APPLICATION OF THE GIGE VISION DIGITAL CAMERA FOR BEAM DIAGNOSTICS IN HLS*

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Abstract

GigE Vision (Gigabit Ethernet vision standard) is a new interface standard for the latest vision of cameras with higher performance compared to analogue vision standard and other digital vision standard. In recent years, the market of industrial vision components is evolving towards GigE Vision. The cameras comply with GigE Vision are capable of providing low distortion for image transmission over long distance with high image rate. This paper will present applications of GigE Vision digital camera for the measurement of beam profile and emittance at the storage ring of HLS (Hefei Light Source).

INSTRUCTION

The electron beam profile and transverse emittance are very important parameters to every particle accelerator, which are beneficial to characterize and analyze properties of electron beam. The beam profile could be measured most often by fluorescence method and various optical diagnostics (SR, OTR, DR, etc.). SR (Synchrotron radiation) monitor is nondestructive method to measure beam profile mostly employed at storage ring [1].

The GigE Vision standard is a new interface standard for the latest vision of cameras with higher performance than analogue vision standard and other digital vision standard. Compared to the analogue camera, the GigE Vision digital camera has three major advantages. First, the A/D conversion is performed closer to the CCD/CMOS sensor and therefore it minimizes electronic noise. Second, unlike the analogue camera, the image acquisition of the GigE Vision digital camera does not suffer from pixel jitter [2]. Last, the digital image data could be acquired directly without frame-grabber.

As a latest vision of camera, GigE Vision is superior to the other digital vision standard such as IEEE 1394a/b and USB 2.0. The GigE Vision standard interface is capable of transmitting image data at lager rate to longer distance. The GigE Vision standard interface is capable of transmitting data at maximum rates of 1000Mbit/s, the maximum distance of lossless image transmission is 100m without any hub.

The GigE Vision owns superiorities of high data rates, widespread Ethernet interface of computer and long haul, which makes Gigabit Ethernet an attractive interface option for beam diagnostics application on accelerator. The implement of SR monitor based on GigE Vision digital cameras would increase the image signal transmission quality, the dynamic range, the linearity of the profile and the superior supports for data analysis [2].

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SYNCHROTRON RADIATION MONITOR BASED ON THE GigE Vision CAMERA

The synchrotron radiation monitor consists of optical imaging, image acquisition, camera, and data analysis tool. As shown in Fig. 1, the synchrotron radiation light radiated from banding magnet is reflected from mirror to a lens through a slit. The lens with focal length 1100mm performs 2:1 optics. To avoid the chromatic aberration of the optical lens, a band- pass filter centered at 532 nm with 20 nm bandwidth is used to monochromate the light. According to the light intensity, we insert appropriate attenuator in the optical imaging path. The essentialities of optics are to optimize the diffraction effect, depth of field and curvature errors. PicSight G32M-GigE camera was selected to capture the SR profile. 8 bits and 12 bits image data captured by the camera can be switched freely. And parameters of the camera are completely programmable so that it is very useful to accommodate with various beam conditions and effectively increases reliability. The GigE Vision digital camera transmits the image of light profile to Ethernet by CAT5e/CAT6 cable, and then a local PC receives the image data from Ethernet.

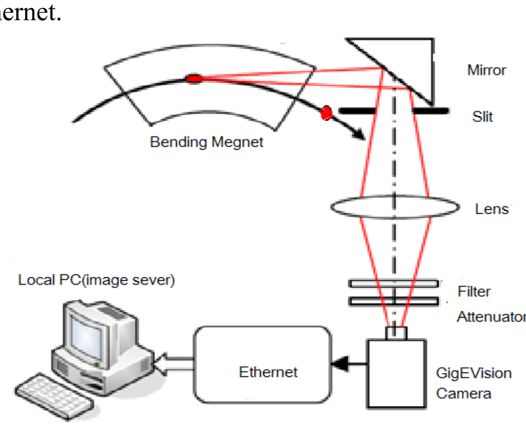


Figure 1: Block diagram of beam profile measurement system

SOFTWARE ENVIRONMENT

The software environment is developed based on LabVIEW running on a local PC, includes a GigE Vision digital camera driver, Ethernet communication, image processing and analysis, and beam status displays.

The beam profile imaging on the CMOS sensor is assumed as two dimensions Gaussian distribution as shown in Fig. 2. The beam profile can be described as in equation (1) [1].

$$f(x,y) = A\frac{1}{\sqrt{2\pi\sigma_x\sigma_y}}e^{-\frac{(x-\mu_x)^2}{2\sigma_x^2}-k\frac{(x-\mu_x)(y-\mu_y)}{\sigma_x\sigma_y}-\frac{(y-\mu_y)^2}{2\sigma_y^2}} \quad (1)$$

Where, σ_x and σ_y are the horizontal and vertical RMS (root mean square) beam size respectively, μ_x and $\mu_y$are the horizontal and vertical photon beam profile centre position respectively.

Firstly, the LabVIEW program will save pixels value of a beam profile image to a two dimensions array. We must subtract the background noise that is brought about by dark current of CMOS sensor from pixels value of the beam image to get meaningful image data [1]. And then in the LabVIEW program the image data obeying two dimensional Gaussian distribution is integrated to one dimensional Gaussian distribution in x and y direction respectively [3] (see Eq.2).

$$\begin{aligned} f(x) &= A\frac{1}{\sqrt{2\pi}\sigma_x}e^{-\frac{(x-\mu_x)^2}{2\sigma_x^2}} \\ f(y) &= A\frac{1}{\sqrt{2\pi}\sigma_y}e^{-\frac{(y-\mu_y)^2}{2\sigma_y^2}} \end{aligned} \quad (2)$$

As shown in Fig. 2, we take one dimensional Gaussian fitting to get the standard variance σ_x (σ_y) and the centre position μ_x (μ_y) of the Gaussian curve. The pixel size of COMS sensor of the GigE Vision digital camera is 9.9×9.9μm, so the values of σx and σy multiply 0.0099mm respectively to get the actual horizontal and vertical sizes of beam profile.

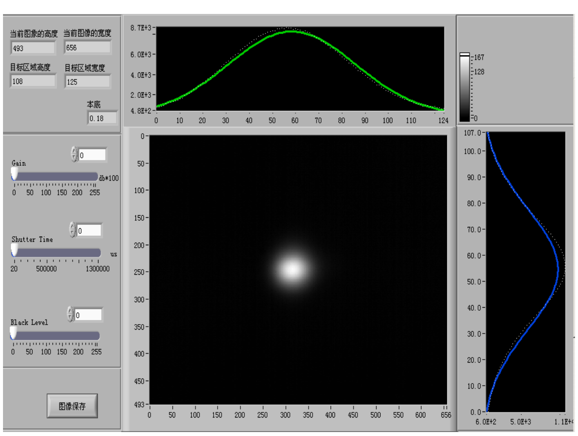


Figure 2: image of beam profile and Gaussian fitting

Using the local bump orbit method, the photon beam position was calibrated to be accordance with the positions from BPM (beam position monitors) system [3].

At storage ring of HLS, we didn't take the dispersion into account. In this case the emittance is given below [1].

$$\varepsilon_{x,y} \approx \frac{\sigma_{x,y}^2}{\beta_{x,y}} \quad (3)$$

Where, $\beta_{x,\ y}$ is β-function. When the values of beam profile size $\sigma_{x,y}$, were obtained, the emittance $\varepsilon_{x,y}$ could be calculated according to equation (3). Then the degree of coupling is given below.

$$K = \frac{\varepsilon_y}{\varepsilon_x} \quad (4)$$

ERRORS ANALYSIS FOR OPTICAL SYSTEM

As the synchrotron radiation light radiated from the bending magnetic, the natural angle is $\Phi_{SR.}$

$$\Phi_{SR} = \frac{1}{\gamma}\cdot\sqrt[3]{\frac{\lambda}{\lambda_c}} \quad (5)$$

Where γ, λ, and λ_C are electron relative energy observed wavelength and critical wavelength respectively. At storage ring of HLS, the natural half opening angle Φ_{SR} is 3.85mrad at 532nm wavelength.

The acceptance angle 2θ depends on the slit size as shown in figure 3, where ρ is the bending magnetic radius. Due to the nature of the source, the curvature of the electron beam contributes an error term that limits the horizontal resolution [4]. The curved orbit error $\Delta_{x,curv}$ is given below.

$$\Delta_{x,curv} = \frac{\rho}{\cos\theta} - \rho \approx \frac{1}{2}\rho\theta^2 \quad (6)$$

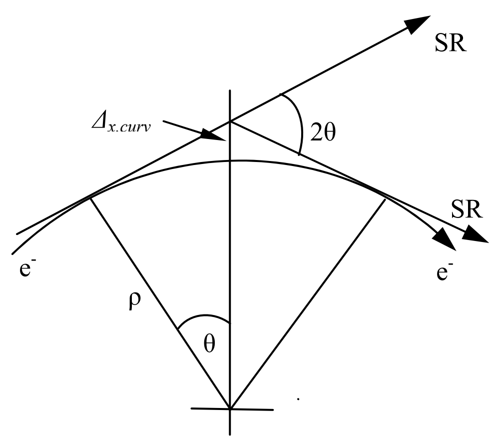


Figure 3: Curved orbit error sketch

Any imaging system that involves apertures will inevitably have a diffraction error. The error is given by equation (7) [4].

$$\Delta_{diff} = F\frac{\lambda}{\sin 2\theta} \approx \frac{1}{2}\frac{\lambda}{\theta} \quad (7)$$

Increasing the half-acceptance angle θ will decrease diffraction error, hence enlarge the error which comes from the curved orbit. The optimized half-acceptance θ was set by equating the curved orbit error $\Delta_{x,curv}$ and diffraction error $\Delta_{x,diff}$.

The optimized half-acceptance θ is given below:

$$\theta = \sqrt[6]{\frac{\lambda^2}{2\rho^2}} \tag{8}$$

With regard to HLS, ρ=2.2221m and λ=532nm, the optimum value of θ is 5.532mrad for horizontal direction.

According to equations (6) and (7), the value of curvature error $\Delta_{x,curv}$ is 34.00μm and diffraction error $\Delta_{x,diff}$ is 48.08μm. The calibrated horizontal size is given by equation (9).

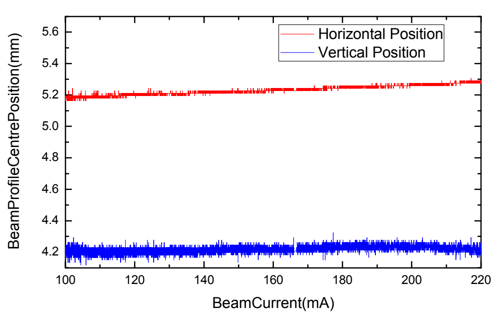
$$\sigma_{x,calibration} = \sqrt{\sigma^2_{x,measurement} - \Delta^2_{x,curv} - \Delta^2_{x,diff}} \tag{9}$$

For the vertical case, the diffraction error primarily affects the vertical size. The minimum diffraction error is determined by the natural opening angle of the SR light. According to the equation (7), the diffraction error can be estimated by replacing the half opening angle θ of slit by nature SR angle Φ_{SR}. The value of $\Delta_{y,diff}$ is 69.09μm, and the calibrated vertical size is given below.

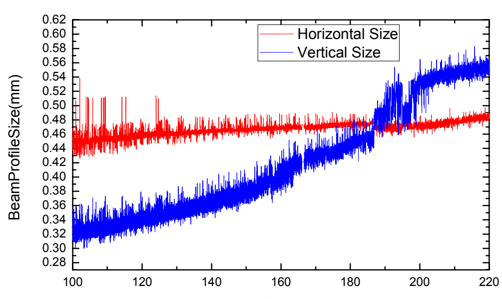
$$\sigma_{y,calibration} = \sqrt{\sigma^2_{y,measurement} - \Delta^2_{y,diff}} \tag{10}$$

OPERATION STATUS

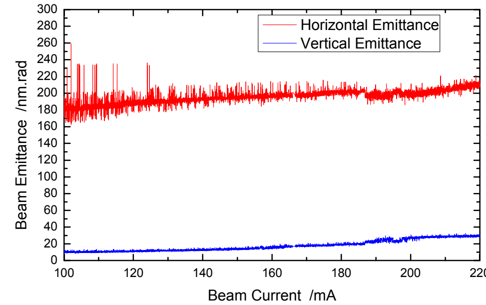
The operation status of the beam profile and emittance measurement system based on the GigE Vision digital camera at HLS is shown in Fig. 4.



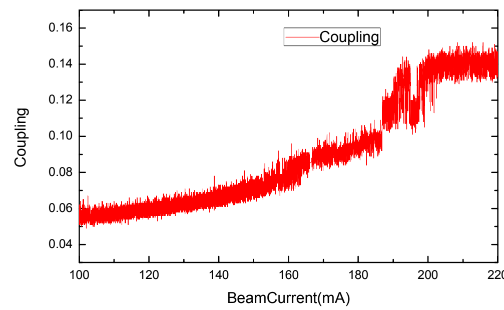
(a) Position



(b) Beam size



(c) Emittance



(d) Coupling

Figure 4: Beam transverse parameters varying with beam current

CONCLUSION

The GigE Vision digital camera had been tested successfully at HLS for measuring beam profile and emittance. Gigabit Ethernet provides high performance camera interface to convey control parameters and image information. Image quality is scarcely affected by transmission distance. In the future, we will apply the GigE Vision digital camera at injector of HLS for beam profile and emittance measurement, and put on more effects for system integration. A large distributed digital camera system for accelerator beam diagnostic will be designed.

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