A LASER WIRE SYSTEM AT ELECTRON BEAM TRANSPORT LINE IN BEPCII*

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Abstract

A Laser Wire system is under development at transport line in BEPCII (Beijing Electron Positron Collider). The structure of whole system is briefly described in this paper. Some work on laser and detector are presented. We also discussed the challenge of Laser Wire and some other things that can affect measurement. According to the plan, the Laser Wire will be installed in electron beam transport line in the summer of 2012.

INTRODUCTION

Laser Wire is a kind of beam profile monitor by using focused laser beam to measure electron (positron) or H^- beam profile. The measured signal comes from Compton scattering between electron (positron) and photon, or photon-ionization of H^- ion. Compared to many other beam profile monitors, it has advantages of high resolution, non-destructive and no current limit. Laser Wire has been used in many kinds of accelerators [1-4], such as collider, synchrotron radiation light source, spallation neutron source, accelerator test facility, and it will be used in more accelerators. Specially, it will be used in beam delivery line in future linear collider, either ILC or CLIC, as the standard beam profile measurement device [5-6].

BEPCII is the upgrade of Beijing Electron-Positron Collider (BEPC). It mainly serves for high energy physics, and also can serve for synchrotron radiation research in parasitic and dedicated modes. The 200m Linac can accelerate electron or positron up to 2.5GeV or 2.3GeV, respectively. Electron and positron beam go through the each of 120m transport line, and then injected into the storage ring. Usually, the bunch repetition rate of the Linac is 50Hz, and it can also be 25Hz or 12.5Hz. For 50Hz operation, the charge of electron beam is about 0.5nC in every single bunch, and can be up to 2.5nC for special use.

The plan of Laser Wire in BEPCII was considered in several years ago, and the work started in 2010. The design of the whole system has been completed. Research and test work on sub-system are underway, such as laser parameter measurement and stability test, laser transport line design, scanning system control, detector simulation and construction.

SCHEME OF LASER WIRE SYSTEM

An overview of the Laser Wire system in BEPCII is illustrated in Fig. 1. The Laser Wire will be installed in the electron beam transport line. The laser comes from a Q-switch Nd:YAG laser system. The laser beam is expanded to a bigger diameter through the beam expander, and then goes to the scanning system. The scanning system is made up of three motorized translation stage to scan the focused laser in vertical direction and change the focus beam waist position in horizontal direction. The laser interacts with electron beam in the interaction chamber, a four-way cross with two viewports for laser passing through. The viewports are two plane mirror made of fused silica with 100mm diameter and 12.7mm thickness. The interaction chamber located after the quadrupole magnet TEQF7. Coming out from the interaction chamber, the laser is directed to the laser diagnostic part. The laser diagnostic part includes laser power meter at least, and maybe have some other laser measurement devices, such as laser profile monitor and photodiode for time measurement.

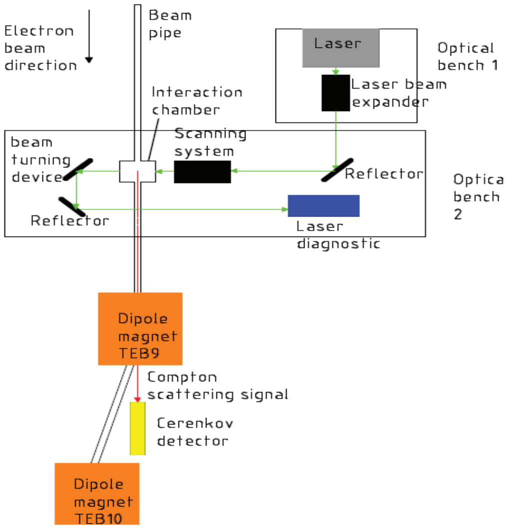

Figure 1: Layout of Laser Wire system.

The detector is about 5m downstream from the interaction chamber, after the dipole magnet TEB9. The detector is Cerenkov detector, and the material is lead glass.

LASER

The Laser Wire uses the second harmonic, the 532nm wavelength laser. The repetition rate of laser pulse is 10Hz. The energy of one pulse is about 150mJ. The pulse width is about 8ns.

The M^2 and pointing jitter are two important parameters. The Fig. 2 shows the measurement result of the two parameters for horizontal direction. The fit result of M^2 is

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6.741 ± 0.305, a little bigger than we expected. The RMS of pointing jitter is 28.1μrad. We found that there is an obvious tail in the vertical direction in the profile measurement, which makes the vertical measurement obviously larger than it should be. We are solving this problem, together with the laser company.

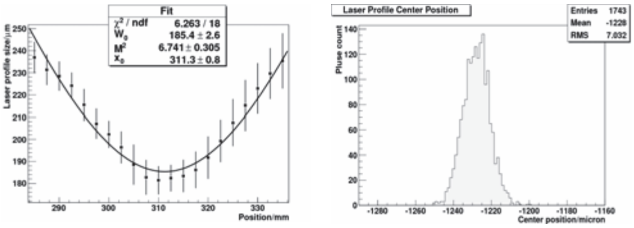

Figure 2: Left: Fit result of M^2. Right: Laser profile center position distribution, the focus length of lens is 250mm.

Another important work is to test the stability of laser system, especially the power stability. From our monitor, the power does not vary too much in a short time, for example, in1~2 hours. But in a long time run, such as more than 8 hours, we find the power vary above 10% and sometime even more tan 20% in the whole time scale. At the same time, the power RMS of every minute is bigger than the first hour. This means the short time stability also become worse. We monitored the first harmonic of the laser, the 1064nm, and found the stability of the power and the RMS of every minute is much better than the second harmonic. So we think the problem may come from the frequency doubling crystal, and changed a new frequency doubling crystal. The monitor of power with new frequency doubling crystal is under way.

DETECTOR

Because the beam loss may cause serious background, we decide to use Cerenkov detector. The threshold of Cerenkov detector can help suppress the background signal, and get a better signal to noise ratio.

We simulated the Cerenkov detector performance with Geant4. With consideration of photon production ratio and radiation length, the material used in simulation is SF5 [7] lead glass. We simulated the electromagnetic shower in the lead glass, to decide the approximate dimensions of detector for including the major shower energy in the detector. Then we varied the dimensions, and simulated the performance of the detector to get the optimized dimensions, with which the PMT (PhotoMultiplier Tubes) can collect as many photons as possible. With optimized dimensions, we can expect a larger signal and better signal to noise ratio.

Some simulation results are showed in Fig. 3. To decide the dimensions of the detector, we must also consider some other things except the simulation result. For example, there should be some space between the detector and the beam pipe for lead to shield, and the back of the detector should be not too close to the dipole magnet TEB10 (see Fig. 1), because the magnetic field of TEB10 may affect the PMT on the top of the detector. With the simulation result and other considerations, the dimensions of detector are 220mm*40mm*40mm.

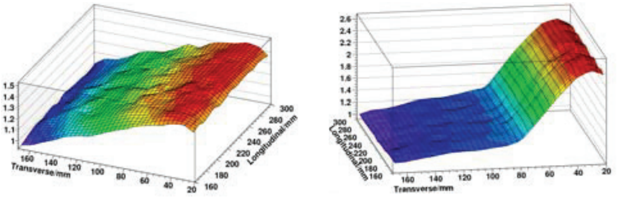

Figure 3: Relative quantity of photon collected in PMT in 50ns (left) and 300ns (right) from the time of Compton scattering, with different detector dimensions.

We also simulated the respond of the detector with Compton signal produced in different position in beam pipe, which is just the situation when the laser scans. For the same Compton signals, the photon collected in PMT is showed in Fig. 4. There are three possible reasons for the different respond of the detector. First, though the Compton signals are the same when they are produced in beam pipe, when they traverse the beam pipe, the lost ratios are different. Because Compton signals produced in different position have a different traversal length in beam pipe. The Compton signals arriving in detector are different. Second, the detector responds differently with gammas which go into the detector in different position on the surface, even they have the same energy and direction. Last, the number of Compton signals is not large enough, and there is stochastic fluctuating component. The beam pipe and detector effect can be calibrated. We can also change the detector position together with the scanning laser to eliminate the effect of different gamma incident position on detector. To reduce fluctuating component, the signal quantity should be as large as possible. The linearity of the detector needs more research.

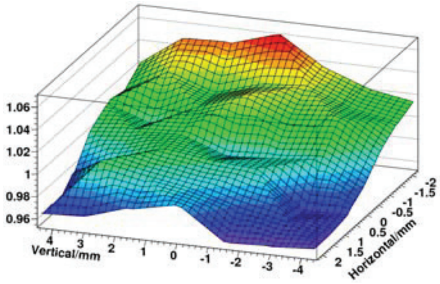

Figure 4: Relative quantity of photon collected in PMT for Compton signals produced in different positions in beam pipe.

SOME DISCUSSION

The biggest challenge is the low signal for Laser Wire in BEPCⅡ transport line. The vertical beam profile is about 1.5mm. The charge of one bunch at the Laser Wire location can be above 0.5nC or even be 1nC for the accelerator's best performance. The laser pulse energy may be increase to about 200mJ. From the theory, the maximum energy of the Compton scattered gamma is about 67MeV, and the number of scattered gammas is about 20 every bunch at most. After traverse the beam pipe, a little more than 40% of signals will be lost according to simulation. It's possible for the detector to detect even one gamma with the background shield and high-gain PMT, but it will be take a long time to get enough signals for measurement.

Many other things can affect the measurement with Laser Wire, such as Rayleigh range, laser pulse energy and bunch charge fluctuating, laser pointing and bunch position jitter, timing error and jitter.

If the Rayleigh range is too small, the distribution of signal will be far from Gaussian, resulting in a measurement error. The horizontal beam profile at the Laser Wire location is about 0.75mm, only half of vertical profile. So it can be expected the Rayleigh range effect is not too serious. We estimated numerically this error for different Rayleigh range, from different input laser diameter on focus lens and focus length of focus lens. We find the error is small for our experiment.

The laser pulse energy and bunch charge can be monitor in the Laser Wire measurement. The data are used to normalize the measured signal. A laser power peter will monitor the laser power fluctuating. There is no BPM at the location of Laser Wire. The nearest two BPM are TEBPM2 before and TEBPM3 after the Laser Wire. We found that the bunch charge is almost no difference after TEBPM2. So the bunch charge information from TEBPM2 and TEBPM3 may be useful for monitoring the bunch charge fluctuating at the Laser Wire location.

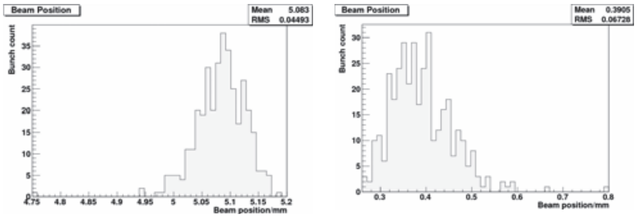

Figure 5: Beam vertical position distribution of TEBPM2 (left) and TEBPM3 (right).

Laser pointing jitter have been measured, see Fig. 2. Because of no BPM at the Laser Wire location, we took a look at the vertical beam jitter at TEBPM2 and TEBPM3 when electron beam is injected in storage ring, as shown in Fig. 5. It should be pointed out that we exclude the beam position data of the first few seconds in injection, because of the unusual bigger jitter than normal situation. The RMS of vertical jitter is 44.9μm for TEBPM2 and 67.3μm for TEBPM3, which are much smaller than the beam profile size.

The timing error and jitter only result in a signal reduction. We suppose the timing jitter distribution is Gaussian. For vertical scan, when $\sigma_e \gg \sigma_l$ and $\sigma_s \gg \sigma_h$, the signal attenuation factor from timing error and jitter, f_1 and f_2, can be estimated as

$$f_1 = \exp\left(-\frac{1}{2}\frac{\Delta t^2}{\sigma_t^2 + \sigma_{et}^2 + \sigma_{st}^2}\right) \tag{1}$$

and

$$f_2 = \sqrt{\frac{\sigma_{et}^2 + \sigma_{st}^2}{\sigma_t^2 + \sigma_{et}^2 + \sigma_{st}^2}} \tag{2}$$

where σ_e is electron bunch length, σ_l is laser focus size, σ_s is laser pulse length, σ_h is horizontal beam profile size, Δt is timing error, σ_t is the RMS of timing jitter, σ_{et} and σ_{st} are in time unit. The timing error and jitter effect are small in our experiment.

CONCLUSION AND OUTLOOK

The Laser Wire system at BEPCII is under development. We have completed the design of the whole system. Works on subsystems are underway. There are many things which can affect Laser Wire measurement, and need to be treated carefully. The next step is to finish the work on all subsystem and run as a whole system without electron beam in laboratory. According to the plan, the Laser Wire will be installed in the electron beam transport line in this summer, and Laser Wire measurement experiment will start in the next accelerator run.

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