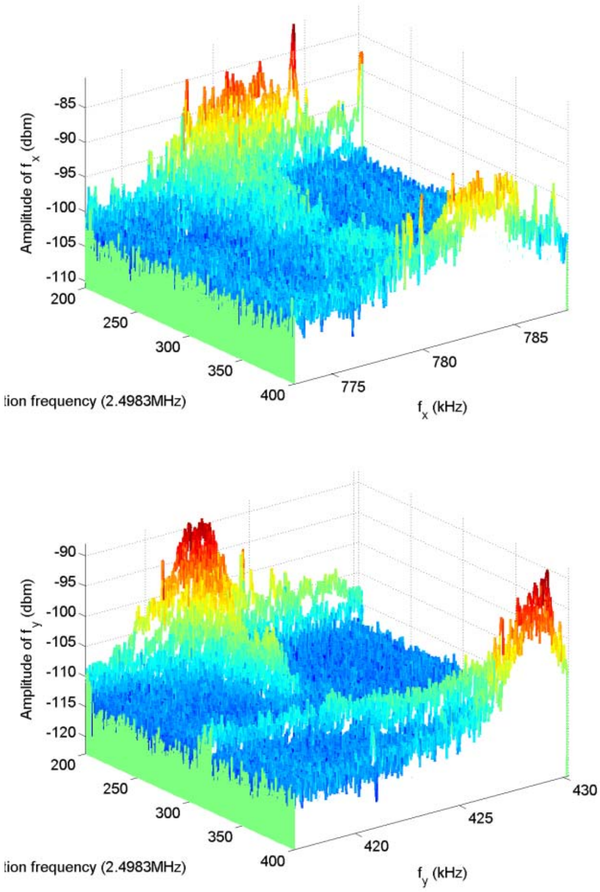

Figure 4: The spectrum of transverse BPM signal measured in user operation. The beam current was 180 mA and the transverse feedback was turned on. The top graph is the spectrum of horizontal BPM and the bottom is the one of vertical BPM.

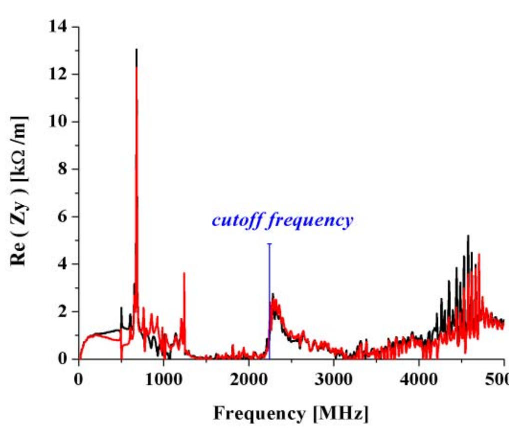

Figure 5: The vertical impedance of SC rf cavity simulated by the rf code GdfidL. The vertical beam offset is 15 mm for the black line and –15 mm for the red line respectively. The cutoff frequency of transverse waveguide mode in the beam pipe is 2.237 GHz.

ACKNOWLEDGEMENTS

The authors would like to thank the accelerator operation group for many helps in beam experiments. The authors would also like to thank S.Y. Lee and A.W. Chao for helpful discussions.

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