A LIGHT-SOURCE OPERATION AT THE TRISTAN MR

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Abstract

The TRISTAN MR was operated as a light-source from September to December 1995 to pursue the possibility of using the MR as a future light source and to carry out research programs suitable at future light sources. The beam current was stored to a design value of 10mA in 8 bunch operation. The measurement of the acceptance showed that the chromaticity correction by the non-interleaved sextupole arrangement worked well. A feedback system suppressed the change of the orbit to the level of the requirement. Preliminary result of the emittance measurement shows that the horizontal emittance was about 7 nm.

1 INTRODUCTION

The plan of modifying the MR for the light-source study was already described in ref. [1]. Main features of the plan were 1)Installation of an X ray undulator of 5.4 m long and a photon beam line of 100m long, 2)Increase of betatron phase advance in normal cell and use of the existing wigglers as emittance damping wigglers to achieve the low emittance, 3)Chromaticity correction based on so called non-interleaved sextupole arrangement to keep the dynamic aperture large, 4)Removal of all superconducting cavities and 60% of normal-conducting cavities and introduction of head-tail damping by high chromaticity to overcome the coupled bunch instability, 5) Feedback system to stabilize the slow orbit movement and 6)Alkaline cleaning of the vacuum chamber surface to improve the expected worse vacuum pressure due to new installation of the vacuum chambers in the place of the removed cavities.

Table 1 shows design and achieved parameters for the MR light-source study. In the following the results of the commissioning and machine studies during this period are described.

2 LATTICE AND RELATED SUBJECTS

A low emittance was achieved by increasing the betatron phase advance in normal cell from 60˚ to 90˚ in both the horizontal and vertical planes and by using the emittance damping wigglers.

Table 1 Design and achieved parameters

	Design	Achieved
Beam energy(GeV)	10	10
Number of bunches	8	1, 8, ,16, 32
Beam current(mA)	10	10 :8 bunches 16:32bunches
Cell phase advance(hor.)	90˚	
(ver.)	90˚	
Momentum compaction	0.00073	
Betatron tune (hor.)	48.20	47.64
(ver.)	41.15	40.76
Natural chromaticity(hor.)	-65	
(ver.)	-57	
RF voltage(MV)	90	80-110
Synchrotron tune	0.073	
Damping wiggler field(T)	1.2	1.17
Radiation damping time(ms) (trans./long.)	30/15	
Natural bunch length(mm)	5.3	
Natural emittance(nm)	5.0	about 7
Orbit stability with feedback		
position(μm) (hor./ver.)	±1500/±50	±30/±40
angle (μrad) (hor./ver.)	± 15/± 5	± 5/± 5
Beam life time(min)	120	210 at 10mA

Figure 1 shows the emittance observed by a visible light monitor as a function of wiggler field. The emittance has a minima around the design value 1.17T.

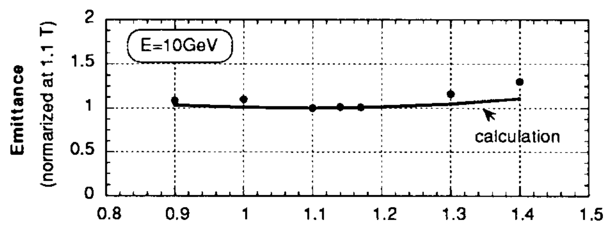

Figure 1: Emittance vs. field of the damping wigglers

For the chromaticity correction, sextupoles were excited based on so called non-interleaved sextupole arrangement. In this arrangement sextupoles make a pair of same strength. A sextupole and a companion are placed such that betatron phase advance between them is 180˚ and there is no sextupoles between them. Nonlinear effect is canceled each other out. To confirm validity of this

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arrangement the energy and transverse acceptance were measured and compared with a simulation by the computer code SAD(Fig.2). The measured energy and horizontal acceptances are consistent with the simulation. The measured vertical acceptance, which was a tenth of that of the simulation, can be explained by the physical aperture at the vacuum chamber in the undulator.

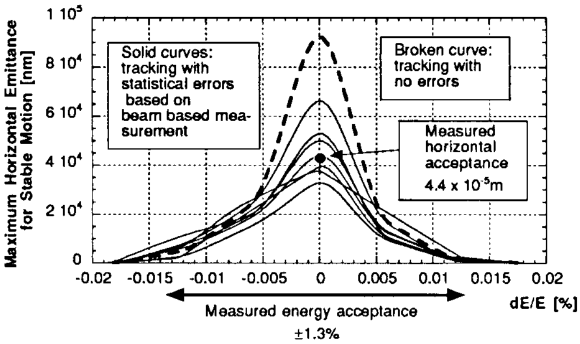

Figure 2: Comparison of acceptance between the measurement and the simulation

Betatron and synchrotron tunes were surveyed to reduce the emittance. Fig. 3 shows the horizontal and vertical emittances as a function of the horizontal tune. The emittance was measured by the visible light monitor. The growth of the horizontal emittance by coupling resonance and synchro-betatron resonance are clearly visible. The operating point was set far from resonance to avoid the emittance growth.

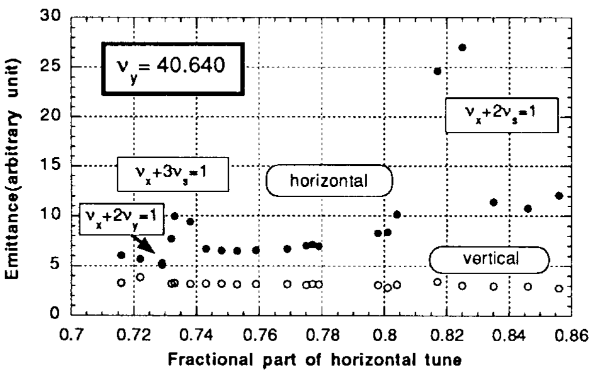

Figure 3: Horizontal tune vs. emittance

Vertical orbit at a sextupole was swept while observing the vertical beam size to decrease the vertical emittance. The procedure was repeated for almost all the sextupoles. This reduced the vertical emittance by 10%.

3 ORBIT STABILITY AND FEEDBACK

The requirements on the orbit stability at the source point in horizontal position, vertical position, horizontal angle and vertical angle were ±1500μm, ±50μm, ±15μrad and ±5μrad, respectively. On the design stage of the light source operation orbit movement was measured. The measurement showed that the fast movement of 3-100Hz was small enough to satisfy the requirements but the slow movement should be stabilized by the feed back system.

Fig. 4 shows the schematic layout of the feedback system[2]. Beam position and angle at the center of the undulator were measured every turn by two beam position monitors(BPM). Four horizontal steering magnets(STFH) and four vertical one's (STFV) controlled the beam position and angle at the center of the undurator. The steering magnets were fabricated by laminated steels to get fast response of the magnetic field and reduce the hysterisis effect. The control system was based on the EPICS. A VME computer stabilized the orbit by PID control.

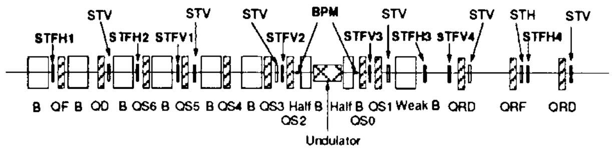

Figure 4: Arrangement of the orbit feedback system

Performance of the feedback is summarized in Table 1. As an example shown in Fig. 5 is the vertical angle for about 5hr with and without the feedback. Data were taken every 2 sec. Each data was obtained by averaging beam position over 100 turns.

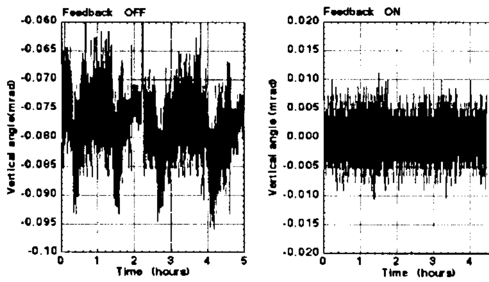

Figure 5: Change of vertical angle at the source point with and without the orbit feedback

4 EMITTANCE MEASUREMENT

Emittance was measured by observing visible light emitted from a bending magnet. Experimental set up is shown in Fig. 6. Light was extracted from a vacuum chamber by a Be mirror, defined by a slit and focused on a CCD camera by a lens of focal length of 1000mm. A filter selected the light whose wave length λ is 500±5nm. Intensity of light accepted by the CCD camera was adjusted by a circular linear-wedge type ND filter. All devices were located in a TRISTAN tunnel.

The image was projected on horizontal and vertical axes and fitted to a Gaussian distribution with linear background. The standard deviation of the distribution gives the beam size $\sigma_{x,y}$(obs.).

The $\sigma_{x,y}$(obs.) is expressed as

$$\sigma^2_{x,y}(\text{obs.}) = \sigma^2_{x,y} + \sigma^2_d + \sigma^2_f + \sigma^2_a + \sigma^2_\beta + \sigma^2_{CCD}, \quad (1)$$

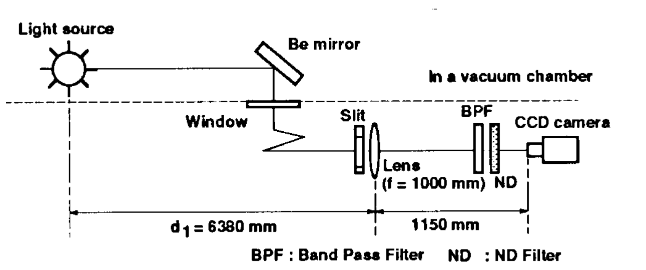

Figure 6: Experimental setup of the emittance measurement

where $\sigma_{x,y}$ is the horizontal and vertical beam size expressed as $\sqrt{\varepsilon_{x,y}\beta_{x,y}}$ because the dispersion is negligibly small at the source point. σ_d is the broadening of the beam size by diffraction and determined vertically by radiation angle of synchrotron radiation σ'_r and horizontally Fraunhofer diffraction by the slit. σ_f arises because the camera accepts the light emitted from a finite region σ_l along the orbit and which is unfocused on the camera. The error by astigmatism by a deformation of Be mirror σ_a was estimated from the positions of horizontal and vertical focal points, which shifted each other by 127mm(=Δf) when converted back to the source point. σ_β is caused by the change of beta function $\Delta\beta_{x,\ y}$ in the region σ_l. σ_{CCD} is the digitizing error by the CCD camera. Table 2 summarizes the errors.

Table 2 Error sources in beam size measurement

	Horizontal	Vertical
σ_d	$0.380\ \lambda\ d_1\ /D$	$(\lambda/4\pi)\ /\ \sigma'_r$
σ_f	$\sigma_s / d_1\ \sigma_l$	$\sigma'_r\ \sigma_l$
σ_a	$\sigma_s / d_1\ \Delta f/2$	$\sigma'_r\ \Delta f/2$
σ_β	$0.5(\Delta\beta/\beta_x)\ \sigma_x$	$0.5(\Delta\beta/\beta_y)\ \sigma_y$
σ_{CCD}	17.6μm	17.6μm

$\sigma'_r = 0.723/\gamma\ (\lambda/\ \lambda_C)^{1/3}$, $\sigma_s = D/\sqrt{12}$, $\sigma_l = \rho D/\ d_1/\sqrt{12}$

(λ_C:critical wave length, ρ:bending radius, D:opening of the slit)

$\sigma_{x,y}$(obs) was measured as a function of the slit width D and compared with the theoretical $\sigma_{x,y}$(obs.) calculated by (1) assuming various values of $\varepsilon_{x,y}$. Preliminary result shown in Fig. 7 indicates that horizontal and vertical emittance are about 7nm and 0.4-0.8nm, respectively.

5 MISCELLANEOUS

Achieved beam current was 10 mA in 8 bunch operation and 16 mA in 32 bunch operation. The head tail damping rate at the injection energy of 8 GeV was 3.3 ms horizontally and 1.3 ms vertically in the bunch current of 1.4mA[3]. This strong damping, which is ten times higher than the radiation damping rate, must be helpful to suppress the coupled bunch instability.

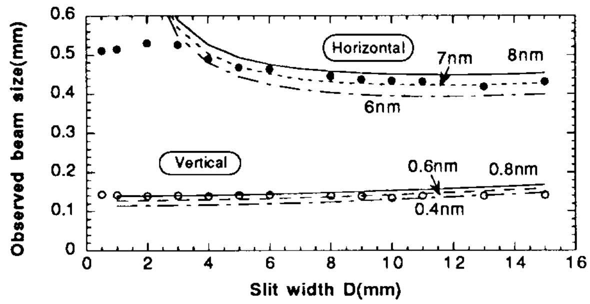

Figure 7: Observed beam size vs. the slit width

Longitudinal loss factor k_L and transverse loss factor k_T in the ring were measured and compared with calculation[4]. k_L was obtained by detecting the synchronous phase angle as a function of current and k_T from current dependence of betatron tunes. The calculation of the loss factors were done by ABCI taking into account 40 RF cavities, 160 RF bellows, 32 gate valve bellows and 560 shielded bellows. The results of the measurement and the calculation are shown in Table 3. The cause of the discrepancy between the measurement and the calculation is not understood yet.

Table 3 Measured and calculated loss factors

	Measured	Calculated
Longitudinal(10^{14}V/C)	6.3-8.0	4.1
Horizontal(10^{15}V/C/m)	2.41 - 3.14	2.1
Vertical(10^{15}V/C/m)	5.6 - 5.9	2.9

The beam lifetime reached 210min at the beam current of 10mA. This lifetime is longer than expected life time of 2hr after the operation for three months. This better performance could be explained by the alkaline cleaning of the vacuum chamber to decrease the out gas rate.

The vertical closed orbit depended on the gap height of the undulator. The amount of the orbit change increased almost linearly with the vertical magnetic field B_p of the undulator. The equivalent kick of 20 μrad at 8GeV at the undulator explains the change of the closed orbit at B_p of 2500Gauss. This implies the horizontal magnetic field amounting to 5.3Gm arose in the undulator gap. Detailed simulation study is underway to explore the effect of the horizontal magnetic field upon the characteristics of the undulator radiation.

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[2] T. Mimashi et al., Int. Conf. on Acc. and Large Exp. Phys. Cont. Systems, Chicago, U.S.A. 1995.
[3] N. Akasaka et al., these proceedings.
[4] C. Zhang et al, these proceedings.