Electron Beam Guns for High Intensity Linear Accelerators and Technological Purposes

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Abstract

The design and performance characteristics of electron beam guns are described. Three electrode electron optical system with lantanum hexaboride cathode and electromagnetic lense ensures continuous beam current from 1 mA to 2 A and small (near 1 mm) spot diameter at the gun output. The original design of cathode assembly with indirect heating permits increased working period of guns without taking apart. These guns were used as injector for 10 MeV electron linear accelerator and for electron beam technology in industry such as welding and surface hardening of important components, materials evaporation.

1. INTRODUCTION

Electron beam guns used in linacs and for many technological applications have a number of similar requirements and characteristics. Accelerating voltage or electron energy varies from 25-30 kV till 100-120 kV in both uses, maximum beam current is about several Amperes. Good beam formation is also very important in the above fields. The most exact beam parameter describing transverse beam dynamics is beam brightness at gun output. It was shown in [1, 2] using analysis of beams parameters at the output of many linacs, that one of the most important factors defining the transverse formation quality is a beam brightness at the injector output, which normalized value is maximum in the injector and decreases during the beam acceleration. In the case of technological applications of electron beams other parameters, such as beam current density and beam power density at the sample surface are used. These ones are directly connected with beam brightness. Electron guns for both applications considered have important requirement for working period without taking apart. They must ensure a stable and reliable operation of high voltage assembly. The important peculiarity of electron guns for technology is higher pressure in inter-electrode space — 10^{-2} - 10^{-3} Pa while vacuum in accelerators is always better than 10^{-4} Pa. The possibility of beam current control is useful for both applications.

The purpose of this work was to carry out research and development of electron beam guns for accelerators and independent application in several technological processes.

2. DESCRIPTION OF THE DESIGN

Taking into account hard vacuum conditions in electron beam technological guns it was decided to choose a massive lanthanum hexaboride cathode in the form of a pill. This material is also very advantageous in case of linac injector because of periodic air exposures during taking apart. The cathode diameters were chosen in the range of 4-8 mm and the indirect heating method with electron bombardment from uxiliary cathode was used. As a result of a number of both theoretical and experimental investigations the cathode assembly design was developed (see fig. 1). It consist of a hollow cone-shaped cathode holder 1, a lanthanum hexaboride cathode pill 2, a hollow cone-shaped component 3 for pressing the pill 2 to the holder 1 and a ribbon heater 4, which produces an electron flow to bombard the cathode 2. Because of the cathode material is sufficiently fragile, it is necessary to ensure elastic pressing of cathode pill to the holder during the whole working period.

During the heating and cooling of cathode and other components termodeformations in component 3 lead to gradual deformation of its elastic elements. Original feature of proposed cathode assembly is execution of this component 3 with the projections 5 at the larger side of the cone. These

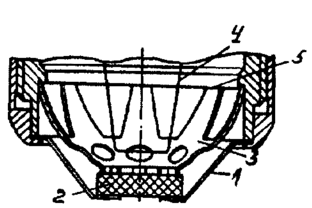

Figure 1. Scheme of the cathode assembly.

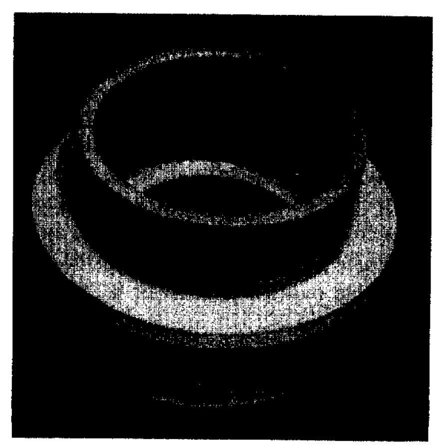

Figure 2. Overall view of high voltage isolator.

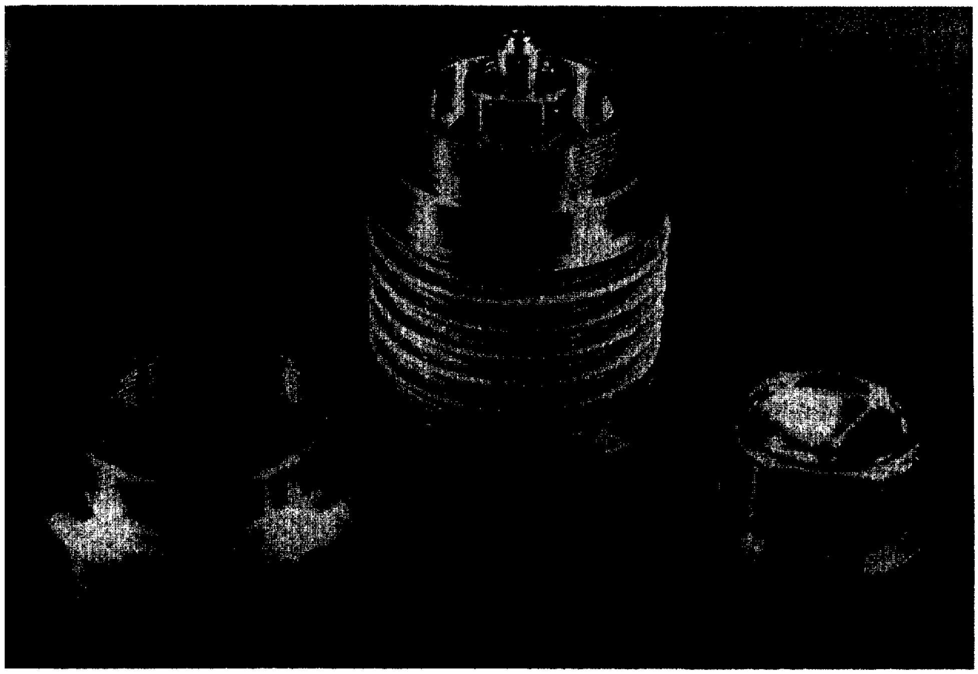

Figure 3. The main parts of electron gun high voltage assembly.

elements are placed in the region of low temperature and thus the influence of nonelastic deformations in these projections can be considerably decreased. Another important difference of this cathode assembly is an auxiliary cathode — heater 4. It made of a refractory metal strip, which is supplied by cuts in emitter part alternately spaced from both sides. In this case the cathode heating is more uniform and the undesirable influence of magnetic field connected with heating current can be minimized. These improvements developed lead to increase of cathode working life and improvement of beam formation quality. Both in technological electron beam guns and electron injectors the most frequent reason for gun to be out of work is a damage of strip or wire heater. To eliminate this deficiency we suggested the following original manner and arrangement for above cathode assembly. A screen made of refractory metal is situated between the heater 4 and the cathode 2. Power supplies produce electric fields in the spaces heater-screen and screen-cathode, which accelerate electrons towards the screen. The heating of this screen to high temperature is provided by electron bombardment from the heater 4. Screen heated to high temperature radiates the heat flow towards the cathode 2 and heats it. After the cathode reaches his working temperature it begins to emit electrons from both sides. One electron flow ensures main beam and the electrons from opposite side are accelerated towards the screen and bombard it. From this moment the heater 4 can be switched off because the heating of the screen is provided by electron bombardment from cathode 2, which in turn is heated by the radiance from the screen. In this device the heater 4 is used in short periods of turning on only and the working period of the whole cathode assembly increases many times. This manner ensures more uniform heating of the cathode and avoids

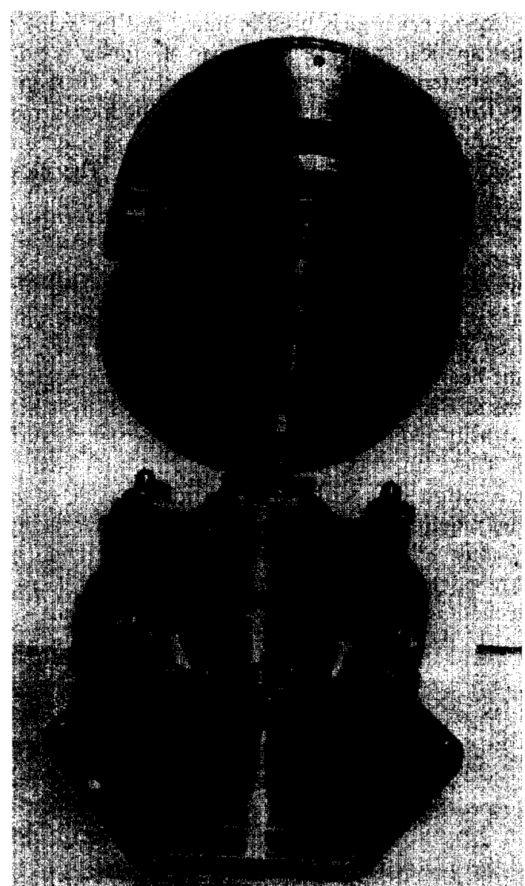

Figure 4. Overall view of electron beam gun for technology.

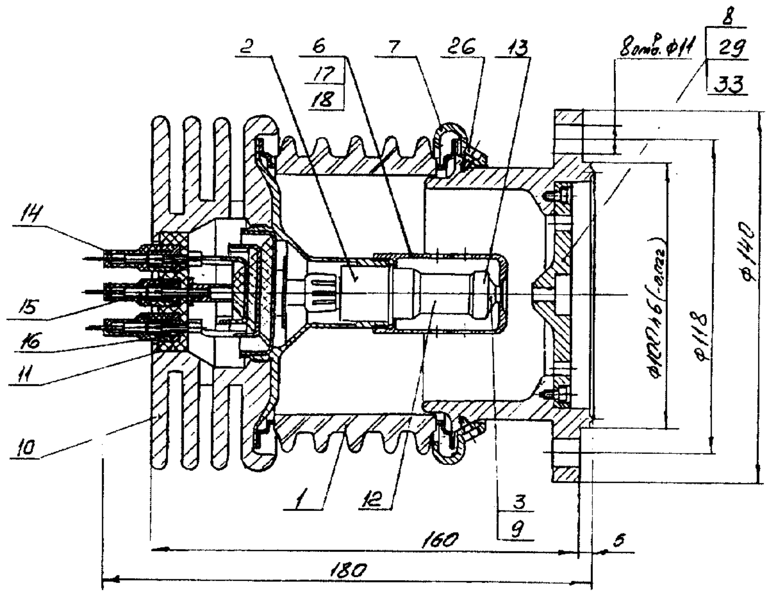

Figure 5. Assembly drawing of electron injector for linac.

erosion of the cathode surface by electron bombardment in usual methods.

Another important problem of electron beam guns design is stable and reliable operation of high-voltage electric isolator assembly. We developed several reliable high voltage assemblies with Al_2O_3 ceramic isolators (see figs. 2,3). They ensure stable work with voltages up to the 100-120 kV and lead-in four different voltages in vacuum part of a gun. All of above designs were tested, applied in industry and showed good results.

3. PERFORMANCE CHARACTERISTICS

A number of electron guns for technology and linacs were developed on the basis of above design solutions. The overall view of the electron guns is shown in fig. 3,4. Accelerating voltage can vary from 20-30 kV up to 100 kV. Continuous beam current is controlled from several mA up to 1 A by variation of grid voltage within 0-5 kV. Power consumption of cathode assembly is equal 50-60 W. It allows gun to operate without compulsory water cooling for four and more hours. The heat released by cathode assembly is transferred to the gun components via liquid dielectric-castor oil or special silicon oil. In the latter case it is possible for gun to operate for about ten hours without turning off. This design is very advantageous in case of portable linac or if electron gun is to move inside technological vacuum chamber.

Vacuum conditions under which the electron gun has capacity for work are extended to 10^{-1} Pa, however the working period of cathode assembly sharply decreases. It equals tens hours under such high pressure. In high vacuum (10^{-3} - 10^{-4} Pa) the working period is equal hundreds hours.

Electron beam formation is carried out by both electrostatic optical system and electromagnetic focusing lense. They provide convergent beam at the gun output with crossover diameter less 1 mm and beam currents up to 1 A. It corresponds to densities about 10 MW/cm^2.

High power density permits to carry out such technological processes as electron beam welding of thick metal components. These guns were used in aviation industry for welding and thermoprocessing of various components. The gun with 60 kV and 1 A beam ensures joining of steel details with thickness up to 100 mm and aluminium alloy components with thickness up to 300 mm. Electron technological guns are supplied with fast electromagnetic deflecting systems of ring-shaped type, which provides scanning of electron beam over large area. Such devices were used for surface hardening of various important components, for example working surface of ball-bearings for oil industry. Electron beam processing forms surface layer of 1-2 mm thickness with high hardness up to 62 HRC which increases working period of ball-bearings to 50% and more.

Electron injector for 10 MeV travelling wave linac was developed. Energy of electrons at the gun output 40 kV, beam current 2 A, pulse length duration 4 mcs. The assembly drawing of this injector is shown in fig. 5. The gun design includes the same cathode assembly and high-voltage isolator. This injector is now assembling and will be tested. The guns described can be used in various fields of physics and industry. The authors are ready to fruitful cooperation with organizations interested.

REFERENCES

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