Design and Commissioning of Flying Wires in the Fermilab Accumulator

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Abstract

Six flying wire systems have been installed in the Fermilab Accumulator to measure the transverse beam profiles during antiproton stacking and extraction, and the beam momentum distribution during deceleration through transition. Each system measures a transverse beam profile by passing a 25 micron carbon filament through the beam transversely, and recording the flux of secondary particles which are produced from the collisions between the beam particles and the wire. The wire motion, data acquisition, and communication with the control system are managed by a 32-bit VME based microcomputer system. This paper summarizes the hardware and software features of the Accumulator flying wire systems. The measured effect of wire passages on beam emittance is described.

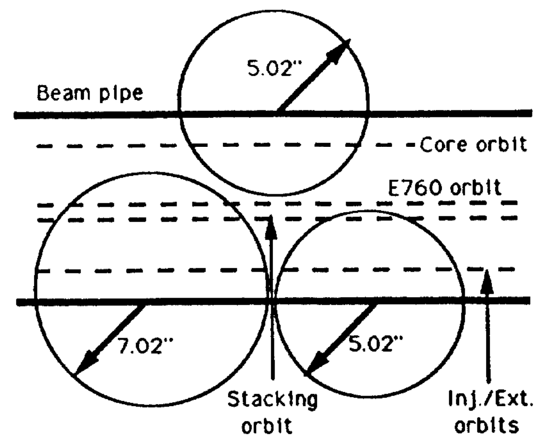

Figure 1: Location of the horizontal flying wires in the AP40 high dispersion region.

1 Introduction

The Accumulator flying wire systems have been installed for measuring the transverse beam profiles during $\bar{p}$ stacking, extraction and the E760 deceleration operation [1]. Their design is very similar to that of the Main Ring and the Tevatron flying wire systems [2]. Each detector passes a 25 micron carbon fiber through the beam transversely at a constant velocity of 10 m/s. As the wire traverses the beam, collisions between the beam particles and the wire produce secondary particle cascades with the intensity proportional to the number of the beam particles at the wire position. These secondary particles are intercepted by a scintillator in which photons are then produced. A photomultiplier is used to measure the light intensity, and the wire position is determined by an optical encoder.

2 Wire Location

In the Accumulator, the two horizontal and two vertical flying wires to be used in normal stacking operation are located in the AP40 high dispersion section, covering the core orbit and the extraction orbit respectively. The two wires for E760 are both horizontal, one is located in the AP40 high dispersion region and covers the central orbit, the other in the AP30 low dispersion region. They are to be used to measure the momentum distribution of the beam. Figure 1 shows the covering range of the horizontal wires in the AP40 high dispersion region. The fork arm length of the E760 high dispersion wire is 7.02″ and that of the other five wires is 5.02″. The optical encoder provides an angular resolution of 0.022 degree (16384 steps per revolution).

3 System Features

Since the Accumulator requires a higher vacuum than the other rings, commercially available bellows-sealed rotary motion feedthroughs (manufactured by Varian Vacuum Products, pt.#954-5151) are used for the Accumulator flying wire systems. These feedthroughs are capable of maintaining a vacuum of 10^{-11} Torr and are bakeable to a temperature of $300°C$. Another major difference of the Accumulator wire systems from the existing Main Ring and

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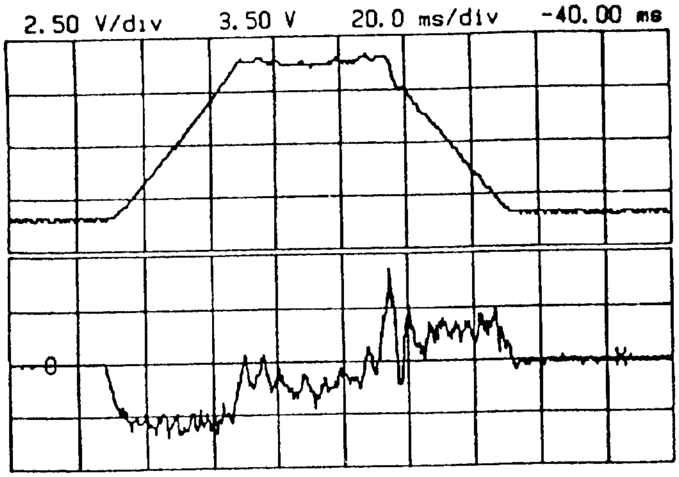

Figure 2: Top trace is the velocity profile of the wire in the AP30 low dispersion region. The bottom trace is the motor current.

Tevatron systems is that they also have an option to measure the beam profile by measuring the depletion current generated by the secondary emission of electrons. A $BeCu$ spiral coiled torsion spring attached to each wire provides the path for the output signal. The wires, instead of being able to spin around, must stop within a single turn (2π) and reverse its direction for the next fly. Even though the wire motion is controlled via software, a limit switch is mounted on each flying wire to prevent further rotation which would damage the torsion spring.

The motion control and data acquisition of the Accumulator systems follow the design of the existing systems. The motion of the wire is controlled by a commercial 8-bit servo controller chip set (GL-2010 microprocessor chip and GL-100 interface chip manufactured by Galil Motion Control). The wire motion follows a preprogrammed trapezoidal velocity profile, and the maximum velocity is reached and maintained while the wire is passing through the beam aperture. In the process of the wire motion, the controller compares the actual position, measured by the optical encoder, with the programmed position. The error signal is filtered and sent to the power amplifier to drive the DC servomotor. In order for the closed-loop feedback system to have a fast and stable response, its bandwidth has been properly chosen. In the testing of the motion control, a resonance caused system trip. The resonance was removed by replacing the mechanical coupler between the optical encoder and the fork arm. Figure 2 shows the measured velocity profile of the wire in the A30 low dispersion region.

Data acquisition is initiated by an external triggering pulse. The amplitude signal from the phototube is processed with a gated integrator, digitised with a 12-bit high speed A/D convertor, and stored in a sixteen kilobyte FIFO memory. The position of the wire is also stored in another FIFO memory.

4 Wire Heating

In estimating the temperature rise of the wire in a single scan, we assume that only ionization loss of the incoming particles contributes to heating and that there is no cooling during wire traversal. Ignoring the relativistic effect, ionisation loss as a charged particle travels in a media can be expressed as [3]

$$\frac{dE}{dz} = \left.\frac{dE}{dz}\right|_{\min} \cdot \frac{1}{\beta^2}, \tag{1}$$

where z is the direction of the particle's motion. If all this deposited energy is assumed to heat the wire, for a constant specific heat c_p the temperature rise of the wire in a single scan is

$$\Delta T = \frac{N_p k f_{\text{rev}} \left.\frac{dE}{d(\rho z)}\right|_{\min}}{V_w c_p \beta^2} \sqrt{\frac{3\beta\gamma}{\epsilon_y \beta_y}}, \tag{2}$$

where N_p is the total number of particles, k is the Boltzmann constant, ρ is the mass density of the wire, V_w is the sweeping speed of wire, f_{rev} is the revolution frequency of the beam particle, and ϵ_y and β_y are the beam emittance and the β-function respectively. Since carbon fiber has a specific heat which is a function of the temperature, eq. (2) should be modified for a correct result. The final temperature of the wire after one scan can be obtained from the equation below:

$$\int_{300}^{T_f} c_p(T)\, dT = \frac{N_p k f_{\text{rev}} \left.\frac{dE}{d(\rho z)}\right|_{\min}}{V_w c_p \beta^2} \sqrt{\frac{3\beta\gamma}{\epsilon_y \beta_y}}. \tag{3}$$

Since the beam size in the low dispersion region is much smaller than that in the high dispersion region, the temperature rise of the wire in the low dispersion region is expected to be much greater than that of the high dispersion wires. For a beam of 5×10^{11} particles and with a horizonal emittance of 1πmm-mrad, the temperature rise of AP30 low dispersion wire is estimated to be

$$\Delta T \approx 950\,^\circ C. \tag{4}$$

The sweeping speed used in the calculation is 6 m/s. For a faster speed of 10 m/s, the temperature rise is lower. The result remains the same when taking into account the heat conduction along the wire.

According to this estimate, the temperature rise of the wire in a single scan is much lower than the melting point of the carbon wire, which is approximately $3550°C$. In addition, study shows that only about 30% of the deposited energy heats the wire [4]. This fact will lead to a further reduction on the temperature rise of the wire. Therefore wire heating is not a problem.

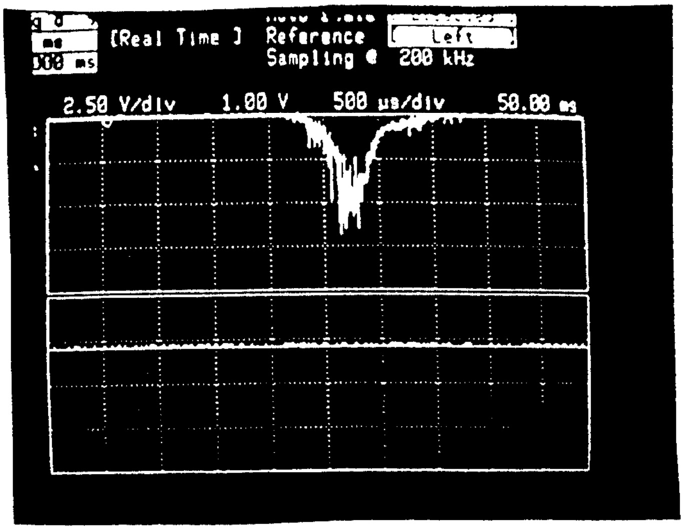

Figure 3: Photomultiplier output signal.

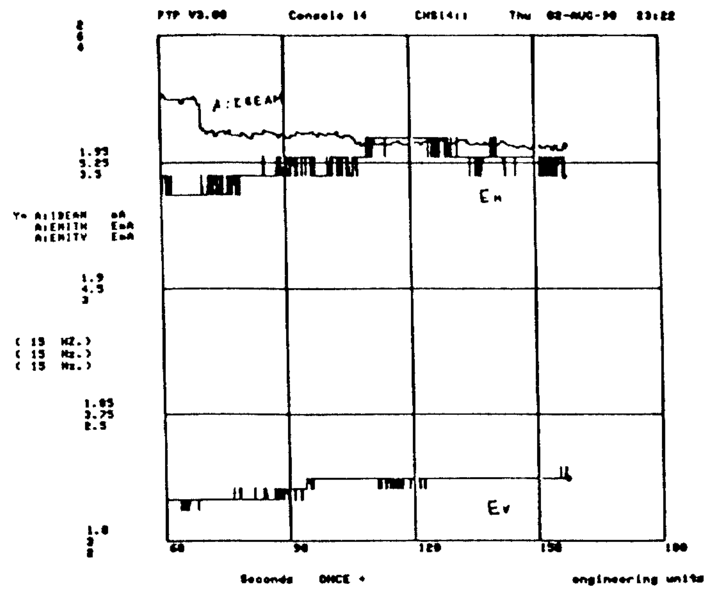

Figure 4: Beam current and transverse emittances.

5 Test Results

Figure 3 shows the output signal from the photomultiplier in a test fly of the E760 low dispersion wire. The trace represents the particle distribution of the beam in the horizontal direction. It was also found in a test fly that as the wire traversed the beam, it caused a beam intensity loss and emittance blow up. Figure 4 shows the measured beam intensity and transverse emittances in the test fly. For each sweep, the wire passed through the beam twice, and the beam loss was about 1%. The transverse emittance is obtained by measuring the total power of a betatron sideband. In figure 4, A:EMITH (A:EMITV) divided by the beam current A:IBEAM gives the horizontal (vertical) emittance, but the calibration is not accurate. Nonetheless, these measurements show emittance blow up in both transverse directions. The beam has an initial horizontal emittance of 2.6π mm-mrad and a vertical emittance of 1.1π mm-mrad. The increases of the horizontal and vertical emittances are roughly 0.1π mm-mrad and 0.05π mm-mrad respectively.

6 Future Work

In order to make the Accumulator flying wire systems fully operational, the data acquisition and reduction system must be calibrated so that the measured profile truly represents the beam particle distribution. This includes choosing the proper high voltage for each photomultiplier, and integrating time for obtaining the integrated light intensity. In addition, the depletion current readout capability will be completed in the upgrades of the Fermilab flying wire systems.

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