FORMATION OF SCANNER MAGNETIC-OPTICAL CHARACTERISTICS IN THE NSC KIPT NEW-GENERATION ELECTRON LINAC KUT-20

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In view of the requirements for the new accelerator KUT-20, results of the preoperational test-bench development of electromagnetic scanner characteristics are reported. Urgent tasks are outlined for further improvement of the whole extraction unit.
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The operating experience of technological electron accelerators at KIPT gives evidence that these devices can be used to solve a wide range of applied and research problems. Considerable recent interest has been shown to this class of electron linacs (ELA) on the radiation medicine side, in particular, for production of medical radionuclides. At the same time, the calculations show that an advantageous solution of the problems is possible if the following conditions are provided:

- increase in the accelerated electron energy up to $E_0 \geq$ 25-40 MeV and a rise in the average extracted-beam current up to 1 mA;
- effective high-power beam extraction from vacuum to the atmosphere into the target-converter;
- formation of linear-angular beam characteristics at the exit window (long-time reliability) and at the converter (maximum current density);
- a possibility of prompt accelerated electron energy control without interrupting the technological process.

The last two conditions impose stricter requirements on the design, manufacturing methods, arrangement and calibration of magnetic elements of electron beam formation in the scanner-exit window-target section. Among other issues, these ones were of crucial importance in the process of creating a new ELA - KUT-20 [1]. The methods of tackling the arising problems have been developed and improved during the preoperational-up period and the following service of now-operating devices [2, 3]. The decisive steps of the work should be the comprehensive investigations and development of magnetic characteristics of the device at "cold conditions" at the test bench [4].

The main scanner's unit - sweeping electromagnet (SEM) - was originally designed for the first ELA to be operated at $E \cong 10$ MeV, $\varphi_{max} \approx \pm 20°$; the reduced field strength in the magnet gap was required to be $H_m \approx 0.075$ T and the sawtooth current amplitude - to be $I \approx \pm 20$ A [2]. Similar operating conditions have appeared acceptable for the following two accelerators of the same class.

From May to December, 2000, the work on preoperational preparation of electromagnetic equipment for the KUT-20 and LU-10 exit units was done at the test bench of the SPC "Accelerator". The scope and level of investigations were assigned by the above-given conditions.

First of all, it was necessary to establish the potentialities of the equipment in providing the magnetic field strength value and the field quality as applied to the electron energy above 20 MeV. To this end, complying with the recommendations of [4] and using the NMR-nutation method we have eliminated several functions of type $H=f(I_{exc})$ in the range I_{exc}= (0 ... 30) A with a ΔI=2A step. As a result, the calibration derivative *dH/dI* = 36.578 Oe/A was obtained, and theinearity of the function $H(I_{exc})$ was established (within the measurement error) up to I_{exc} ~30A, this corresponding to $H_{op} = \pm 0.11$T.

To determine the spatial characteristics of the magnetic field (nonlinearity in radius *dH/dr*, effective angle of particle rotation in the magnet $\frac{1}{H\rho}\int_{-\infty}^{+\infty} H_z\, dl$), the field measurements were made on the graticule with a $\Delta l \times \Delta r$=1sm step along the principal trajectories of electron beam sweep with an exact reference to the input and output boundaries.

The integration and processing of the measurements have given L_n =164.12 mm; $dH/H \leq 10^{-3}$.

The studies into magnetic characteristics of the a.c. scanner have called for the development and use of new measuring and calibrating means: induction monitors (IM) and Helmholtz coils (HC). A number of induction coils were developed and created as applied to our conditions. The one-layered IM with a total area of turns SW=0.08148 m^2 has appeared the most acceptable. The monitor in combination with the oscillograph S8-17 provided measurements in a wide range of current and frequency values (I_{exc} and f_I) in both the scanner electromagnet and the HC.

Recall that the extracted electron beam energy is controlled at our conditions with the use of the standard electromagnet of scanner. In this case, the excitation current value (I_{exc}, formula in [4]) is determined from the signal read from the calibrated shunt (S) in the excitation circuit. Considering that the electromagnet with iron for alternating current is the reactive load, one would expect first a voltage-current phase shift, and secondly, the losses in the iron of the magnetic circuit. These phenomena are strongly dependent on the I_{exc} frequency and the ferromagnetic core structure.

For quantitative studies of the effects, the measurement scheme had to be complicated and improved. It was decided to measure the magnetic field strength in the SEM clearance (spatial homogeneity region) by three methods simultaneously: by the current shunt signal, the induction monitor and the NMR signal (for $f = 3$Hz). The same was done at $f = 50$ Hz (except for the NMR).

Similar measurements were also performed for the HC, the other conditions being the same. The final results of all the mentioned measurements are, in our opinion, of more than a special interest.

SEM

$$(f\text{=50Hz, S+IM}) \rightarrow \frac{\overline{\Delta H}}{\overline{H}} = 2\frac{H_S - H_{IM}}{H_S + H_{IM}} \cong +6.5\cdot 10^{-2}$$

HC

$$(f\text{=50Hz, S+IM}) \rightarrow \frac{\overline{\Delta H}}{\overline{H}} = 2\frac{H_S - H_{IM}}{H_S + H_{IM}} \cong +2.5\cdot 10^{-2}$$

SEM

$$(f\text{=3 Hz, S + NMR}) \rightarrow \frac{\overline{\Delta H}}{\overline{H}} \leq +1\cdot 10^{-2}.$$

So, in all the cases, the H value measured by the “direct method” (NMR, IM) turns out smaller than the one measured with the shunt, i.e., the above-mentioned effects do take place. The values averaged over 3 to 4 measurements (in percentage, 6.5, 2.5 and 1%) give an idea about the contributions of the current frequency and the ferromagnetic core to the measurement error of the effective magnetic field H_m, i.e., eventually, the electron energy E.

To summarize, the following conclusions recommendations can be suggested:

- electromagnetic scanner for the new accelerator KUT-20 can operate at long-time operation conditions at an excitation current $I \cong \pm 30$A, $f = 3$ Hz (“saw”);
- for $E \geq 25$ MeV, the beam sweep angle will be $\varphi_m \cong \pm 12.5°$, this corresponding to $\Delta r \cong \pm 12$ cm at the exit window;
- as preliminary tests show, the homogeneity of the irradiation zone meets strict requirements;
- prompt control over the electron energy on the basis of I_{exc} measurements using the shunt signal in the SEM (technique used up to the present day) can be employed up to $f \leq 3$ Hz with the energy measurement error $\Delta E/E \leq 1\%$ (towards overestimation);
- to provide the steady-state operation of the scanner at $I_{exc} \geq \pm 30$ A and $E \geq 25$ MeV, the existing “saw” source must be improved (its power must be raised), or a new source with $I \geq \pm 30$ A must be created;
- to improve the accuracy of electron energy measurements, new methods of prompt field strength measurement at operating accelerator conditions must be developed, as well as the accuracy in determining the beam coordinate (Δr) at the moment of measurement must be substantially increased.

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