DESIGN OF CAVITY BEAM QUADRUPOLE MOMENT MONITOR AT HLS *

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Abstract

Traditional ways to get beam emittance of linacs, such as multi-slits method, are destructive and then not able to be used in on-line beam diagnostics. To meet the requirements of XFEL equipments and improve the quality of electron beam, non-destructive on-line beam emittance measurement methods basing on getting the quadrupole moment of a beam non-destructively are then required. An advanced way to pick up beam information non-destructively with great precision is making use of eigenmodes of resonant cavities. High brightness injector at Hefei light source is used to study FEL based on photocathode RF electron gun. Cavity beam quadrupole moment monitor system designed for the high brightness injector consists of a square pill-box cavity used to pick up quadrupole signal, a cylindrical pill-box reference cavity, a waveguide coupling network that can suppress monopole and dipole signal, and a superheterodyne receiver used as front-end signal processing system. The whole system works at 5.712 GHz. Focusing strength of quadrupole magnet is adjust to construct a matrix which can be used to work out beam parameters.

INTRODUCTION

X-FEL based on linac is one of the most attractive topics in accelerator science and related areas nowadays. It requires electron beam with high brightness and high stability, thus precious control of beam transverse emittance is essential. Methods to get beam emittance are very important. Traditional ways to get beam emittance of linac, such as multi-slits method and quadrupole magnet scanning method, are destructive and then invalid in on-line beam diagnostics. To meet the requirements of XFEL equipments and improve the quality of electron beam, non-destructive on-line beam emittance measurement methods are then required [1]. Non-destructive beam emittance measurement methods usually base on getting the quadrupole moment of a beam non-destructively [1-7]. Since cavity BPM is a novel method that promises high resolution of beam position, it is logical that eigenmodes of resonant cavities can be used to pick up quadrupole moment information of electron beam non-destructively and accurately.

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Hefei light source is to complete an upgrade in two years. During this upgrade a high brightness injector is established. The injector is based on photocathode RF electron gun, which can also be used to study FEL. The beam from photocathode RF gun has a quality of 1nC and energy of 4~5 MeV and the normalized emittance should be no more than 6mm·mrad. Instead of stripline BPM [8], cavity beam quadrupole moment monitor system is designed. The monitor consists of two square pill-box cavities used to pick up quadrupole signal, a cylindrical pill-box reference cavity, a waveguide coupling network that can suppress monopole and dipole signal, and a superheterodyne receiver used as front-end signal processing system. The whole system works at 5.712 GHz. Strength of quadrupole magnets is adjust to construct a matrix which can be used to work out beam parameters.

BEAM DIAGNOSTIC SYSTEM OF PHOTOCATHODE RF ELECTRON GUN

The photocathode RF gun is now trial running after aging stage completed. The energy of bunch is now limited to about 2 MeV. The emittance measurement method used is multi-slits method.

Figure 1 shows the sketch of original beam diagnostic system designed for the photocathode RF gun. The system consists of BPMs, FCT, ICT, Faraday cup, flags and multi-slits beam emittance measurement equipment. As shown in Figure 1, multi-slits method uses screen monitors to intercept the beam and get the emittance.

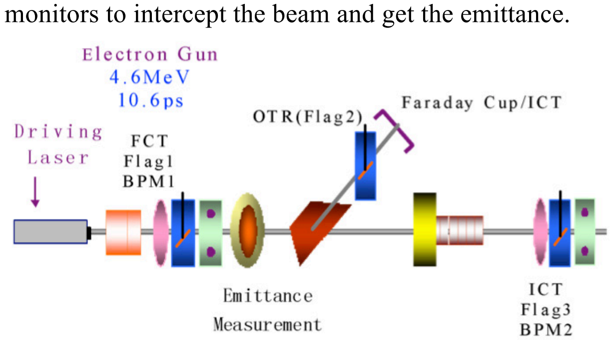

Figure 1: Original beam diagnostic system of RF gun

Beam measurement group of NSRL has worked on using stripline BPM to get the quadrupole moment of beam [8]. An s-band re-entrant cavity BPM is also developed [9, 10]. On this basis, multi-cell cavity beam monitor is given. The whole diagnostic system will be then re-arranged.

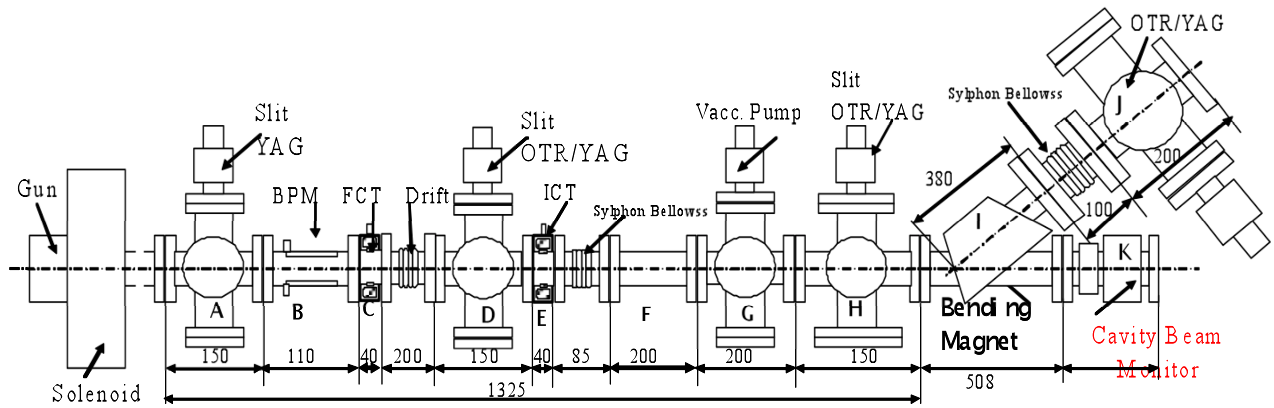

Figure 2: Complex installation drawing of beam diagnostic system

NON-DESTRUCTIVE BEAM QUADRUPOLE MOMENT MONITOR

Beam emittance is defined by the equation

$$\varepsilon = \sqrt{\sigma_u^2 \sigma_{u'}^2 - \sigma_{uu'}^2} \quad (1)$$

Assume there are two points f and b on beam path, the transformation matrix from f to b is

$$\left[M_f^b\right]_x = \begin{bmatrix} m_{11} & m_{12} \\ m_{21} & m_{22} \end{bmatrix},\ \left[M_f^b\right]_y = \begin{bmatrix} m_{33} & m_{34} \\ m_{43} & m_{44} \end{bmatrix},$$ then

there is

$$\sigma_{xb}^2 - \sigma_{yb}^2 = m_{11}^2 \sigma_{xf}^2 + 2m_{11}m_{12}\sigma_{xx'f}^2 + m_{12}^2\sigma_{x'f}^2 \quad (2)$$
$$-m_{33}^2\sigma_{yf}^2 - 2m_{33}m_{34}\sigma_{yy'f}^2 - m_{34}^2\sigma_{y'f}^2$$

In this case, people can change the transformation matrix at least six times and then establish a system of equations and work out σ_{uf}^2, $\sigma_{u'f}^2$ and $\sigma_{uu'f}^2$. Beam emittance at f can then be gotten. To establish the system of equations, one can measure the transformation matrix at several different points or change the focusing strength of the quadrupole magnets [8].

Quadrupole mode of resonant cavities can be used to detect the quadrupole moment of beam [6]. Compared to stripline BPM, resonant cavities can provide signal with higher voltage and higher SNR [9, 10]. A cavity beam quadrupole moment monitor is then designed.

To get the quadrupole moment of beam, monopole and dipole modes of resonant cavity must be suppressed. Though cylindrical cavities are easier to manufacture, rectangular cavities, especially square cavities, can push the nearest non-quadrupole mode further away and is proved to be a better choice. The power coupled out from the TM220 mode will satisfy,

$$P_{out} \propto \left(x^2 - y^2 + \sigma_x^2 - \sigma_y^2\right)^2 \quad (3)$$

The influence of beam position x and y can be deduced from the dipole moment of beam. Power coupled out from dipole modes of cavity satisfy [9],

$$P_{dipole,x} \propto x,\ P_{dipole,y} \propto y \quad (4)$$

So a series of resonant cavities combined can be used to extract beam information such as transverse position and emittance from eigenmodes excited. The new cavity beam monitor will be installed at the end of the original diagnostic system, showed in figure 2.

After computer simulation, a quadrupole moment monitor was designed. As it is showed in figure 3, there will be two quadrupole cavities to couple out skew quadrupole mode and normal quadrupole mode separately. A re-entrant cavity beam position monitor is connected to measure dipole modes.

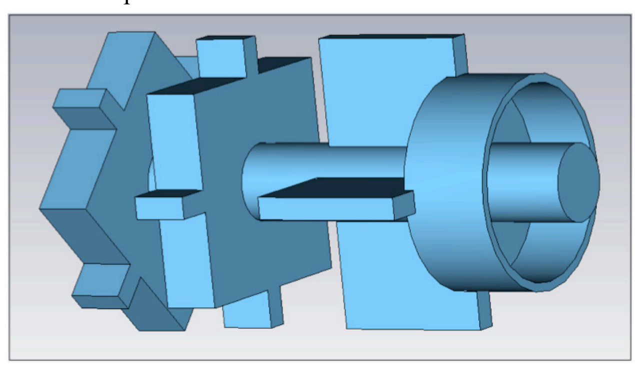

Figure 3: Multi-cell cavity beam monitor

To pick up signals, network consists of waveguides is used. With proper cut-off frequencies, waveguide coupling method can suppress the monopole mode leakage in position cavity [9] and both monopole and dipole mode leakage in quadrupole moment cavity. The quadrupole moment monitor works at 5.712 GHz, space to all the non-quadrupole mode is 400 MHz, which is far enough for signal processing. The dipole mode monitor works out beam position at 2.448 GHz.

SIGNAL PROCESS OF QUADRUPOLE MOMENT MONITOR

To work out the transverse emittance there should be at least six equations so the parameters in equation (1) can be deduced. Measure quadrupole moment at more than six points would be too expensive, besides the results could make up a singular matrix that does not have unique solution. Change focusing strength of quadrupole magnet is a proper approach to make up equations that can be solved.

Figure 4 shows signal processing system of beam quadrupole moment monitor. As system works at C band, down-conversion front-end module is needed. Reference cavity is used to provide amplitude and phase reference signal.

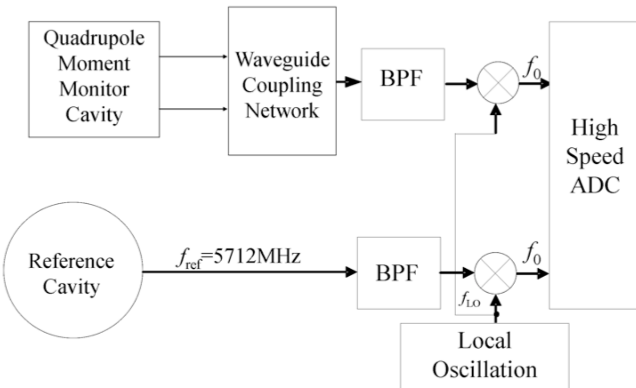

Figure 4: Signal processing system of beam quadrupole moment monitor

Libera digital processors developed by Instrumentation Technologies, d.o.o provide a useful signal processing method that can process signal at 204MHz. Use libera as high speed ADC and signal processing module can simplify the design of front-end module.

CONCLUSIONS

A C-band beam quadrupole moment monitor is designed and can be used to work out transverse emittance. Multi-cell cavity beam monitor is a way to get beam emittance and position simultaneously.

Using cavity beam monitor to replace traditional beam position monitors and beam emittance measurement method is reasonable and feasible. Further work will be meaningful while more computer simulation and cold test is needed.

Work at signal processing system is also useful because non-destructive diagnostic method needs high speed signal processing module with good accuracy.

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