Article
https://doi.org/10.31489/2024PH4/20-26
UDC 621.3.038.624

Received: 28.06.2024
Accepted: 15.08.2024

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Electron beam oscillations in ELV-type accelerators, their diagnostics and suppression method

In the article a method for diagnosing electron beam oscillations in ELV-type accelerators associated with the penetration of a transverse magnetic field from the primary and secondary windings into the accelerating tube was described. A method for suppressing these oscillations was developed and tested using the ELV-8 accelerator with an extraction device capable of extract a focused electron beam into the atmosphere. After suppressing the oscillations, it was possible to extract a focused electron beam with a power of 100 kW into the atmosphere and increase the service life of the diaphragms.

Keywords: electron accelerator, ELV, focused electron beam, electron beam oscillations, electron beam oscillation suppression method, electron beam oscillation diagnostics.

Introduction

In ELV-type accelerators, there are electron beam oscillations associated with the penetration of the transverse magnetic field into the accelerating tube from the primary and secondary windings of the accelerator, since the accelerating tube is located inside these windings and may be non-coaxial or tilted due to the accelerator design. For accelerators with an extraction device with a foil, these oscillations are not critical. Since in this case the electron beam passes through a diaphragm with an opening diameter of 50 mm, and then is extraction into the atmosphere through a titanium foil and unfolds in the length of the foil by 1500 mm and in the width by 70 mm [1]. However, for ELV accelerators that are capable of extracting a focused electron beam into the atmosphere, beam oscillations lead to the destruction of the diaphragms in the differential vacuum pumping system. Their destruction leads to a deterioration in the vacuum in the accelerating tube, which is unacceptable [2, 3].

Therefore, we needed to diagnose these oscillations and propose a solution to suppress them in order to increase the service life of the diaphragms.

Shot description construction of the accelerator capable of extraction a focused electron beam into the atmosphere

The general appearance of the ELV accelerator capable of extraction a focused electron beam into the atmosphere (Fig. 1). The primary winding and rectifier sections, which contain the secondary winding of the accelerator, are located inside the high-pressure vessel filled with SF_6 gas. The number of sections ranges from 20 to 68 pieces, depending on the required energy of the accelerator. The operating frequency of the accelerator can be from 400 Hz to 800 Hz. An alternating voltage with the operating frequency is induced in the windings of the sections, which is subsequently rectified using a voltage doubling circuit. The total voltage of the column of rectifier sections is applied to the accelerating tube.

In this particular case, the ELV-8 accelerator with 68 sections and an operating frequency of 438 Hz was used, the operating energy range of this accelerator is from 1.4-2.5 MeV, the maximum beam current is 50 mA and the maximum beam power is 100 kW.

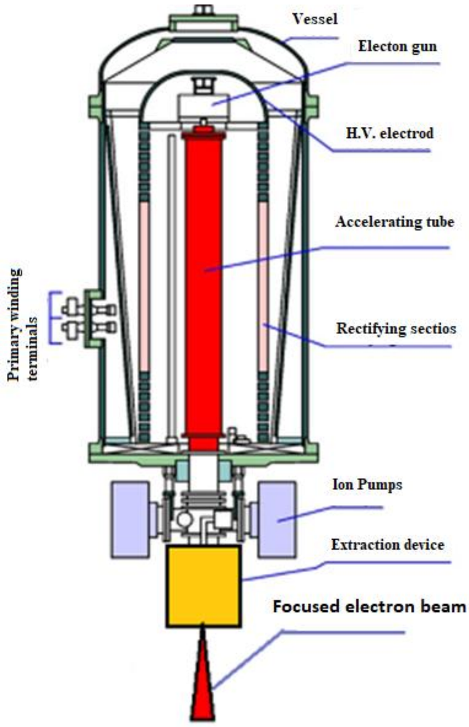

Figure 1. General view of the ELV accelerator capable of extraction a focused electron beam into the atmosphere

The optical diagram of the extraction device (Fig. 2) [2].

The lens L1 is located directly at the lower end of the accelerating tube. After passing the lens L1, the beam is focused to pass the diaphragm D6 with a diameter of 12 mm, a length of 100 mm, and the diaphragm D5, which is a tube with a diameter of 10 mm and a length of 200 mm. The diaphragms separate the stages of the differential pumping system. To guide the beam along the axis of the diaphragms, there are correction coils C1, C2, C3.

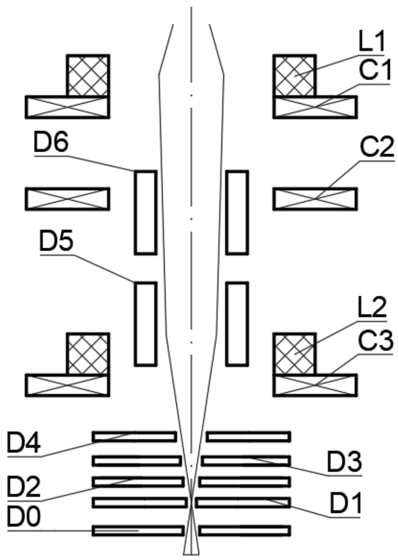

Figure 2. Optical diagram of the output device: D0 — Additional stage with a hole diameters of 5 mm;
D1, D2, D3, D4 — diaphragms with holes diameters of 2.5; 3; 4 and 4.5 mm respectively;
D5 — water-cooled diaphragm with hole diameter of 10 mm and a length of 200 mm;
D6 — water-cooled diaphragm with hole diameter of 12 mm and a length of 100 mm;
C1, C2, C3 — correction coils; L1, L2 — focusing electromagnetic lenses

The size of the holes in the diaphragms is set in accordance with the calculated value of the beam envelope. For these hole diameters, air leakages were calculated and pumps for the differential pumping system were selected, which provide the ability to obtain a pressure difference from atmospheric outside the extraction device to 10^{-6} Torr in the accelerating tube. The lens and correction coils are located outside the vacuum chamber. Diaphragm D5 is cooled with water through a tube sealed into the diaphragm housing and is designed to remove a power of about 1-1.5 kW. Diaphragms D1, D2, D3, D4 are cooled due to direct contact with the copper water-cooled extraction device. Cooling of the housing allows removing a power of up to 1-2 kW, provided that each of the four diaphragms accepts a power of up to 0.5 kW. The detailed design of the exhaust device is described in other papers [2–4].

Electron beam oscillation diagnostic method

To analyze the oscillations of the electron beam and suppress these oscillations, as well as the correct passage of the electron beam along the axis of the output device, the circuit shown in Figure 3 was used.

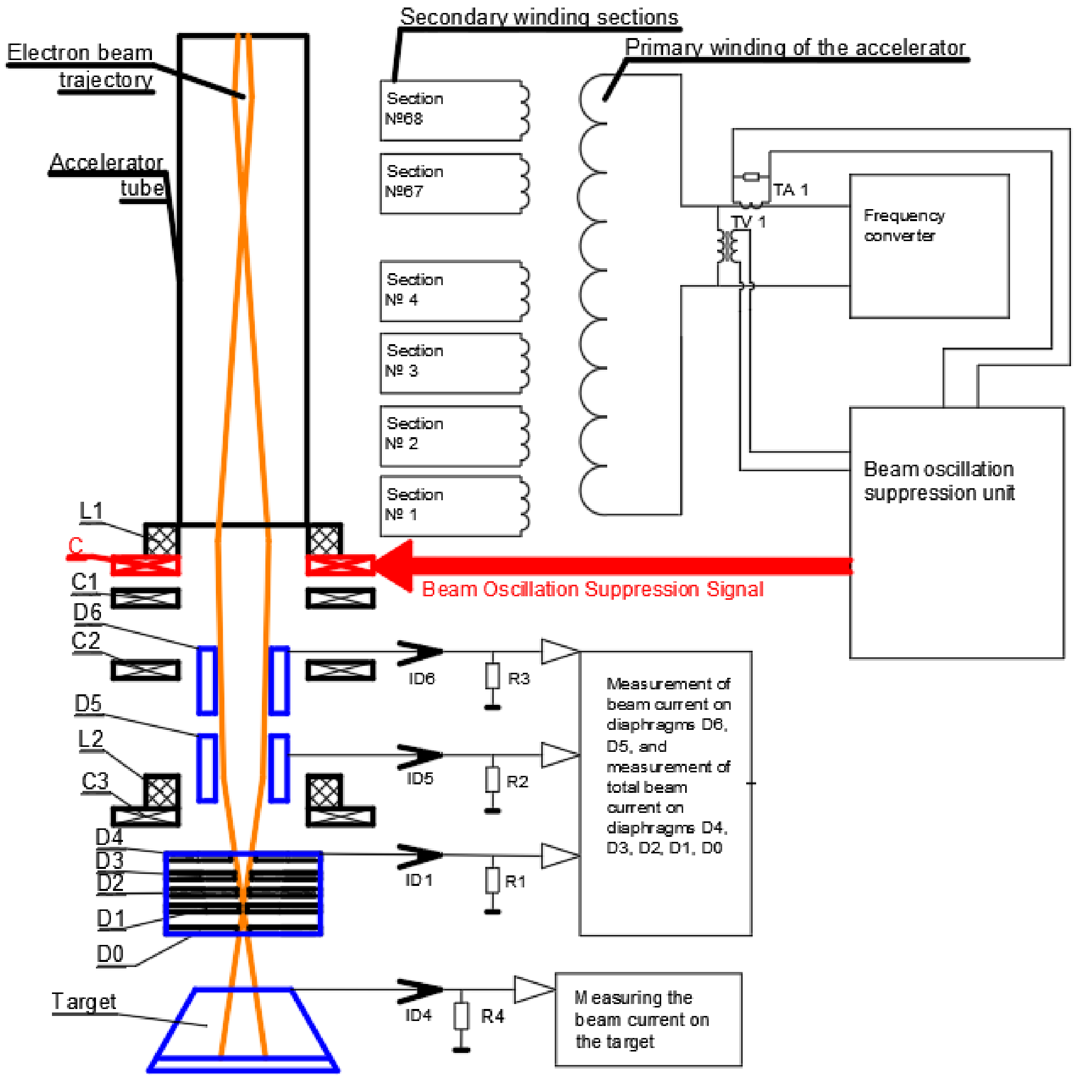

Figure 3. Oscillation suppression circuit: TA1 — current transformer; TV1 — voltage transformer;
C — anti-oscillation coils; R1, R2, R3, R4 — measuring resistances;
ID1 — total signal of current of diaphragms D0, D1, D2, D3, D4, caused by electrons deflecting from the axis;
ID5 — signal of current of diaphragm D5, caused by electrons deflecting from the axis;
ID6 — signal of current of diaphragm D6, caused by electrons deflecting from the axis; ID4 — target current.

Diaphragms D6, D5 and the box body are isolated from the ground by means of caprolon flanges. The signals of the electron beam current deposition on the diaphragms and the box are measured from resistors R3, R2 and R1 (Fig. 3) (ID6 — electron beam current deposition on diaphragm D6, ID5 — electron beam current deposition on diaphragm D5, ID1 — total electron beam current deposition on diaphragms D0, D1, D2, D3, D4). It is not possible to separately monitor the current of each of the diaphragms D0, D1, D2, D3 and D4, since they have electrical contact with the body of the extraction device.

Before starting the work on the accelerator to develop the technologies using the beam, it was necessary to receive the beam extract into the atmosphere onto the target. This target is a four-angel pyramid. The bottom of the pyramid is cooled with water, and the sidewalls protect the surrounding objects from scattered electrons and ozone. Ozone is evacuating through an opening in the pyramid into the ventilation. The entire pyramid and water-cooled targets are isolated from the ground via a resistor R4 = 86 Ohm (Fig. 3). Thus, using an oscilloscope in real time, we can diagnose the electron beam received by the target.

During the accelerator operation, electron beam oscillations were detected due to the penetration of the transverse magnetic field from the primary and secondary windings of the accelerator, since the accelerator tube is located inside these windings and may be misaligned or tilted due to the accelerator design. The beam current signal from the target is shown in Figure 4

Figure. 4. Oscillogram of the target current signal, with a beam current of I_0 = 15 mA and a beam energy of E = 2.5 MeV. The green beam is the total target current. The zero for the green signal on the oscillogram is located at the top; ΔI = 2.3 mA is the value of the target current decrease. Peak 1 and 2 are the decrease in the total target current associated with the electron beam touching the opposite sides of the diaphragm holes.

From the oscillogram (Fig. 4) it is evident that the maximum ratio $\Delta I/I_0$ = 2.3 mA/15 mA = 0.15, and the period between peaks 1 and 2 is 1.14 ms or 876 Hz — this corresponds to the double frequency of the supply voltage to the primary winding. With this frequency, the electron beam touches the diaphragms and the target current decreases by the value of the diaphragm touch current. The double frequency is obtained due to the electron beam touching two sides of the diaphragms. In this case, the integral beam current touch the diaphragms are ID6 = 0 μA, ID5 = 20 μA, ID1 = 600 μA. The total power of the beam deposited on the diaphragms D0, D1, D2, D3, D4 is 1.5 kW, further increase in the beam current will lead to the destruction of these diaphragms, it is necessary to release an electron beam into the atmosphere with a value of 40 mA. Therefore, it is necessary to reduce beam oscillations.

Method of suppressing electron beam oscillations

To suppress electron beam oscillations, standard correction coils used in serial ELV accelerators were used. These coils "C" (Fig. 3) will be referred to as anti-oscillation coils in the future. They are located below the focusing lens L1. Anti-oscillation coils are capable of moving the electron beam in two coordinates "X" and "Y", which are located at 90^0 relatives to each other. Voltage signals supplied to the coils "Ux" and "Uy" were measured using an oscilloscope directly on the coils themselves. The total resistance of the coils at a frequency of 438 Hz was 73 Ohm along the coordinates "X" and "Y".

The coils were pre-calibrated using the D6 diaphragm by touching the electron beam at a level of 100 µA [2]. The calibration of this coil was 123 mA/mm, for beam energy of 2.5 MeV.

For complete compensation of electron beam oscillations, it is necessary to suppress the resulting component of the transverse magnetic field. The phase of this transverse magnetic field is determined by the phases of the primary and secondary windings, and the phases of these windings are shifted between each other. As a feedback, a total correcting signal is fed to the anti-oscillation coils: the current of the primary winding from the current transformer TA1 and the voltage of the primary winding from the step-down voltage transformer TV1. Summation and adjustment of these signals is carried out using laboratory autotransformers. This made it possible not only to change the amplitude of the current of the anti-oscillation coils, but also to change their phase along the coordinates "X" and "Y".

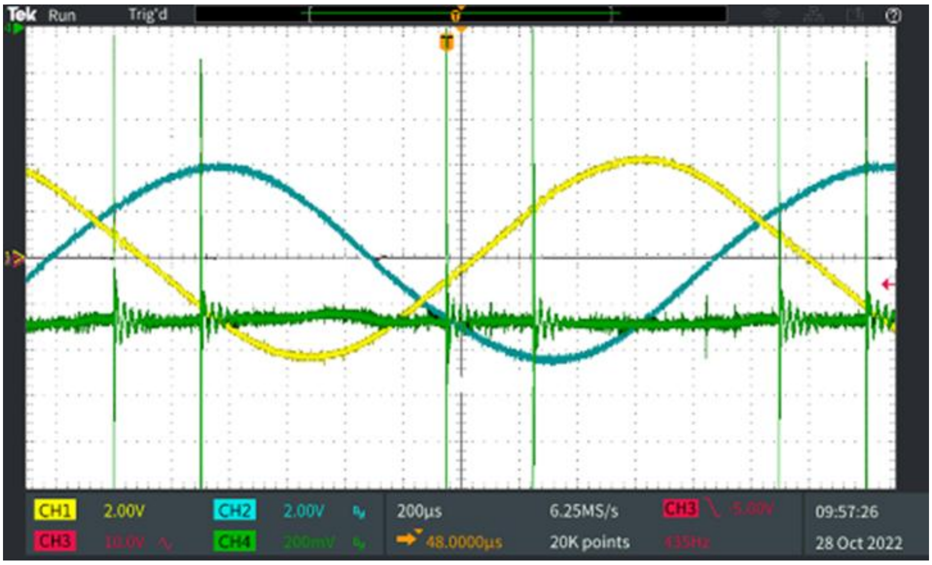

Figure 5. Oscillogram of beam oscillation suppression using current and voltage signals of the primary winding of the accelerator at beam energy of 2.5 MeV and beam current of 15 mA. The green beam is the total targetcurrent, which corresponds to 15 mA. The yellow beam is the current in the anti-oscillation coil along the "X" coordinate, the amplitude is 60 mA. The blue beam is the current in the anti-oscillation coil along the "Y"coordinate, the amplitude is 55 mA.

The oscillogram of electron beam oscillation suppression using primary winding current and primary winding voltage signals is shown in Figure 5. It is evident from the oscillogram that we managed to suppress oscillations to the noise level. In this case, the amplitudes of the currents in the anti-oscillation coils along the "X" and "Y" coordinates are approximately the same and are 60 mA and 55 mA, respectively, and the phases are shifted between themselves by 120^0. Taking into account the calibration of the anti-oscillation coils, the electron beam has oscillations in the D6 diaphragm along the "X" coordinate of $\Delta x = \pm 0.48$ mm, and along the "Y" coordinate of $\Delta y = \pm 0.44$ mm. The beam current deposition on the diaphragms has decreased dramatically and is ID6 = 0 µA, ID5 = 0 µA, ID1 = 20 µA

Conclusions

By means of beam oscillation suppression, it was possible to extract an electron beam with a power of 100 kW with minimal touch of beam current the diaphragms. At an energy of 2.5 MeV and a beam current of

40 mA, the current touch the diaphragms was ID6 = 0 μA, ID5 = 30 μA, ID1 = 50 μA. Due to this, the service life of the diaphragms increased.

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ЭЛВ типті үдеткіштердегі электронды сәуленің тербелісі, олардың диагностикасы және басу әдісі

Мақалада көлденең магнит өрісінің бастапқы және қайталама орамалардан үдеткіш түтікке енуіне байланысты ЭЛВ типті үдеткіштердегі электронды сәуленің тербелістерін диагностикалау әдісі сипатталған. Бұл тербелістерді басу әдісі атмосфераға фокусталған электронды сәулені жеткізуге қабілетті сору құрылғысы бар ЭЛВ-8 үдеткішінің мысалында әзірленді және сыналды. Тербелістерді басқаннан кейін атмосфераға қуаты 100 квт фокусталған электронды сәулені шығаруға және диафрагмалардың қызмет ету мерзімін ұзартуға мүмкіндік туды.

Кілт сөздер: электронды үдеткіш, ЭЛВ, фокусталған электронды сәуле, электронды сәуленің тербелісі, электронды сәуленің тербелісін басу әдісі, электронды сәуленің тербелісін диагностикалау.

Е.В. Домаров, Д.С. Воробьев, Ю.И. Голубенко, А.И. Корчагин, Н.К. Куксанов, Р.А. Салимов, С.Н. Фадеев, В.Г. Черепков, И.К. Чакин

Колебания электронного пучка в ускорителях типа ЭЛВ, их диагностика и метод подавления

В статье описан метод диагностики колебаний электронного пучка в ускорителях типа ЭЛВ, связанный с проникновением в ускорительную трубку поперечного магнитного поля от первичной и вторичной обмоток. Был разработан и испытан метод подавления этих колебаний на примере ускорителя ЭЛВ–8 с выпускным устройством, способным выводить сфокусированный электронный пучок в атмосферу. После подавления колебаний удалось выпустить сфокусированный электронный пучок мощностью 100 кВт в атмосферу и увеличить ресурс диафрагм.

Ключевые слова: ускоритель электронов, ЭЛВ, сфокусированный электронный пучок, колебания электронного пучка, метод подавления колебаний электронного пучка, диагностика колебаний электронного пучка.

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