BEAM POSITION MONITORING IN PULSED HIGH-CURRENT ELECTRON LINEAR ACCELERATORS

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The paper presents design and test results for the channel measuring the position (relative to the accelerator axis) of the center of the electron beam with a pulse length of 4 μs, a pulse current up to 1000 mA, a pulse frequency of 150(300) Hz and energy up to 30 MeV. The measurement error was 0.5 mm for a 42 mm aperture. A magneto-inductive-type four-winding monitor was used. The signals from the monitor could be computer-processed in two ways: either by the signal peak or by the integral value of the signal. The procedure of averaging the results was provided. Two measuring channels ensuring safe beam guiding were created in the two-section electron linac "EPOS". A three-year operation with the beam has demonstrated their reliability and convenience in service.

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A two-section electron linac with a pulse length of 4 μs, a pulse current between 500 and 1000 mA, a pulse frequency of 150(300) Hz and an energy up to 30 MeV was created to operate successfully at NSC KIPT. The operating experience has shown that the control and guiding system devised previously for the one-section electron linac (ELA) [1,2] and including two induction pulsed-current monitors and a device protecting against the beam current hazard [3] must be completed with a beam-position control channel. To provide a safe beam guiding, two such channels were created to measure the position of the beam current center relative to the accelerator axis with an error of ± 0.5 mm at the input and output of the second accelerating section. The paper presents design and test results for this measuring channel.

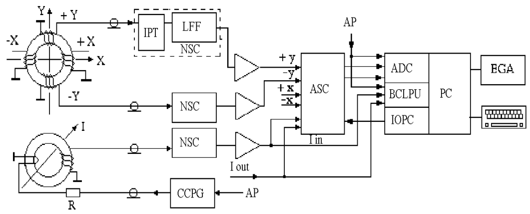
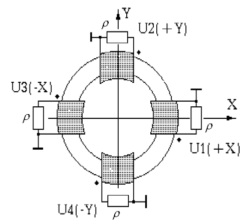


Fig. 1. *Block diagram of the channel to monitor beam position and current in a high current ELA. NSC - noise suppression circuit, IPT - isolation peaking transformer; LFF - low-frequency filter; ASC - analog signal commutator; ADC - analog-digital converter; BCLPU– beam current loss protection unit; IOPC - input-output port controller; CCPG - calibrated current pulse generator; AP - accelerator sync pulse.*

Fig. 1 shows the block diagram of one channel to monitor the beam position and the beam current value. The pulses from the windings of monitors loaded directly in the communication line go from the accelerator to the matched input of noise suppression circuits (NSC) at the control panel and then to the scaling amplifiers (K_{amp}=3, front up to 0.1 μs). The low-frequency noise is suppressed by means of the IPT transformer with an ungrounded primary winding, and the high-frequency noise is suppressed by the LFF with a cut-off frequency of 2 MHz. The signals from the amplifier outputs arrive at the input of the commutator (ASC) and then at the two-channel 8-digit ADC having a dynamic range of 2 V, a 256 byte buffer storage and a clock rate of 10 MHz.



turns	4X40
ferrite type	1000NN
inductance	5.3mH
load resistance	75 Om
coupling coefficient	0.975
beam aperture	⌀ 42 mm
assembly length	110 mm

Fig. 2. *Scheme and main design data for the beam position monitor. ρ-wave impedance of cable lines;* U_1 *-* U_4 *- voltages across matched loads with due account of coupling between the windings*

The scheme of the position monitor is shown in Fig. 2. The monitor comprises four independent windings, the signals from which carry information on both the current and position of the beam. Unlike the popular circuit with a back-to-back connection of windings (e.g., see [4]), the circuit used here makes possible rather high unipolar signals being easier for processing. To estimate horizontal (H) and vertical (V) beam center displacements from the monitor axis, we have used the following dimensionless functions, respectively: $H = (U_1 - U_3)/(U_1+U_3)$ and $V = (U_2 - U_4)/(U_2 + U_4)$. In principle, the use of a computer allows performing the calibration provided that H and V are the functions of two variables, namely, beam displacements Δx and Δy. However, it is more preferable if H and V are linearly dependent on only one coordinate: $H=S_x\Delta x$, $V = S_y\Delta y$, where the steepness of S_x and S_y is determined when calibrating. This is satisfied on the condition that the intrinsic magnetic field of paired windings is dipole [5] owing to the optimum configuration of windings and the design of the monitor shield. Figs. 3, 4,a, 4,b present the results of monitor calibration. The beam displacement from the x and y axes was calculated by the formulae $\Delta x=\alpha_x H$, $\Delta y=$

$\alpha_y V$, where $\alpha_x = 1/S_x$ and $\alpha_y = 1/S_y$ are the calibration coefficients. À string, along which current pulses with amplitude from 250 mA to 700 mA were passed, was used as an electron beam simulator.

The function of deflection of the accelerated electron bunch center from the monitor axis for each coordinate is calculated by the following formula

$$\Delta\alpha = (\alpha_1 - \alpha_2)/(\alpha_1 + \alpha_2) \qquad (1)$$

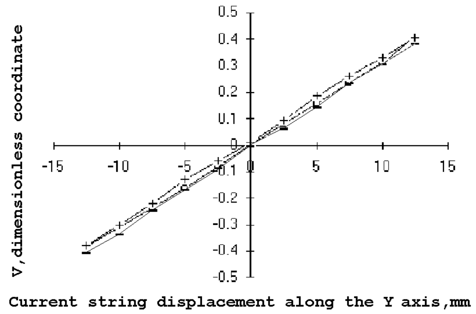


Fig. 3. *Dimensionless coordinate V =(U$_2$-U$_4$)/(U$_2$+U$_4$) versus current string displacement Δy at three values of string displacement from the x axis, Δx=0, ± 10 mm and I_c = 700 mA, t_c = 4μs. The averaged slope of transform is $S_y = \delta V/\delta_y$ = 3.2%/mm.*

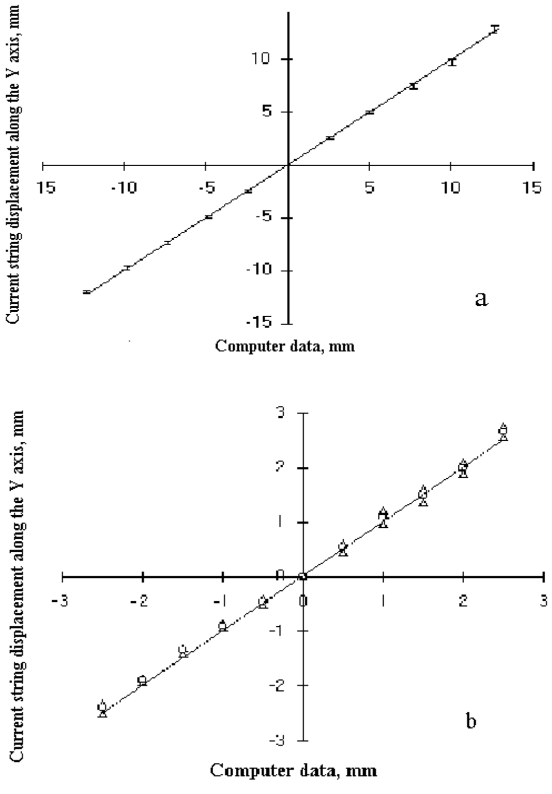


Fig. 4. *Lines of monitor calibration along the coordinate y over the whole aperture (4a) and in the vicinity of the monitor axis (4b) at Δx = 0 and I_c = 700 mA, t_c = 4 μs. Computer data: $\Delta y = a_y V$, where the calibration coefficient is $a_y = 1/S_y$ = 31.3 mm.*

The arguments of the function can be considered as average values of random processes responsible for the signals from the corresponding windings of the monitor and the noise induced by ELA systems and external sources. In our case, there are generally two types of noise.

These are (i) high-frequency noise, with which the top of the beam current pulse is modulated (see Fig. 5 (a,b)) and (ii) low-frequency noise mainly due to the supply line; it changes the signal amplitude from pulse to pulse. It should be noted that apart from hf noise, the shape of the current pulse top is also influenced by the space-time structure of the beam; this is also seen in Fig. 5a. The coefficient of current pulse variation, observed for the LUE now in operation and determined by sampling from 8 to 200 pulses, does not generally exceed 3%. Therefore, to reduce the influence of hf noise on the calculations of deflection from the axis, the arguments a_1 and a_2 are calculated as $\alpha = \sum_{i=1}^{n} \alpha_i$, where a denotes the results of sampling by the use of ADC pulses from the corresponding monitor windings at a step of 100 nsec. The summation interval was chosen empirically, and was not above half the duration of the current pulse. As it follows from ref. [6], in order to attain the unbiased estimation of mean of the random function calculated by formula (1), it is advisable to determine the function value for each pair of arguments, and then to average over the whole interval observed (no less than 8 pulses in our case). Based on the above reasoning, the algorithm was developed to calculate the beam center coordinate; the results of its work are exemplified in Figs. 5(a,b). In this case, the total error of the operation of the entire channel was not above ± 0.5 mm.

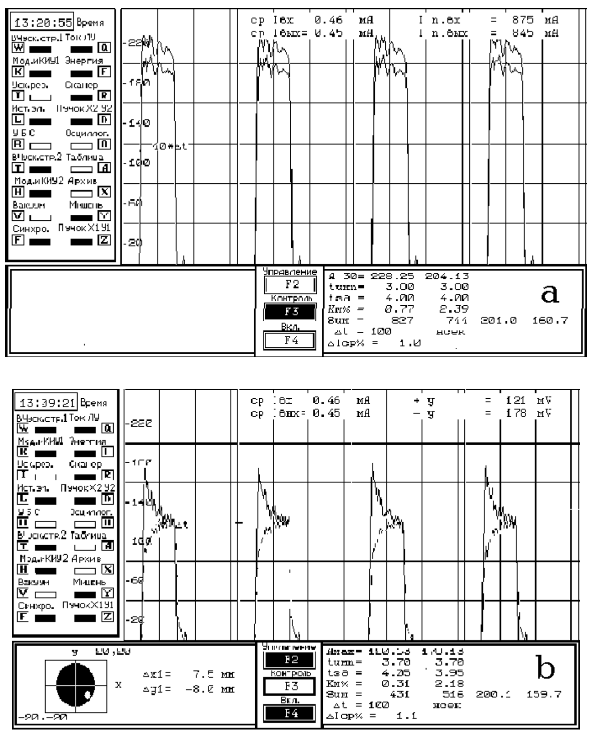


Fig. 5. *Videograms of monitoring the beam current (a) and position (b) on the display of the ELA operator.*

The four-winding magnetoinductive monitors make it possible not only to determine the beam center coordinates (x,y), but also to estimate the beam profile asymmetry in the cross section, $Q = (\sigma_x^2 - \sigma_y^2)$. It is known [5, 7-13] that the function relating the amplitudes of signals induced in the windings to the geometry characteristics of the beam cross section is written in the simplified form as

$$(\sigma_x^2 - \sigma_y^2) = k_1 \frac{U_1 + U_3 - U_2 - U_4}{\sum_1^4 U_i} - (\Delta x^2 - \Delta y^2) + k_0,$$

where U_i is the signal amplitude, k_i is the coupling coefficient. The coefficients k_1 and k_0 were defined at the test stand. Two strings equidistant from the monitor center are used for the imitation of the electron beam. The equal current pulses were passed through the strings.

At present, the control system of the accelerator EPOS [14] is equipped with two coordinate monitors.

A special software unit estimates the values of x, y and Q [15]. Examples of registering variations in the beam center position and in Q at the exit of the accelerator are given in Fig. 6. Measurement performed 12.09.99 from 14:50 to 17:20.

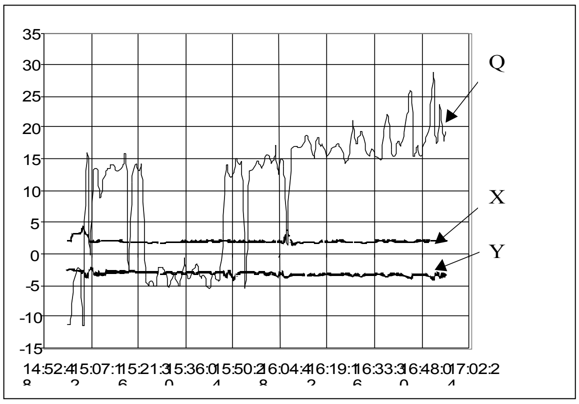


***Fig. 6**. Relative coordinates time-dependence of the center beam positionin (X Y coordinates in mm) and of the section beam asymmetry $Q = \sigma_x^2 - \sigma_y^2$ in mm^2 at the exit of the accelerator with the energy E=22 MeV and pulse current I=0.71 A.*

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