

NEW BEAM DIAGNOSTICS AND RELATED STUDY ON HLS PHOTO-INJECTOR AND HLS II*

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Abstract

A team in NSRL is now doing research about small model accelerators and carrying out series of related experiments on HLS photo-injector and HLS II storage ring. Cavity beam multi-parameter monitor system designed for the HLS photocathode RF electron gun consists of a beam position monitor, a beam quadrupole moment monitor and a beam density and bunch length monitor. TM_{0n0} modes of cavity can be used to work out beam density and bunch length simultaneously. Miniaturization of FEL facilities is now being studied based on results of experiments and theoretical work before. The team also participate in commissioning of HLS II, i.e. measured the tune of the new storage ring and did some research on longitudinal bunch-by-bunch feedback system.

INTRODUCTION

Linac-based X-Ray free electron laser has been the frontier in the research of the fourth generation light source [1]. New technologies of accelerators and light sources need precise control of beam parameters, such as position, transverse emittance, beam density, bunch length, etc. It is very helpful to develop non-destructive beam diagnostic methods due to importance of real-time beam control and feedback. Besides, research of FEL theory and techniques on small experimental facility is beneficial to future fourth generation light sources.

To work out linac beam parameters non-destructively, novel technologies of multi-parameter beam diagnostics based on resonant cavities are studied based on experiment platform of Hefei Light Source (HLS) high brightness injector. The cavity beam monitor system designed for the photo-injector includes a position monitor, a quadrupole moment monitor and a beam density & bunch length monitor. The pick-up station of cavity BPM contains a re-entrant position cavity and a reference cavity tuned to TM_{010} mode [2]. The cavity beam quadrupole moment monitor shares the reference cavity. Strength of quadrupole magnets is adjusted to construct a matrix which can be used to work out beam parameters. The reference cavity of position and quadrupole moment monitor also provides TM_{0n0} mode signal [3, 4], which can be used to work out the beam density and bunch length as well [5-7]. Here a new approach to measure peak current of photocathode RF

gun is showed while eigenmodes of TM_{0n0} are used in combined measurement so that the whole diagnostic system is simplified and compact.

High speed data acquisition system based on high speed ADC, high density FPGA and high performance DSP chips is used as signal processing system of cavity beam monitors. Meanwhile, high speed data acquisition techniques can also be useful to other applications in accelerators' beam control and diagnostics. Members of the team participate in commissioning of HLS II, i.e. measured the current and tune of the new storage ring and did some research on longitudinal bunch-by-bunch feedback system [8-10].

A 70-170 nm wavelength tunable fully coherent free electron laser is required due to research demands of the synchrotron radiation users of HLS. It is a very broad range of wavelength for an FEL facility. On the basis of past research, a fully coherent VUV FEL experiment facility has been designed [11].

BEAM DIAGNOSTIC SYSTEM OF PHOTOCATHODE RF ELECTRON GUN

In the past years NSRL has worked on measurement of quadrupole moment of linac beam [12]. Cavity-based method for beam position diagnostic is also developed [2, 13]. Furthermore, a multi-cell cavity beam monitor is designed. The new cavity beam monitor is planned to be installed at the end of the original diagnostic system, showed in Fig. 2. NSRL is now upgrading HLS to HLS II, the multi-parameter monitor designed for the photo injector facility can also be useful to the HLS II linac.

Beam emittance is defined by the equation

$$\varepsilon = \sqrt{\sigma_u^2 \sigma_v^2 - \sigma_{uv}^2} \quad (1)$$

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

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

there is

$$\begin{aligned} \sigma_{xb}^2 - \sigma_{yb}^2 &= m_{11}^2 \sigma_{xf}^2 + 2m_{11}m_{12} \sigma_{xx'f}^2 + m_{12}^2 \sigma_{x'f}^2 \\ &- m_{23}^2 \sigma_{yf}^2 - 2m_{33}m_{34} \sigma_{yy'f}^2 - m_{34}^2 \sigma_{y'f}^2 \end{aligned} \quad (2)$$

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 $\sigma_{uu'f}^2$. [8].

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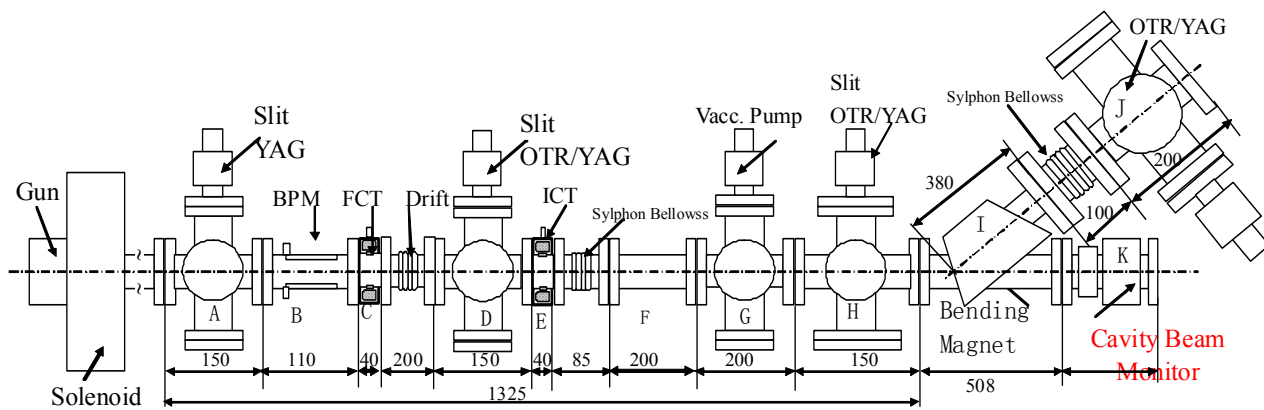


Figure 1: Complex installation drawing of beam diagnostic system.

Quadrupole mode of resonant cavities can be used to detect the quadrupole moment of beam [14]. 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. 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,

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

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 [2],

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

Method of coupling out the TM₀₁₀ modes of different cavities to work out bunch length are widely used [5, 6], while the reference cavities of cavity beam monitors provides TM₀₁₀ mode signal as phase and beam density reference. It is only natural that the scientists want to use this reference signal to work out the beam density and bunch length as well, the only difficulty is if the beam signal can be coupled out clearly with a high enough amplitude.

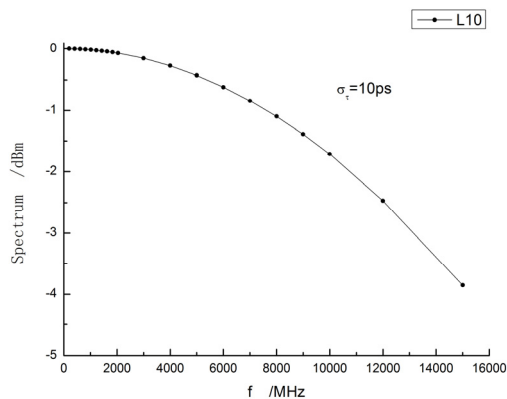


Figure 2: Spectrum of 10ps beam.

For low repetition rate and single bunch photocathode RF electron gun, one can assume that the spectrum of beam is broadband and continuous. Figure 2 shows the beam spectrum of a 10ps bunch length. Here we can see

the spectrum contains abundant components, so it is not necessary to tune the eigenmodes of cavities to high order harmonics. Instead, different TM_{0n0} modes of the reference cavity can be coupled out and afford the beam density and bunch length signal.

For TM_{0n0} mode and TM₀₁₀ mode, there is:

$$\sigma_z = \frac{1}{\omega_0} \sqrt{\frac{Z_n P_1 - Z_1 P_n}{n^2 Z_n P_1}} \quad (5)$$

Where Z is shunt impedance.

To get high SNR, modes with more than 10GHz frequency difference and 3dB amplitude difference are chosen as work modes. In this design, we chose TM₀₁₀ mode and TM₀₅₀ mode. After computer simulation, frequency of TM₀₁₀ mode is tuned to 2448MHz, while resonant frequency of TM₀₅₀ mode is then set to 15193MHz. The beam density and bunch length monitor at HLS works on 2448MHz, which is the same as the cavity beam position monitor, so the reference cavity of the BPM can be used as beam density and bunch length monitor and the whole system is simplified.

HIGH SPEED DATA ACQUISITION

To work out the transverse emittance there should be at least six equations so the parameters in equation (1) can be deduced. Change focusing strength of quadrupole magnet is a proper approach to make up equations that can be solved.

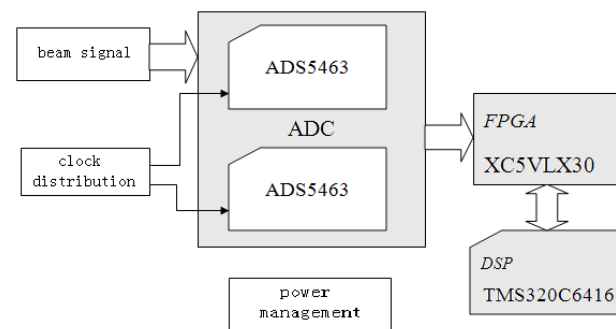


Figure 3: Sketch of high speed data acquisition system for cavity-based multi-parameter beam diagnostics.

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Figure 3 shows the sketch of high speed data acquisition system of the multi-parameter beam monitor. The double channel data acquisition system is based on parallel time-interleaved sampling method, using high density FPGA and high performance DSP chips. The sampling rate can be as high as 1Gsp/s.

As system works at both S-band and C band, down-conversion front-end module is needed. Reference cavity is used to provide amplitude and phase reference signal.

WORKS FOR HLS II COMMISSIONING

The upgraded light source of HLS II is now at commissioning stage and is expected to be put in full operation before this September. Clearly, it is important to measure the tune of the new storage ring [8, 9]. Figure 4 shows the interface of tune measurement system in remote PC.

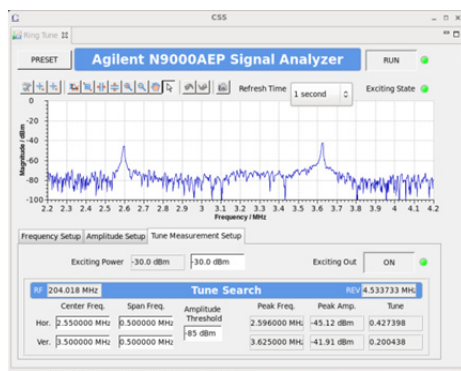


Figure 4: Tune measurement system in remote PC.

To suppress the longitudinal coupled bunch instabilities, a digital longitudinal bunch-by-bunch feedback system has been developed in the upgrade project of HLS II [11]. The longitudinal feedback system consists of a pickup BPM, a front-end/back-end signal processor to detect the phase errors of all electron bunches, an iGp signal processor to calculate correction signals, two RF power amplifiers, and a waveguide overloaded cavity longitudinal kicker.

STUDY OF FEL TECHNIQUES

In order to meet requirements of the synchrotron radiation users, a fully coherent VUV FEL has been preliminarily designed. One important goal of this design is that the radiation wavelength can be easily tuned in a broad range of 70-170 nm. The self-seeding scheme is adopted for this proposal. Because of the great difference of the power gain length and FEL efficiency at different wavelength, dividing the wavelength range into three subareas is considered. In each subarea, a constant electron energy is used and the wavelength tuning is realized only by adjusting the undulator gap. The simulation results shows that this scheme has an acceptable performance. Further information will be published in Chinese Physics C [11].

CONCLUSIONS

Multi-cell cavity beam monitor is a way to get transverse emittance, beam position, beam density and bunch length simultaneously. Work at signal processing system is also useful because non-destructive diagnostic method needs high speed signal processing module with good accuracy.

Technical results have already been applied in HLS II commissioning and the team has more potential to achieve. Further work will be meaningful while more computer simulation and on-line and off-line tests are needed.

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