BUNCH LENGTH MEASUREMENT USING A TRAVELLING WAVE RF DEFLECTOR*

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Abstract

RF deflectors can be used for bunch length measurement with high resolution. This paper describes the completed S-band travelling wave RF deflector and the bunch length measurement of the electron beam produced by the photocathode RF gun of Shanghai DUV-FEL facility. The deflector's VSWR is 1.06, the whole attenuation 0.5dB, and the bandwidth 4.77MHz for VSWR less than 1.1. With laser pulse width of 8.5ps, beam energy of 4.2 MeV, bunch charge of 0.64 nC, the bunch lengths for different RF input power into the deflector were measured, and the averaged rms bunch length of 5.25 ps was obtained. A YAG crystal is used as a screen downstream of the deflector, with the calibrated value of 1*pix* =136*um*.

INTRODUCTION

The development of future free electron lasers and linear colliders requires high brightness electron beams with bunch lengths on the order of ps or sub-ps. Reliable measurement of such a short bunch is not a trivial problem. Using an RF deflector to measurement bunch length is quite promising, shown by the demonstrated results at SLAC[1] and DESY[2]. It is an advanced, reliable and economical method.

In order to handle the RF deflector method and measure the bunch length of Shanghai Deep Ultra-Violet FEL (SDUV-FEL), a short travelling wave RF deflector was developed and used to measure the bunch length of the photocathode RF gun of SDUV-FEL as a first step.

RF DEFLECTOR

A short travelling wave RF deflector was designed and fabricated[3]. The transverse RF deflector is of an iris-loaded waveguide structure. The deflecting mode is TM_{11}-like or HEM_{11} mode. It operates at 2856MHz because the high power klystrons and other equipments are readily available in our lab. A $2\pi/3$ phase shift per cell has been chosen. It works in backward-wave type mode. Two additional holes are provided to stabilize the mode and to prevent mode rotations.

The main parameters of the deflector are reported in Table 1, while Figure 1 shows a picture of the completed deflector. The VSWR of the deflector is 1.06. The whole attenuation is 0.5dB from input to output. The bandwidth is 4.77MHz when VSWR is less than 1.1.

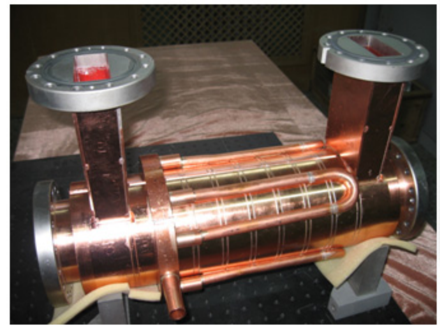

Figure 1: The completed deflector.

Table 1: The Main Parameters of the Deflector

Type of structure	Constant impedance structure
Mode type	HEM_{11} (Hybrid mode)
Frequency	2856 MHz
Number of cell	8cells+2couplers
Phase shift/cell	$2\pi/3$ (120^o)
Cell length	35 mm
Wavelength	105 mm
Relative group velocity	-0.0189
Transverse shunt impedance	~10Mohm/m

EXPERIMENTAL SETUP

Power Feeding System

There is only one 25MW klystron to provide the power. A 3dB directional coupler is used to divide the power into the photocathode RF electron gun and the deflector. Figure 2 gives the power feeding system sketch. The RF gun needs to feed more than 10MW, so the power to the deflector will also be more than 10MW. Yet the input power needed for the deflector is less than 1MW, therefore a high power attenuator is installed in the deflector branch. In order to change the phase of the input power to the deflector, a high power phase shifter is installed downstream the attenuator. A 50 dB directional coupler is installed downstream the phase shifter in order to monitor the RF power level and phase into the deflector.

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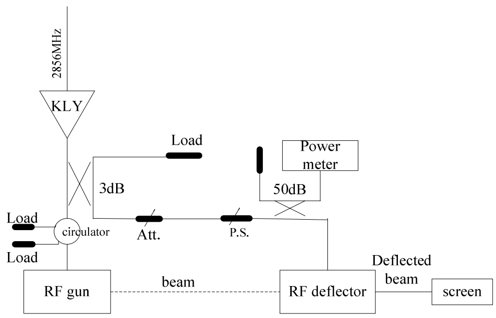


Figure 2: The power feed system sketch.

Measurement System

The system consists of the photocathode RF gun and some beam diagnostic elements, as shown in Figure 3. The RF gun could produce high brightness electron beam with the rms bunch length of about 4~6 ps. At 2.7meters from the gun exit, the deflector is installed. The YAG screen is 0.984meters away from the centre of the deflector.

The photocathode RF gun consists of a 1.6-cell cavity with a Cu incorporated metallic cathode, operating at S band (2856MHz). It generates a 4.2MeV electron beam with the charge of 0.64 nC. The laser pulse has a width of 8.5 ps. The emittance is about 4 mm.mrad.

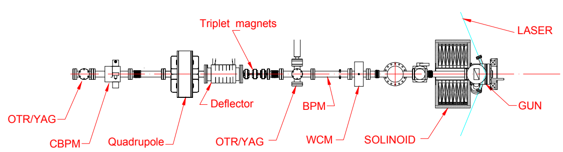


Figure 3: Layout of the bunch length measurement setup.

BUNCH LENGTH MEASUREMENT PRINCIPLE

Figure 4 shows the principle of bunch length measurement[4]. Assuming two electrons e1 and e2 enter the cavity on axis of the vacuum chamber one after another. The RF phase experienced by the particles is different from each other. With a velocity v_c and a longitudinal distance d_{long}, the phase difference $\Delta\varphi$ according to the RF frequency f amounts to

$$\Delta\varphi = 2\pi \cdot \frac{d_{long}}{c} \cdot f \approx 360\,\mathrm{deg} \cdot \frac{d_{long}}{c} \cdot f \qquad (1)$$

After the electrons leave the cavity, the motion is straight. They strike on the screen with a vertical distance d_{ver} and produce radiation. That is imaged with a profile downstream. If the particles are located within the linear range of the sine, the vertical distance on the screen is proportional to their longitudinal distance in there motion.

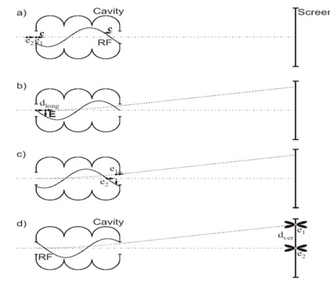


Figure 4: Bunch length measurement principle.

The measured intensity distribution is a convolution of the streaked longitudinal and vertical beam distribution. Assuming a Gaussian beam distribution in both the y and z direction, where y and z are the vertical and longitudinal coordinates respectively, the measured beam size σ_{meas} can be expressed as

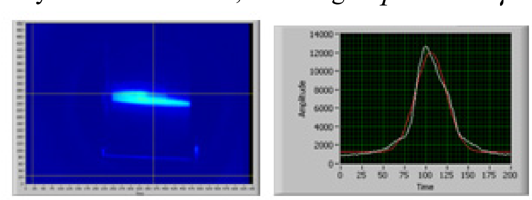
$$\sigma_{meas}^2 = \sigma_{hor}^2 + \sigma_{long}^2 \qquad (2)$$

where σ_{hor} is the horizontal beam size without deflection. σ_{long} is the longitudinal beam size on the screen.

MEASUREMENT PROCEDURE

System calibration

For the deflecting direction is vertical, we use triplet magnets to focus the vertical beam size small, as shown in Figure 5(a). The data are the means of 10 images and then Gauss fitted, shown in Figure 5(b). The maximum value of the graph is the centroid position of the bunch. The optical system is calibrated, and we get $1\,pix = 136\,\mu m$.



(a) (b)

Figure 5: The compressed bunch and Gauss fitting graph

The zero crossing was confirmed by the downstream profile. The input power was fixed and the phase changed by 180^0. We can see the beam spot from down to up, and the mean place is consider as the zero crossing.

The Transverse Bunch Size

When the gun works, we can not stop the input power to the deflector. In order to obtain the transverse beam size, we tune the attenuator value to the maximum and change the phase shifter till the bunch on the RF crest (phase is 90^0 or-90^0). This size is used as the vertical beam size of the deflecting direction. Its rms value is 0.64mm.

The Reference Longitudinal Resolution

In order to evaluate better the scaling factor between the bunch longitudinal length and its vertical dimension on the screen, the deflector deviation is calibrated by measuring the beam centre position vs. the varying deflector phase. From the curve slop the scaling factor between the longitudinal and the vertical dimensions is obtained.

We choose the input power of 9.16kW as a reference power. This is the biggest input power to the deflector which does not make the beam image out of the profile when the phase is changed in the range of 180^0. As the phase shifter is changed by 180^0, we can see that the change of the centroid position of the beam on the profile is like a sine graph. Fig. 6 shows the centroid position and the corresponding measured beam size on the screen when we change the phase shifter more than 180^0. At this power, the longitudinal resolution is 4deg/mm, the measured beam size at zero crossing on the screen is 1.26mm. So the bunch length is 4.22ps(rms).

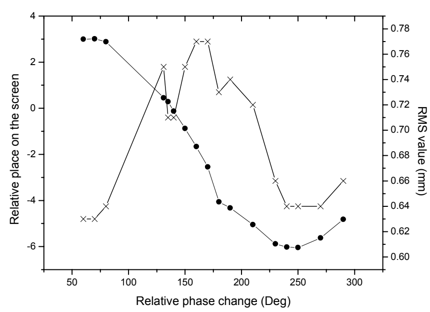


Figure 6: Centroid positions and beam sizes for different RF phase.

Measurement Result

Figure 7 gives the beam spot at zero crossing when different power is input.

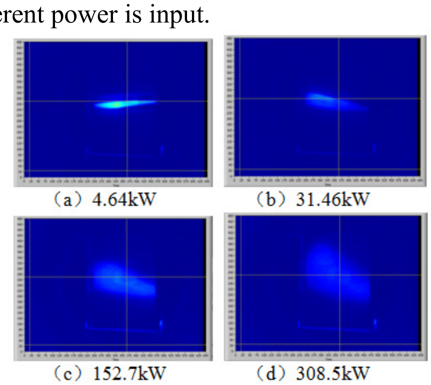


Figure 7: Beam spots for different input power.

We know that the acceleration of a charged particle within an electric field is proportional to the voltage square V^2. The corresponding power P is proportional to V^2. Thus the resolution r at an arbitrary power P is calculated by

$$r = r_{ref} \cdot \sqrt{\frac{P_{ref}}{P}} \qquad (3)$$

where r_{ref} is the reference longitudinal resolution corresponding to the reference input power P_{ref}. From this relationship, we get the bunch length at different input power. See Figure 8. Finally we get the mean value of the bunch length 5.25ps (rms).

For our system, the transverse bunch length is 0.64mm. So the maximum beam size at the YAG scream of the streaked longitudinal bunch length is 0.64mm. Our permitted maximum input power is 308.5kW for the test system. At this power, the longitudinal resolution is 0.69deg/mm. So the whole system's resolution of the bunch length is 0.43ps (rms).

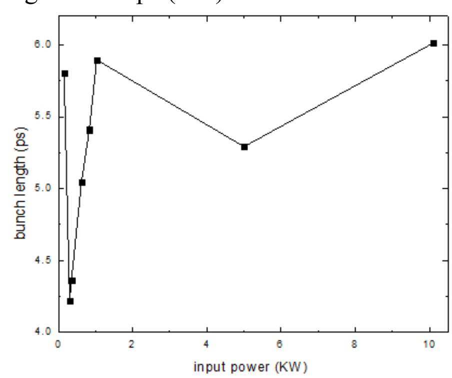


Figure 8: Bunch lengths for different input power.

CONCLUSIONS

A transverse RF deflector was fabricated and tested. The bunch length was measured and reasonable results were obtained. More work will be done at the Shanghai DUV FEL facility using this deflector, and to prepare for the reliable bunch length monitor in the future.

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