DEVELOPMENT OF A PASSING METHOD FOR CONTROL OF A MEAN BEAM ENERGY IN THE TECHNOLOGICAL ELECTRON LINAC

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Abstract

The problem of on-line measurements of the mean electron beam energy in the technological electron linac, without using a magnetic scanning device, is very important. An example of such an accelerator is a two-section ~20 MeV accelerator KUT-20 comprising a quadrupole with a constant field for beam forming on the target [1]. To control the beam energy under these conditions one needs a method without technological process interruption. This method should be sufficiently fast, simple and safe from the viewpoint of electron guide breaking by a high-current (up to 1 A/pulse) beam. The authors have offered and tested the method based on combination of a pulsed deflecting magnet that deflects the beam at an insignificant angle (by a factor of ~0.02), with a beam-centroid position monitor, separated by the short drift space.

BLOCK DIAGRAM OF THE METHOD

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

![Block diagram of beam energy monitoring](image)

Let a thin monoenergetic electron beam arrives normally at the entry of a magnet having parallel edges. Then the angle of beam trajectory deflection \( \alpha \) is: \( \sin \alpha = \frac{l}{\rho} \), where \( l \) is the effective magnet length and \( \rho \) is the radius of the beam orbit in the 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 angle of deflection \( \alpha \ll 1 \) we obtain

\[
W = \frac{3Bm \cdot \rho \cdot L_0}{10^4 \cdot \gamma_m} - E_0 \tag{1}
\]

where \( W \) - the beam kinetic energy, MeV;  
\( E_0 = 0.511 \text{ MeV} \) - 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;  
\( \gamma_m \) - beam deviation from the starting trajectory, \( y_0 = y_0 \) 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 \( \alpha \ll 1 \):

\[
y_2 = y_1 \left(1 - \frac{\alpha^2}{2}\right) + y_1' \left(L + l + L \cdot \frac{\alpha^2}{2}\right) + L \alpha \frac{\Delta W}{W} \tag{2}
\]

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;  
\( \Delta W/W \) - the energy spread.

In Eq.(2) the terms \( \alpha^2 \) can be neglected, since at \( \alpha \approx 0.02 \) their contribution is very low. Then, it can be seen that the presence of the spread of particles 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 \( \Delta W/W \approx 0 \). 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 the 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 on the initial deflection of \( y_0 \) and on other factors.

Let us introduce the estimation of the measurement error. If a random error in the energy measurement should not exceed \( \delta W/W \leq \pm 2.5\% \), then the field in the magnet and the coordinate of beam centroid should be measured with an error not worse than \( \delta B/B \leq \pm 1.5\% \), and \( \delta y/y \leq \pm 2\% \). In our case (\( L_0 = 250 \text{ mm}, \alpha \approx 0.02, W \approx 20 \text{ MeV}, Y_m \approx 5 \text{ mm} \)). Therefore it is required that an accuracy of coordinate measurements be equal to \( \pm 0.1 \text{ mm} \). For our BPM under conditions of noise this value is limiting. To avoid a systematic error it is necessary to provide the energy calibration by the reliable metrological methods.

**INVESTIGATION OF DEFLECTING MAGNET PARAMETERS**

In Fig.2 the block-diagram of the 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 the continuous or waiting mode. In the continuous mode a pulse train is formed in the form of a “meander” with a repetition rate \( \sim 3.125 \text{ Hz} \). 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 \( \sim 300 \text{ ms} \). To process them correctly it is necessary to perform synchronization of the timer starting with the accelerator triggering.

![Block diagram of the pulsed deflecting magnet excitation](image)

Figure 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

The main parameters of the unit are given in Table I.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current pulse duration</td>
<td>( \sim 300 \text{ ms} )</td>
</tr>
<tr>
<td>Current amplitude, max</td>
<td>( \pm 15 \text{ A} )</td>
</tr>
<tr>
<td>Load resistance (magnet windings)</td>
<td>0.5 Ohm</td>
</tr>
<tr>
<td>Pulse top nonuniformity</td>
<td>( \pm 1% )</td>
</tr>
<tr>
<td>Time of current build-up up to a level of 0.99, max</td>
<td>( &lt; 20 \text{ ms} )</td>
</tr>
</tbody>
</table>

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. \( B = K_m I \), where \( K_m = 20 \text{ Gs/A} \). The shape and amplitude of a current pulse were measured by means of a digital oscillograph using a measuring shunt, \( R = 0.005 \text{ Ohm} \). 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 the magnet gap.

The main DM parameters are given in Table II.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effective length</td>
<td>( \sim 7.3 \text{ cm} )</td>
</tr>
<tr>
<td>Field amplitude at a current of ( \pm 10 \text{ A} )</td>
<td>( \pm 200 \text{ Gs} )</td>
</tr>
<tr>
<td>Angle of deflection at ( W = 20 \text{ MeV} )</td>
<td>( -0.02 \text{ rad} )</td>
</tr>
<tr>
<td>Time constant</td>
<td>2.1 ms</td>
</tr>
<tr>
<td>Residual field</td>
<td>( \pm 1 \text{ Gs} )</td>
</tr>
</tbody>
</table>

**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 ($I_c$) is calculated. In the given example the amplitude was 22.8 A.

\[ I_c = 22.8 \text{ A} \]

\[ I_b = 514 \text{ mA} \]

Figure 3. Videogram of the monitoring of the deflecting magnet current ($I_c$) and the pulsed beam current ($I_b$) at the output of the accelerator KUT-20, $I_c = 22.8$ A, $I_b = 514$ 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)

\[ W[\text{MeV}] = \frac{6I_c * I_l * L_0}{10^3 * dY} - E_0 \]  

(3)

where $I_c$- 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 $26 \pm 1$ MeV.

Figure 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


