TEST BENCH EXPERIMENTS FOR ENERGY MEASUREMENT AND BEAM LOSS OF ESS-BILBAO

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Abstract

Various test benches have been developed at ESS-Bilbao in order to characterize different beam diagnostics and control systems prior to their installation on several parts of the accelerator. One test bench includes time-of-flight (TOF) characterization for energy measurement using fast current transformers (FCT). Using FCTs for the TOF measurement would allow us to measure accurately the delay between two successive bunched or un-bunched beam pulses of low energy ions. The other test bench includes a beam loss monitoring and interlock system using ACCTs, cRIO and PXI chassis with some acquisition modules and optical fiber link which represent a complete system of beam loss detection, interlock logic and trigger signal transmission. Having an integration on the ACCT output also allows us to measure the beam charge at the location of monitoring. In the test benches the functionality of hardware and software, the logic and required signal specifications like rise time, jitters and delays are measured. An overview of test benches and their measurement results are reported in this paper.

INTRODUCTION

Before the commissioning and installation of Mobile Test Stand (MOTS) [1] as a general diagnostics measurement stand, there will be various small separate test benches for different diagnostics purposes. The idea is to characterize each device and diagnostics system before assembly on the accelerator sections. One test bench is designed for energy measurement using fast current transformers (FCTs). The other test bench consists of beam loss monitor system using the ACCTs and electronic modules.

ENERGY MEASUREMENT

The energy measurement test bench is based on Time-Of-Flight (TOF) technique to measure the energy of the non-relativistic beam [2]. The idea is to measure precisely with subnano seconds resolution the delay of the signals from two beam sensors. Since the velocity and energy of the beam is calculated from the timing delay between two sensors, therefore the resolution and accuracy of the timing measurement are of high importance. The ion source will give a fix kinetic energy of 75 keV to the ions. The ions then cross the LEBT with the same initial energy and therefore identical time of flight. Afterwards, they are accelerated in the RFQ to the nominal energy of 3 MeV [1]. The primary purpose of TOF setup was to characterize the delay and measurement uncertainty in the time domain in order to define the accuracy of beam energy measurement after ion source, LEBT and RFQ. Since before RFQ, the beam is not bunched, then the normal BPM pickup would not be used as the front end sensors. In this case, two high bandwidth in-vacuum FCTs are used as the beam passage detectors. As a complementary scheme for beam energy measurement after RFQ, also two shorted stripline BPMs with length of 61 mm are foreseen and designed. These shorted striplines will be installed at a distance of 1m from each other on the MOTS, as close as possible to the exit of RFQ where the beam is well bunched. Due to the characteristics of striplines, which in general do not have good response to the low frequency or dc pulses without bunches, the FCTs are foreseen for the measurement. In order to maximize the accuracy of TOF measurement with the FCTs, the manufacturer of FCTs (Bergoz®) [3] was asked to fabricate the two in a similar condition and with identical characteristics. The rise time of the FCTs was 320 ps and a bandwidth of 950 MHz, appropriate to the RF bunch level. The lower cut-off frequency of both FCTs was 1.2 kHz and the droop was less than 1 %/µs. A low attenuation coaxial cable with length of 15 ns was used as the beam signal transporter and representation of delay in the absence of real ion beam. For each FCT, two covers with signal feedthroughs were designed in order to keep the integrity of pulse signal at high frequency modes. At the exit of the second FCT, a 50 Ω termination was installed which minimizes the transient signal reflection and possible timing error effects [4].

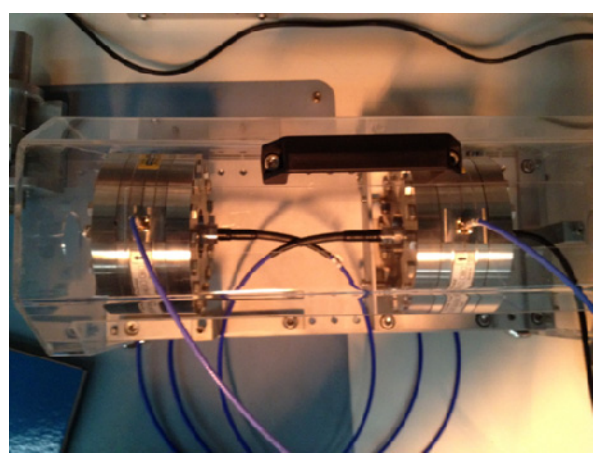

Figure 1: Two FCTs assembly on the test bench.

The energy measurement with FCTs could be used both before RFQ where the beam is still un-bunched or after RFQ where the beam is bunched with RF frequency. Therefore bunched and un-bunched beam were fed as the beam pulse.

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Un-Bunched Beam Pulse

Various pulse current amplitudes were fed to the coaxial reconstructing the signal corresponding to the working current amplitudes of ESS-Bilbao after the ion source and the LEBT.

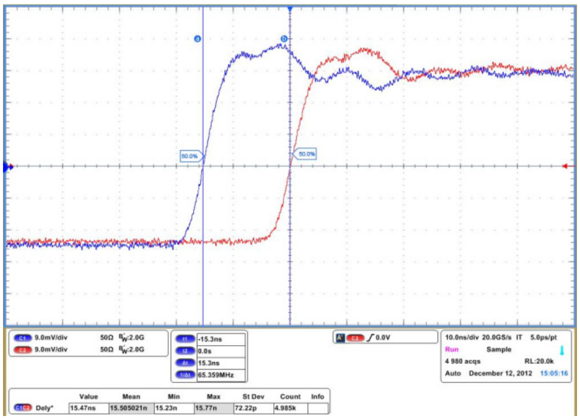

Figure 2: FCTs TOF for un-bunched pulsed current.

The un-bunched pulse measurement results show the rms delay jitter of TOF gets higher with the decrease in pulse current amplitude. For the current of 80 mA and 10 mA, the rms jitter of 85 ps and 130 ps were observed accordingly. The mean energy accuracy for a beam current of 40 mA was smaller than 0.5%.

Bunched Beam Pulse

The same TOF setup was used for the bunched beam pulse energy measurement. This setup is simulating the beam current working amplitudes after RFQ where the beam is already bunched. For the same beam current amplitude, the rms jitter value for a bunched signal was smaller and accuracy was better. Furthermore the jitter value for the bunched beam was changing with the bunch frequency variation. For a beam signal with bunch frequency of 352 MHz and current of 72 mA and 12 mA, the rms jitter was 8 ps and 17 ps accordingly. The mean energy accuracy for a beam current of 40 mA and 352 MHz was 0.1%.

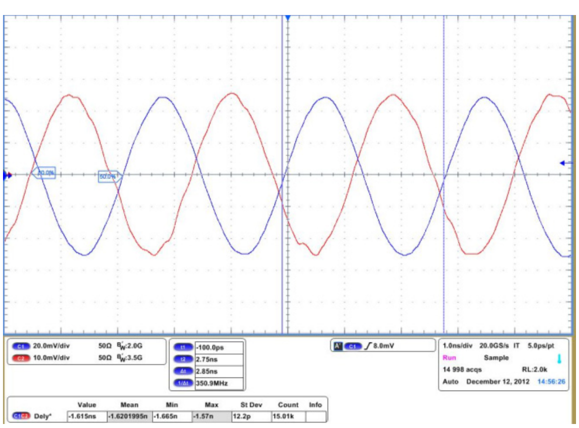

Figure 3: Timing jitter measurement for FCTs rf signal.

BEAM LOSS MONITORING

Another test bench which is assembled prior to the installation on MOTS is the beam loss monitoring (BLM) using ACCTs as the beam detectors. The principle idea is to measure the beam current at two locations, then by comparing the corresponding beam charge values in the FPGA, the beam loss can be detected and if required an output interlock signal would be generated. In the current system, the sole comparison of beam amplitude was avoided due to possible beam pulse shape evolution between two points at low energies. Beam charge was deduced from beam current signal by integration the signal over time. The data corresponding to the beam current signal and its integration is performed by an FPGA embedded in a NI (National Instruments) PXIe chassis. The whole process is carried out in an online manner.

It is worth mentioning that in order to detect the beam loss, it is not always required to integrate over the whole beam pulse. For less deshaped beam pulses between two points, it could be possible to perform the integration on a shorter interval than a whole pulse. Since the logic of beam loss interlock is constructed within FPGA, it is outmost flexible to introduce different schemes in order to define the beam loss and generate the corresponding interlock signal. The integration period and sample number of the input signals from ACCTs can be configured based on the shape and transient characteristics of real beam current pulse. Furthermore the beam charge in the locations of two ACCTs can be deduced from the beam current integration considering a conversion factor. This conversion factor depends on the ACCTs electronics sensitivity, PXI controller and FPGA signal reading.

BLM Assembly Setup

As presented in Fig.4, two ACCTs are used as the front end detectors of the beam current. The beam current loss between ACCT1 and ACCT2 is carried out by means of R1 and R2. R1 is a fixed resistor of 100 Ω, while R2 is a potentiometer ranging from 1 Ω to 3 kΩ. After amplification and noise filtering, the signal from ACCTs are fed to PXI-7852R NI card [5]. The card is programmed for acquisition and logic generator of the interlock signal. Due to the development in low energy beam pulse from ACCT1 to ACCT2, the two signals are integrated over a time duration of pulse width (or if necessary a shorter interval) rather than directly used for amplitude comparison. The interlock master is a cRIO chassis with realtime controller cRIO-9024 [6]. cRIO would make the acquisition and performs calculation or logic in order to generate the global interlock signal with the NI-9402 card.

In order to have a realistic scheme of the delays and so on, the 30m optical fiber and its electrical to optical (EO) and optical to electrical (OE) converters are also integrated into the measurement test setup.

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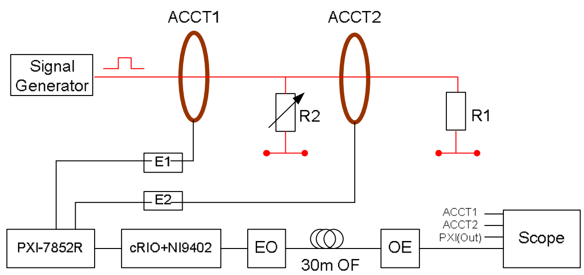

Figure 4: Schematic of laboratory test bench set up.

The EO/OE converter modules are 5MBd optical transceiver which are fabricated at the laboratory for high impedance TTL signal application.

LabVIEW Code and Interlock Logic

The logic and interlock signal generation was implemented within FPGA with the LabVIEW. This gives the highest flexibility for signal acquisition, conditioning and interlock logic generation. In the current scheme, it acquires the input signal from ACCT1 and ACCT2 and integrates the two values every 2µs. After a defined number of sample-integration (e.g 450 samples), the two resulted values, S2 and S1, are compared. If S2 is less than *factor*×S1, then an interlock signal is generated. *factor* is defined as a value related to the percentage of beam loss, which acts as a threshold value of beam charge loss between ACCT1 and ACCT2 (Fig. 5).

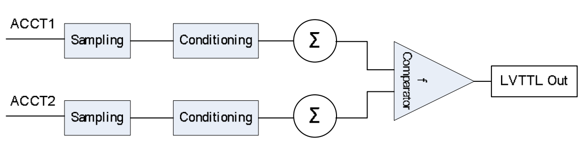

Figure 5: PXI FPGA simplified logic diagram.

Integration of the input signals from ACCT1 and ACCT2 could be held to whole or part of the pulse width. This mainly depends on the beam pulse transient time and shape and the required speed to generate interlock signal. The charge loss factor can be defined within FPGA program, where the logic to produce the interlock is software based and reprogrammable.

Measurement Results

Figure. 6 shows various signals as the input signal and output interlock. In the Fig. 6, the beam current signal output of ACCT1 and ACCT2 are coloured as red and blue, respectively. The green colour signal is the output local interlock from PXI. This signal will produce a global interlock in the cRIO output, which is then converted to optical signal with the EO. The optical signal is transmitted through a 30m optical fiber and, at the end, converted back to electrical signal in the OE (purple colour signal). Due to characteristics of the optical conversion, we have chosen to activate the interlock signal from low to high, which is converted high to low after optical transmission and conversion. The delay between rising edge of interlock and falling edge of EO shows a time duration of 400ns which includes the time required for the cRIO acquisition, logic execution within cRIO, EO conversion, transmission via a 30m optical fiber and OE conversion. The number of samples in this specific measurement was 225 samples(450 µs). The overall delay is measured to be 540 µs, which after deduction of 450 µs of sample real time acquisition, provides 90 µs time consumption for interlock activation. The measured rms jitter on the output signal was 450 ns.

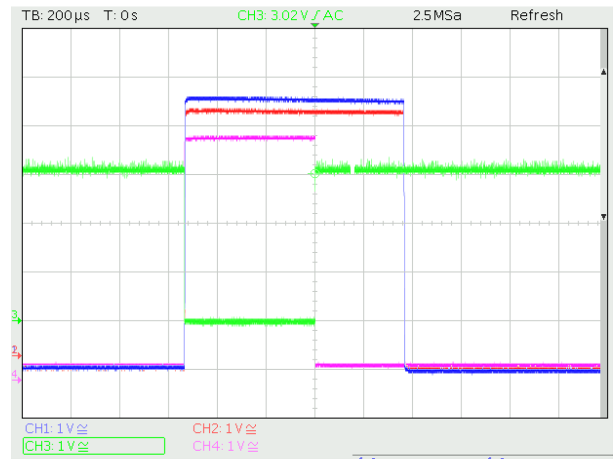

Figure 6: Output signals, ACCT1 (blue), ACCT2 (red), PXI-Out (green) and OE (purple).

CONCLUSION

In the test bench for TOF, the bunched and un-bunched signal corresponding to the beam specs after LEBT and RFQ are used. The jitter rms values for bunched beam of 352 MHz and current down to 10 mA was less than 20 ps. The jitter values for bunched and un-bunched beam show that using FCTs for the TOF measurement gives the required accuracy for energy measurement of Ion source, LEBT and RFQ. In the test bench for interlock, the response time to a beam loss can be configured from seconds down to a short slice of the beam. By reducing the beam integration time, considering a clean beam pulse, the process of interlock generation and optical transmission can be reduced to less than 100µs. If it requires to shutdown the beam within a pulse, it is possible to have a shorter integration time to some extent within the system, detecting the beam loss and providing the interlock signal for the beam shutdown within the same pulse.

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