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FAST WIRE SCANNERS FOR U-70 ACCELERATOR OF IHEP

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Abstract

The fast wire scanners are used for the transverse beam profile measurement in horizontal and vertical planes at the IHEP U-70 Accelerator. They cover the total range of operating beam intensities and energies of the circulating of proton and ion beams. The scheme of the scanners is based on a rotary brushless servomotor produced by the "Faulhaber" company. The speed of the fork with the carbon fiber is 16 m/s. The rotation mechanism and the control electronics was done to take into account the available radiation levels at the locations of the wire scanners. This report gives the mechatronic design of the wire scanners and provides a system overview.

INTRODUCTION

For the operational work of the U-70 accelerator the measuring of transverse circulating beam profiles in both planes is necessary. Initially the ionization beam profile monitors with industry television components were used for these purposes [1]. That was very bulky and provided a poor resolution. The measuring targets are also used to determine the beam transverse boundaries. During the last 30 years new techniques based on wire scanners were developed at many labs: CERN, FNAL, BNL and others. At IHEP the several types of wire scanners were built and tested at the real beam with the speeds 1 m/s [2] and 10 m/s [3]. An alternative method has been proposed and tested: the beam is guided by a deflecting magnetic field on a fixed carbon wire. In the case of the using standard equipment for the beam was put spilled on the absorber the speed of 3 m/s was obtained [4]. However, these devices were not highly reliable and had large errors in the measuring profile. The estimated resolution was of 0,1 mm and a low speed of the wire motion caused the overheating and destruction of fibers at full beam intensity. That is why the new wire scanners at U-70 were designed and put in pilot operation to measure the profiles of the circulating beam all over the machine cycle and over a full operational range of intensity and energies of the protons and ions.

PRINCIPLE OF OPERATION OF WIRE SCANNER

The U-70 wire scanners are based on a circle movement of a thin carbon fiber through the circulating beam at a speed of 10÷20 m/s. Such parameters insure the fiber saving because of weak heating when they move through the beam. Beam profile data are provided due to a radiation generated by the interaction of protons or ions with the material of the carbon fiber. The radiation is registered in a scintillation detector located in the downstream of ~ 5 m. The movement of the wire occurs an arc. When calculating the beam profile it is necessary to take this circumstance into account.

At the first wire scanners control of electric motors was carried out by analog signals in combination with mechanical devices and organization of movement through bellows. At CERN a new generation of devices in which the rotor of the servomotor is isolated from the stator by vacuum has recently been developed [5], [6]. This project stimulated our development of the wire scanners, in which the entire motor was located inside the vacuum chamber of the accelerator. The work was started in 2014 and contained the choice of the servomotor and control electronics [7], the mechanical design, manufacture and installation of these wire scanners at U-70.

COMPONENTS OF WIRE SCANNER FOR ACCELERATOR U-70

Servomotors

The servomotor shaft with a U-shaped fork is mounted on the boundary of the vacuum chamber. The device is characterized by the presence of a trapezoidal operating mode of a fast servomotor. The U-shaped fork with the carbon fiber is accelerated to the required speed during ¼ turn, then there is an area of ½ turn for a steady motion of the wire when crossing the ion beam and then the fork slows down and returns to its original position for the remaining ¼ turn.

A general approach to the development of such a device implemented in IHEP using servomotors is described in [7]. We chose a brushless high-performance servomotor 4490H024BS, developed by the company "Faulhaber". The advantages of this type of motors are a wide range of operating speeds, high overload capacity and good dynamic features. A high unit torque and lack of a core in the winding are its special features. The dynamically balanced rotor and light-weight also positively affect the ability of the motor to accelerate and maintain the speed in the prescribed limits.

An additional advantage of this servomotor is the ability to operate under pressure up to 10^{-7} Torr when a special option is used. This allows to install the motor inside the vacuum chamber of the U-70 accelerator. When selecting this series it was taken into account that it is possible to produce a motor with two shaft ends on both sides of the motor, with an extended shaft length of one of the ends. At the extension of the shaft an electromagnetic brake "Faulhaber" series MBZ is mounted for fixing the frame position when the power is off. We further mounted on the shaft a resolver RE-10-1-C64 by "LTN Servotechnik" which contains no active elements, the radiation hardness of the resolver being much higher than the radiation hardness of Hall sensors.

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The U-shaped fork is fixed on the second end of the shaft. The resolver stator is fastened in the special casing mounted onto the motor.

Design of the Wire Scanners

The aperture of the vacuum chamber of the IHEP U-70 accelerator is 200x100 mm^2 (RxZ). For the U-70 accelerator, two wire scanners were developed in the IHEP design department. A scanner in the Straight Section (SS)104 is installed to measure the horizontal profile. The fork with the shoulder of the length 190 mm (190x100) was chosen. A scanner for measuring the vertical profile of the circulating beam is installed in the SS94 and the fork with a shoulder 150 mm length (150x150) was chosen. The general view of the horizontal and vertical wire scanner installed in the accelerator U-70 is shown in Figs. 1 and 2. The mechanisms of rotation of the wire scanner which are fixed on the cap of the vacuum box are also shown.

Both boxes are rigged with viewing quartz windows for easy control of the wire condition. In addition, each box has a vacuum pump PVIG-250 type. The motor shaft in both units is connected to the aluminum fork shaft by means of a metal bellows coupling type WK 3/15. Shaft bearings of vacuum design are installed at the ends of the forks.

Figure 1: Vacuum box and rotation mechanism of horizontal wire scanner.

Figure 2: Vacuum box and rotation mechanism of vertical wire scanner.

The Motor Control

The control operation of the wire scanner is based on a PC and carried out via the cable before ~400 m length. The servomotor controller is located in the accelerator basement, where the radiation level is moderate, 9 m apart from the vacuum chamber. The wire scanners flowchart is shown in Figure 3.

The controller communicates with the computer via an RS-232 interface. Since the PC should be placed at a distance of 270-400 m from the controller, the shielded cable cat5e was selected for interconnection controller – PC, with the controller and the additional board of the RS-422/RS-485 PCI-1601B interfaces is used in the computer. The converter of interfaces MOXA TransioA52/A53 is installed near the controller for the organization of connection. The ACJ-055-18-R controller is regulated via the Java- based configuration software Copley Motion Explorer CME2, produced by the Copley Controls company. The controller causes the drive shaft to rotate in accordance with the program flow stored in a flash memory. The flow editing and the controller parameter setting are controlled in the Windows 7 operating system through the shell CME2. CME2 allows to configure digital inputs and outputs of the controller and to set an external start signal, to control an electromagnetic brake, to set the signal output of amplitude of 5 V with a specified duration to run the ADC. The program oscilloscope is embedded in the CME2 software, a graph of variance from 1 to 6 selected parameters within a specified time period is plotted in real time. The point-to-point graph for the measurement period is displayed on the PC monitor after a delay of 1.5 s.

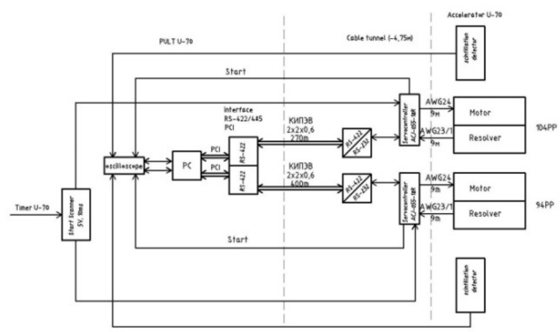

Figure 3: Controlling flowchart block diagram.

The main purpose of this system is the management of a steady motion of the carbon fiber when crossing a proton beam and the usage of the measured speed for the subsequent processing of a signal from the scintillation detector.

When designing the wire scanner, various fork rotation modes were considered [6]. The final mode was chosen taking into account the achieved rotation speed and the maximum intensity in the accelerator U-70, in which the carbon fiber located on the fork twice crosses the beam of particles. The results of the measurements are shown in Figure 4. The oscillograms show the set and realized mode of operation of the engine during one revolution, the currents in the windings, the angular velocity and the angular position of the fork.

As noted, the forks for the horizontal and vertical scanners have different sizes. To ensure the same linear speed V=16 m/s of the carbon fibers, different angular velocities ω=805 rpm were chosen for the horizontal scanner and ω=1020 rpm for the vertical scanner. The oscillograms of acceleration, even motion and deceleration of the carbon fiber for the horizontal and vertical scanners are given in Figure 4. The fluctuation in

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the values of the angular velocity in the interval between the cursors is shown on these oscillograms. During the passage of the beam by a carbon fiber, this speed fluctuation does not exceed ~ 1 %. To control the recording instrumentation the controller generates two pulse with a duration of 3 ms is shown on the waveform, at times corresponding to the beginning and end of the even motion of the carbon fiber for the angles 90 ° and 270 ° degrees, respectively. The torque can be determined using these oscillograms and a tabular of the constant moment M= Kt•I=0.042 Nm/A•5 A=0.21 N·m. From Figure 4 it is possible to determine the angle acceleration for the horizontal and vertical scanners ε_H=3500 rad/s^2 and ε_V=6300 rad/s^2, and the equivalent moments of inertia of the load in the shaft is J_H=M/εH=600 g·cm^2 and J_V=330 g·sm^2, respectively. Note that the maximum angular acceleration for this servomotor is 1.2·10^5 rad/s^2 and the maximum torque is M=2.6 N·m. The choice of the speed V=16 m/s was determined by the maximum intensity of the accelerator and the minimum of the errors in the angular velocity of each motion.

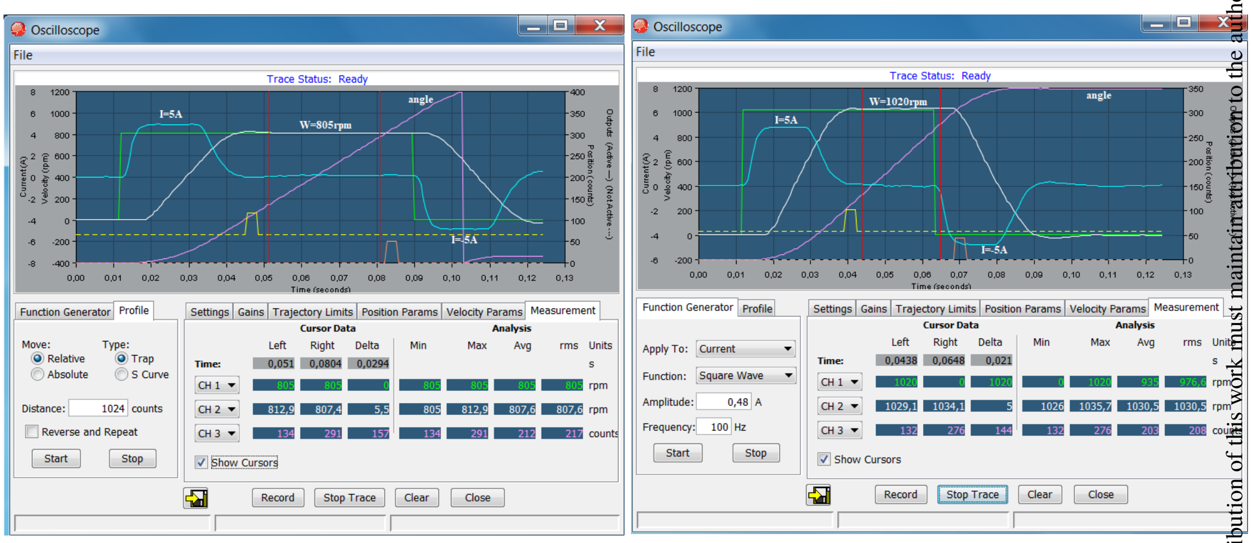

Figure 4: Oscillograms of acceleration, uniform motion and braking of the carbon fiber for a horizontal and vertical wire scanner.

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