DEVELOPMENT OF HIGH RESOLUTION BEAM CURRENT MEASUREMENT SYSTEM FOR COSY-JÜLICH

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Abstract

An experiment to test Time Reversal Invariance at COSY (TRIC) requires a precise beam life-time determination. For this, a high resolution bunched beam current measurement system based on the Fast Current Transformer and Lock-In Amplifier has been build. The first tests of the system, read out by a new DAQ, have been done at COSY and at a test stand in the laboratory where bunched beam current was simulated using a conductive wire. A relative resolution of 1.9×10^{-4} for the signal in the wire, equivalent to 1 mA of bunched beam current in COSY, has been obtained in the laboratory. This resolution is sufficient for the realization of the TRIC experiment.

MOTIVATION

A test of Time Reversal Invariance (TRIC experiment) is under preparation at COSY-Jülich [1]. The experiment is planned as a null transmission experiment in the storage ring using a T-violation sensitive observable $A_{Y,XZ}$ available in double-polarised pd scattering. A polarised proton beam, together with a tensor polarised deuterium gas target located in one of the straight sections of COSY, will be used for the TRIC experiment. The $A_{Y,XZ}$ observable will be determined from the difference of beam life-times measured for two independent beam-target spin polarisation states. This is the reason why the TRIC experiment puts very stringent requirements on the precision of beam life-time determination and hence resolution in the beam current measurement. The minimal resolution of 10^{-4} integrated over one second in the beam current measurement will allow us to reach the goal of the project after one month of measurement and to improve the present upper limit on the T-violation by an order of magnitude.

COSY BEAM PARAMETERS

Unfortunately, it is not possible to reach resolution better than 10^{-3} in the coasted beam current measurement using a conventional DC Beam Current Transformers (BCT) [2]. But a much higher sensitivity and resolution can be obtained

for the averaged bunched beam current measurement using inductive or capacitive pick-ups [3]. Since COSY can provide both bunched and unbunched beams at the energy of the TRIC experiment (see parameters of the COSY beam in Tab. 1) it was decided to construct a new high resolution beam current measurement system for COSY using an inductive sensor, sensitive to the bunched beam, together with modern readout electronics.

Table 1: COSY Beam Parameters During the TRIC Experiment

Beam Parameter	Expected value
Beam momentum	521 MeV/c
Revolution Frequency	793345 Hz
Bunch length	200 ns
Bunch shape	Gaussian
Number of protons in ring	$\sim 10^{10}$
Averaged current	1 mA

Since TRIC is a precision experiment, which crucially depends on the precision of the beam current measurement, it was decided to build a test stand in the laboratory to have possibility to study parameters of the sensors and the readout chain with conductive wire independently from the availability of the COSY beam.

FAST CURRENT TRANSFORMER

Two Fast Current Transformers (FCT) with similar parameters have been ordered from the Bergoz Instrumentation company for the TRIC experiment at COSY [4]. Sensors are made in on-flange UHV compatible configuration with a calibration winding. This kind of configuration simplifies sensor installation and requires less than 10 cm of space in the ring. The FCT installed in one of the straight section of the COSY ring is presented in Fig. 1. The device has a conductive break inside and is ready to use after the installation. Since beam intensity in COSY is relatively small, the device installed in the ring is equipped with a custom build low noise preamplifier to work with readout electronics located outside of the accelerator tunnel. Calibration winding

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Figure 1: The Fast Current Transformer from Bergoz Instrumentation installed at COSY. The FCT in the ring is equipped with a custom build preamplifier and a current source for calibration. The main parts of the readout and calibration module are installed outside the tunnel.

is connected to the custom build precision current source which allows one to calibrate the FCT using a dedicated calibration module in parallel to the normal COSY operation. Analog parts of readout electronics and the calibration module described in Ref. [5].

TEST STAND IN THE LABORATORY

The test stand (see Ref. [6]) for the beam current measurement devices has been build to study the performance of equipment for the precision experiments planned at COSY. In the test stand, presented in Fig. 2, a beam current of COSY is simulated using a precisely positioned conductive wire and an arbitrary wave form generator. The test stand consists of a wire positioning system, COSY beam position monitor (BPM) and sets of tubes used to support and accommodate devices under study. Modular construction enables fast implementation of new devices in the laboratory and cross checking with devices at COSY. Main parameters of the wire positioning system of the laboratory test stand are summarized in Tab. 2.

Table 2: Parameters of the Test Stand for the Beam Current Sensitive Devices

Parameters of test stand	Value
Wire diameter	50 μm
Movement range	$\pm$8 cm
Movement step	10 μm
Positioning uncertainty horizontal	100 μm
Positioning uncertainty vertical	92 μm

The signal in the wire is generated by a custom-built current source which is driven by an arbitrary wave form generator [7]. The signal is terminated by an active load system on the other side of the wire. The load system enables monitoring of the signal generated in the wire and of the amount of reflections and noise.
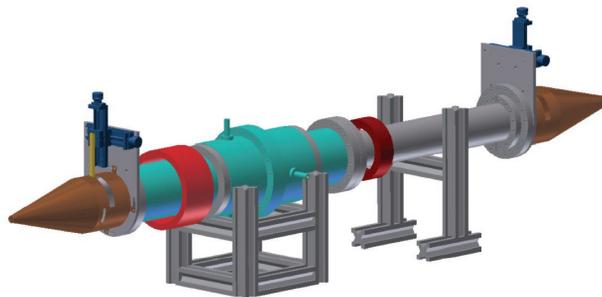
Figure 2: The test station for the beam current measurement devices. Different beam current sensors can be implemented in to the test stand. The wire inside the tube is moved using XY tables (blue) mounted on both sides of the system. The wire tension system is covered inside the tapers (copper colored).

MEASUREMENTS AT COSY

The scheme of the FCT measurement system prepared for COSY is presented in Fig. 3. The preamplifier and current source are connected to the FCT installed in the COSY tunnel. An amplified signal is transferred over a coaxial cable to the measurement setup inside the COSY hall. The signal is split between the Lock-In Amplifier [8] (LIA), readout over the Ethernet, and main amplifier which distribute it to other users. COSY RF system is used as a reference frequency for LIA. The hardware trigger signal for all the systems in the readout is prepared using a dedicated trigger module which accepts all the important for the experiment signals from COSY and other parts of experimental apparatus. This module, as well as all the other devices, is read out and controlled by an common Data Acquisition (DAQ) software over Ethernet. The calibration module provides a high precision rectangular voltage signal to the current source connected to a calibration winding of the FCT.

The first measurements done at COSY confirmed the extremely good sensitivity of the FCT from the Bergoz Instrumentation. At first, the bunched beam intensity in the ring was calibrated using a standard COSY BCT and later was reduced by readjusting the injection beam line. Beam current in the range from 2×10^9 down to 4×10^4 protons in the ring has been detected by the FCT.

MEASUREMENTS IN THE LABORATORY

To perform a detailed studies of the FCT parameters in the laboratory the second readout system, presented in Fig. 4, analogous to the one used at COSY, has been build. The signal from the FCT is readout using the same set of devices as at COSY and readout over Ethernet using the same DAQ. The signal in the conductive wire of the test stand is generated using a sender device and an Arbitrary Waveform Generator which is controlled by the DAQ. The signal in the
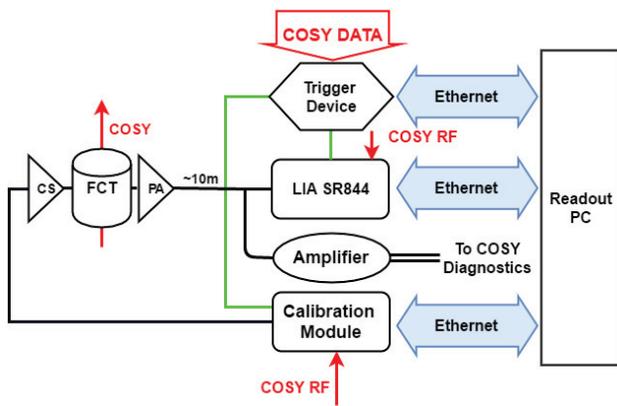
Figure 3: The Fast Current Transformer readout scheme at COSY. The pre-amplifier (PA) and the current source (CA) are connected to the FCT installed at COSY, while all the other systems are installed outside of the tunnel. The trigger and calibration modules as well as the Lock-In Amplifier are readout via Ethernet using a common DAQ which runs on a readout PC.

wire is monitored using a receiver device on the other side of the test stand using a readout scheme identical to that of the FCT. In the laboratory, the trigger module, controlled over the network, generates all the necessary hardware trigger signals for our readout system.
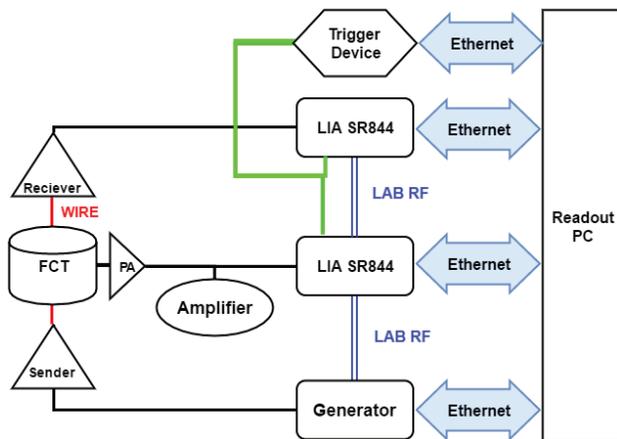
Figure 4: The Fast Current Transformer readout scheme in the laboratory. Similar to the readout scheme presented in Fig. 3 all the devices controlled by a common DAQ discussed in a next section but instead of COSY beam, an electrical signal in a conductive wire is generated by an arbitrary wave form generator.

DATA ACQUSITION SYSTEM

The data acquisition system was developed to perform series of measurements initiated either by a trigger device or a software process (see Fig. 5). Most of the code is written in C++11 under the Linux operations system. The system is oriented on the usage of commercially available devices with TCP/IP or RS-232 serial interfaces with LAN-Serial
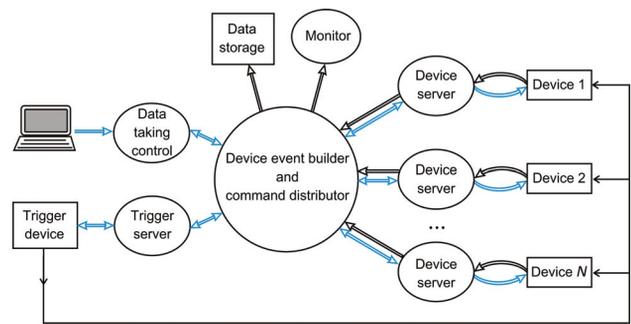
Figure 5: Layout of the DAQ prepared for the high resolution beam current measurement system. All the physical devices (rectangles), including custom build trigger model, are communicating with software (ovals) running on a readout and control PCs over the 1Gb Ethernet. All the readout devices get hardware trigger signals from the trigger device via dedicated coaxial lines.

adapters. It allows one to make the software more uniform and escape the limitations on length of the serial bus.

An interactive `dt_commander` control process gets ASCII text commands on standard input and sends them to an event builder and command distributor (`dev_evb` process) as XDR strings. One can write a simple process which writes commands required to perform long series of measurement to standard output. For example, initialize devices, start measurements, sleep for a measurement time, pause data taking, change parameters, resume data taking, and so on. The output of this process is piped to `dt_commander` to provide exactly the same execution as for interactive input.

A dedicated trigger device obtains input TTL signals from an external source (accelerator synchronization module or multichannel generator), handles them by FPGA and provides output hardware signals: BOS (begin of series), BOM (begin of measurement), EOM (end of measurement) and EOS (end of series). The device (as well as software trigger simulator) can also send corresponding XDR strings to LAN and obtain commands on the same socket. The use of hardware signals allows one to provide better synchronization between devices than using string commands distributed by TCP/IP.

A trigger server process (`trg_server`) controls the trigger device and provides communication with an event builder and command distributor. It allows to get data-taking control commands and correspondingly changes the state of the trigger device. The event builder and command distributor (`dev_evb`) process sends trigger and data taking commands to device servers, obtains data from them and build an event corresponding to one measurement (in BOM – EOM time interval), writes (if requested) a data file and sends data to TCP/IP socket for on-line monitoring or including them in a data stream of a global DAQ.

Device server code (`dev_server`) is an interface process between the `dev_evb` process and the hardware device. It translates input commands into series of device specific commands for execution, loads them in the device and re-

ceives answers. The main function of `dev_server` does not depend on the device type. The device specifics are implemented in a child class which inherits from the base interface class providing abstract methods to execute common data-taking and trigger commands, and read out data. Hence, no changes to `trg_server` are needed to add a new device into the readout. All used devices allowed one to perform measurements in parallel with data read- out, and make a few measurements per one trigger signal. This allows one not to overload the host computer by device services.

In the laboratory, all processes are running on the Intel(R) Core(TM) i3-3220 CPU@3.30GHz computer with 4 cores under the disk-less Debian Wheezy operation system. As an option, each `dev_server` may be used directly as part of a global DAQ, but a dead time larger than BOM – EOM time interval makes simultaneous work with fast systems like VME or CAMAC problematic. The output data provided by `dev_evb` could be included in a common data stream asynchronously with dead time depending on data transfer time only.

For the analysis and presentation of the experimental data, stored with new DAQ, a simple analysis software has been written using the ROOT package from CERN.

RESULTS
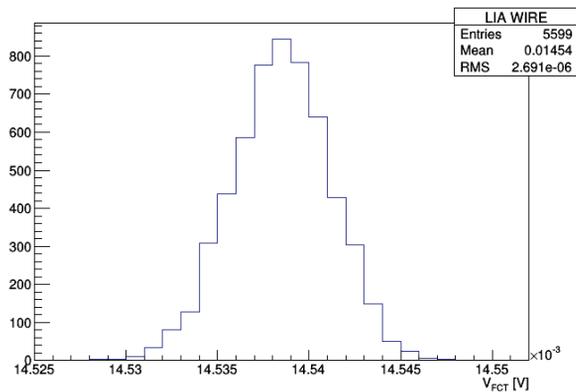
Figure 6: Current in the wire measured using the FCT in the laboratory. An electrical current which simulates 1 mA beam current of COSY has been measured by an FCT in the test stand using the measurement scheme presented in Fig. 4. The voltage signal generated by FCT was measured for 1.5 h using a LIA.

The relative resolution of 1.9×10^{-4} for the bunched beam current of 1 mA has been obtained in the laboratory (see Fig. 6). Parameters of the LIA used in the readout allows an order of magnitude better resolution but our measurements in the laboratory are limited by external factors like general system stability and temperature variations (2×10^{-3} per grad. Celsius), which need further understanding.

CONCLUSION

A system for the high resolution beam current measurement, based on the Fast Current Transformer from the Bergoz Instrumentation, has been built and installed at COSY and in the laboratory. The FCT sensitivity to the COSY bunched beam current across almost five orders of magnitude has been demonstrated. The relative resolution of 1.9×10^{-4} has been reached in the laboratory for the current of 1 mA in a conductive wire. To improve system resolution and better understand possible systematic effects of the FCT on a TRIC result further tests in the laboratory and at COSY are planned.

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