THE SUPERCONDUCTING RF CAVITY AND 500 mA BEAM CURRENT UPGRADE PROJECT AT TAIWAN LIGHT SOURCE

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Abstract

The 500 mA beam current upgrade project at Taiwan Light Source (TLS) is expected to reach the following basic goals: 1) reducing the longitudinal coupled bunch instability by using a single cavity, 2) being damped Higher-Order-Mode (HOM) in cavity to provide very stable photon beam, 3) increasing the stored beam current up to 500 mA, 4) maintaining the beam lifetime by increasing the operating gap voltage from 0.8 MV to 1.6 MV. The Superconducting RF cavity designed by Cornell University and tested at Cornell Electron Storage Ring (CESR) will be installed at TLS. The basic layout of the construction plan will be presented. The beam parameters calculation will be discussed.

1 INTRODUCTION

The synchrotron Radiation Research Centre is located at Hsinchu, Taiwan where the first third-generation light source among Asia has been constructed and operation since 1994.

Two Doris cavities were installed to provide proper operation power and gap voltage. A broadband loop-type damping antenna attached to the cavity cannot effectively suppress the HOM. The damping antenna was replaced by a plunger-type tuner in each cavity. The second tuner was used to detune the most troublesome HOM with acceptable results for some modes [1].

To avoid some harmful HOM modes, the improved temperature control for each cavity can reach ±0.1 °C with adjustable dynamic range up to 20 °C. RF voltage modulation has also been implemented for the routine operation [2]. With all of these manners, the photon fluctuation can be suppressed down to 0.3% during the routine users' operation [3].

Currently, there are 16 beamlines under operation and 6 beamlines under commissioning or construction. Three branches of beam lines are used as diagnostics purpose. One serves as synchrotron light monitor, the other two beam ports are using 50 μm diameter pinhole and detector to measure the photon intensity fluctuation.

The storage ring is a six fold symmetric Triple-Bend-Archomat (TBA) lattice with six straight sections in the storage ring, one section for injection, one for the RF cavities and diagnostic instrumentation, and four sections for the insertion devices. The basic parameters of TBA lattice at TLS are shown in Table 1.

Table 1. The basic parameter of the TLS storage ring

Beam Energy ***E***	1.5 GeV
Working tune (H/V)	7.18/4.13
Nature chromaticity (H/V)	-15.7/-6.61
RF frequency f_{RF}	499.654 MHz
Compaction factor α	0.00678
Nature emittance ε	25.5 nm-rad.
Nature energy spread	0.000756
Operation RF voltage V_{RF}	800kV
Particle numbers (200mA/140)	$3.95*10^9$/bunch

Table 2 . The comparison of operating parameters for the Doris cavities and SRF cavity.

Parameter	Doris cavity	SRF cavity
Beam Energy (GeV)	1.5	1.5
Circumference (m)	120	120
RF Frequency (MHz)	499.666	499.666
Harmonic Number	200	200
Beam Current (mA)	200	500
Energy Spread	0.075%	0.075%
Bunch Length (mm)	9.2	6.5
Compaction Factor	0.00678	0.00678
Energy Loss (keV/turn)	128	128 (168)
RF Gap voltage (kV)	800	1600
Number of Cavities	2	1
Number of klystrons	2	1
Wall Dissip. (W/cavity)	27.5k	<30
Beam Power (kW)	64	64 (84)
Klystron P_{out} (kW/kly.)	60	60 (100)
R_s/Q_0	77.441	44.5
Synchro. Freq. (kHz)	26.5	37.8
Energy Acceptance	± 1.4%	± 2.1%
RF Transmission Line	EIA6 1/8"	WR1800
Tuning Angle Offset	0^o	$0^o > \psi_{offset} > -10^o$

2 SUPERCONDUCTING CAVITY

The installation of SRF cavity will be one of the major renovation of TLS in the next decade. It will be also the first installation of SRF cavity in a dedicated synchrotron light source facility around the world. The dramatic reduction of the Q-value and shunt impedance of higher-order-mode in the SRF cavity will help increasing the threshold current [4]. A comparison of operation parameters for Doris cavity and CESR's SRF cavity is shown in Table 2.

The CESR's Nb cavity is shown in Fig. 1. The round beam tube can couple most of the HOM out of the cavity. The flute-type beam tube will couple two deflecting modes (TM_{110} and TE_{111}) from the SRF cavity [5]. A rectangular waveguide is connected to the round beam tube to sever as the input coupler. Two ferrite-tiles HOM absorbers are located at the upstream and downstream of the Nb cavity at room temperature. The Nb cavity is then bath in a 4.5 K LHe vessel. The LHe vessel is insulated by vacuum, LN_2 jacket and multi-layers insulation. The earth magnetic field, 500 mG, is shield by two mu-metal layers, hence the residual magnetic field at the equator of the Nb cavity can be reduce to less than 20 mG to reduce the residual resistance and cryogenic loss.

The potentially of operating SRF cavity up to 8 MV/m is very attracting point to TLS to increase the stored beam current and prolong the Touschek lifetime by increasing the operation gap voltage.

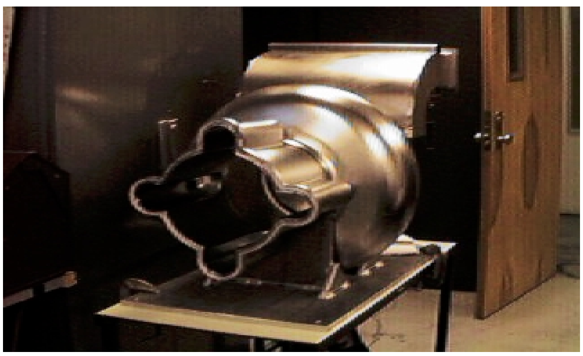

Figure 1: CESR's Nb cavity with flute beam tube for HOM coupling and high-power input coupler.

3 THE CRYOGENIC SYSTEM

There is a maximum 50 W's heater inside the LHe vessel of cryostat in order to maintain the operation pressure and cryogenic load. Vacuum vessel, LN_2 insulation layer and multi-layers insulator have been used to keep the static heat loss of cryostat and distribution box very low.

Table 3. The estimated cryogenic budget for the transmission loss, the static and dynamic loss of cryostat.

Cryostat	80 W
Distribution Box	10 W
Multi-Channel Line (5 m)	1.5 W
Flexible Transfer Line	12 W
Dewar	0.5 W
Junctions, Valves and Misc.	21 W
Total	125 W

A 100 m^3 and 250 psig gas helium tank will be installed nearby the compressors area. A 2000 liters liquid helium dewar is used to provide at least two times refill of LHe vessel in cryostat. The detail heat loss budget is listed in Table 3. The total heat loss plus 50% of operation margin will be the capacity of a desired refrigerator, which is expected to have 200 W refrigeration capacity without LN_2 pre-cooling. Screw compressor and turbine type expander are the expected combination of cryogenic system for the reliability and easy maintenance. The turbine expander and dewar will be allocated nearby the cryostat in order to reduce the multi-channel line's heat loss.

An SC harmonic cavity is another long-term plan to increase the beam life time at TLS. There should not be any major capital upgrade for the cryogenic system. An extra screw compressor with LN_2 pre-cooling in the expander is expected to increase the cooling capacity to 400 W in the future.

4 BEAM LIFETIME CALCULATION

Beam lifetime is one of the key issue in the SRF project. Touschek lifetime is a dominating factor for a low-energy synchrotron facility. The bunch length, dynamic aperture, energy acceptance and the gap voltage are the major parameters in the evaluation.

The radiation of bending and insertion devices will tend to increase the quantum fluctuations and lower the damping time. The definition of Synchrotron Radiation Integrals (SRI) constants for the operation lattice can be evaluated as reference [6]. The emittance, energy spread and bunch length can be expressed in terms of SRI. The bunch length can be expressed as:

$$\sigma_L = \left[\frac{2\pi\alpha h c^2}{\varpi_{RF}^2 \cos\phi_s}\frac{E}{eV_{RF}}\right]^{1/2}\left[\frac{55\hbar\gamma^2}{32\sqrt{3}}\frac{I_3}{2I_2+I_4}\right]^{1/2},$$

where I_1 to I_5 are SRI defined as reference [6], φ_s is the synchrotron phase and h is the harmonic number.

The relationship between bunch length and gap voltage is shown in Fig. 2, where we assume the TLS SR is operated at 1.5 GeV with basic parameters described in Table 1.

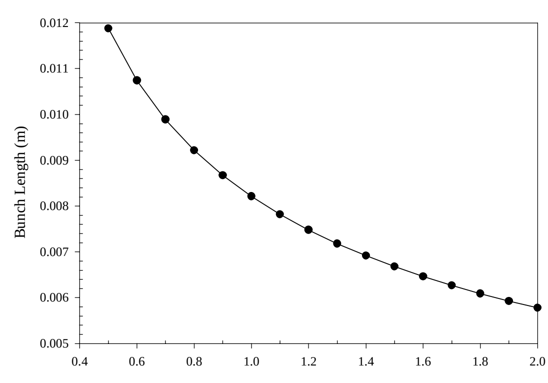

Figure 2: The bunch length is inverse proportional to the square root of the operation gap voltage.

The RF acceptance can be expressed as following:

$$\varepsilon_{RF} = \pm\sqrt{\frac{2U_0}{\pi\alpha h E}\{\sqrt{\frac{eV_{RF}}{U_0}} - \cos^{-1}(\frac{U_0}{eV_{RF}})},$$

where U_0 is the radiation loss, 168 keV/turn, which includes the radiation loss from bending magnets and all the installed insertion devices. Figure 3 shows the RF acceptance verse the operating gap voltage where we use the parameters listed in Table 1.

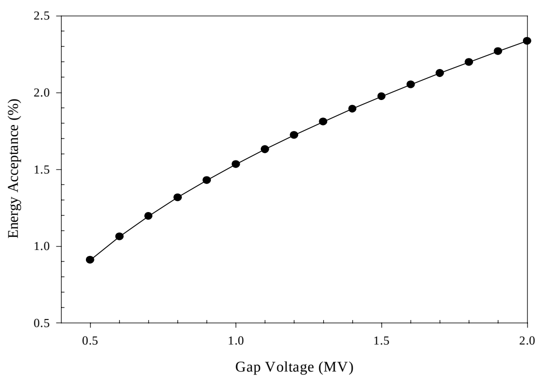

Figure 3: The RF acceptance is increasing with increasing operation gap voltage.

The Half-Touschek lifetime can be expressed as:

$$\frac{1}{\tau} = \frac{\sqrt{\pi} r_e c N F(\varsigma)}{\sigma_x^{'} \gamma^3 \varepsilon_{accpt}^{\ 2} 8\pi^{1.5} \sigma_x \sigma_y \sigma_L},$$

where σ_x, σ_y, σ_L are the bunch size in x, y, and z dimension, r_e is the classical electron radius, N is the number of electrons per bunch and $\varsigma = [\varepsilon_{accpt} / \gamma\sigma_x^{'}]^2$.

The half-Touschek lifetime by ZAP [7] for different operation gap voltage is shown is Fig. 4 and 5, where we assume the bunch density is 500 mA/140 bunches. From the graphs, we could find the beam lifetime will not increase, if the gap voltage greater than 1.6 MeV. It is an indication of a changing dominating factor between the bunch shorting and the energy acceptance of the ring.

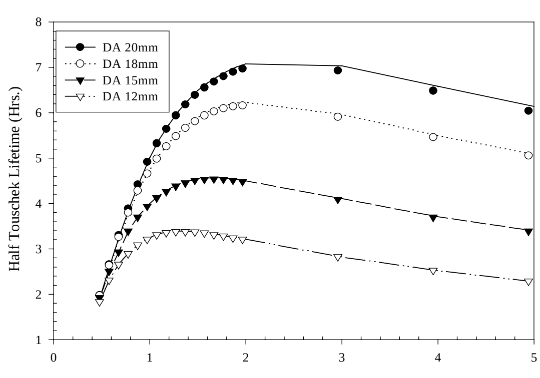

Figure 4: The half Touschek lifetime verse operation gap voltage under the different assumption of dynamic aperture of the storage ring.

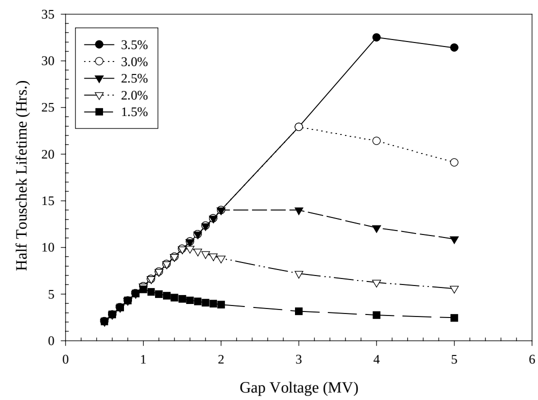

Figure 5: Half Touschek Lifetime verse the operation gap voltage under the assumption of different transverse energy acceptance.

5 SUMMARY

The Touschek lifetime is increasing with gap voltage. The target operation condition will be 500 mA with gap voltage up to 1.6 MV. To reach the goal of extended beam lifetime, a third harmonic cavity will be proposed to increase the beam volume in the longitudinal direction. The current RF tube and transmitter will be also upgraded to have enough capability to processing and stable operating for the storage ring.

A new utility building, which is going to house the cryogenic system and SRF testing laboratory, is under construction. Two SRF cryostats have been contracted to ACCEL. One of the cryostat is expected to be installed and commission at TLS at the very beginning of 2003. A second phase upgrade plan will focus on the increasing RF output power to 150 kW.

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