A PRELIMINARY STUDY OF BEAM INSTABILITIES IN TOP-UP OPERATION AT TAIWAN LIGHT SOURCE

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Abstract

The storage ring of Taiwan Light Source (TLS) started to operate fully in top-up mode since October 2005. The beam current has been gradually increased to 300 mA in routine user operation. Phenomena of collective effects were observed at 300 mA in top-up operation mode. Active feedback systems were implemented to stabilize the beam in top-up mode. Results of beam observation and analysis will be presented.

INTRODUCTION

The TLS storage began to operate with a superconducting (SC) rf cavity in December 2004. The top-up operation was started in October 2005[1] at TLS with a beam current 200 mA. The beam current of top-up operation was gradually increased to 300 mA when both the longitudinal and transverse digital feedback systems were commissioned successfully in March 2006. After the operation of SC rf cavity, many harmful cavity higher-order-modes (HOMs) were removed. Nonetheless, there are still two dominant longitudinal coupled bunch modes observed in the TLS storage ring which are believed to be caused by cavity-like vacuum components. The transverse coupled bunch instability due to resistive wall impedance is manifested after the longitudinal coupled bunch instability being less severe. Both longitudinal and transverse bunch-by-bunch feedback systems are employed to suppress those collective instabilities. There is sign of multi-turn ion instability which is also well suppressed by the transverse feedback system and proper choice of fill pattern. The relative deviation of photon beam intensity within 0.1 % is achieved over 90% of scheduled user beam time.

OBSERVATION OF COLLECTIVE INSTABILITIES

The top-up operation at TLS is running with an injection interval of 60 seconds due to low lifetime (250 minutes). The variation of stored beam current is confined within $\pm 0.25\%$. The rf frequency f_{RF} is 499.654 MHz. The horizontal and vertical tune is 7.304 and 4.160 respectively.

Longitudinal Coupled Bunch Instability

There are two dominant coupled bunch modes observed in TLS storage ring [2], i.e. mode number μ=63 and μ=106. The threshold current for mode number 63 is around 140 mA and around 160 mA for mode number 106 respectively. The measured spectra of sum signal at different beam current without the longitudinal feedback are shown in Fig. 1. The typical fill pattern used in top-up operation has a gap around 45 rf buckets. The harmonic number of the storage ring is 200.

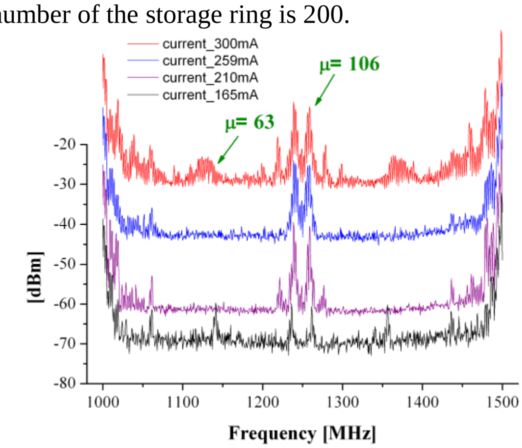

Figure 1: Spectra of sum signal measured at different beam current when the longitudinal feedback is turned off. The frequency span is from 2*f_{RF} to 3*f_{RF} .

When the longitudinal feedback is turned on, the beam is stabilized longitudinally. The time-domain snapshot measured by a streak camera is shown in Fig. 2. Figure 3 depicts the spectrum of sum signal measured at 300 mA with longitudinal feedback on.

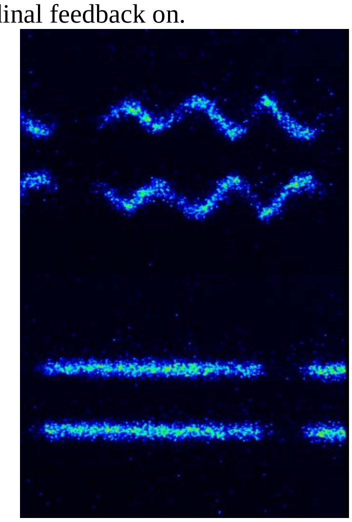

Figure 2: Snapshot of the one turn streak camera image. The top picture is the longitudinal feedback off, and the

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bottom one is the longitudinal feedback on. Vertical time span is 1.4 ns, horizontal time span is 500 ns in this dual scan configuration.

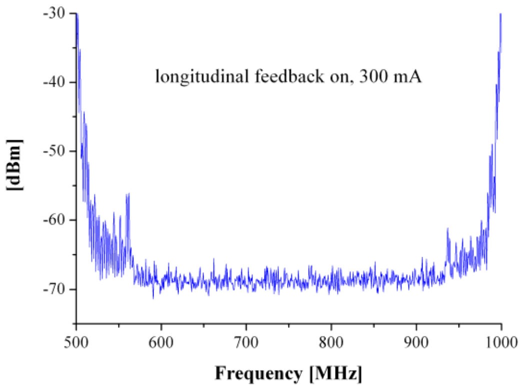

Figure 3: The spectrum of sum signal measured at 300 mA when the longitudinal feedback is on. The frequency span is from f_{RF} to $2*f_{RF}$.

The HOMs of SC rf cavity has been thoroughly analyzed by 3D numerical simulations [3]. The growth rate of the worst residual HOM at 400 mA is calculated and is found to be smaller than the radiation damping rate in the storage ring [3]. There is no high-Q resonator modes observed in the signal of HOM monitor of SC rf module that corresponds to the frequency of unstable modes in the longitudinal beam spectra as shown in Fig. 1. Based on theoretical analysis and measured signals, it is concluded that the SC rf cavity will not cause longitudinal coupled bunch instability at 400 mA. Those two dominant longitudinal modes should be caused by cavity-like vacuum chambers in the storage ring.

Transverse Instability

The resistive wall impedance is known to drive the transverse coupled bunch instability in TLS storage ring at 300 mA, particularly in the vertical direction. There is an analog transverse feedback system operating in the storage ring prior to January 2006. The analog feedback system is replaced by a digital feedback system which uses a single feedback loop to damp both the horizontal and vertical beam oscillation [4]. The transverse beam profile measured from a synchrotron light monitor at a location of nonzero dispersion is shown in Fig. 4. The digital transverse feedback can suppress the transverse instability effectively at 300 mA as shown in Fig. 4.

In addition to the transverse instability caused by the resistive wall of beam pipe, there is evidence of multi-turn ion instability in the storage ring. There is noticeable thermal desorption near the superconducting wavelength shifter due to contamination of vacuum chamber. Vertical beam instability is readily observed during machine studies at low beam current where the resistive wall instability is not expected to occur. Figure 5 depicts the measured vertical beam spectra at 25 mA for different fill patterns. The transverse feedback was turned off during the experiment. In the top picture of Fig. 5 the betatron sidebands are quite pronounced with a fill gap of 80 rf buckets. The transverse beam profile measured by the synchrotron light monitor also showed violent vertical oscillation. When the fill gap was changed to 45 rf buckets, the beam was stable. There was no sign of vertical instability both from the measured vertical beam spectrum (the bottom picture of Fig. 5) and the signal of synchrotron light monitor. The average vacuum pressure of storage ring was 0.28 nTorr during the experiment. The local maximum pressure was 2.73 nTorr near the superconducting wavelength shifter.

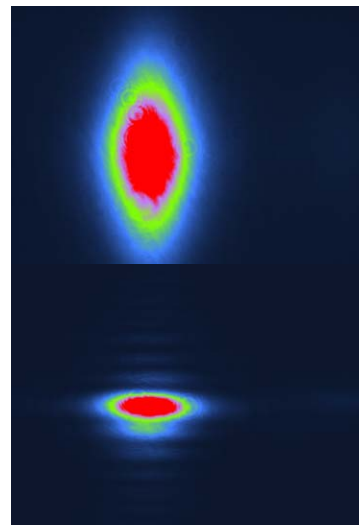

Figure 4: The transverse beam profile measured by a synchrotron light monitor at a location of nonzero dispersion. The top picture is the transverse feedback off, and the bottom one is the transverse feedback on.

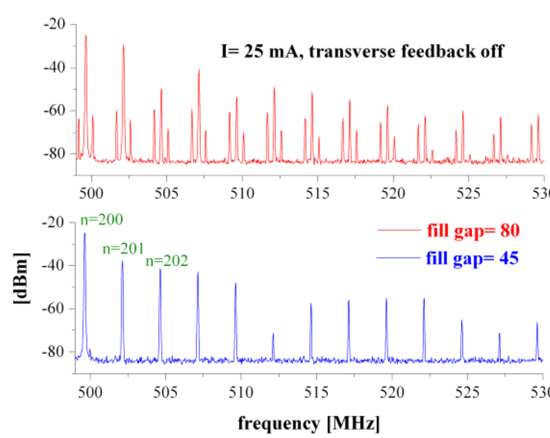

Figure 5: The vertical beam spectra at 25 mA measured for different fill patterns. The transverse feedback was turned off. The beam was unstable in the top picture when the fill gap was 80 rf buckets. The average pressure of storage ring was 0.28 nTorr. The local maximum pressure was 2.73 nTorr during the experiment.

The ion trapping condition is evaluated with the following criterion [5]:

$$\left|\cos(\omega_i \ell_T/c) - \frac{\omega_i \ell_g}{2c}\sin(\omega_i \ell_T/c)\right| \quad (1)$$

where ℓ_T is the length of bunch train, ℓ_T is the gap length, and ω_i is the angular ion frequency. The population distributions of major gas species are H2(85%), CO(12%), and CO2(2%) as measured by a residual gas analyzer. The trapping conditions calculated with Eq.(1) for those three major gas species are shown in Fig. 6. As shown in Fig. 6 the ion trapping occurs for a fill gap of 80 rf buckets. This provides a strong correlation with the top picture of measured beam spectra in Fig. 5.

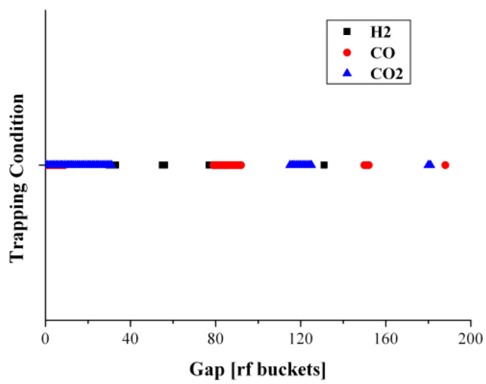

Figure 6: The trapping conditions calculated for major gas species with beam parameters used in the machine studies at 25 mA.

The growth rate of vertical resistive wall instability with a uniform fill pattern is calculated with the following expression [5]:

$$-\frac{i\Gamma(1/2)}{4\pi}\frac{N_B e^2 c}{\omega_\beta T_0 E \sigma_\tau}\frac{\sum_{p=-\infty}^{\infty} Z_\perp(\omega_p) h_0(\omega_p - \omega_\xi)}{\sum_{p=-\infty}^{\infty} h_0(\omega_p - \omega_\xi)} \quad (2)$$

The calculated growth rate of vertical resistive wall instability at 30 mA for a uniform fill pattern is shown in Fig. 7. The vertical radiation damping rate is 151 sec^{-1} for TLS storage ring. All vacuum chambers of insertion devices have been included in the calculation of instability growth rate shown in Fig. 7. The vertical resistive wall instability will not occur at a beam current 25 mA. Based on the predicted trapping conditions, measured beam spectra at different fill patterns, and calculated growth rate of resistive wall instability as shown in Figs. 5- 7, we are certain that there is multi-turn ion instability in the TLS storage ring when the fill pattern is not chosen properly. With a properly chosen fill pattern, we can avoid the ion instability.

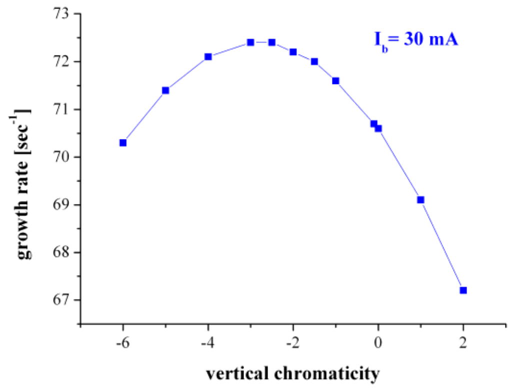

Figure 7: The calculated growth rate of vertical resistive wall instability at 30 mA. The growth rate is much smaller than the vertical radiation damping rate 151 sec^{-1}. The vertical beam instability observed in Fig. 5 can not be attributed to the resistive wall impedance.

CONCLUSION

The top-up operation of TLS storage ring has achieved high photon beam stability (relative intensity variation within 0.1%) over 90% of scheduled beam time. The SC rf cavity and bunch-by-bunch feedback systems play essential roles in the top-up operation. The longitudinal coupled bunch instability observed in the top-up operation is caused by cavity-like vacuum chambers. The longitudinal digital feedback system can effectively suppress those unstable modes. The transverse feedback system is effective in suppressing the resistive wall instability at high beam current.

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