ISBN: 978-3-95450-199-1 doi:10.18429/JACoW-SAP2017-WEAH4

BUNCH LENGTH MEASUREMENT SYSTEM FOR 500 kV PHOTOCATHODE DC GUN AT IHEP

O. Z. Xiao[1], J. R. Zhang, X. P. Li, X.J.Wang, D.R.Sun
Institute of High Energy Physics, Chinese Academy of Sciences, Beijing, China
[1]also at Key Laboratory of Particle Acceleration Physics and Technology,
Institute of High Energy Physics, Chinese Academy of Sciences, Beijing, China

Abstract

In September of 2011, a 500 kV photocathode DC gun was proposed for FEL-ERL two purpose facility at Institute of High Energy Physics (IHEP). So far, the whole system has been installed and the preliminary high voltage conditioning has been carried out. Since the photocathode response time influence the beam quality, the bunch length measurement system is required, which consist of a solenoid, a 1.3 GHz standing wave deflecting cavity, a slit and a YAG screen. In this paper, the design of a deflecting cavity with TM_{210} mode is presented. In addition, the beam dynamics study of the bunch measurement system is performed using ASTRA and the layout of the bunch measurement system is determined. The bunch length in simulation is in good agreement with theoretical calculation.

INTRODUCTION

High voltage DC electron guns based on GaAs photocathode are proposed for energy recovery linac and free electron laser in many laboratories around the world. Compared with RF guns, DC guns can produce high average current beam with low emittance and operate at CW mode. As a key technology for future advanced light source, the R&D of photocathode dc electron gun was supported at IHEP in 2012. So far, the construction of the DC gun had been completed and a preliminary high voltage conditioning was carried out up to 440 kV [1]. The performance of photocathode depends on many factors such as cathode material, the preparation and activation condition, which will influence the beam parameter. For example, the photocathode with slow response time will generate a long tail compared with laser pulse width, which will cause the emittance growth. For this reason, a bunch length and longitudinal profile measurement system based on deflecting cavity is essential to investigate cathode property.

BUNCH LENGTH MEASUREMENT SYSTEM DESIGN

To reduce the space charge effect in the gun region, the laser pulse illuminating the photocathode is necessary to shape and extend to tens of picoseconds. In our case, the laser pulse is like plateau distribution with flat top of 20 ps and rise and fall time each of 2 ps. The beam longitudinal distribution is almost the same as the laser pulse when the photocathode response time is rapid. In order to study the properties of photocathode, a bunch length measurement system is proposed, which includes a solenoid, a 1.3 GHz standing wave deflecting cavity, a slit and a YAG screen. The deflecting cavity is 1.15 m away from the cathode of the electron gun. A YAG screen to measure the transverse beam profile is put at downstream of 1.4 m from deflecting cavity. To improve the resolution length of measurement, a solenoid after the gun and a slit before the deflecting cavity are used to reduce the horizontal beam size. The resolution length determine the measurement accuracy, which is defined as

$$L_{res\_t} = \frac{\sigma_{x0}(E/e)}{wV_{def}L} \quad (1)$$

Where σ_{x0} is the horizontal beam size at screen with deflecting cavity turn-off, E is the beam energy, V_{def} is the deflecting voltage, w is the circular frequency of cavity. The layout of the bunch measurement system is shown in Fig. 1.

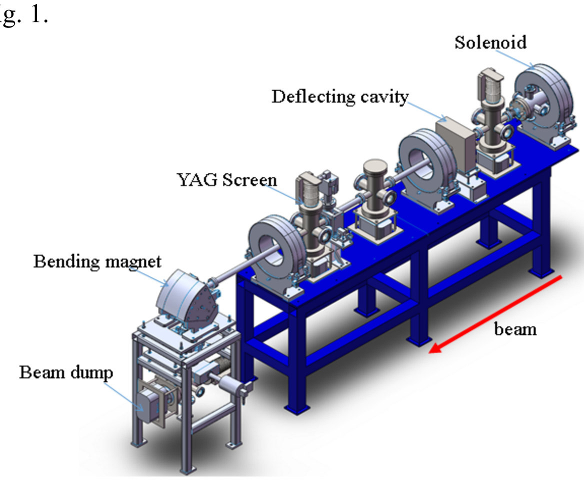


Figure 1: The layout of the bunch measurement system.

The parameters of the bunch measurement system are presented in Table 1. Using these parameters, the relation between the resolution length and the input power is shown in Fig. 2.

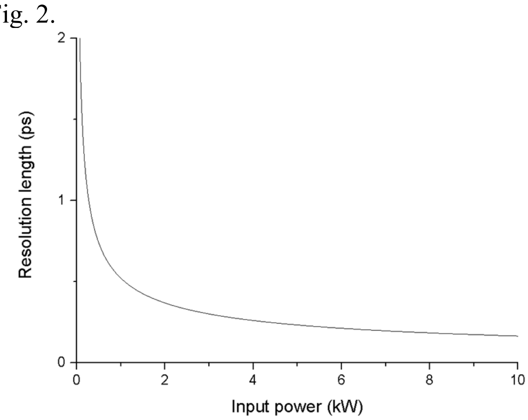


Figure 2: The relation between the resolution length and the input power.

ISBN: 978-3-95450-199-1 doi:10.18429/JACoW-SAP2017-WEAH4

Table 1: The Parameters for Bunch Measurement System

Parameters	Value
Beam Energy(MeV)	0.5
Beam Normalized Emittance(mm.mrad)	0.3
Bunch Total Length(ps)	30
Bunch RMS Length(ps)	6
Beam Size without Deflecting Cavity(mm)	0.5
Resolution length(ps)	1
Drift Length（m）	1.4
Deflecting Cavity Frequency（GHz）	1.3
Deflecting Voltage(kV)	23
Input Power(W)	250
Solenoid Magnetic Field（Gs）	310

DEFLECTING CAVITY DESIGN AND MEASUREMENT RESULTS

The multi-cell deflecting cavity can be used for high energy or low energy beam. However the beam energy of 0.5 MeV is relative low, a single-cell cavity will be applied to reduce the complexity of cavity design. The cavity operating at TM_{210} is similar to the RF deflector at KEK [2]. The amplitude of transverse deflecting voltage acting on a beam on axis is

$$V_\perp = \left| c\int_{-\infty}^{\infty} B_\perp(z).e^{jkz/\beta}dz - j\frac{1}{\beta}\int_{-\infty}^{\infty} E_\perp(z).e^{jkz/\beta}dz \right| \quad (2)$$

where $B_\perp(z)$ and $E_\perp(z)$ are the transverse components of the magnetic and electric fields on axis, k is the wave number, z is the longitudinal coordinate, c is the speed of light, β is the particle relative velocity. According to the Panofsky-Wenzel theorem, the deflecting voltage can be defined as

$$V_\perp = \left| \frac{1}{\beta ka} \int_{-\infty}^{\infty} E_z(z).e^{jkz/\beta}dz \right| \quad (3)$$

The transverse shunt impedance is defined as

$$Z_\perp = \left| \frac{V_\perp^2}{2P} \right| \quad (4)$$

P is the power dissipated in the cavity walls. The higher the transverse impedance value, the less power is required to get a certain deflecting voltage. The cavity shape and dimension is optimized to maximize $Z_\perp$ and unloaded Q factor using CST [3]. To separate the orthogonal dipole modes, the cavity horizontal width is slight larger than vertical width. The parasitic modes are also simulated, which should not be exited. The oxygen free high conductivity copper material is used for fabrication of the cavity because of the low ohmic losses and the high thermal conductivity. After the cavity was fabricated and assembled, some characteristic parameters are measured with a network analyser. Table 2 and Table 3 summarize cavity parameters and the frequency of parasitic modes respectively. The vacuum leak detection of the cavity is shown in Fig. 3. The electromagnetic field pattern of TM_{210} is shown in Fig. 4.

Table 2: Comparison of Cavity Parameters

Parameters	Simulation	Test
f (GHz)	1.3	1.3
Q_0	23323	20964
$Z_\perp$(Mohm)	0.88	-
β	1.02	1.01

Table 3: Parasitic Modes Frequency

Mode	Frequency (MHz)
TM_{110}	849.6
TM_{120}	1363
TM_{220}	1692
TM_{310}	1838

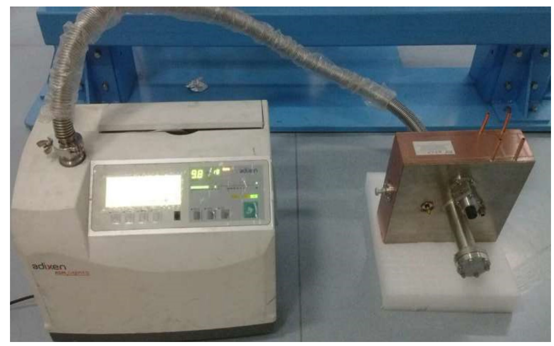


Figure 3: The vacuum leak detection of the cavity.

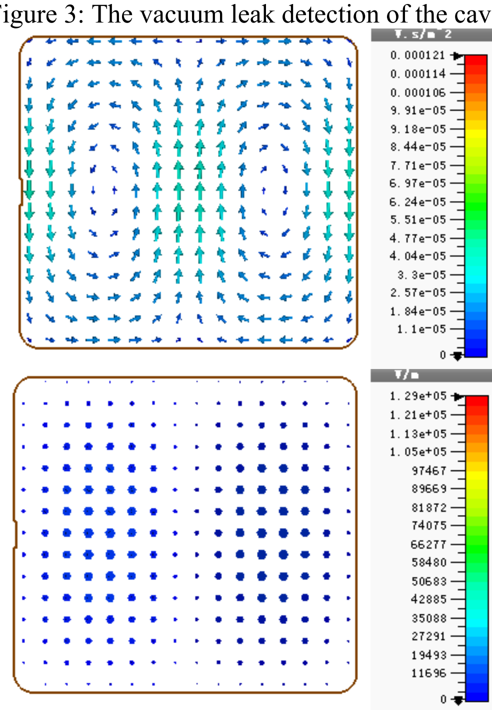


Figure 4: Electromagnetic field pattern of TM_{210} with 1 W input power.

BEAM DYNAMIC SIMULATION

The beam dynamics of the whole bunch measurement system is simulated in two different cases using ASTRA [4]. One case is low input power of 250 Watts with slit to collimate the beam in horizontal direction, and the other case is high input power of 1000 Watts without slit.

ISBN: 978-3-95450-199-1 doi:10.18429/JACoW-SAP2017-WEAH4

The resolution length of both cases is almost the same. After the deflector, the beam longitudinal position relative to the bunch centre is transformed into transverse displacement on the screen. Then the bunch length can be calculated according to bunch spot size, which is defined as

$$\sigma_t = \frac{(E/e)}{2\pi f V_{def} L}\sqrt{\sigma_x^2 - \sigma_{x0}^2} \quad (5)$$

Where σ_x is the beam spot size on screen in horizontal direction when the deflector is turn-on. The bunch length calculation results of both cases are summarized in Table 4, which are agreement with the bunch length of 6.15 ps before deflecting cavity.

Table 3: The Bunch Length Calculation Results

Parameters	Case1	Case2
V_{def}(kV)	42	21
σ_{x0}(mm)	1.08	0.58
σ_x(mm)	5.96	3.02
σ_t(ps)	6.1	6.18

The electromagnetic field along the longitudinal direction of the latter case is shown in Fig. 5.

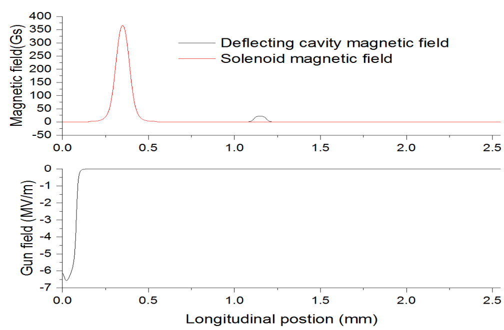
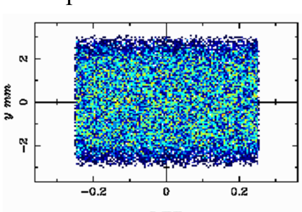
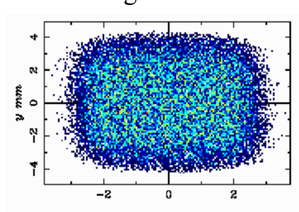


Figure 5: Electromagnetic field along the longitudinal direction.

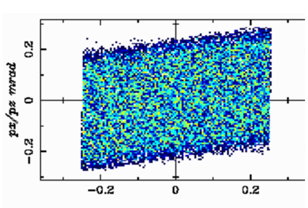
The evolution of the bunch transverse distribution and phase space of both cases are shown in Figs. 6 and 7.



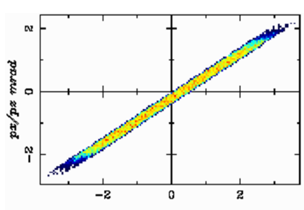
a)Transverse distribution before deflector



b)Transverse distribution after deflector

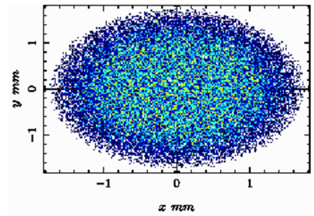


c)Horizontal space phase before deflector

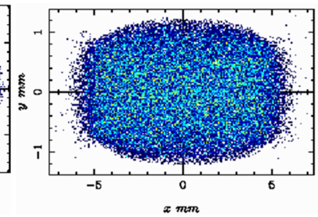


d) Horizontal space phase after deflector

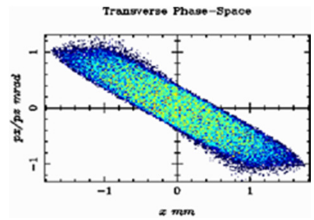
Figure 6: The transverse beam distribution with slit.



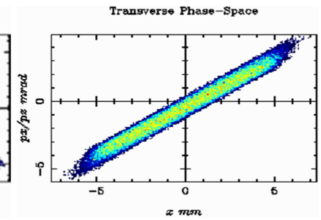
a)Transverse distribution before deflector



b)Transverse distribution after deflector



c)Horizontal space phase before deflector



d) Horizontal space phase after deflector

Figure 7: The transverse beam distribution without slit.

The Figs. 6 and 7 indicate that the beam horizontal energy spread and spot size increase due to the horizontal kick of deflector. Also the horizontal distribution on the screen can be converted to longitudinal profile after some mathematical treatment, as shown in Fig. 8. The profile from the screen is in agreement with that before deflector.

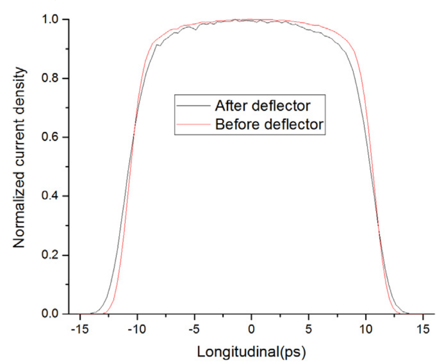


Figure 8: Comparison of the beam longitudinal profile.

CONCLUSION

The transverse deflecting cavity is an accurate and effective means to measure bunch length and distribution. This paper presented the bunch measurement system based on deflector for 500 kV photocathode dc gun at IHEP. A 1.3 GHz rectangular deflecting cavity operating at TM_{210} mode has been designed and fabricated. The cold test has been completed and the characteristic parameters are in good agreement with simulation in CST. So far all components used in the beam length measurement system have been installed. The beam dynamics of the bunch length measurement system has been simulated. The slit before the deflecting cavity can be used to reduce the input power requirement. The error analysis and simulation are in progress.

ISBN: 978-3-95450-199-1 doi:10.18429/JACoW-SAP2017-WEAH4

REFERENCES

[1] Xiao-Ping Li, Jiu-Qing Wang ,Jin-Qiang Xu *et al.*, "Constructions and Preliminary HV Conditioning of a Photocathode Direct-Current Electron Gun at IHEP", *Chin. Phys. Lett* ,Vol. 34, No. 7 ,2017.

[2] S. Matsuba *et al.*, "Deflecting cavity for bunch length diagnostics at compact ERL Injector", in *Proc. IPAC'10*, Kyoto, Japan, 2010.

[3] *CST 2017 Manual*, 2017.

[4] Klaus Floettmann, *ASTRA Manual V3*, 2011.