COMPUTER SIMULATION OF THE ELECTRON BEAM ENERGY SPECTRUM MEASUREMENT BY THE MAGNETIC ANALYZER METHOD BASED ON SCANNING SYSTEM OF THE STERILIZATION INSTALLATION

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INTRODUCTION

Currently, there is a demand for the sterilization of medical products using radiation technology, including the use of accelerated electron beams. To meet this demand sterilizing devices are being developed. Such a device, with a compact local radiation shielding, was created in the Moscow Radiotechnical Institute [1]. This installation is based on a linear high-frequency accelerator working on a standing wave, with the focusing of electron beam by the radial component of the electric microwave field [2].

Energy spectrum of accelerated electron beam is one of the important characteristics that define the efficiency of sterilizing installation. The task to create the electron beam with the optimal spectrum for the accelerator with relatively short grouping part has not been yet stated. So the form of the spectrum is defined by physical mechanisms of the beam accelerating process, and it is still, in general, has satisfied the basic requirements.

While working on increasing the efficiency of sterilizing installation, there is a need for a physical-mathematical model of processes in systems of output the beam into the atmosphere and scanning system for the sterilization of the objects. Such model that uses the information about the electron beam from the calculations of acceleration process of the beam [3] was created [4]. Perfection of this model requires the establishment of correspondence between calculated energy spectrum and real spectrum of the beam.

This paper describes a method for measuring the characteristic, which allows restoring the energy spectrum of the beam in one of the regimes of operation of the accelerator of the sterilization installation. It is based on the method of magnetic analyzer, implemented on the basis of scanning system of the electron beam of the installation. This method does not require the use of additional equipment, and this fact is important one for installation with local radiation shielding. Result of measurement is the dependence of the beam current, deflected by a transverse magnetic field, which falls in the region of the induction current sensor, on the value of deflecting magnetic field. With the computer code "BEAM SCANNING" [4], specially modified for this purpose [5], the simulation of processes in the scanning system in the regime of measuring of this characteristic was performed. It is shown that the important factors which influence the form of curve of the measured characteristic are the reflections of the beam electrons from the walls of the funnel of the scanning system and

the non uniform distribution of the magnetic field in the direction of the scanning. In this case, the calculated dependence of the current in the induction sensor on deflecting magnetic field is consistent with the experimental dependence, and the restored form of the energy spectrum corresponds to the calculated beam spectrum in a particular regime of operation of the accelerator.

THE SCHEME OF MEASURMENT THE CHARACTERISTICS FOR RESTORING THE ELECTRON BEAM ENERGY SPECTRUM

Fig. 1 shows the measurement scheme, which in its time was conventionally called "scheme of spectrum measurement at the edge of the funnel".
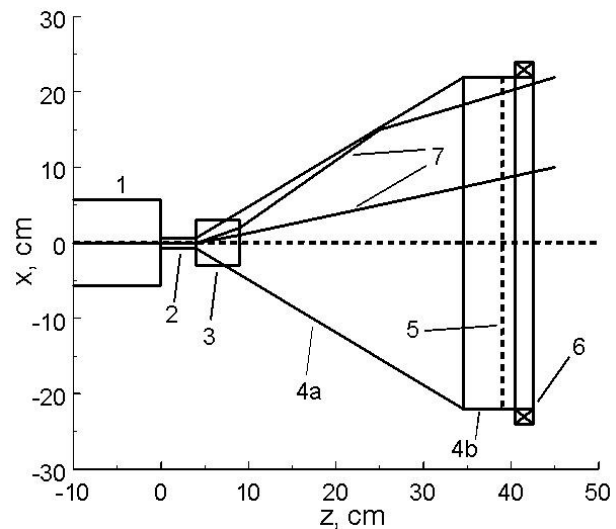

Figure 1: The scheme for measurement the characteristics for restoring the electron beam energy spectrum. 1 - end of the accelerating structure, 2 - drift tube, 3 - the area of the transverse deflecting magnetic field of scanning system, 4 - the funnel of the scanning system (a - cone part, b - rectangular part), 5 - titanium foil, 6 - inductive sensor for measure the beam current, 7 - some electron trajectories.

The electron beam emerging from accelerating structure passes the short length drift tube and appears in the location of an electromagnet that is creating a transverse magnetic field of the beam scanning system of the sterilization installation. Passing region of the

magnetic field, the beam experiences its impact of deflection (in the plane of the figure). Some of the electrons falls within the induction sensor, a part - is landed on the walls of the funnel. Inductive sensor is in fact a pulse transformer in which the primary "winding" is a part of the beam, that passes the sensor, and from the secondary "winding" the signal is taken. At relatively low magnetic fields the entire beam reaches the end of funnel, passes the titanium foil of thickness 50 microns separating the vacuum part of the system from the atmosphere, and falls into the inductive sensor completely. In this regime, inductive sensor detects a current equal to the beam current at the output of the accelerator. The current value is determined by the oscillogram of a signal from the induction sensor. Measurements were performed in single-pulse regime for beam pulses up to 6 microseconds. The current value was determined by the value on the "plato" of the oscillogram. The particles of different energies are deflected on different angles, either reaching the walls of the funnel, or being registered by the induction sensor.

In Fig. 2 the measured dependence of the current registered by inductive sensor (I_{is}) on the value of the deflecting magnetic field (B) is shown.
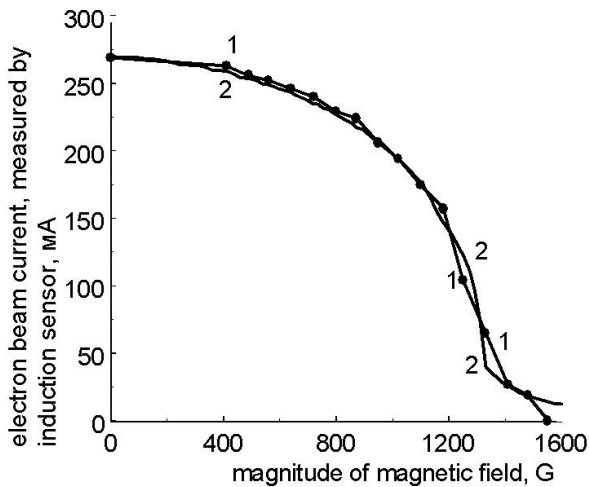

Figure 2: The dependencies of the electron beam current, measured by the induction sensor, on the magnitude of deflecting transverse magnetic field. Curve 1 - the measured dependence, 2 - calculated curve.

As follows from the figure, the experimental curve can be divided into three parts - for small, medium and large magnetic fields. At relatively small fields one can see a slow decline of current in induction sensor, which is explained by the gradual loss of low-energy electrons on the funnel walls. At moderate values of the magnetic field a pace of decline of current noticeably increases. It is explains by the "landing" of a lot of high-energy electrons on the walls of the funnel. Finally, at high magnetic fields it is seen slowing of the decrease of the measured current depending on the field. As shown below, this part of the experimental curve is due to the presence of the reflection effect of strongly deflected electrons from the walls of the

funnel, leading to penetration of the electrons in the region of the induction sensor, even at high magnetic fields. This dependence allows restoring the energy spectrum of the electron beam.

THE ENERGY SPECTRUM OF THE ELECTRON BEAM

Energy spectrum - is the dependence of the energy beam current density on the energy, i.e., dependence on energy (E) of the small fraction of the current (dI), created by the electrons with energies in the small interval between E and $E+dE$: dI/dE. The integral of the spectrum over the energy (from zero to infinity) is equal to the total current of the beam. Sometimes, instead of the absolute value of the current fraction dI the normalized current is used, for example, normalized to the injected beam current. In this case, the integral over the energies of this normalized spectrum is equal to coefficient of capture of the beam into the acceleration regime. The energy spectrum of the electron beam is one of the most important characteristics that determine the effectiveness of the sterilization installation. Calculations of the spectrum were performed repeatedly, and, through a variety of computer codes. In Fig. 3 the energy spectrum of the beam calculated by using "DINA-TIME" computer code from the software package "DINA" [3] is shown.
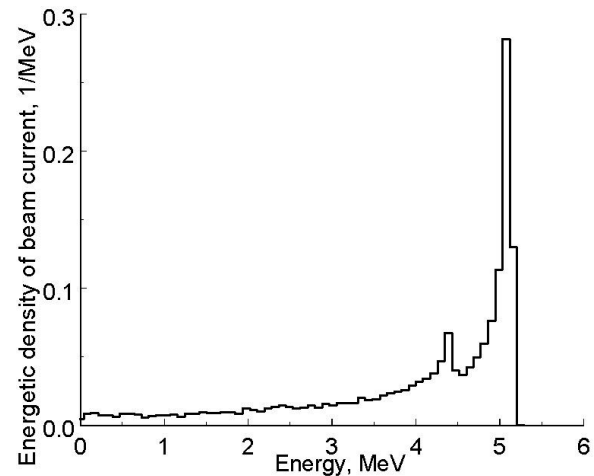

Figure 3: The energy spectrum of the electron beam: the dependence of the energetic density $d(I/I_{inj})/dE$ of the beam current, normalized to the injection current I_{inj}, on the energy E.

It has a number of features. First, one can see a long enough low-energy "tail" extending to lower energies down to very small values. It is the presence of the "tail" that gives a very strong contrast of the average energy in spectrum to the most probable energy and to the maximum energy in the energy spectrum. Second, the spectrum has a sharp peak at the energy corresponding to the most probable energy. Third, there is a very sharp drop in the interval from the most probable energy to the maximum energy in the energy spectrum.

COMPUTER SIMULATION OF THE MEASUREMENT PROCESS AND RESTORING OF THE ELECTRON BEAM ENERGY SPECTRUM

A simple way to restore the energy spectrum from the measured curve $I_{is}(B)$ could be a method based on its differentiation. Indeed, it is easy to verify that the derivative $dI_{is}(B)/dB$ is proportional to the energy density of the beam current dI/dE, called by the spectrum of the beam. In this method, energy is calculated by using the value of the uniform magnetic field, according to the formula for the trajectory of a single electron. However, this method may be used only if a number of conditions are fulfilled. These include: small radius of the beam and its transverse velocity at the exit of the accelerator, the weak expansion of the beam due to scattering on the foil of the end of scanning system, the uniformity of the magnetic field, and the lack of reflection of electrons from the walls of the funnel. The last two factors do not allow using this method.

To model the processes occurring in the measurement of the above-described experimental curve $I_{is}(B)$, the computer code "BEAM SCANNING" [4] was used. The code uses an information about the accelerated beam from calculations of acceleration processes, creates three-dimensional distribution of the three components of the magnetic field of the deflecting magnet, allows accounting processes due to hysteresis [6] in the ferromagnetic elements of the scanning system, and the scattering on the titanium foil, calculates the dynamics of electrons in the "6-microsecond" bunch during the process of scanning, calculates the distribution of radiation dose in an sterilizing object.

A detailed investigation of the possible reasons of appearing of the part of the experimental curve with a relatively slow decline in current of the sensor for high values of the deflecting magnetic field showed the following. The most important of these are the presence of effect of electron reflection from the funnel walls and the nonuniformity of the field of the magnet in the direction of the deflection (x-coordinate). To model the first effect the code "BEAM SCANNING" was modified [5]. Now, it simulates the reflection of electrons from the inner surface of the funnel, with the use of the reflection coefficients for current, electron energy losses, distributions of reflected electrons on the angles of refraction, etc. [7], and also takes into account the loss of the beam while passing the output titanium foil [8]. The distribution of the deflecting magnetic field on the x and z directions in the calculations were taken from measurements in real magnet installation.

Calculated dependence is shown on Fig. 2. One can see a good agreement of the measured dependence (curve 1) and the calculated curve (2). Thus, at low magnetic fields one can see a slow decline of the current, which is explained by the gradual "landing" of low-energy electrons on the funnel walls. At moderate values of the magnetic field the rate of decline of sensor current

noticeably increases - both in the calculation and in the experiment. It is connected with the "landing" a lot of high-energy electrons on the wall of the funnel. Finally, at high magnetic fields it is seen slowing of decline of sensor current with the field.

In calculation of the dependence, shown on Fig. 2, the information about the particles of the beam was used. This information was obtained as a result of modelling of the beam acceleration by using the code "DINA-TIME" (see above, including, energy spectrum of the beam on Fig. 3). Acceleration regime in these calculations was chosen on the basis, in particular, the need to obtain the best fit of the experimental curve and calculated curve in Fig. 2. And this accordance, as can be seen, has been reached. This means that the energy spectrum of the electron beam in the same regime, which gave the experimental curve in Fig. 2, corresponds to the calculated spectrum shown in Fig. 3. Also, the acceleration regime in the experiment described above corresponds to the regime that was founded in calculation of acceleration and which gives the electron beam with the mentioned above spectrum..

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