A NEW FLYING WIRE SYSTEM FOR THE TEVATRON

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Abstract

A new flying wire system replaces an older system to enhance the analysis of beam emittance, improve reliability, and support future upgrades to the Tevatron. New VME data acquisition and timing modules allow for more bunches to be sampled more precisely. A LabVIEW application, running on a Macintosh computer, controls the data acquisition and wire motion. The application also analyzes and stores the data as well as handles local and remote commands. The new system flies three wires and fits profiles of 72 bunches to a gaussian function in a total of three seconds. A new console application allows remote operator control and display from any control console. This paper discusses the hardware and software setup, capabilities, and measurement results of the new flying wire system.

1 INTRODUCTION

The flying wire system measures the transverse beam size by moving a wire through the beam. The collision of the beam particles with the wire generates a spray of secondary particles with an intensity proportional to the number of beam particles present at the position of the wire. A portion of the secondary particles hits a nearby scintillator paddle to produce light. The light is converted into an electrical signal by a photo multiplier tube. This signal is plotted versus the position of the wire to obtain the profile of the beam. A gaussian function is fitted to the profile and its sigma represents the transverse beam size.

1.1 Problems with the old system

The old system, described in [1] and [2], suffered from reliability problems and a lack of an upgrade path. The VME hardware often generated bus errors resulting in an aborted fly or corrupted data. The optical encoder module that measured the position of the wire was sensitive to radiation and needed to be replaced every month. Sometimes the damage to the encoder would halt the wire in the middle of the beam, destroying the wire. The old hardware would also not be able to measure the additional beam bunches for the planned Tevatron upgrade. The results, sigma and mean, were not consistent. Each counterclockwise fly was followed with a clockwise fly but the results were often more than ten percent apart. The profile could also contain bad points due to, as later diagnosed, a vibration from the drive belt and the use of a soft coupler between the encoder and fork. The analysis itself was very sensitive to noise if the beam intensity was low. The software for the system was written in C and Assembly, and no one with knowledge of the programs was available to update it. The old system used two different embedded processors with slightly different programs to control the three wires. The difference in programs turned out rather tedious to maintain.

As the Instrumentation Group had good prior experience with LabVIEW based systems, it was decided to use LabVIEW on a single Macintosh computer along with commercial motion control and digitizers.

2 HARDWARE CONFIGURATION

In the new configuration, the integrator, position FIFO, and timer modules are all new or upgraded in-house designs. In addition, we switched from the optical encoders to resolvers to minimize radiation induced failures. A direct drive replaced the belt drive of the earlier system and the resolver was hard coupled to the fork shaft, with a floating mount to prevent binding.

The wire can has a diameter of 21 centimeters, the fork has a radius of 10 centimeters and holds a 33 micron carbon filament that flies at a speed of about 5 m/s. The position is measured with a resolver and 14-bit R/D converter, providing an angular resolution of 0.022 degrees. To reduce the number of samples, the R/D converter implements programmable aperture gates to turn sampling on during that part of the fly path where beam might be present. The beamloss signal from the phototube is first integrated by an in-house fast integrator VME board and then A/D converted by a 12-bit Omnibyte Comet 2MS/s VME digitizer. The high voltage to the phototube can be adjusted for low and high intensity beam by using a Vero model VME48240 4-channel D/A converter module card that controls a rack-mounted high voltage power supply. Beam synchronous timing is provided by standard in-house VME timing cards. A Macintosh computer using a National Instruments NB-MXI interface controls the VME crate. The Macintosh computer also has a Nulogic motion control board that is connected to a drive amp to provide motor control.

The fly path of the wires is a total 540 degrees. The wire first accelerates, then passes through beam twice, and then decelerates. The resulting rest position is different from the start position, but by flying in the opposite direction for the next fly, the next rest position will be the original start position while giving us extra length to accelerate and decelerate. A simplified configuration with only one wire, instead of two horizontal and one vertical wire, is shown in figure 1.

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[1]† Operated by Universities Research Association

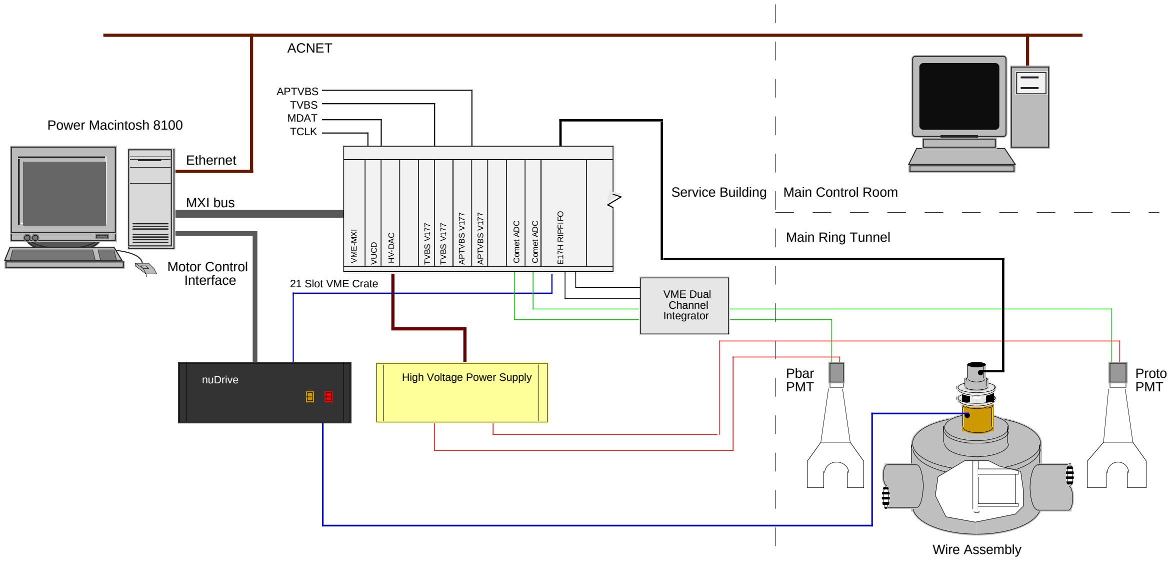

Figure 1. Single Wire Configuration.

3 SOFTWARE SETUP

3.1 User-interface

The local graphical user interface (GUI), see figure 2, can display current or saved profiles, manually control the wires, and, using menus, modify all hardware settings and analysis parameters on-line or in the default setting files. The local GUI can also be remotely controlled using an utility like Timbuktu. Each fly must use one out of 40 user-defined specifications. These specifications include which bunches are sampled at what multiple of beam turns, the integration time, when to fly, whether the data is to be saved or not, the type of analysis (full or quick), the next fly specification, the aperture, and the high voltage.

The console application Tevatron Flying Wires T46, provides remote control for operators and experimenters from any standard X Windows based console located anywhere in the lab. The consoles use the ACNET communication protocol which is supported by the LabVIEW application, see[3]. All of the programming for the console application was done in C. The two main menu items to the program are Fly Spec and Plot Six. Under Fly Spec one is able to modify the fly specifications just as under the local GUI. The menu item Plot Six allows one to view new ACNET data or saved disk data from a given fly. The plots generated under Plot Six very closely resemble the ones shown in figure 2.

3.2 Analysis algorithm

The old system’s analysis routine first did a background subtraction and then did a second moment calculation to estimate the sigma. As it turned out this calculation was very sensitive to noise during low beam intensity and could not handle a slope in the background noise. Knowing this, the new system's analysis is made more robust for background noise and poor signals. Using LabVIEW, we could select from a library of filter and fitting routines and check the processing by plotting the data at different stages.

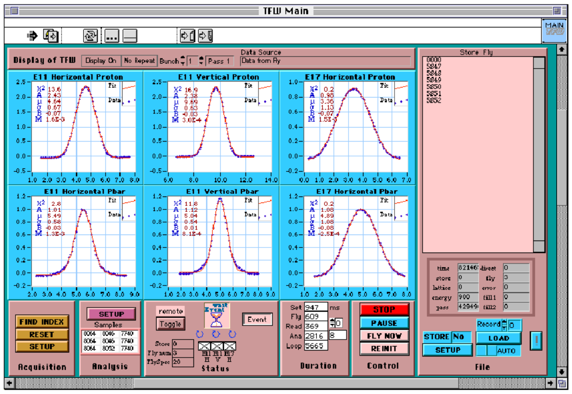

Figure 2. The local GUI.

The new analysis has two parts: the first part performs a quick analysis of the data to serve as an estimate for the second optional part, a least-squares fit. The quick analysis starts by cutting out data acquired while the wire moves within the aperture gates but doesn’t intercept any of the particle beam. Next, it will do a quick estimate by smoothing the data, finding the peak with a quadratic peak finder, estimating the background noise using data right before and after the profile, determining the slope of the background noise, and estimating the sigma from the half peak value.

The new system flies the wire through the beam twice, once upstream and once downstream, producing two peak locations. Knowing that the beam travels straight and given the locations of the peaks, we calculate and correct for any rotational misalignment of the resolver. The resolver counts can now be properly mapped into millimeters perpendicular to the beam. The estimates are also corrected, given the rotation and mapping.

The second part of the analysis uses the estimates as an initial guess to fit the rotated and mapped profile with a non-linear Levenberg-Marquardt method to the function:

$$a \cdot e^{\left(\frac{-(x-\mu)^2}{2\sigma^2}\right)} + b \cdot x + c \qquad (1)$$

The Levenberg-Marquardt method that came with the LabVIEW libraries has been optimized to obtain a ten-fold increase in speed. This particular routine is also used in other instrumentation systems that also deal with beam parameters, see [4].

4 PERFORMANCE

4.1 Speed

Using a PowerMac 8100 at 110 MHz, the system acquires data and fits profiles of three wires for a beam of six proton and six pbar bunches and two passes within 3 seconds (total of 72 fits) with 80 points per profile. Faster than 2 seconds speeds but with reduced accuracy are obtained by reducing the number of points of the profile or by completely turning the fit off and using the estimates as final results.

4.2 Repeatability

We looked at RMS (Root Mean Square) values of the measurements to quantify the repeatability. Figure 3 shows the sigma for the first proton bunch. The first part of the graph shows results from measurements taken at 149 GeV. As bunches are injected into the Tevatron, first proton than pbar, the emittance is changing. Once the ring accelerates to 900 GeV and the collision is turned on, we have measured an average of about 1% RMS with a worst case of 2% RMS around a logarithmic growing sigma. The error in the emittance is twice that of the sigma. RMS percentages of the other parameters have similar values.

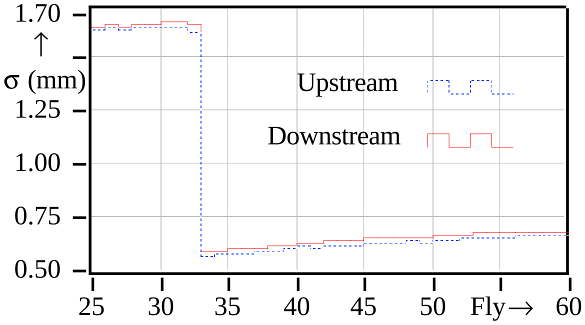

Figure 3. The sigma of bunch #1 in store 5905.

4.3 Reliability

The number of failures has been drastically reduced. We have not lost a wire since commissioning the new system. Some crashes have occurred, but after completing modifications to the program, the system has stabilized.

5 CONCLUSION AND FUTURE

The new system delivers a big improvement in reliability and gives more consistent results with a typical repeatability of around 1% RMS.

We will further investigate the accuracy of the flying wire data. We found a consistent difference for one of the wires in the upstream and downstream sigma, much larger than would be expected, due to emittance growth from the wire colliding with the beam. We plan to find out if this is related to phototube saturation by reducing light coming from the paddles or to the position of the beam/wire interaction by varying the position of the paddles.

The Tevatron will be upgraded to hold 36 proton and 36 pbar bunches instead of 6 each. A test setup supporting this upgrade has been made and is currently being tested. This setup will also be used for the Main Ring (and later Main injector) flying wires, which has a cycle of 3 to 5 seconds. To perform multiple flies during this cycle, the program is structured into different tasks with different priorities. The acquisition task runs under the highest priority and can be retriggered independently from the analysis task that runs at a lower priority. Thus, the wires can fly again before all data has been fully analyzed. The analysis can take part during the following flying of a wire and after the Main Ring cycle has been completed. Retrigger rates of almost 2 Hz are possible.

As the number of bunches increases six fold, we must also process six times as much data. We plan to upgrade the 8100 with a newer model. As three times faster models are already available, we expect that future Macintoshes will give us close to a six times speed increase compared to the current system.

6 ACKNOWLEDGEMENTS

Many people other than the authors have helped develop the new system. Special thanks go to Dong Chen for his early work, Alan Hahn for the analysis optimization, Jim Crisp for his work on the vibration of the old wire system, Jim Zagel and Brian Chase for their experience with the old system and suggestions, and Shoua Moua and Brian Fellenz for the technical support and hardware design.

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