ABSTRACT

At the present time cost reduction of titanium products probably is the most important problem for everybody who involved to titanium industry. EBCHM has being considered as one of the effective ways to reduce cost of titanium especially of civil application for a long time [1]. Nevertheless existing industrial EBCHM furnaces are still very expensive and this fact does not allow obtaining of significant saving effect.

Application of gas-discharge electron beam guns in EBCHM furnaces is one of the most effective ways to provide real qualitative leap in cost reduction of titanium ingots/slabs.

Report is dedicated to main features of gas-discharge EB guns and their influence on technological and economical efficiency in melting of titanium.

INTRODUCTION

Unfortunately multiple attempts to solve the problem of high cost of titanium in one stroke have not being successful. There remains only to quest for lowering-cost technical and technological solutions separately at each stage of complete titanium processing chain from sponge to final product. So titanium melting specialists should think about their proper contribution to this common struggle.

Technological and commercial advantages of EBCHM melting of titanium are well-known for a long time. From standpoint of civil market which is much more sensitive to price this technology is interesting first of all as the best scrap recycling method and as direct cast slab process [1].

The main drawback of this technology at the moment is still very high cost of investments for creation of EBCHM facilities which form as result more than 50% of total melting cost.

Careful analysis of currently applied EBM equipment and technological approach demonstrates apparent reserves for further reduction of titanium ingots/slabs production cost.

Total production cost of titanium ingots/slabs (as cast) consists of:
1) cost of raw materials (sponge, scrap, master alloys),
2) metal loss during melting (evaporation and splashing),
3) cost of melting process (including labor cost, electricity, investments and maintenance).

All these components including first one depend on type and configuration of applied equipment. EBCHM furnace does not set prices of raw materials but it determines types and grades of raw materials permissible for melting to provide specified quality of final ingots.

Consequently EBCHM furnace must provide maximum possible optimization of all above mentioned components to be suitable for production of low-cost titanium. Crucial role in such optimization belongs to electron beam guns as generative part of any EBM equipment.

GAS-DISCHARGE ELECTRON BEAM GUNS AS KEY FACTOR IN THE WAY TO LOW-COST EBCHM FURNACES

Electron beam gun is a heart of EBM installation. This equipment defines the main features of the complete EBCHM furnace and properly influences on its design, available technological possibilities, packaging by other equipment, permissible raw materials to be melted as well.

Conventional thermionic axial EB guns are used mainly in EBCHM furnaces until recently. Such guns excellently operate in high and stable vacuum, they have a number of attractive technical attributes. But there is one complicated engineering problem has to be solved in such gun to provide its normal operation – its hot thermionic cathode must be reliably protected from any influence of processes running in operating chamber. This problem is especially difficult if gun is used for melting of gas-saturated charge such as titanium sponge when vacuum conditions are very hard and unstable.
Thermionic EB guns have being permanently upgraded to meet such operating requirements resulting in very complex design and high cost of purchase and maintenance. At the moment conventional thermionic EB guns are forming large part of total cost of EBCHM furnaces and maintenance expenses.

Gas-discharge EB guns (named also plasma guns, cold cathode guns as well) were specially developed for running of stable technological processes (melting and others) in unstable vacuum within the limits $10^{-2}$ Pa [2].

Operation of gas-discharge EB gun is based on other physical principles than conventional thermionic EB guns – secondary electron emission from cooled cathode caused by ion bombardment from glow-discharge is source of beam in this gun (see figure 1).

![Fig.1. Principle of operation of gas-discharge EB gun.](image)

The main technical and technological features of gas-discharge EB guns are the following:

- normal operation during process instabilities in operating chamber (outgas spikes, direct drop of metal sprays on the cathode etc) – this feature provides stable running of process under hard vacuum conditions within the limits $10^{-2}$ Pa;
- no separate vacuum system is required to provide gun operation – internal space of the gun is evacuated through beam transmitter channel together with furnace operating chamber;
- they have very simple and compact design (see design scheme on figure 2);
- they are very easy in operation and maintenance;
- cathode of the gas-discharge EB gun made of aluminum alloy has very long life time (up to 1000 hours and more);
- inexpensive industrial materials used in gun’s structure provides lower price.

All above listed features can be combined in two summarized attributes which determine general technical and commercial attraction of gas-discharge EB guns:

1) Ability to sustain normal running of technological process under hard vacuum conditions in operating chamber;
2) Lower price.

Since first experimental melting of titanium sponge executed in Paton Welding Institute in early 1990th [3] gas-discharge EB guns were installed at number of companies worldwide where they have proved their operational and commercial advantages in production of ingots from Titanium, Niobium, Tantalum, Molybdenum, Platinum, Zirconium, Silicon and others.

General estimation demonstrates possible cost cutback of EBCHM furnace equipped by gas-discharge EB guns 2 (two) times and more in comparison with conventional EBCHM equipment. Evidently this fact directly reduces melting cost on appropriate value (up to 25-35% together with reduction of maintenance cost).

Good operability of gas-discharge EB guns under hard vacuum conditions permits to increase considerably usage of low grade titanium sponge (TG-120…TG-150) for melting in EBCHM furnaces. It is well known that standard chemical composition of titanium sponge of grades TG-120…TG-150 corresponds with standard requirements to chemical composition of ingots for example of Grades 2, 3, 4, 5. That is these sponge grades are absolutely suitable for production of ingots/slabs for ordinary commercial application.
Average price on titanium sponge of grades TG-120…TG-150 is 20-30% less than price of TG-100. So cost of ingots/slabs made of such sponge could be reduced appropriately.

But sponge of low grades has much more developed porosity and consequently contents increased amount of contaminations mainly in gaseous state [4]. During melting this intense outgas flow causes extra complicated vacuum conditions inside operating chamber with proper influence on guns workability. That’s why usage of low grade sponge was rather limited until recently mainly due to technical problems.

Gas-discharge EB guns surely remove this artificial constraint. They permit usage of up to 100% of low grade titanium sponge (TG-120…TG-150) with normal running of the melting process and satisfactory final result.

Above listed attributes of gas-discharge EB guns permits to conclude that their application in EBCHM furnaces can provide significant reduction of production cost of titanium ingots and slabs especially for civil application – in total up to 20-30% in comparison with current typical calculations.

It is worth to emphasize separately that gas-discharge EB guns can make proper contribution to reduction of VAR production cost.

Recently plasma and electron beam consolidators have been considered as cheaper alternative to high-capacity compacting press for making electrodes for VAR. Press for electrodes is conventional solution and it accounts up to 30-40% of total investments to VAR production complex. In consolidators charge is supplied directly to crucible with rather high rate because the only requirements to ingots are high density and uniform distribution of components in ingot body. Operating chamber of consolidator is rather small and vacuum conditions are very hard because of very intensive outgas flow inside. Gas-discharge EB guns are excellent solution for consolidators due to their good workability under hard vacuum conditions and lower price.

Also gas-discharge EB guns with their lower prices are good for electron beam welders of VAR electrodes. There is successful experience in application of gas-discharge EB guns for welding of compacted briquettes from sponge for making VAR electrodes.

**DEVELOPMENT OF NOVEL GAS-DISCHARGE ELECTRON BEAM GUNS IN JSC NVO CHERVONA HVILYA**

JSC NVO Chervona Hvilya is busy with development and manufacture of gas-discharge EB guns since 2005. The family of novel guns under common name BTP with nominal power 60, 100, 300, 450 kW has been developed and implemented to industrial operation till now. At the moment novel high power gas-discharge EB gun BTP-600/40 with nominal power 600 kW and accelerating voltage 40 kV is at final stage of development.

Gas-discharge EB guns BTP-300 (300 kW) and BTP-450 (450 kW) developed in JSC NVO Chervona Hvilya are presented on figure 3.

![Fig.3. Gas-discharge EB guns BTP-300 (300 kW) and BTP-450 (450 kW)](image)

Gas-discharge EB guns BTP-300 installed at EBCHM furnace are presented on figure 4.

![Fig.4. Gas-discharge EB guns BTP-300 installed at EBCHM furnace](image)
CONCLUSION

Gas-discharge EB guns have already demonstrated their technological capabilities and commercial efficiency by long term operation in many EBCHM furnaces producing titanium ingots and slabs. Estimated reduction of melting cost with application of such guns can reach 25-35%. Permissible by these guns usage of low grade titanium sponge can reduce cost of ingots/slabs up to 20-30% in comparison with sponge of conventional melting grades. Total progress in cost cutback of titanium ingots/slabs provided by application of gas-discharge EB guns can make up to 20-30%.

Probably these values look not to be revolution in advancement to low-cost titanium taking into account not so high contribution of melting stage in complete production chain of titanium products. But this modest progress could be a motivation to move forward step by step, innovation by innovation to challenging purpose of titanium metallurgist – to low cost titanium.

REFERENCES