PHASE AND ENERGY MEASUREMENT SYSTEM
FOR C-ADS INJECTOR I

J.H. Yue, J. Hu, Q.Y. Deng, S.J.Wei, Q.Ye, IHEP, CAS, Institute of High Energy Physics, Chinese Academy of Sciences, Beijing, China

Abstract

For proton linac, phase and energy measurement is very important. Beam phase always can be measured by quadrature sampling [1][2], energy can be calculated by the method of time of flight (TOF), in this way we need to know the beam phase of two points whose distance is given. C-ADS injector I is a 10MeV proton linac with 10mA continuous current. It consists of an ECR (Electron Cyclotron Resonance) ion source, a LEBT (Low Energy Beam Transport), a 3MeV RFQ (Radio-frequency Quadruple) and a superconductivity linac accelerator with 3~10MeV. In the initial phase, the beam energy is about 3MeV. In this paper, phase and beam energy system of C-ADS Injector I have been introduced and some preliminary results have been shown.

INTRODUCTION

The ADS accelerator in China is a Continuous-Wave (CW) proton linac with 1.5 GeV beam energy, 10 mA beam current, and 15 MW beam power [3]. Its main task is to cope with nuclear waste material and produce clean nuclear power. It have two injectors, C-ADS injector I is a 10MeV proton linac with 10mA continuous current made by IHEP. It consists of an ECR (Electron Cyclotron Resonance) ion source, a LEBT (Low Energy Beam Transport), a 3MeV RFQ (Radio-frequency Quadruple) with 325MHz frequency and a superconductivity linac accelerator with 3~10MeV. In the initial phase, the beam energy is about 3MeV. The schematic diagram of C-ADS injector I is shown in Fig.1.
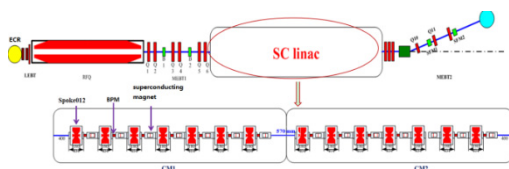

Figure 1: The Schematic diagram of C-ADS injector I.

In order to measure the beam phase and energy, we design the frontend electronics and fast data acquisition system shown in Fig.2. We take the FCT (Fast Current Former) monitors as the pickup, take the quadrature sampling to measure the phase of the FCT1and FCT2 and phase difference between FCTs. We use the method of TOF to get the beam energy.

The phase of sinusoidal signal is can be got by its in-phase and quadrature-phase (I&Q) components. The arctangent of the ratio of I and Q gives the angle of the signal relative to the phase of the sampling clock used to define I and Q.

To get the I and Q components, a signal is sampled at four times its frequency, that means once every 90 degrees. I, Q, -I, and –Q data sequences can be got. I subtract –I produce 2I, Q subtracts –Q makes 2Q, all common-mode errors are consequentially eliminated and low frequency noise is attenuated.

FRONTEND ELECTRONICS

As shown in Fig.2, the pulsed signal from FCT is broadband which comprise 325MHz sine wave. We use a high pass filter and low pass filter to make a narrowband filter. This narrowband signal be sent to DBM (double balanced mixer) to transfer signal to 16.25MHz and to filter again, so here we can get a 16.25MHz sine wave, this signal be input to a 14 bit ADC, the sample frequency is 65MHz, is quadruple of 16.25MHz. 65MHz sample frequency can promise to get a value every 90 degree, so we can get an orthogonal sequence data, the arctangent value of them is phase of the beam. The ADC can receive 325MHz reference signal, then output the 308.75MHz (19/20 of 325MHz) signal as the local signal of DBM.

FPGA CARD AND DAQ

ADC card named 100MAD_DA is selected to sample the waveforms, cope with the data and produce the timing signal. This card has two input tunnels, one is for FCT signal and the other is for reference signal. The analog signals digitize by the ADC, then sent to FPGA, in which we get I/Q data sequence and beam phase, then data are sent to computer by PCI express bus. It also produces the timing signal. The 325MHz reference signal are input to ADC, then 308.75MHz signal are output to send to DBM to down-convert the signal.

PRELIMINARY MEASURE RESULTS

As shown in Fig.3, beam phase of FCT1 and FCT2 have been got. You will find the effective data is not continuous because of two reasons, one is our beam is pulsed mode, not CW mode, the other reason is self-trigger mode. We got the beam phase is -86.98 and 57.66, so the beam phase difference is 144.64 degree. So the time of flight t is (144.64/360)*3.07778ns, equal to 1.237ns, the total flight time is 38.17ns which is 12 high frequency periods plus 1.237ns.

In order to calculate the beam energy, Eq 1, 2, and 3 are needed.
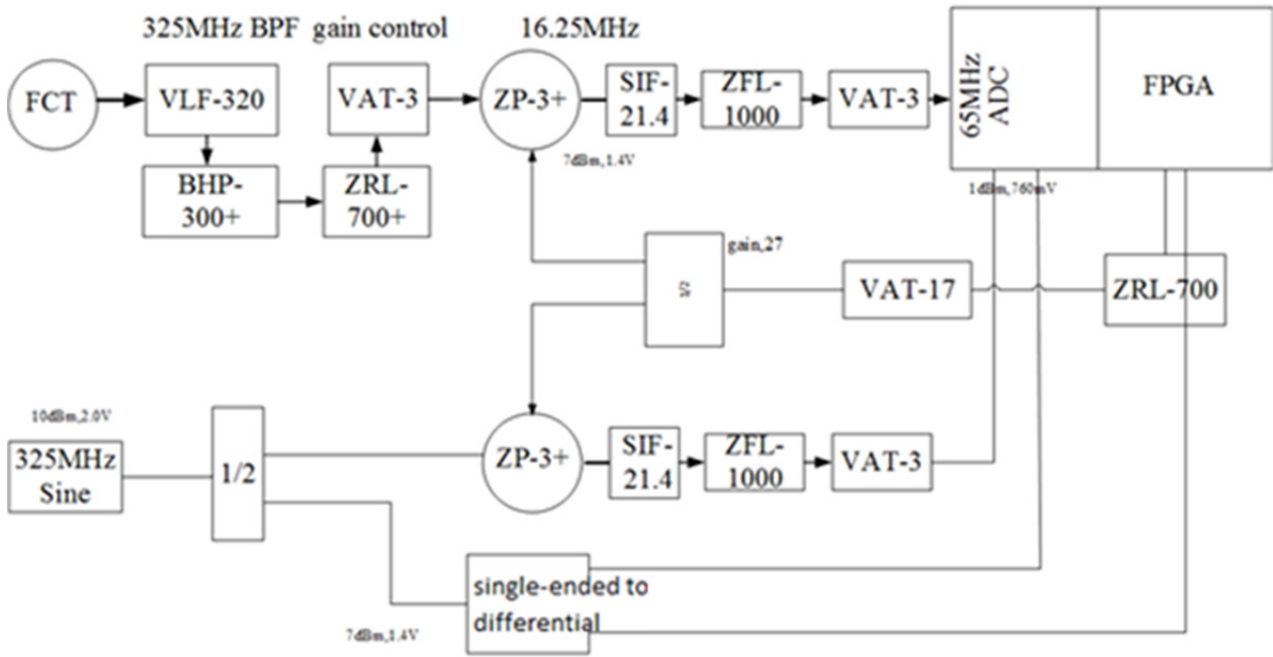
$$V=L/t \qquad (1)$$

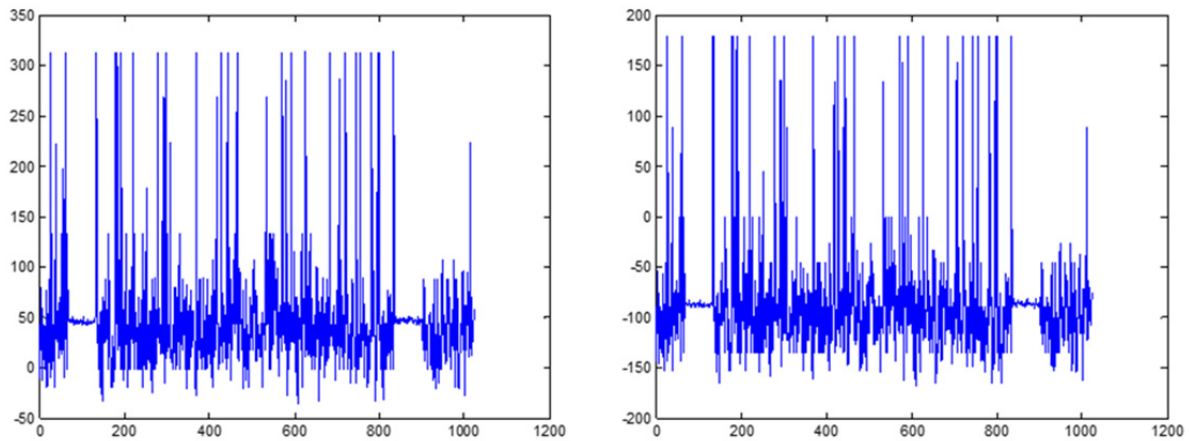Figure 2: Phase measurement system of C-ADS injector I.
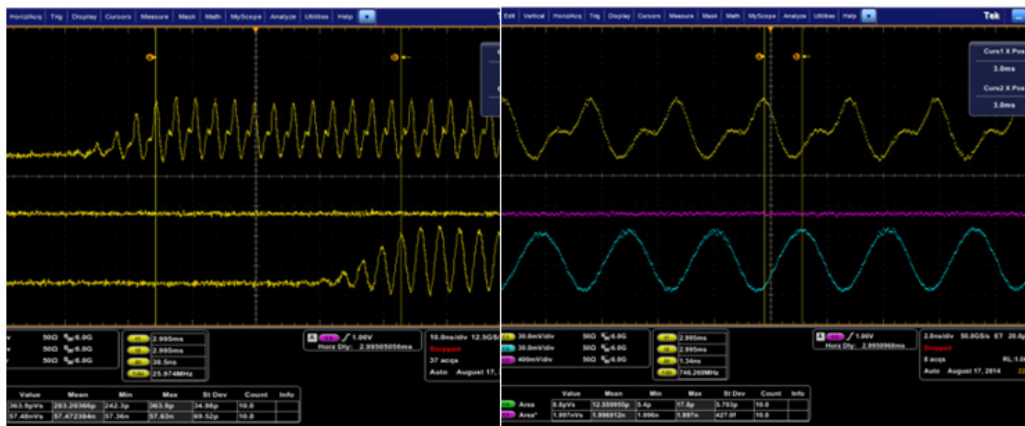

Figure 3: The phase value of different FCTs.

Figure 4: Rough and fine phase difference between FCTs.

$$\gamma = \frac{1}{\sqrt{1-(v/c)^2}} \qquad (2)$$

$$\gamma = \frac{E_k + E_0}{E_0} \quad (E_0 = 938MeV) \qquad (3)$$

Here L is distance of FCT1and FCT2, its value is 0.943m, and E_0 is static energy of proton, we put L, t and E_0 into the above equation, we can get the beam energy is 3.196820MeV.

We also can use the oscilloscope to check the measure results. Fig.4 shows the waveforms of FCT1 and FCT2 on the screen. In Fig.4, we can see the time of signal of FCT1 is in advance of FCT2 12 high frequency periods. That means 36.92ns. In Fig.4, fine time difference between the FCT1 and FCT2 is 1.34ns in one high frequency period, so the total flight time is 38.26ns which is coincide with 38.17ns measured by beam phase measurement system.

CONCLUSION

In this paper, the beam energy system and some preliminary results have been shown. In-phase and quadrature-phase (I&Q) method were taken to get the beam phase, and TOF method were taken to get the beam energy, the measure results is both coincide with design value and the measure results from the oscilloscope, so this method is reasonable, but some further study is need to do like as the resolution of this system.

REFERENCES

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