Recent Progress in Development of Gas-Discharge Electron Beam Guns Providing Extension of Their Technological Capabilities

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Long operating experience of gas-discharge electron beam guns in different technological processes has allowed to investigate their special behavior features and to determine what must be improved in their design for providing the best operation reliability and extension of their technological applications. Appropriate theoretical and experimental R&D works were performed for this purpose. Engineering upgrade of gas-discharge electron beam guns of BTP family with power from 60 kW to 450 kW was provided by these works resulting in better consistency and reliability of guns operation in extended limits of operating conditions. Gas-discharge electron beam gun BTP-600 with maximum power 600 kW and accelerating voltage 40 kV was developed for the first time also on the base of performed R&D works.

Introduction

Gas-discharge electron beam guns are covering more and more wide application in different industries – mainly thanks to their ability of stable operation in hard vacuum conditions which are typical to number of technological processes. Our own experience of operation of gas-discharge electron beam guns of BTP type with power range 60-450 kW during last decade has confirmed suitability and availability of their usage in such industrial applications as electron beam melting of titanium, tantalum, niobium, molybdenum, electron beam refining of silicon, specific kinds of electron beam welding, EB PVD processes as well [1, 2].

Fig.1. Gas-discharge EB guns BTP-100 (100 kW), BTP-300 (300 kW) and BTP-450 (450 kW)

Gas-discharge EB guns BTP-100 (100 kW), BTP-300 (300 kW) and BTP-450 (450 kW) developed in JSC NVO Chervona Hvilya are presented on Fig. 1.

Modern industrial equipment developed on the base of gas-discharge EB guns is distinguished by comparative simplicity, stable operation, easy maintenance, high production and economic efficiency. In addition some specific operation features of gas-discharge EB guns provide possibility to realize new technological modes of production technologies.

Actual operation experience with gas-discharge EB guns of BTP type has also enabled to investigate their running features in different running conditions. This important information helped us to determine the ways of perfection of gas-discharge EB guns to provide further increase of their technological and commercial attractiveness. Improvement of their operation stability, increase of general reliability, prolongation of lifetime of complete guns and separate parts, reduction of downtime by means of more easy maintenance procedure and less number of specific service requirements were the main directions of our development.

The main directions of R&D activity in improvement of gas-discharge EB guns

Special theoretical research and experimental works were executed with the purpose of BTP guns perfection including investigations of the following aspects:

- analysis of cold cathode operation under condition of different characteristics of high voltage glow discharge in wide range of pressure and composition of gas medium,
- evaluation and testing of ultimate energy parameters of electrode systems,
- optimization of geometry characteristics of electrode systems and its electron-optic parameters,
- development of beam transportation system with big convergence angle from discharge zone to operation chamber as well.

Construction scheme of gas-discharge EB gun BTP type is presented on Fig. 2.

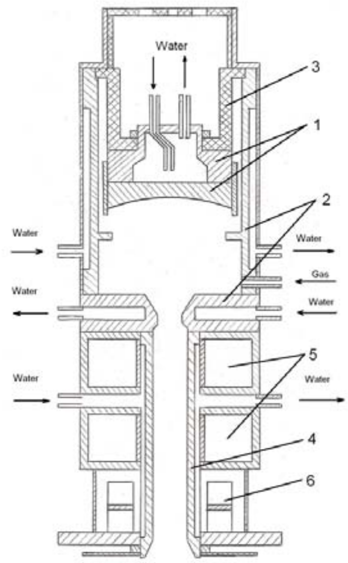

Fig.2. Construction scheme of gas-discharge EB gun BTP type (1- cathode assembly; 2 – anodic assembly; 3 – insulator; 4 – beam transmission system; 5 – focusing coils; 6 – deflection coil)

As a rule low-alloy aluminum alloys are used in production of cold cathodes mainly due to relatively high ion-electron emission coefficient (current density more than 0.1 A/sm²) and good heat conduction. Optimization of configuration of cathode assembly which all parts are under high negative voltage has provided uniform distribution of electric field in insulating vacuum gap resulting in decreased probability of arcing. Cathode is mounted directly at bottom end of high voltage insulator which eliminates presence of sealing gasket between vacuum space of gun and internal water cooling space of cathode excluding any probability of water vapor penetration to discharge chamber of the gun. Cold cathode of gas-discharge EB gun BTP-450 is presented on Fig. 3.

Optimization of geometry of anode disk has provided much better stability of focus distance of electron beam under different discharge current. This feature improves transportation of the beam through anode hole without significant energy losses and simplifies cooling of this unit accordingly.

Fig.3.Cold cathode of gas-discharge EB gun BTP-450

Suitable ultimate energy parameters of electrode systems are provided by the optimized choice of material and geometry of cold cathode and hollow anode of BTP guns taking into account maximum permissible energy dissipation in the discharge chamber of the gun. The required power density depends on the ultimate power which can be extracted from the electrodes at their operating temperatures. Limiting current density depends on cold cathode emission properties and quantity of power which can be extracted from cathode when heated by ion bombardment. Optimization of the main EB gun parameters was performed on the base of above mentioned consideration of physical properties and conditions.

Limitation of lateral dimension of beam transmitter which cross-section corresponds with shape of transmitted beam provides pressure differential between discharge chamber of the gun and operating chamber up to two orders under condition of proper pumping capacity. It allows evacuation of gun space together with operating chamber by general vacuum system of EB technological installation and expands range of operating vacuum level during technological processes.

Transportation of the beam from discharge chamber of the gun to operating chamber through beam transmitter with limited lateral dimension is provided by appropriate placement of two focusing coils.

Deflection system consisting of specified number of toroidal lenses mounted on ring-type magnet is applied for scanning of electron beam at the beam transmitter outlet. Beam transmitter is attached to gun's base flange with which gun is mounted at operating chamber.

Reasonable accelerating voltage consideration

Gas-discharge EB guns of BTP type with power range from tens to hundreds kW are working mainly under accelerating voltage within limits 25-30 kV, which basically meets specific operating conditions of guns and their usage in different industrial equipment. In addition such voltage limits simplifies X-ray protection of equipment which is important for labor safety.

But analysis of guns operation in some special technological processes has revealed that sometimes application of higher or lower accelerating voltage can provide more flexible and/or suitable heating conditions at the treated target.

For example operation of high-power gas-discharge EB guns as heating component of extra large industrial electron beam melting furnaces requires higher accelerating voltage. Voltage rise provides better conditions of electron beam transportation on longer distance in bad vacuum for example when technological process is accompanied by intensive evaporation or gassing. In this case increased specific power is provided by higher accelerating voltage resulting in higher efficiency of heating processes.

New gas-discharge EB gun BTP-600/40 with power 600 kW and accelerating voltage 40 kV was developed as result of these R&D works. Rise of accelerating voltage to 40 kV has allowed increase of ion-electron emission coefficient of cold cathode, which reduces energy loss on electrodes and improves energy and geometry parameters of electron beam. At the same time rise of accelerating voltage can cause more intensive arcing between cathode and anode resulting in less stable operation of the gun. Special design of cathode assembly configuration was developed to minimize intensity of arcing and it influence on operation of guns and complete installation.

There are many fine metallurgical processes which require very soft heating of targets such as thin parts or small zones of treatment. It could be welding of elements with very thin walls, brazing joints, surface treatment etc. Accelerating voltage within limits 10-20 kV can be applied in proper gas-discharge EB guns with good efficiency.

Gas-discharge EB guns as universal technological instrument

Gas-discharge EB guns of wide range of different configurations and power were developed till now [3]. Base technical parameters of available gas-discharge EB guns for different applications are presented in Table 1.

Application of gas-discharge EB guns of BTP series in different industrial equipment is demonstrated on figures 4-6.

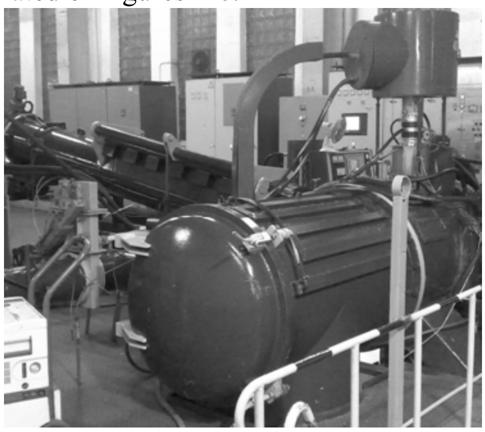

Fig.4. Gas-discharge EB gun BTP-300 at EBM installation

Power, kW	Accelerating voltage, kV	Beam current, A	Beam diameter at the target, mm	Permitted range of pressure in operating chamber, Pa	Operating gases	Technologies and applications
1-10	10-40	0.1 -1	0.5-4	10-0.1	Air, Oxygen Argon Helium	Welding of thin-wall parts, brazing, surface treatment
30-100	25-30	1-4	5-8	$10 - 10^{-3}$	Hydrogen Oxygen	Welding of pressed materials, EB-PVD, single-crystal growing
100-450	30	3.3-15	8-20	$5 - 10^{-2}$	Hydrogen with Oxygen addition	Melting and refining of refractory and reactive metals and alloys
600	40	15	15-20	$5 - 10^{-2}$	Hydrogen with Oxygen addition	Melting and refining of refractory and reactive metals and alloys

Fig.5. Gas-discharge EB guns BTP-100 at EB-PVD installation

Fig.6. Gas-discharge EB gun BTP-60 at R&D installation

Currently we can state that gas-discharge EB guns can be considered as very reasonable and very prospective equipment for wide range of industrial application.

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