Journal of Applied Mechanics and Technical Physics, Vol. 51, No. 2, pp. 145–147, 2010

EXTRACTION OF A POWERFUL ELECTRON BEAM INTO THE ATMOSPHERE THROUGH TWO PARALLEL TITANIUM FOILS

Yu. I. Golubenko, N. K. Kuksanov, R. A. Salimov, and P. I. Nemytov

UDC 621.384.663

This paper described the system used in ELV-6 *and* ELV-12 *industrial accelerators for electron beam extraction into the atmosphere through two parallel titanium foils.*

Key words: *electron accelerator, discharger, magnetic field.*

Large-scale industrial applications of radiating technologies (cleaning of gas emissions from thermal power stations or manufacture and processing of metals; sewage treatment, etc.) requires increasing the output of industrial electron accelerators to several hundred kilowatts.

In most radiation-beam technologies, the products are treated by an electron beam directly in the atmosphere. The most extensively used method is the beam extraction into the atmosphere through a thin vacuum-dense foil. A titanium foil 30–50 μm thick is most often used. The strength of the current passing through unit area of the foil is determined by the losses in the foil and cooling conditions. To raise the extraction current strength, it is required to increase the foil area; for this reason, it is necessary to increase the foil length or place two foils in parallel, with successive scanning of the beam over each of them.

The optimal energy of an electron beam, as a rule, is 0.7–1.5 MeV; therefore, to attain the required power, it is required to extract electron beams into the atmosphere with a current strength equal to several hundred milliamperes. For long-term trouble-free operation of the extraction device with beam extraction through a window from a titanium foil 50 μm thick, the maximum average value of the beam current density should be approximately 100 μA/cm^2. The maximum value of the extraction current is limited by the heating of the foil due to energy losses in it and by cooling conditions [1]. The width of the window of the extraction device is limited by the mechanical strength of the foil. The atmospheric air pressure produces a load on the foil that should not exceed the strength limit of the foil at specified temperature and foil curvature radius. In high-voltage linear electron accelerators (ELV accelerators) the width of the extraction window is equal to 70 mm, i.e., close to the optimal value. All basic manufacturers of industrial electron accelerators in both Russia and abroad have windows of approximately this width. Thus, at an extraction current strength of 100 mA (which is equivalent to 100 kW in a 1-MeV energy beam), the window length should be 150 cm. Commercial ELV accelerators of power up to 100 kW use extraction windows of this length and this maximum beam current strength.

Increasing the accelerator power by severalfold requires a proportional increase in the beam current strength and the foil area. However, increasing the foil length leads to an increase in the overall dimensions of the extraction device and, hence, the entire accelerator. In addition, increasing the length of the extraction window considerably complicates the design and increases the weight of the extraction device.

A two-window extraction device in which two foils are placed in parallel was developed to eliminate the above-mentioned disadvantages (Fig. 1) [2]. Use of two foils provides a factor of two increase in the area of the extraction window without significantly changing the dimensions of the entire device.

Budker Institute of Nuclear Physics, Siberian Division, Russian Academy of Sciences, Novosibirsk 630090; nemytov@inp.nsk.su. Translated from Prikladnaya Mekhanika i Tekhnicheskaya Fizika, Vol. 51, No. 2, pp. 3–6, March–April, 2010. Original article submitted March 30, 2009.

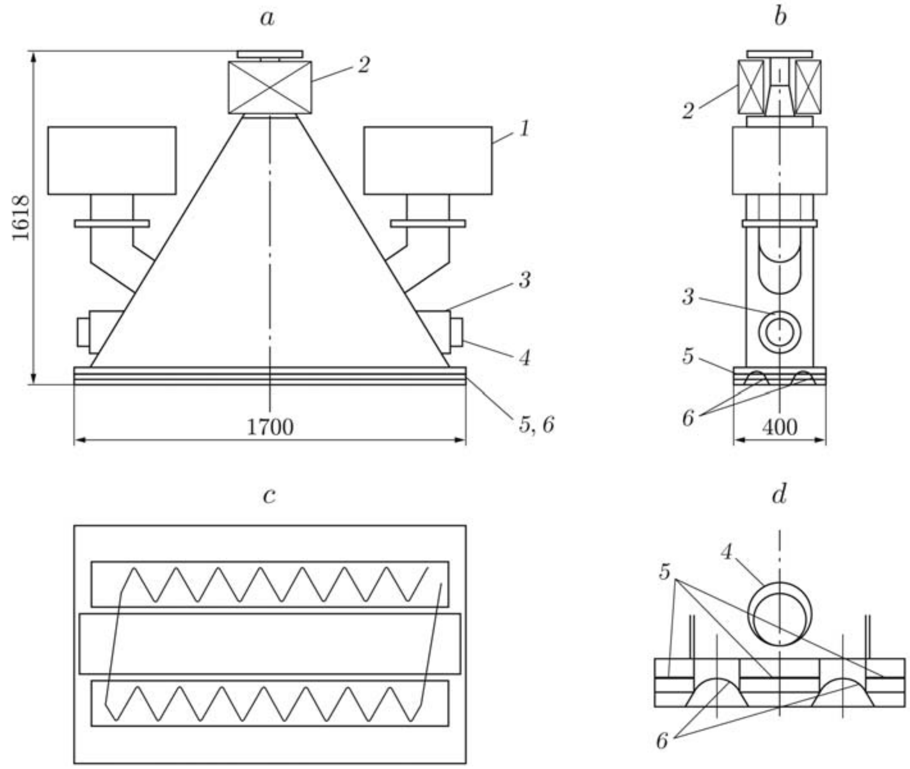

Fig. 1. Diagram of the two-window extraction device: (a) front view; (b) side view; (c) foils with the trajectory of motion of the beam; (d) water-cooled cylinder; 1) ion pumps; 2) coils and cores of the beam scanning and transfer system; 3) flange of the protection cylinder; 4) water-cooled cylinder; 5) foil fixation frame; 6) foils.

Figure 1c shows the trajectory of motion of the electron beam on the foils. It is evident that the beam runs on one foil and moves onto the second foil near the end of the extraction device. Thus, the moment of beam transfer needs to be synchronized with the phase of the current, which has a sawteeth trajectory in the longitudinal scanning. Scanning on each foil is performed by the standard deflection systems of ELV accelerators. For the beam to move alternatively on each foil, the field produced by the deflection electromagnets for transverse scanning of the beam should be supplemented by an alternating field which is constant during the scanning half-cycle along the window and is produced by an additional switching electromagnet.

The foil fixation elements and sealing are prevented from being exposed to the direct beam during its transfer by using a water-cooled cylinder (see Fig. 1d), which is simultaneously a reinforcing member of the structure. Cooling of the extraction window foil is performed by compressed air, with a separate high-pressure fan used for each window.

The main criterion for estimating the performance of the beam transfer system is the beam travel time on the internal target (cylinder) because this time determines the beam power losses during transfer. It is reasonable that these losses should not exceed the ionization (inevitable) power losses, which for the specified energy values for the beam passage through the foil, are equal to the product of the voltage $U \approx 35$ kV into the beam current strength. Hence, at a beam current strength equal to 200 mA, the thermal load of the foil is 7 kW.

The switching magnet is placed outside the vacuum chamber made of stainless steel. Thus, the beam transfer time depends on the wall thickness of the extraction device (time of field penetration into the vacuum chamber) and on the length of the current reversal front in the switching magnet coils.

Figure 2 shows the results of computer modeling of the field in the vacuum chamber. The field strength rise time was calculated assuming that outside the vacuum chamber, the field direction is instantaneously reversed. The calculation results show that if the field strength is 0.9 T and the vacuum chamber walls near the switching magnet are 1 mm thick, the length of the field polarity reversal front in the vacuum chamber is approximately 0.15–0.20 msec.

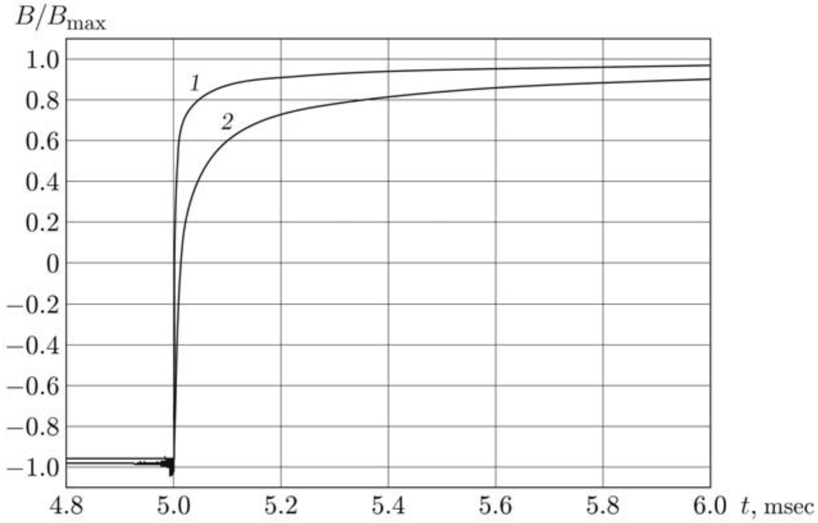

Fig. 2. Time dependence of the magnetic field strength in the extraction device with stainless steel walls 1 mm thick (1) and 3 mm thick (2).

The parameters of the switching magnet whose windings are located on the core are as follows. For a reduction in magnetic reversal losses of the core, the magnet is made of ferrite and has a 25×25 mm cross section and a 2×50 coil winding. The winding inductance L is approximately 0.5 mH, and at an energy of 1 MeV, the required amplitude of the current transfer through the winding is 7 A. The active resistance of the windings and leads R is approximately equal to 1 Ω. This implies that the current polarity reversal time is determined by the time constant of this circuit ($L/R = 0.5$ msec). To reduce the front length, a voltage far exceeding the working value should be applied to the winding at the moment of winding current reversal. Without considering details of the technical implementation, we note that if the steady-state winding voltage is close to 10 V, then, at the moment of magnetic reversal of the core, the voltage has the opposite sign and is approximately 300 V. This reduces the length of the winding current switching front to approximately 0.1 msec.

The rate of change in the switching-magnet field strength in the vacuum chamber was determined experimentally. For this, a measuring coil at a voltage proportional to the rate of change in the field strength dB/dt was placed in the vacuum chamber. The measurements show that beam transfer time, which depends on the effect of the vacuum chamber walls and the power supply, does not exceed 0.25 msec.

Because the beam travel time through the foil, which depends on the beam scanning frequency along this foil, is 10 msec, the power losses in the beam are $P = 0.25/10$ or 2.5%.

The method of electron beam extraction described above was first used by the authors of the present paper in an ELV-6 accelerator and in designing an ELV-12 accelerator with a power of up to 500 kW and a beam current strength of up to 500 mA.

An ELV-12 accelerator is successfully operated for dying waste water treatment in the Republic of Korea. Similar methods of electron beam extraction are also used by other companies producing industrial accelerators.

REFERENCES

1. N. K. Kuksanov, R. A. Salimov, and V. G. Cherepkov, "Extraction of a scanned electron beam with a current of up to 100 mA into the atmosphere," *Prib. Tekh. Éksp.*, No. 4, 20–22 (1988).
2. S. N. Fadeev, Yu. I. Golubenko, N. K. Kuksanov, et al., "Accelerator ELV-12 and its applications in environment protection technologies," *Probl. Atom. Sci. Technol. Ser. Nucl. Phys. Investigat.*, No. 1, 178–180 (2004).