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DESIGN OF BEAM INTENSITY MEASUREMENT SYSTEM IN INJECTOR FOR HLS II*

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Abstract

A new beam intensity measurement (BIM) system has been developed and has been used in the upgrade project of HLS II. After the upgrading is accomplished, electron energy in Injector endpoint will increase from 200MeV to 800MeV to achieve the goal of top-off injector. Meanwhile, macro pulse width changes from 1μs to 1ns and peak intensity from 50mA to 1A approximately. So three fast current transformers (FCTs) and two integrating current transformer (ICTs) are installed in Linac and Transport Line to measure single pass beam parameters. In this article, off-line calibration of beam transformer is elaborated. Since the fast pulse signals from beam transformer will be hugely distorted after they transmit from Injector vacuum chamber to the Injector beam diagnostic centre room after hundreds of meters long LMR-400 cable, signal recovery algorithm based on FFT/IFFT is used to re-appear the true original signal and calculate the calibration efficient. In the end, resolution and measurement result of the BIM system is presented.

INTRODUCTION

HLS has started its upgrade from May, 2012 and is debugging at the moment. As the pre-injector the storage ring of HLS II, performance and stability of injector consisting of Linac and Transport Line is crucial and electron beam intensity (beam current and charge) is the direct reflection with the first-hand data [1]. In HLS II, there have been installed 5 beam current transformers along the injector. Among them, 3 FCTs are installed behind the electron gun, in the end of the Linac and in the middle of Transport Line respectively. The one of the ICT is installed behind the first FCT and the other in the end of Transport Line close to the injector point. With these transformers being monitoring, many machine parameters such as electron gun gird voltage can be debugged to a relatively optimized states to improve the injector performance and injection efficiency.

Table 1 shows the beam parameters before and after upgrade of the injector with beam pulse width reducing from 1μs to 1ns and peak current increasing from 80mA to about 1A. The previous beam current measurement system with 33MHz sample clock can't be qualified with the new beam measurement task requirement. So an upgraded BIM system with the ability of measuring ns order pulse width beam parameters is necessary and inevitable.

Table 1: HLS Injector Main Parameters Comparison

Injector Parameter	HLS	HLS II
Injector Electron Energy	200MeV	800MeV
Length of Macro Pulse	1μs	1ns
Beam Current	80mA	1A
Beam Charge	NA	1nC

DIAGRAM OF THE SYSTEM

According to the accelerator physical design of the injector and beam signal characteristic, a data acquisition (DAQ) system shown in Fig. 1 is applied.

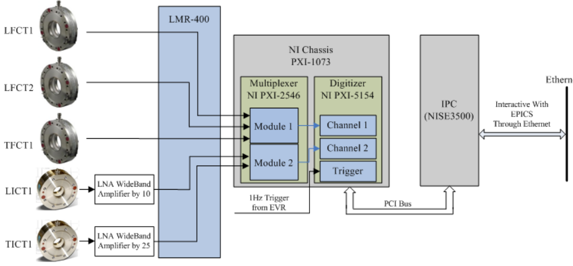

Figure 1: Schematic diagram of BIM system.

In Fig. 1, FCTs and ICTs are all made by Bergoz. The passive FCT has a rise time less than 300ps [2] and 50Ω output impedance so as to connect with oscilloscope. The ICT [3] is a capacitive shorted transformer coupled to a fast readout transformer with two nested transformers. It integrates the input pulse charge and generates a slower output signal. Meanwhile, Output pulse integral is exactly in proportion to the beam charge.

FCT signals are directly sent into the digitizer, but ICT signals with the stretched signal peak voltage less than 100mV is amplified by low noise amplifier (LNA) close to the ICT before transferred to the digitizer.

With cost and requirement being considered, the dual channel high-speed digitizer NI PXI-5154 in combination with dual 4×1 multiplexer NI PXI-2546 are used. Beam signals are first received by multiplexer and then switched to analog input channel. The two cards are all embedded in a NI PXI Chassis with backplane bus. In order to synchronize with the accelerator timing system, a trigger signal from an EVR device is connected to the digitizer.

The whole control and communicate software is developed in LabVIEW environment including the part of client and server which works in the same subnet based on EPICS. An industrial personal computer (IPC) takes the responsibility in data acquisition, beam parameters calculation, data storage and display, etc. It communicates

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with the PXI card via PCI bus in local. The server utilizes CA Lab [4] to send the acquired waveform and post-processed beam parameters to the client to monitor and debug machine.

CALIBRATION AND CALCULATION

In the BIM system, sensitivity of beam transformer, skin effect of the long cable, sample rate, and LNA magnification factor are the key impacts. FCT and its connected cable are calibrated by a simple and off-line method, but ICT cables are calibrated on-line.

Off-line Calibration

When high speed beam pulse signals up to GHz pass through the long coaxial cable, they distort with the pulse width spreading and amplitude decreasing.

The calculation procedure is simplified by measuring the given signal source and the other-side signal of the cable and then calculate the amplitude ratio and pulse width ratio. By fitting the amplitude ratio with quadratic equation and pulse width ratio width with exponential equation, off-line calibration factors of these cables can be more smoothly and accurately. Fig. 2 shows an example of the calibration results for LFCT2.

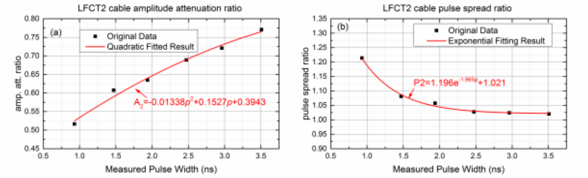

Figure 2: calibration coefficient for LFCT2; (a) indicates the amplitude attenuation varies from 0.45 to 0.75; (b) indicates the pulse width spread ratio varies from 1.25 to 1.02.

From Fig. 2 and extrapolation, we can get the equation $A_2 = 0.01338p^2 + 0.1527p + 0.3943, p \in (1.0, 5.0)$ for the amplitude attenuation, and pulse width ratio fitting equation $P_2 = 1.196e^{-1.965p} + 1.021, p \in (1.0, 5.0)$.

LNA Wideband Amplifier

As the ICT stretches the picoseconds beam signal into tens of nanoseconds but keep the same beam charge, we assume the output signal is approximate Gaussian distribution and expressed in Eq. 1.

$$V(t) = \frac{V_0}{\sqrt{2\pi}\sigma_t} \exp\left(-\frac{(t-u)^2}{2\sigma_t^2}\right). \qquad (1)$$

Where σ_t is RMS value of integral beam pulse; V_0 is the beam intensity; μ is the time excursion.

The typical pulse width full width at half maximum (FWHM) from the ICT is 30ns，and the relation between the FHWM and RMS value is shown in Eq. 2.

$$FWHM = 2.35\sigma_t . \qquad (2)$$

As a result, the maximum of the output signal level is $V(t)|_{t=u} = 78mV$ when beam charge is 1nC.

In the temporal application, output signal from the LICT1 is amplified by 10 times and the other amplifier for the TICT1 is amplified by 25 times.

Off-line Magnification Factor

The two LNA wideband amplifier modules adopt the same structure with two-stage amplifier based on AD8099. To ensure that the useful signal is fully amplified with good gain flatness and eliminate the high frequency noise disturbance, we set the amplifier's bandwidth from DC to 80MHz and gain flatness better than 0.5dB.

Take strict and versatile conditions into account; time domain test signal is chosen with rise and fall time from 5ns to 15ns, pulse width from 20ns to 30ns, and one of the integral results is illustrated in Fig. 3.

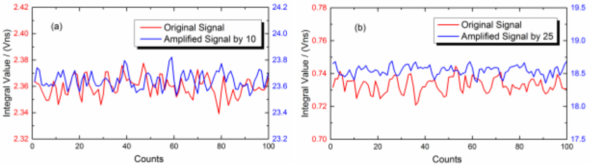

Figure 3: Test signal integral result for LICT1 and TICT1; (a) is integral result for LICT1 and (b) is integral result for TICT1; rise and fall time t_r = t_f =5ns, pulse width t_w=30ns, red line denotes original signal integral result, blue line denotes amplified signal integral result.

According to the test result shown in Fig. 3, actual magnification factor for LICT1 is about 10.02 and actual magnification factor is about 25.31 for TICT1.

More off-line tests have been done and results show that magnification factor of LICT1 vary from 9.975-10.02 and magnification factor of TICT1 vary from 25.22-25.36 which indicates the magnification factor for these two modules are steady and gain error is within 0.6%.

On-line Calibration

In general, output signal amplitude attenuates to about 0.7 times of the original value for LICT1 cable with frequency 80MHz and length 86.5m measured by a time domain reflect meter (TDR).

An easily achieved method to calculation the beam loss ration for LICT1 and TICT1 cable is utilizing the FFT/IFFT algorithm. First, we choose a higher speed pulse signal faster than rise time of used ICT with ~10ns. Then test signal with 5ns rise time and other-side signal of the cable are sampled by the DAQ card which works in interpolation sampling (TIS) with 4Gs/a sample rate. At last the frequency response of the ICT cable can be calculated with the time domain waveform.

With the measured output signal and frequency response of the cable, actual output signal from ICT can be restored. Fig. 4 shows the output signal waveform before and after the signal reconstruction. Integral the measured data and restored data, we can get the beam charge loss factor K_{LICT1} for LICT1 is approximate to 0.92.

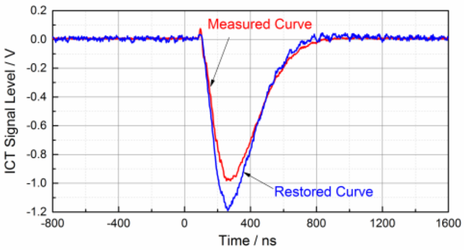

Figure 4: LICT1 output signal, red line denotes the actual measured waveform; blue line denotes the restored data with calibrated data, beam charge loss factor K_{LICT1}=0.92.

As the real-time FFT/IFFT algorithm cost too much CPU and memory resources and waveform of the ICT output signal is almost the same when injector runs steady, beam loss factor is usually saved to a variable and used to revise the beam charge calculation result.

Rejecting Noise

The DAQ device usually works in 1Ga/s sample rate and DC couple. For the ICT output signal, there exists baseline drift when AC couple is applied. But low frequency noise signal such as 50Hz and each harmonics up to tens of kHz may add to the waveform with DC couple. In addition, quantization noise, electronics thermal noise and environmental noise also influences the measurement result. So we eliminate the noise in software using the first 100 points of the whole 1000 points when processing ICT output signal.

Figure 5 gives the beam charge noise measurement result with and without beam in the injector. With noise, RMS of the beam charge noise is 0.064nC and noise fluctuations are very shape; on the other hand, RMS of the beam charge noise is only 0.075nC and most of the measured noise is lower than 0.025nC. So rejecting the floor noise is a well way to increase measured accuracy.

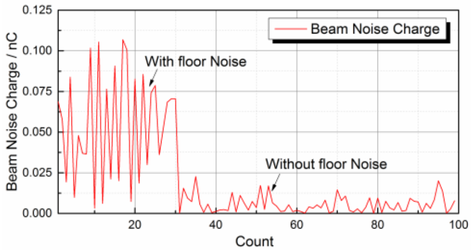

Figure 5: Beam charge measurement result with and without floor noise, without beam in the injector, 1Ga/s sample rate, and DC couple.

EXPERIMENT RESULTS

With injector debugging and commissioning period, we utilize the BIM system to measure its resolution and machine parameters.

Figure 6 draws the measured waveform of FCT and ICT. Fig.6 (a) shows that beam amplitude acquired by 3 FCTs is 0.57A, 0.25A and 0.15A respectively, and electron beam injector efficiency is about 26.3%. From Fig. 6(b) we know magnified ICT output signal becomes smooth and peak voltage reaches -1.0V, but TICT1 is still slightly disturbed by noise generating from beam in storage ring and kicker noise which should be improved in the next.

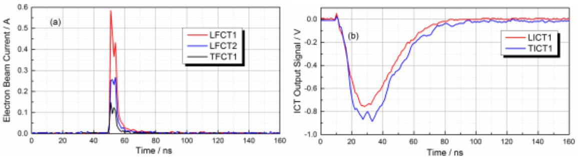

Figure 6: FCT and ICT output signal waveform.

Figure 7 shows beam current amplitude resolution test result for LFCT1. Fig. 7(a) indicates the beam amplitude varies from 0.53A to 0.60A in 200 seconds. According to the Fig. 7(b), the measured average is 0.562A and beam amplitude measurement stability is about 1.6%, so BIM system resolution for LFCT1 is better than 2%.

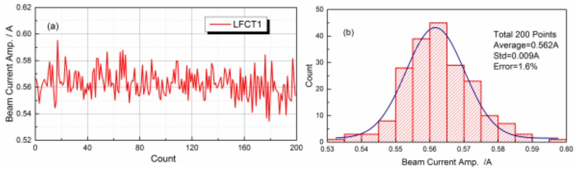

Figure 7: Beam amplitude resolution test for LFCT1.

Figure 8 gives beam charge resolution test result for LICT1. According to Fig.8 (a), the beam charge is within 1.06-1.14nC, and Fig. 8(b) shows the measured average is 1.102nC and beam charge measurement stability is approximate 1.5%, so BIM system resolution for LICT1 is better than 2%.

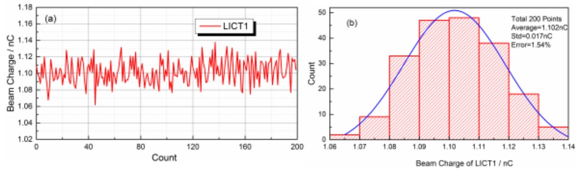

Figure 8: Beam charge resolution test result for LICT1.

CONCLUSION

The newly designed beam intensity measurement system for HLS II works well and has been used in injector debugging and commissioning. According to the resolution measurement result, the system has a resolution better than 2% for beam current amplitude and beam charge. And in general conditions, injector efficiency can reach about 25% utilizing the system.

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