Infrastructure Development

TLS aims for a beam with an orbit fluctuation of < 1 μm (rms), an orbit drift of < 5 μm per shift (8 hr), and a photon beam intensity fluctuation of < 0.1% in the photon beam line. The frequency range that is concern to the users from 0.1 to 50 Hz is mostly utility and mechanical related. It was observed in the beginning years of TLS operation that the temperature fluctuations in air and water affected the beam quality significantly.

After the successful installation and commissioning of the storage ring of TLS in 1993, the machine groups were reorganized to face to the challenges in the inexperienced beam stabilities. Among them, the Utility Group, originating from the former Engineering Division, was merged as a "machine-group" to be responsible for maintaining the stability of utilities, which strongly influence the stability of the machine. The Mechanical Positioning Group was formed to address precision mechanical issues in the micron and sub-micron range.

A series of studies has been undertaken to investigate the effects of utility, mechanical and electrical system on the beam stability. The utility system and some mechanical system were upgraded. Most sources, transfer mechanisms and the sensitivities have been identified. Table 1 presents a time chart of studies on mechanical stability and improvements made to TLS in recent years. The beam quality of the TLS was noted to be seriously affected by the conditions of the utility system, following the first few years of operation after Oct. 1993. Six major categories of work - improving cooling capacity, stabilizing the heat source, studying mechanical effects, implementing sensors, and upgrading the control system - were initiated after the energy of the storage ring was increased from 1.3 GeV to 1.5 GeV in 1996.

Water Temperature

The cooling water system of TLS consists of three subsystems - cooling tower water (CTW) system, chilled water (CHW) system, and de-ionized water (DIW) system. The CHW is divided into two major branches, one for DIW system and

Table.1: The infrastructure improvements made to TLS (1997-2002)

	1997 Program initiation	1998	1999	2000	2001	2002
Performance, △T **orbit** **△I**	>±1°C (drift >50 μm) >1%	~±0.25°C	<±0.2°C (drift ~20 μm)	~±0.15°C <3 μm rms ~0.5%	<±0.1°C (drift <5 μm)	<±0.1°C <1 μm rms ~0.3%
1. Utility Capacity Improvement				Utility building #2 construction CHW capacity improved		
2. Heat Source Stabilization	CTW, CHW Temp. stab.	Injector energy upgrade full energy injection		EPU air temp. Power supply heating		U5 air temp.
3. Thermal-Mechanical Effects	Global effect studies (air/water temp., cable heat)		Girder, thermal insulator, vacuum chamber, SR heat mask	BL-, RF-DIW temp.		△I monitor
4. Vibration	AHU, crane vibration pre-reduced		Damping study		Floor meas.	Piping improv.
5. Sensors Implementation	Air temp. sensors		Position sensors	SCADA implementation electrical sensors		
6. Control System	Water control system upgrade VF controller implementation Utility data archive system				AHU controller upgrade AHUs reorganized	

the other for the air-handling units. Three individual DIW loops supply DIW to the storage ring copper system, aluminum vacuum system and beam line system. The copper DIW system is used for cooling magnets, power supplies, and two secondary-loop heat exchangers of RF system. The temperature of the DIW was controlled by regulating the flow rate of the chilled water through the heat exchanger in the loop of DIW.

The temperature fluctuation of DIW was originally ~ ±1℃, which is too high for beam stability. An improvement project has been carried out since 1997. Not only variable frequency controllers were adopted, but also the device sensitivity was improved. Water temperature sensors were upgraded to digital one with a resolution of ~ 0.02 ℃. The linearity of valve response at the beam line water system was improved. In addition to the improvement of the DIW systems, the improvement of the CTW and CHW systems contributed significantly in decreasing the temperature fluctuations of the DIW system and of the air conditioning system. The CHW outlet temperature was improved to 7.6 ± 0.2 ℃. The temperature fluctuation of DIW was improved to < ± 0.1 ℃.

Air Temperature

Ten sub-branches of CHW system supplied chilled water to ten air handling units (AHUs), with two for the booster synchrotron, three for offices and labs, four for the storage ring tunnel and beam line floor, and one for the core area of the storage ring. In the core area, all the magnet power supplies, RF transmitters, vacuum controllers, and many other instruments were located.

The air temperature control at TLS tunnel is complicated. First, the air conditioning system is not a closed system. The exchange of air among the storage ring tunnel, outdoors, the core area and the experimental area of the machine affected the tunnel air temperature. Second, same AHUs are used in the tunnel and the experimental area. The control algorithm becomes complicated to keep the temperature constant in both large areas. Third, the installations of the air inlet- and outlet- ports allow little room for maintaining the uniformity of air temperature. Fourth, heat sources that contribute to air temperature fluctuations are diversely distributed. Also, it is not easy to prevent the interferences from the offices and labs, where the same CHW system was used.

The effects of air temperature fluctuations are significant in changing beam orbit and size at TLS. Improvement work has been conducted in spite of constraints mentioned above. Many air temperature sensors, with a resolution of < 0.1 ℃, were installed in the storage ring tunnel in 1997, and revealed a temperature transient during injection. After the upgrade of the injector energy from 1.3 GeV to 1.5 GeV in year 2000, the temperature transient behavior in the storage ring tunnel due to the ramp up-and-down injection process was significantly reduced. About fifty temperature sensors, each with a resolution of < 0.1 ℃, were installed in the tunnel and the core area. The temperature sensors, dampers, hot water and chilled water components and the temperature control systems of TLS were reviewed. The temperature fluctuations have been reduced from ± 1 ℃ to within ± 0.1 ℃ in one operation shift ~ 8 hours. However, the absolute temperature (about 25 ℃) could change from place to place depending on different heat sources at different locations in the tunnel.

Mechanical Stability

Mechanical displacements could result in disturbances to the magnetic and rf fields. The closed orbit, orbit length, betatron function and betatron tune could therefore be affected. Stringent requirements on mechanical stability are necessary to obtain a stable beam with a low emittance. The thermal-mechanical effects at TLS were thoroughly studied during the past few years to identify the most sensitive mechanical components that translate the thermal forces from heat sources into the fluctuations in the orbit or size of electron beams. The cures were followed and the results showed quite successful.

Girder

Mechanical position sensors, with a resolution of < 0.1 μm, were installed in the second and the fifth superperiod of the storage ring. The position sensors helped to elucidate the mechanical effects. The girder displacement through the mechanical structure was observed the major factor of orbit distortion at TLS. A strong correlation between the girder displacement and the tunnel temperature was observed.

The girder of TLS is designed to support magnets, vacuum chambers and other components. An unstable girder will move all the components on it, making the beam unstable. All the magnet girders in the storage ring were wrapped with thermal insulators in 2002. The time constant of temperature variation of the girders was increased from 7 hours to 18 hours after the thermal insulation. The displacement of the girders was reduced to one-third of its original value. Together with a good air-temperature control of $\triangle T \sim 0.1$ ℃, now the displacement is about 0.1 μm in an 8hr-shift.

Vacuum Chamber

Due to the changing thermal load at different beam currents, the phenomenon of "chamber-breathing" has been observed. The irradiation of synchrotron light on vacuum chamber caused the chamber to expand. The expansion moved the beam position monitors (BPM) and the magnets which were in contact with the vacuum chamber. The force through the frame on which the BPM was fixed also affected the girder (Fig. 1). The beam orbit was disturbed accordingly. A beam orbit drift of ~ 1-10 μm was measured.

An independent photon absorber was designed for bending chambers to reduce the thermal load on bending chamber. Three sets of the absorber were fabricated and installed in the R1 section in 2002. More absorber will be installed in the rest of the bending chambers of TLS in the near future. This "chamber-breathing" phenomenon will be further reduced with top-up mode injection.

RF cavity

The cavity is a major heat source in the rf system. The beam size has been found to be quite sensitive to the temperature fluctuations of the DIW in the cavity. The variation in the beam size was significantly reduced after the water temperature fluctuations were reduced to < 0.02 ℃. It was also found that the fluctuations in ac line voltage caused the temperature fluctuations of the cooling water for transmitter and resulted in beam size fluctuation.

Photon beam Monitor

The photon beam stability monitoring system (ΔI monitor), which consists of a vertical focusing mirror, a pinhole, and a photo-detector, has been improved to give more accurate reading at the side branch of the LSGM beamline. The measured photon beam intensity is sensitive to the mechanical stability of the mirror and its supporting structure, the stability and resolution of the pinhole stage, and the temperature stability of the environment and the cooling water. A photon beam intensity fluctuation of ~ 0.1 % was achieved (Fig. 2) after masking the scattered light, improving the mirror mounting mechanisms, and controlling the temperature of cooling water (± 0.01 ℃) and environment (± 0.1 ℃).

Vibration

Vibration spectra of the storage ring tunnel and experimental hall were mapped in 2001-2002. The measuring points include ground, girders, and quadruple magnets in the storage ring, and various spots of the experimental floor. The major vibration source was tracked down to be the air handling units (AHU), located on the second floor in the storage ring core-area. The ground vibration nearby the AHU was reduced to one-tenth of its original amplitude after installing double-stage

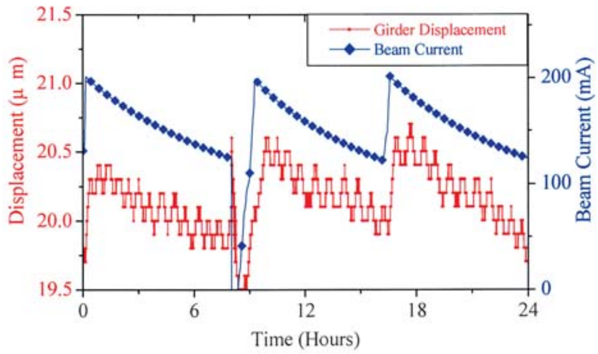

Fig. 1: The correlation between beam current and girder displacement.

insulators. The vibration caused by AHUs is to be further reduced by replacing new AHUs with better balance and suspensions.

Electrical Stability

System Reliability

Reliability is one of the most important factors for the TLS. The trip rate of TLS was found to be extraordinarily high, since early 2000. After the power line grounding system, the protection circuits of the rf circulator and the electrical power supplied to control room were all improved, the beam trip rate has been greatly reduced to approximately once per month, since 2001. Upgrades of grounding and electrical power systems have continued since then. Electrical power and grounding systems are to be re-organized; "clean" and "dirty" systems will be separated.

Power Supply

A correlation among the beam orbit, the power supply output, and the air temperature was observed. A fluctuation of the A.C. line voltage varies the air temperature, possibly because the power is proportional to the square of the voltage. In contrast, fluctuations of temperature alter the output of the power supply and hence the orbit and size of the electron beam. The A.C. line voltage fluctuation is ~ ± 1.5 % at TLS. This value seems too high for some sensitive devices. The effects of the line voltage fluctuations was reduced to < ± 0.15 % after using a precision voltage regulator. The photon beam fluctuation was reduced to ~

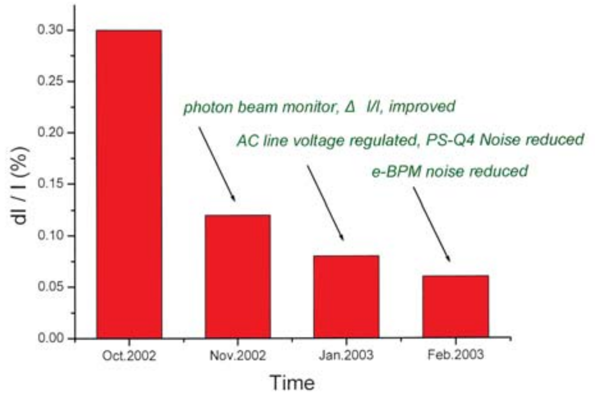

Fig. 2: Reductions in the photon beam fluctuation in 2002-2003.

0.07 % after the improvement in Jan. 2003 (Fig. 3). A further improvement in reducing the noise of e-BPM, the photon beam stability achieved a better value of ~ 0.06 %.

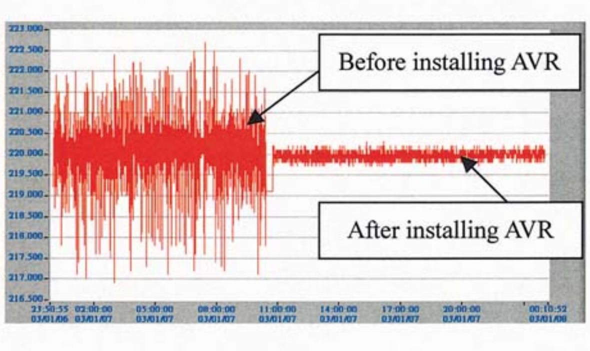

Fig. 3: The AC line voltage, supplied to the Q4 power supply, before and after using a precision voltage regulator of 300kVA.

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