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TREATMENT OF THE RESULTS MEASUREMENT OF PROFILE BEAM USING WIRE SCANNERS AT ACCELERATOR U-70 IHEP

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Abstract

The IHEP has developed fast wire scanners based on servomotors with a scanning speed of V=16 m/s. For processing of analog signals from detectors, a digital USB oscilloscope NI USB-5133 manufactured by National Instruments has been chosen. The paper describes methods of data processing from a wire scanner using a program developed in the LabVIEW environment and obtaining information about beam parameters as well. To determine the beam revolution frequency, a fast Fourier transform is used. The measured input signal is integrated at a chosed number of turns of the beam. The amplitude, center position, offset, rms deviation of the resulting distribution and beam sizes at the corresponding energy level are calculated using the Gaussian Peak Fit VI library element. The beam profile data in different modes of accelerator operation are presented.

INTRODUCTION

When setting up and operating the accelerator, it becomes necessary to measure the profile of the circulating beam. At IHEP, a transition was made to modern methods of developing fast wire scanners, taking into account the latest developments in mechatronics and robotics. The choice and justification of this approach were presented in [1]. Some results on the introduction of horizontal and vertical wire scanners U-70 into operation were presented at the RUPAC 2018 conference [2, 3]. This paper presents methods for processing the beam profile data using a program developed in the LabVIEW environment. Also the results of measurements of some parameters of the U-70 accelerator for proton and carbon beams at the speed of the carbon fiber V=16 m/sec are given.

COMPONENTS OF WIRE SCANNERS FOR THE U-70 ACCELERATOR

Two brushless 4490H024BS (Faulhaber) servo motors with RE-10-1-C64 resolvers (LTN Servotechnik) are controlled by ACJ-055-18R controllers through the Copley Motion Explorer CME2 software shell from Copley Controls. CME2 is installed on a computer under Windows.

The system provides double crossing of the carbon fiber the proton beam per one revolution. The speed of movement is used for processing scintillation detectors signals.

PROCESSING OF BEAM PROFILE MEASUREMENT DATA

For automated processing of analog signals from wire scanners on the U-70 accelerator, an ADC with an external trigger, a conversion frequency of at least 50 MHz per channel, 8-bit capacity and with a memory of at least 3 MB per channel is required. A digital USB oscilloscope NI USB-5133 from National Instruments is used.

This converter allows to measure and analyze the amplitude and time parameters of the recorded signals. Using the National Instruments LabVIEW2012 development environment, we have created software for working with the NI USB-5133 oscilloscope. The software algorithm is as follows:

Initialization of the device; Selection of the measurement mode (AC, DC); Configuration of the measurement channels (ADC frequency, input signal range, number of measurement points); Selection of the number of measurement channels (1 or 2); Selection of the number of measurements (ADC buffer size); Setting the ADC operation mode by an external sync pulse; Reading the measured data; Saving the array of measured data to a file for subsequent processing.

The time of a half a revolution of the carbon fiber at a constant speed is determined as:

$$T_{1/2} = \frac{\pi \cdot r}{v},$$

where r is the length of the arm of the measuring frame (R-190 mm x 100 mm, Z-150 mm x 150 mm), v is the linear speed of movement (v=16 m/s), $T_{1/2}$=37.3 ms (R-axis), $T_{1/2}$=29.45 ms (Z-axis)

Minimum ADC buffer size for measuring half a revolution

$$N = f_{ADC} \cdot T_{1/2},$$

where f_{ADC} is the conversion frequency. For a conversion frequency of 100 MHz, the minimum buffer size is 3.7×10^6 (R axis) and 2.9×10^6 (Z axis). To measure the direct passage of the fiber through the beam, the buffer size at the ADC frequency of 100 MHz was set to 2×10^6, to measure the forward and reverse passage – 3.5×10^6.

The program performs:

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- Selection of the measurement axis (R or Z), according to this, the radius of the frame arm is selected;
- Setting the speed of uniform fiber movement (by default-16 mm/ms);
- Calculation of the frame rotation time;
- Selecting the ADC conversion frequency;
- Subtracting an array of measured data from a file;
- Determining the length of an array;
- The length of the array determines whether only the forward pass was measured, or the forward and reverse;
- All arrays and indicators are reset after the previous processing.

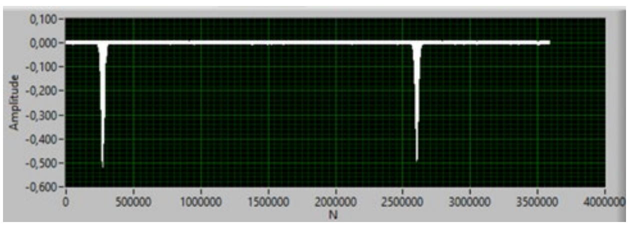

Figure 1: Graphical representation of signal selection during forward and backward pass from the measured data array.

Fragments corresponding to the forward and backward pass of the carbon fiber are selected from the entire data set. Taking into account the value of t_0, arrays are selected for the forward and backward passage of the fiber. The value is determined from the moment of uniform motion of the fiber to the beginning of registration of the beam profile. Since the input signal has negative polarity, the minimums of the input signal in the selected arrays are determined. The difference between the indices in the general array of the found minima is used to determine the real value of t_0. Arrays are selected from the measured data array for forward and backward fiber pass. A graphical representation of signal selection during forward and backward pass from the measured data array is shown in Fig. 1.

At the same time, the average value of the projection of the fiber position on a given axis is calculated. The projection is defined by the formula:

$$x = \sin\left(2 \cdot \pi \cdot \frac{t}{T}\right) \cdot r \,,$$

where $t = t_0 + dt \cdot n$ ($dt = 1/F_{ADC}$, n is the number of dimensions in the array), T is the time of a complete revolution of the carbon fiber with a given constant speed, and t_0 is the setting time measured by double measurement of the profile. The output data is an array of mean values of the measured signal and an array of the corresponding projections of the fiber on a given axis. The initial and final values of the arrays of integrals are used to determine the offset from the zero value. The resulting value is subtracted from the array. After that, the arrays of integrals are normalized to unity.

To determine the beam rotation frequency the fast Fourier transform is used. The frequency of the highest amplitude is determined from the frequency spectrum in the selected range of 133–203 kHz. Next, the input measured signal is integrated over a given number of beam revolutions – n_r. Simultaneously, the average value of the projection of the position of the fiber on the given axis is calculated. The output data is an array of mean values of the measured signal and an array of the corresponding projections of the fiber on a given axis.

Then, using the Gaussian Peak Fit VI library element (the least squares method), the normal distribution corresponding to the input arrays is calculated. The amplitude, center, offset and standard deviation (σ) of the obtained distribution are calculated. The plot displays the array of data to be integrated and the corresponding normal distribution for the forward and backward pass. The result of performing the integration and searching for the corresponding normal distribution is shown in Figs. 2 - 4.

The beam size is determined as $\pm n\sigma$, n is given before the start of the calculation. The beam size in the given example was determined as $\pm 3\sigma$. Similarly to the one described above, the calculation and graphical representation of the dependencies of the input signal on the projection of the fiber position on a given axis for the forward and backward pass is performed.

Before start the program an operator selects several options for making measurements. A given number of beam revolutions is set, during which the signal is integrated. After processing, the program allows selecting several options for the analysis of the beam density distribution: the beam size and its position relative to the center of the vacuum chamber are determined, the shape of the registered signal from the scintillation detector is given taking into account the correction when determining the beam projection in the perpendicular direction relative to the vacuum chamber, the Fourier analysis of the registered signal from the detector is performed.

RESULTS OF MEASUREMENTS

Wire scanners make it possible to measure the dimensions of the proton and carbon beams in various operating modes of the accelerator. Taking into account the need to measure the profile of a carbon beam in the range E=200÷450 MeV/n at an intensity $I = 10^9 \div 10^{10}$ ($_{12}C^{6+}$), a carbon fiber 200 μm thick is installed in the profilometers. Below are the results of measurements of the beam profile at the 3σ level at the beam injection energy E_k=1.3 GeV, at E=50 GeV ($I = 7 \times 10^{11}$ p) and for carbon beam at E=450 MeV/n.

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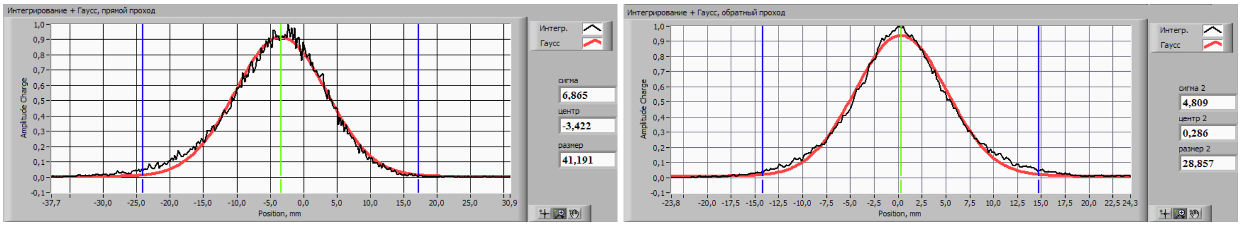

Figure 2: Horizontal (left) and vertical (right) profiles of the proton beam at the injection energy E=1.3 GeV (n_r=5).

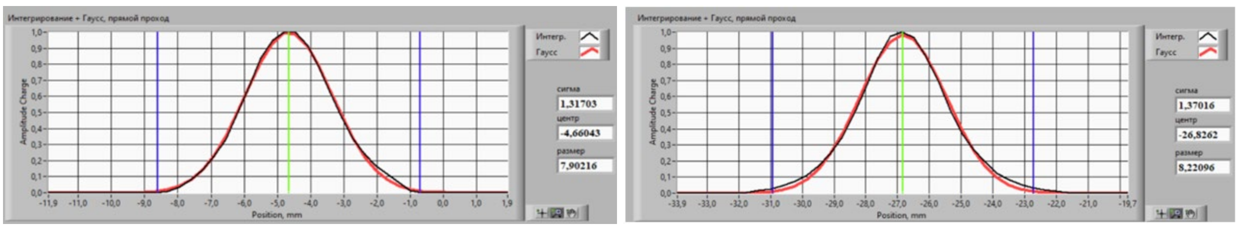

Figure 3: Horizontal (left) and vertical (right) profiles of the proton beam at the energy E=50 GeV (n_r=5).

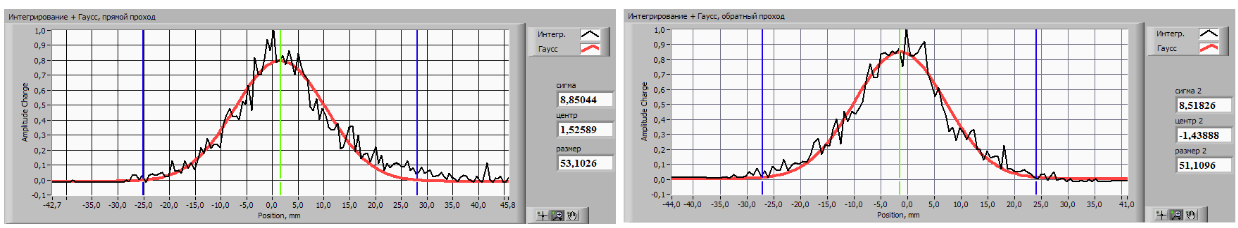

Figure 4: Horizontal (left) and vertical profiles (right) of the carbon beam at E=450 MeV/n, I=3×10^9 ($_{12}C^{6+}$).

At the U-70 accelerator, narrowband analog and wideband digital feedback circuits are used to eliminate errors in beam injection from the booster and to prevent the development of coherent instabilities [4]. Figure 5 shows the results of measurements of the beam profile and Fourier analysis of these data with the feedback circuits on and off.

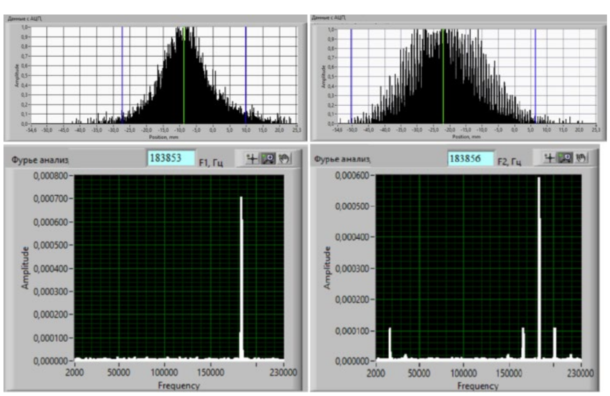

Figure 5: Horizontal profile (top) and Fourier analysis (bottom) with on (left) and off (right) feedback loops.

The local frequency of betatron oscillations is fixed at 17 kHz. This allows us to determine the frequency of betatron oscillations Q_R

$$Q_R = K - \frac{f_l}{F_0},$$

where K - an integer close to the calculated frequency of the betatron oscillations; f_l - local frequency of betatron oscillations; F_0 - frequency of particle circulation in accelerator.

For U-70 IHEP: K=10, F_0=180-200 kHz (for proton beam).

$$Q_R = 10 - \frac{17kHz}{183.8kHz} = 9.9$$

CONCLUSION

The developed program for processing the data for measuring the profile of the circulating beam is successfully used during several sessions of the accelerator for both proton and carbon beams.

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