BEAM PARAMETERS AND AUTOMATIC STABILITY MEASUREMENT SYSTEM USING A PINHOLE DETECTOR

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Abstract

The Taiwan Light Source (TLS) provides 200 mA, 1.5 GeV[1] electron beam to generate photon source for academic and industrial research scientists. The beam stability, lifetime, current, and emittence are the key issues to the photon beam line users. Most of the synchrotron light users demand short-term peak-to-peak beam stability well within 0.5%. A 50 μm pinhole combined with a photon detector, which intercepts the synchrotron light focused by a vertical focusing mirror, is driven by an automatic peak-current detecting program with the compensation of the motor's backlash. The measurement results are one of the archived signals to indicate the crucial performance for TLS. The measurement system, control algorithm, and basic measurement results will be discussed.

1 INTRODUCTION

In order to index the short-term photon stability at TLS, an Automatic Peak Tracking System (APTS) of photon profile has been established. To minimize the interference between normal beam line operation and tracking system, a dedicated diagnostic beam line is built next to Low-energy Spherical Grating Mirror beam line, LSGM. The incident photons are focused by a Vertical Focusing Mirror, VFM, and detected by a photodiode positioned behind a 50 μm pinhole. The size of the pinhole is a compromise between sensitivity and localization of detection. If a pinhole is larger than photon projection spot, photo-diode current will be the summation presentation and will not be sensitive to photon flux fluctuation. If pinhole is too small, the stability calculation will be confined to a localized fluctuation or restrict by the light source diffraction limit.

The assembly of photo-diode is attached to a gear and controlled automatically to retrack to the maximum within preset time interval. Under the assumption of Gaussian distribution of flux intensity, the effective noise on measurement system will be reduced when the position of photo-diode centred to the peak of the Gaussian profile.

Through network connection, the device can be remotely controlled. An index of stability, ΔI/I, is defined and some experiments are taken to test its validation. All parameters related operation status can be accessed simultaneously by the control program. The measured photo-current, pinhole position and calculated data are also sent to the database for further analysis.

2 SIMULATION AND SETUP

We will simulate and make some assumptions to find out the relation between the photon fluctuation and pin hole misalignment. This will help us find out the accuracy of the system can reach.

2.1 Definition of ΔI/I

Assume I is the photo-current detected by the photo-diode and ΔI is the current deviation due to the instability from electron beam, e.g. beam drift due to thermal effect[2], high-order-mode excitation [3], or ion effects [4], etc. Hence, $\Delta I/I$ is function of time and is updated every second in our setup. The $\Delta I/I$ is defined at kth second as following:

$$\frac{\Delta I}{I}_{k} = \frac{\max\{A[k]\}-\min\{A[k]\}}{\mathrm{avg}\{A[k]\}} \times 100\ \%$$

$I(k)$ is photo-current sampled with 10 Hz and take the average at kth second. $A[k]$ is a set composed by elements $I[k]$, $I[k-1]$, … $I[k-9]$. The term of $\max\{A[k]\}$ is the maximum in set $A[k]$ and the term of $\min\{A[k]\}$ is the minimum in set $A[k]$. The $\mathrm{avg}\{A[k]\}$ is the average of 10 elements in set $A[k]$.

2.2 Simulation

The radiated photon flux from a bending magnet is wide spread in x-axis, the horizontal direction, from a beam port. The major concern of the beam intensity fluctuation is in the y-axis, the vertical direction. The Gaussian distribution of the photon intensity can be written as:

$$f(y) = I_0 e^{-\frac{y^2}{2\sigma^2}}$$

where σ is the standard deviation of flux distribution, and I_0 is the measured peak photo-current. The total influx into pinhole can be evaluated by the integration:

$$W(d) = \int_{d-r}^{d+r} f(y)\sqrt{r^2-(y-d)^2}\,dy$$

where r is the radius of pinhole and d is the error-deviation between pinhole and flux center. The simulated $\Delta I/I$ can be expressed as:

$$\frac{\Delta I}{I}(d,\delta) = \frac{\max\{W(d+\delta),W(d),W(d-\delta)\}}{W(d)} - \frac{\min\{W(d+\delta),W(d),W(d-\delta)\}}{W(d)}$$

where δ is the fluctuation of peak-flux-position around pinhole center due to beam instability. The simulated results are shown in Fig. 1.

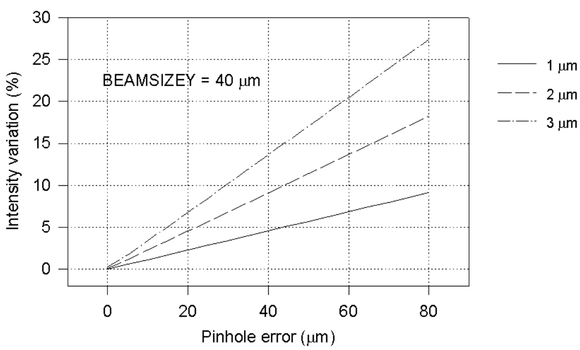

Figure 1. Simulated intensity variation vs. the align error of pinhole position, where we assumed beam size=40 μm.

2.3 Hardware Architecture

The hardware setup of APTS, which is shown in Fig. 2, includes motor driver, pinhole, photo-diode and PC controller. The stepping motor is controlled by a PC through multi I/O interface cards.

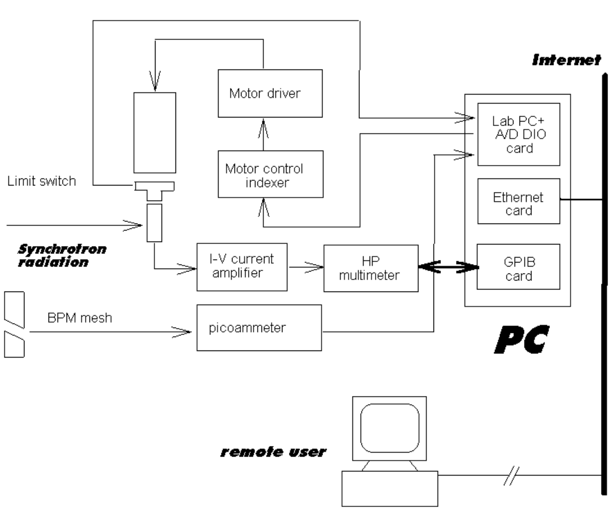

Figure 2. Hardware architecture for the automatic peak tracking system with capability of broadcasting to the network.

In order to improve the accuracy of readout from photodiode and A/D conversion, the photo-current is amplified and connected to a HP multimeter. The transformed digital output is read into PC through GPIB interface.

All programs are developed by Visual C++ under Microsoft Windows operating system. The measured photo-current, pinhole position and calculated current deviation ratio were broadcasting to network for remote access and data archiving.

3 MEASUREMENT RESULTS

Simulation of beam fluctuation, as shown in Fig. 1, indicates that the calculated beam instability is proportion to deviation between pinhole center and the peak-flux position, if a pinhole tracking error occurred. At the same time, instability is proportion to either fast or slow fluctuation of beam-profile center which is due to beam drift or excitation by the coupled-bunch-instability.

3.1Beam Profile Measurement

The relationship between photon flux intensity and position of stepping motor is not reproducible due to mechanical backlash, as shown in Fig. 3. Retracing with cycling process is used to compensate the hysteresis offset and locate the peak position of beam profile. The backlash correction scheme with fast scanning mechanism makes the pinhole reading correlate to the beam movement in the storage ring possible.

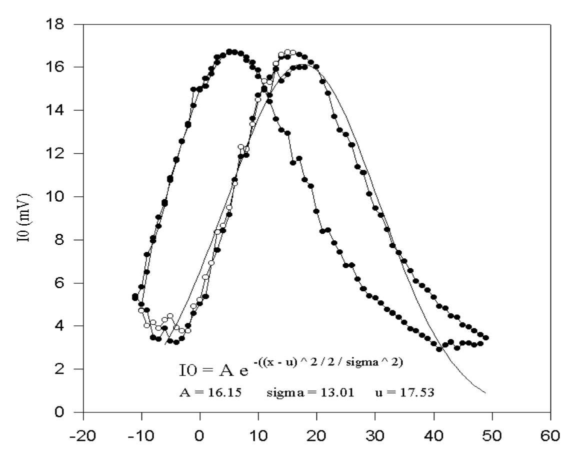

Figure 3. Backlash phenomena of motor movement and the correction scheme for the auto-peak-tracking system. The smooth line indicates the Gaussian-fit beam profile in y-direction.

Figure 3 also can be used as the beam profile measurement instrument. The intensity measurement vs. the pinhole position can be fitted by a Gaussian curve. The fitting parameters for the experiment were listed in Fig.3. The calculated beam size from the curve, with the correction factor of vertical focusing mirror, is 125 μm.

A synchrotron light monitor, using a CCD camera to take the image of synchrotron light with image process, has been setup at TLS[5]. The measurement results, by the CCD camera, of the beam profile is estimated as 115 ± 5 μm which is comparable to the results in this experiment.

3.2 Thermal Effect of Focusing Mirror

Figure 4 is the parameters taken by the APTS after beam current refill during a users' shift. The operation beam current is 180 mA beam current with 1.5 GeV. There is more than a factor of two difference, before and after refill, for the thermal loading of the non-cooled VFM. The induced surface deformation of the VFM at high beam current makes the reflection angle of the incident light drifting, the detected photo-current decaying, faster than expected, and calculated stability worsen accordingly. However, the APTS can trace and lock the peak of beam profile every ten minutes as the system design.

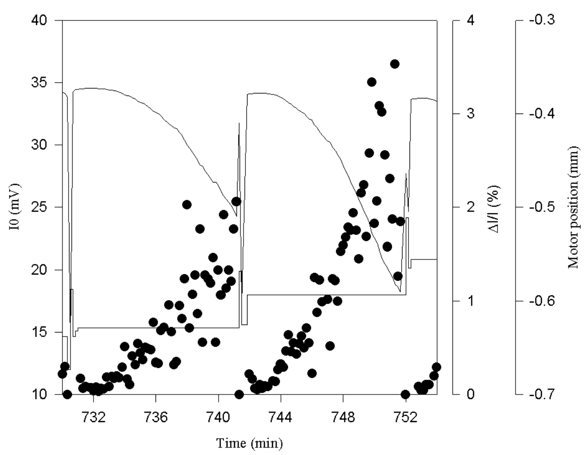

Figure 4. The parameters measured by APTS at 180 mA with 1.5 GeV. The thermal loading effect of focusing mirror causes I_0 drop faster than expected.

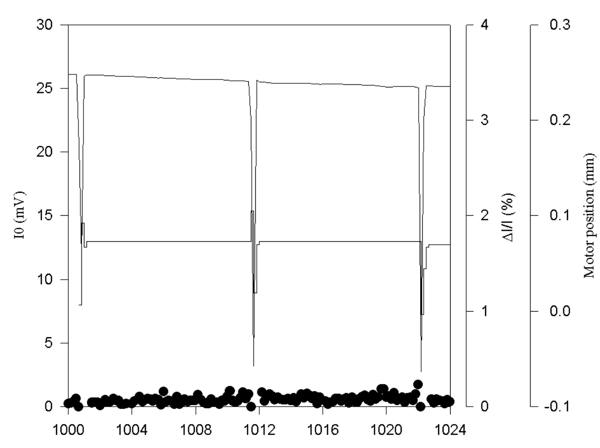

Figure 5. The parameters measured by APTS at 100 mA with 1.5 GeV. The I_0 is function of stored beam current only during thermal equilibrium of focusing mirror. The pinhole position also remains steady.

Figure 5 gives us the parameters taken by APTS with 105 mA beam current. The thermal balance of the VFM is reached. After the only optical component, VFM, reached thermal balance, measured photo-current is function of stored beam current only. The motor position remains unchanging after retracing. The calculated beam stability, 0.1%~0.15%, reflects the very stable synchrotron radiation at TLS.

4 DISCUSSIONS

The backlash of pinhole position and optic-axis drifting problems are compensated by the peak-tracing algorithm. Both simulation and experiment show the stability is proportional to the distance between beam profile and pinhole center. The intensity distribution of beam profile can be determined by a Gaussian fitting program using the APTS. From beam bump creating experiments, we found the photo-current is much more sensitive to the angular change of optic axis, which mainly caused by the thermal effect of the VFM, than beam position offset.

There are many projects were undertaken to improve the reliability of the storage ring and the beam stability. The APTS is the one of the major indicator for the figure of merit of the beam quality during the users' shift. It also provides a convenient tool for machine study. The cure of the longitudinal-couple-bunch effect by a second tuner installed in RF cavity and the change of working lattice [6], increasing the beam emittance and the dispersion function, make the beam stability reached better than 0.2%. A precision driving mechanism of the pinhole position and water-cooled VFM is planned to enhance the measurement reliability and accuracy of the APTS.

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