OPERATIONAL CONTROL OF AN AVERAGE BEAM ENERGY AT A TECHNOLOGICAL ELECTRON LINAC

V.N. Boriskin, A.N. Dovbnya, L.K. Myakushko, L.V. Reprintsev, V.I. Tatanov, V.A. Shendrik
NSC KIPT, Kharkov, Ukraine

The paper reports the results of development of a technique for beam uninterrupted measurement, and also some experimental data from measurements of an average electron beam energy at the technological accelerator KUT-20. The technique involves a compact pulsed magnet-deflector and a transit-time monitor of beam center position. The magnet is excited by a meander-type current pulse of 300 ms duration. The equipment used provides measurements up to 40 MeV. A relative error of measurements makes 5%.

PACS: 07.55.+x

BLOCK DIAGRAM OF THE METHOD

The block diagram for the energy monitoring method is given in Fig.1, where shown are the deflecting magnet (DM) and a passing pick-up of beam position monitor, separated by the drift space L.

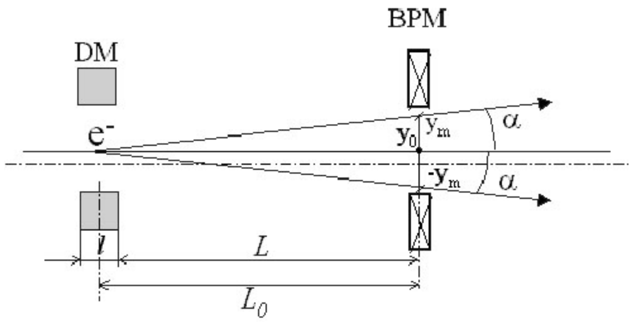

Fig.1. Block diagram of beam energy monitoring: DM – deflecting magnet; BPM – beam position monitor

Let a thin monoenergetic electron beam arrives normally at the entry of the magnet having parallel edges. Then the angle of beam trajectory deflection α is: $\sin\alpha = l/\rho$, where l is the effective magnet length and ρ is the radius of beam orbit in a uniform field. Using the relationship for the electron momentum with the radius of its orbit in the magnetic field, as well as, the geometry shown in Fig.1, we obtain the expression relating the kinetic energy of the beam with its coordinate in the BPM. For the relativistic beam and small deflection angle α <<1 we obtain

$$W = \frac{3Bm * l * L_0}{10^4 * Y_m} - E_0 \qquad (1)$$

where W – the beam kinetic energy, MeV;

Eo = 0.511 MeV – the electron rest energy;

Bm – the DM magnetic field amplitude, Gs;

l – effective magnet length, cm;

L_0 – distance between the centers of DM and BPM, mm;

Ym – beam deviation from the starting trajectory, $y=y_0$ when DM is turned out, mm.

Taking into account the spread of real beam parameters with the help of the matrix analysis [2] we obtain the following result at α <<1:

$$y_2 = y_1\left(1 - \frac{\alpha^2}{2}\right) + y_1'\left(L + l + L\frac{\alpha^2}{2}\right) + L_0\alpha\, \Delta W/W, \qquad (2)$$

where y_1 and y_1' – the spread of coordinates and angles at the DM entry;

y_2 is the spread of coordinates at the BPM entry;

Δ W/W – the energy spread.

In Eq.(2) the α^2 terms can be neglected, since at α ≈ 0.02 their contribution is very small. Then, it can be seen that the presence of the particle spread by coordinates and angles does not change the shape of the beam cross-section when the DM is turned on. Consequently, the beam center position being measured by the BPM will depend only on the energy in the case when Δ W/W ≈ 0. In the presence of the energy spread a corresponding spread by coordinates and measurement results will be an averaged spectrum value W. In the case when the spectrum is symmetric, this value coincides with the most probable one. In practice, it is convenient to perform by turns a beam deflection at equal angles in different directions, as it is shown in Fig.1.

It is reached by passing through the magnet windings of current pulses in the form of a “meander”, as it is shown in Fig.2. Making a deduction of the beam position monitor indications for these two measurements and measuring the real peak-to peak current we obtain the value being independent of an initial deflection y_0 and of other factors.

Let us introduce an estimation of measurement error. If a random error in the energy measurement should not exceed δW/W ≤ ± 2.5%, then the field in the magnet and the coordinate of beam centroid should be measured with an error not worse than δB/B ≤ ±1.5%, and δy/y ≤ ± 2%. In our case L_0=250 mm, α≈0.02, W ≈ 20 MeV, Ym ≈ 5mm. Therefore, it is required that an accuracy of coordinate measurements be equal to ±0.1mm. For our BPM under noise conditions this value is limiting. To avoid a systematic error it is necessary to provide an energy calibration by the reliable metrological methods.

INVESTIGATION OF DEFLECTING MAGNET PARAMETERS

In Fig.2 the block-diagram of pulsed magnet excitation is shown. For this purpose we have applied a power unit provided with a digital driving generator that was designed for energization of a scanner-magnet [3]. The unit allows forming of the current pulses in the pulsed magnet in continuous or waiting mode. In the continuous mode a pulse train is formed in the form of a “meander” with a repetition rate ~ 3.125 Hz. This mode was used in laboratory measurements and in accelerator adjustment. In the waiting mode only one current pulse is formed, schematically shown in Fig.2. This mode will allow one to carry out measurements, at a repetition rate of accelerator pulses up to 300 Hz, taking a necessary number of samples from the BPM during a time of ~300 ms**.** To process them correctly**,** it is necessary to perform synchronization of the timer starting with the accelerator triggering. The main parameters of the unit are given in Table I.

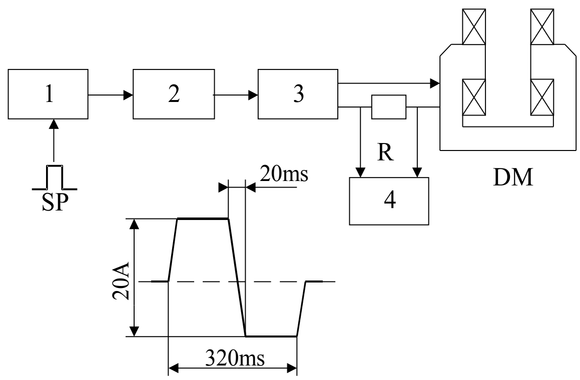

Fig.2. Block diagram of the pulsed deflecting magnet excitation:
1 – timer; 2 – digital driving generator; 3 – power amplifier; 4 – digital processing unit; R – measuring shunt; SP - synchronizing pulse; DM – deflecting magnet

Table 1. *The main parameters of the unit*

Current pulse duration	~300 ms
Current amplitude, max	± 15 A
Load resistance (magnet windings)	0.5 Ohm
Pulse top nonuniformity	± 1%
Time of current build-up up to a level of 0.99, max	< 20 ms

The pulsed deflecting magnet comprises a C-shaped core made of electrical-sheet steel plates of a 0.35 mm thickness. The core length along the beam is 4 cm; the gap value is 5 cm. The electron guide installed in the place of a magnet is made in the form of a 16 mm stainless steel sylphon bellows. Field distribution in the magnet gap was measured at a constant current. From the measurement data it follows that the width and height of the magnetic track equal to 1 cm that is in the good accordance with accelerator beam dimensions. The characteristic of magnet excitation is linear without indications of saturation in our current range, i.e. B = Km·I, where Km = 20 Gs/A. The shape and amplitude of a current pulse were measured by means of a digital oscillograph using a measuring shunt, R= 0.005 Ohm ± 2%. The shape of field pulses was measured by means of an induction coil provided with an integrator. We have not observed a worsening of field rise leading edge in the presence of a sylphon bellows in a magnet gap. The DM parameters are given in Table 2.

Table 2. *The main DM parameters*

Effective length	~ 7.3 cm
Field amplitude at a current of ± 10 A	± 200 Gs
Angle of deflection at W = 20 MeV	~0.02 rad
Time constant	2.1 ms
Residual field	± 1 Gs

ELECTRON BEAM ENERGY MONITORING

Control of the electron beam energy is performed by the lowered repetition rate (6.25 Hz) of current pulses from the accelerator. By the computer command the repetition rate of accelerator current pulses is lowered and a specially designed power source of the deflecting magnet is switched on [3]. The current in the form of a meander (Fig.3) flows through the magnet winding that leads to the beam deflection on the vertical. Fig.1 gives an example of the monitoring of the current in the deflecting magnet winding and the pulsed beam current at the output of the two-section accelerator KUT-20 [1]. From the videogram it is seen that in the case of beam deflection, there is not pulse-to-pulse changes in the amplitude and the shape of the pulsed beam current. It means that our action does not lead to changing in the beam current, and only changes its position in the space. Then the amplitude of the meander peak-to-peak value (Ic) is calculated. In the given example the amplitude was 21.5 A.

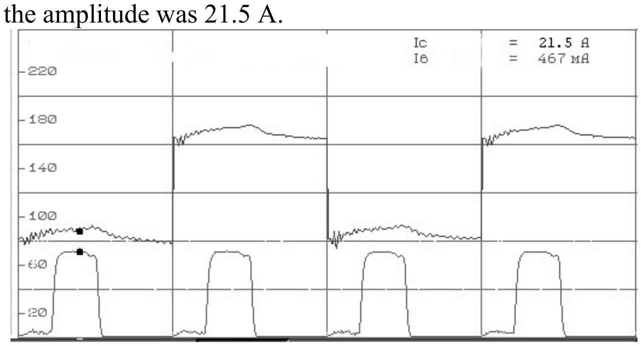

Fig.3. Videogram of the monitoring of the deflecting magnet current (1c) and the pulsed beam current (Ib) at the output of the accelerator KUT-20, Ic = 21.5 A, Ib = 467 mA

Simultaneously, using the beam position monitor [4], the beam position changing on the coordinate Y for every accelerator pulse is measured (Fig.4) and the span of beam center displacement (dY) is calculated. In Fig.4 the process of measuring the pulses from the Y windings of the beam position monitor is shown. In the given example dY is equal to 9.5 mm. The meander amplitude is smoothly decreased to zero and an operating repetition rate of current pulses from the accelerator is set up.

The averaged beam energy is calculated as the function of parameters, see (1)

$$W[MeV] = \frac{6I_c * l * L_0}{10^3 * dY} - E_0, \quad (3)$$

where Ic – peak-to-peak meander current, A;

dY – beam centroid peak-to-peak displacement, mm;

L_0 = 250 mm – distance between the magnet and the position monitor;

L = 7.3 cm – length of the magnet along the field.

In the given example the energy was (33.5 ±1) MeV.

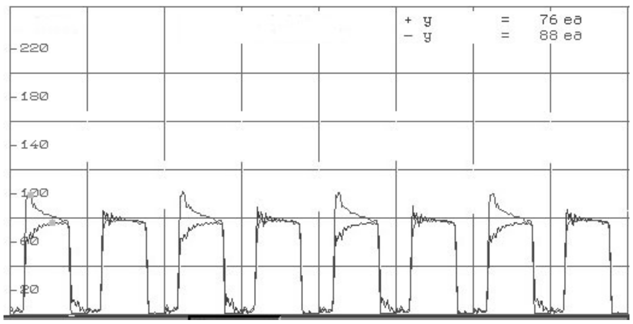

Fig. 4. Videogram of the monitoring of the electron beam position at the output of the accelerator KUT-20

CONCLUSIONS

The methods offered can be used at accelerators equipped with beam position monitors.

REFERENCES

1. K.I. Antipov, M.I. Ayzatsky, I. Yu Akchurin et al. High-Power Electron Linac for Irradiation Applications / *PAC01. Chicago*. 2001.
2. A. Banford. *Charged particle beam transport.* M.: Atomizdat, 1969 (in Russian).
3. V.N. Boriskin, L.V. Reprintsev, V.I. Tatanov, G.M. Tsebenko. The development and study of working regime of the programmed current source for scanning electromagnet of technological linacs of electrons // *Problems of Atomic Science and Technology. Ser."Nucl.ear Physics Investigations"*. 1999, №3(34), p.64-65.
4. V.N.Boriskin, V.A.Gurin, L.V.Reprintsev et al. Channel of the Control of the Beam Position in the High-Current LEA // *Digest of the XV Meeting on the Accelerated Particles*. 1996, v.1, Dubna, Russia, p.374-377.

ОПЕРАТИВНЫЙ КОНТРОЛЬ СРЕДНЕЙ ЭНЕРГИИ ПУЧКА ТЕХНОЛОГИЧЕСКОГО ЛУЭ

В.Н.Борискин, А.Н.Довбня, Л.К.Мякушко, Л.В.Репринцев, В.И.Татанов, В.А.Шендрик

Приведены результаты разработки и некоторые экспериментальные данные измерения средней энергии пучка электронов в технологическом ускорителе КУТ-20 без прерывания пучка. Блок измерения включает в себя компактный импульсный магнит–дефлектор и пролетный монитор положения центра пучка. Магнит возбуждается импульсом тока типа «меандр» длительностью 300 мс. Используемая аппаратура позволяет проводить измерения до 40 МэВ. Относительная погрешность измерений составляет 5%.

ОПЕРАТИВНИЙ КОНТРОЛЬ СЕРЕДНЬОЇ ЕНЕРГІЇ ПУЧКА ТЕХНОЛОГІЧНОГО ЛПЕ

В.М.Борискін, А.М.Довбня, Л.К.М`якушко, Л.В.Репринцев, В.І.Татанов, В.А.Шендрик

Приведені результати розробки і деякі експериментальні дані вимірювання середньої енергії пучка електронів в технологічному прискорювачі КУТ-20 без перерв пучка. Блок вимірювання включає в себе компактний імпульсний магніт–дефлектор і пролітний монітор положення центра пучка. Магніт збуджується імпульсом струму типу «меандр» тривалістю 300 мс. Використовувана апаратура дозволяє проводити вимірювання до 40 МеВ. Відносна похибка вимірювання складає 5%.