

WIRE SCANNER FOR HIGH INTENSITY BEAM PROFILE DIAGNOSTICS*

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Abstract

A control and data acquisition system of a high speed wire scanner is developed for high intensity beam profile diagnostics. The control system of the wire scanner includes two IOCs, a Soft IOC and a VME IOC. The Soft IOC connects with an Aerotech Ensemble motor drive through EPICIS motor record and controls the movement of the wire scanner. An Electrical Input card samples the real-time position of the wire through an incremental encoder, and generates a pulse to synchronize a VME ADC data acquisition card, which digitizes and samples the beam-induced signal after pre-amplification. A VME Relay Output card is installed to control the Brake Solenoid and Actuator Solenoid. All the VME I/O cards are installed on one VME crate and controlled by the VME IOC. The system configuration and software of the wire scanner are under development.

INTRODUCTION

The beam profile measurement device, commonly known as a harp, consists of a 45 degree thin wire and two orthogonal thin wires which pass in a controlled manner through the electron beam[1,2,3]. When the wire intercepts the beam, a beam-induced current, as a function of wire position, produces a functional x-y plot. By plotting the number of steps against the charge collected by an analog-to-digital convertor (ADC), the beam's profile is determined when the data is fitted to a Gaussian distribution. Wire scanners are among the most reliable diagnostic tools presently available at electron- and ion-beam accelerator facilities and are crucial to their operation. Wire scanners are interceptive devices and their wires have damage thresholds that can be exceeded with intense beams, causing them to melt or break. RadiaBeam Technologies has designed and manufactured a robust high speed wire scanner for high intensity beams using a new wire material: boron-nitride nanotubes (BNNT)[4]. The RadiaBeam wire scanner (RWS) will be installed in the Low-Energy Recirculator Facility (LERF) at Jefferson Lab to investigate the behavior of wires in a high-energy electron beam. This paper details the mechanical structure of the scanner, the control, and data acquisition system.

THE WIRE SCANNER SYSTEM

The complete RadiaBeam wire scanner system includes linear motion, vacuum chamber, actuation, detection, and associated controls. Figure 1 shows the picture of the RWS

system. The Aerotech linear motor is driven by an Aerotech Ensemble HPe 75 high power PWM network digital drive which provides deterministic behavior, auto-identification, and easy software setup. The actuator, attached to the linear motor, holds the thread fork and moves the wires inside the chamber without breaking vacuum. As the conductive wire passes through the beam, it collects a very small charge, this current leaves the vacuum assembly via an SMA connector and travels to a pre-amplifier through a cable, and eventually is measured by an ADC DAQ card. However, BNNT wire is non-conductive and it can't pick up a charge, so a high speed photodiode (PD) or a photomultiplier (PMT) is used to investigate the beam profile as the wire passes through the beam. Two types of encoders, an absolute encoder and an incremental encoder, are installed to measure the position of the wires. The absolute encoder sends the position information to the motor drive while the incremental encoder sends it to the control system. During the beam test, the wires will be optically imaged as they move into the beam and recorded in the process. A CCD video camera and a Si photodiode are installed on a viewport of the vacuum chamber so that light emitted from the wires can be collected for imaging and intensity monitoring simultaneously.

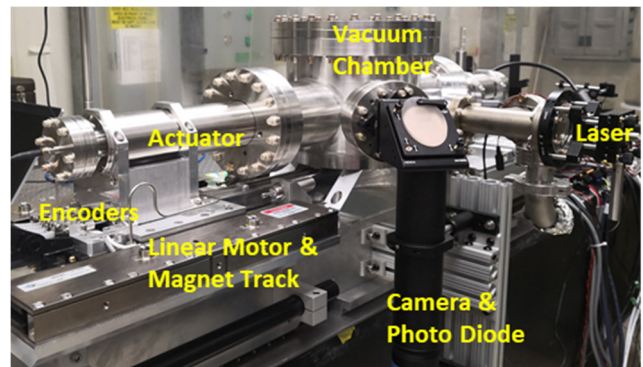


Figure 1: The picture of the RWS system.

SYSTEM CONTROL AND DATA PROCESSING

The control and data processing of the wire scanner system mainly consists of two parts, a software driver for motion control and hardware interface cards for device control and data acquisition. EPICIS applications and firmware for the whole system were developed. Figure 2 shows the block diagram of the system.

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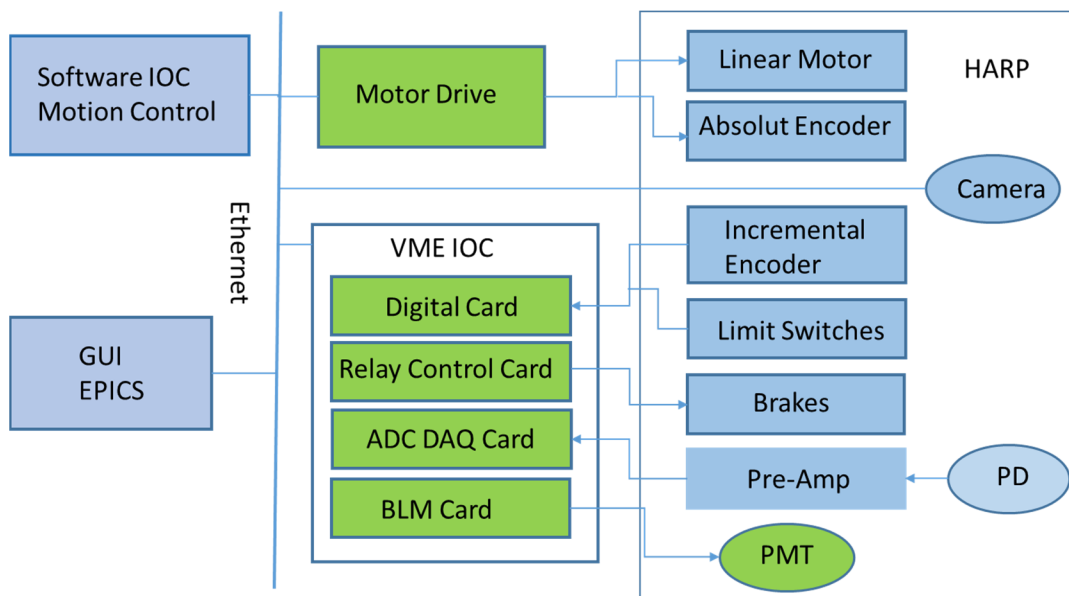


Figure 2: The block diagram of the wire scanner system.

The Ensemble motor drive accepts remote commands over Ethernet and is fully compatible with EPICS set of software tools. In this application a soft IOC is running on a Linux machine that utilizes a TCP/IP port to communicate with the motor drive. The soft IOC calls the EPICS motor module and all the operations of motor are integrated in one motor record. This record includes absolute or incremental moves, speed and acceleration settings, position setting, motor enable/disable, home running, position feedback, etc. The motor drive has multiple connectors that not only provides three phase current to the linear motor with a peak current of 75A, but also interfaces with an absolute encoder, limit switches, thermistor, and other I/O circuits. Here is the formula between the power and the velocity (speed):

$$P[W] = F[N] * V[m/s].$$

P is the power in watts and F is the force in Newtons. If the maximum power of the drive is set to 100 Watts and the force to move the actuator is 500 Newtons, then the maximum linear velocity will be 200 mm/s. The absolute encoder has a resolution of 0.1 μ m per tick so the maximum speed of the motor record would be set to 2000000.

Incremental encoders are sensors that generate signals in response to rotary or linear movement. They supply two square TTL wave pulses offset by 90°, A and B, as well as a reference pulse, Z. The VME Digital card samples these A, B, and Z TTL pulses and calculates the distance of movement. The FPGA on the Digital card is programmed to detect the two pulse edges of A and B, and then generates an output pulse having resolution either standard or high accuracy resolution. Figure 3 shows input waveforms A, B, Z, and the output pulses in Standard and High accuracy evaluation. Standard accuracy is a single evaluation - 2 μ m per pulse and the High accuracy is a quadruple evaluation with 0.5 μ m per pulse. In High accuracy mode, the FPGA logic generates one pulse for each rising and falling edge of A and B with a total of four pulses generated for one evaluation. The output pulse is linked to the ADC DAQ

card and a BLM card to synchronize data acquisition. Currently, the system is configured for 100 kHz pulse, and both the ADC and BLM cards can handle that sample rate. If Standard accuracy is selected, the translation can be up to 200 mm/sec and for the High accuracy up to 50 mm/sec. Currently, the motor speed of the Super Harp at Jefferson Lab is around 1 mm/s. Obviously, the new wire scanner system has a much higher translation speed.

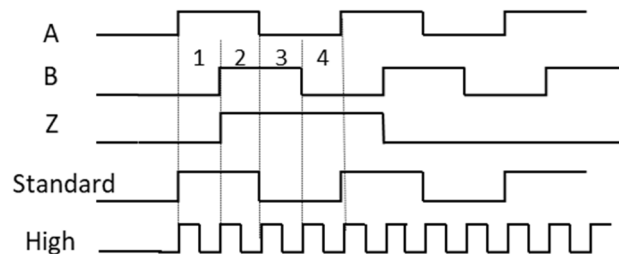


Figure 3: Incremental encoder input signal and the output pulses.

The system can work as either a regular accelerator harp where the ADC DAQ card digitizes and samples the beam-induced signal after pre-amplification or as a PMT harp where the BLM card is used. As a PMT harp, a photomultiplier tube (PMT) is placed downstream of the harp mechanism. As the wires pass through the beam, a stream of electrons are scattered along the beam path and are picked up by the PMT and sampled by the BLM card. Both the ADC DAQ card and the BLM card have an on-board 16-Mbit SDRAM memory buffer for the sampled data. The ADC DAQ card has a 16-bit ADC and can measure an input voltage ranging from -10 V to +10 V or current from -20mA to 20mA in single-ended or differential mode. The BLM card has a large dynamic range for logarithmic signal and can measure a negative current from 10 nA to 1 mA[5].

INITIAL RESULTS

Before installing RWS scanner in the LERF beam line, it was calibrated on the test bench with a laser beam simulating the electron beam. The CCD camera, laser, and photodiode are aligned and focused to provide sharp images of the location of the center of the vacuum chamber. Figure 4 shows the images of the middle wire caught by the CCD camera when passing through the laser light. The images illustrate the intensity change of the reflected light.

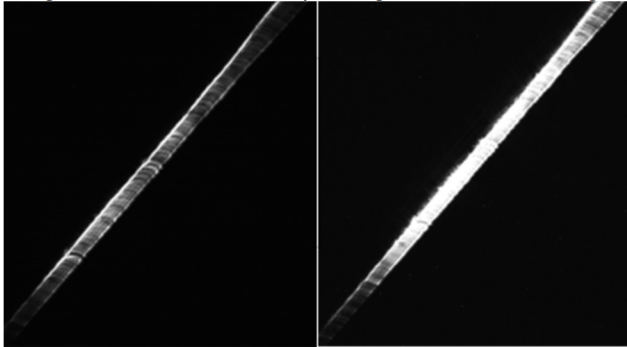


Figure 4: Images of the wire with reflected light.

The EPICS GUI was developed to setup the control parameters such as the maximum speed, running speed, acceleration rate, starting position, and the running distance. A software program, called sequencer, runs in the VME IOC to control the procedure of operations. First, a Relay Control card turns on solenoids to apply cooling air and release the brake. Then, the soft IOC enables the motor drive and moves the wire. At the same time, the ADC DAQ card samples the real-time signal from the pre-amplifier and saves it on the memory buffer. After the scanning is finished, the sequencer turns on the brake, disables the motor drive, and turns off the cooling air. Finally, the data in the memory buffer is dumped to a file for further analysis. Figure 5 shows the reflected laser beam profile measured with the photodiode with a motor speed 50 mm/sec. The vertical axis is the readback signal of the photodiode, after a pre-amplifier, and the horizontal axis is the position of the wire.

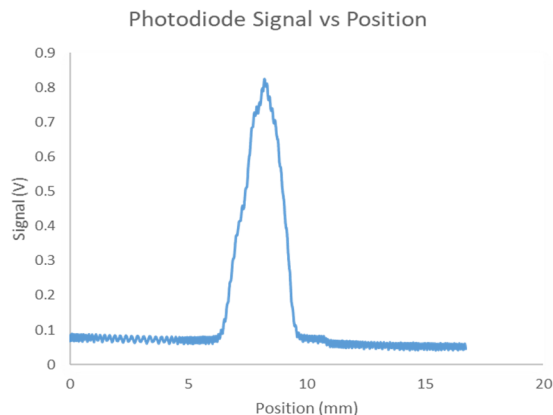


Figure 5: The beam profile measured with a photodiode.

CONCLUSIONS

A high-speed control and data acquisition system for the RadiaBeam wire scanner has been developed for high intensity beam profile diagnostics. The motor drive has been extensively tested with different parameters. The high-power Aerotech Ensemble HPe was chosen to drive the wire scanner. The software package that controls the motor drive and other I/O interfaces has been implemented in the EPICS control system. The hardware for device control and data sampling has been configured to provide multiple harp operations, such as a Super harp and a PMT harp. Initial results have been achieved on the 45° wire by using a laser beam to simulate the electrons and fitting the photodiode signal and the wire position to a Gaussian distribution. The next step is to install the wire scanner in the LERF and CEBAF beam lines at Jefferson Lab for high intensity beam testing. Before installing the wire scanner in a real beam, more testing of the hardware and software need to be performed.

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REFERENCES

- [1] C. Yan *et al.*, “Super-harp- A Wire Scanner with Absolute Position Readout for Beam Energy Measurement at CEBAF.” Nuclear Instruments and Methods in Physics Research A 365 (1995) 261-267.
- [2] A. Freyberger, “Large Dynamic Range Beam Profile Measurements”, in *Proc. 20th Particle Accelerator Conf. (PAC'03)*, Portland, OR, USA, May 2003, paper WPPB070, pp. 2565-2567.
- [3] Jlab.org, https://www.jlab.org/accel/beam_dia/harp/harp_dummy.html
- [4] “Robust Wire Scanner for High Intensity Beam Profile Diagnostics”, <https://www.sbir.gov/sbirsearch/detail/1209049>
- [5] J. Yan and K. L. Mahoney, “New Beam Loss Monitor for 12 GeV Upgrade”, in *Proc. 12th Int. Conf. on Accelerator and Large Experimental Control Systems (ICALEPCS'09)*, Kobe, Japan, Oct. 2009, paper WEP092, pp. 582-584.