ELECTRON ACCELERATORS WITH CONCENTRATED BEAM EJECTION TO ATMOSPHERE AND THEIR APPLICATION IN BEAM EXTRA-VACUUM TECHNOLOGIES

O. A. Gorshkov, A. S. Koroteev, R. N. Rizakhanov

Keldysh Research Center

8, Onezhskaya, Moscow 125438, Russia

Fax: 007-095-456-8228

ABSTRACT

A description of powerful electron accelerators with concentrated beam ejection to the atmosphere, operating in continual regime, that were developed by Keldysh Research Center of Russian Space Agency, is presented. The investigations on electron-beam subject are being carried out at KeRC for more than 25 years. They are started at the beginning of the seventies within the programme of development of advanced space power propulsion systems based on gas-cycle nuclear reactor. The description of the small-sized plant, which allows generating continual electron beam with energy in the range from 60 to 100 keV and power of up to 40 kW in atmosphere is given in this paper. The analysis of usage peculiarities of electron accelerators with concentrated beam ejection in the systems for cleaning waste gases of thermal power stations from toxic components is carried but. Besides there is a description of KeRC accelerating unit of experimental-industrial plant for gas cleaning in Cherepetskaya power plant. The data on the electron-beam hardening of steel in atmosphere are presented too.

1. INTRODUCTION

Experimental investigations concerning generation and application of concentrated electron beams in the atmosphere are being performed for more than 25 years. In this time accumulated is the experience in creation of electron accelerators and devices for electron beams ejection out of vacuum to dense gas atmosphere. At present there is a series of operating plants permitting the generation of continuous electron beams with power from 1 to 500 kW in the atmosphere.

At the Keldysh Center the researches in electron beam problems were started in the beginning of the seventies in the context of program for development of advanced space power-propulsion systems based on gas-cycle nuclear reactor. To simulate the working processes in plasma power plants, the use of powerful stationary electron beams ejected to the dense gas atmosphere was proposed. The unique results were obtained on the experimental plant ONEGA - a stationary electron beam of the order of 1 MW power is ejected to the atmosphere [1].

On the plant the main principles of transportation of electron beams of large power out of vacuum to the atmosphere pressure region have been subjected to finishing development. The peculiarities of transmission of electron beams in dense gas atmosphere were also studied. Shown in Fig. 1 is the pattern of 0.4 MW electron beam relaxation in the atmosphere.

The experience accumulated in the course of this and some other works has become the substantial undertaking for development of advanced technologies based on concentrated energy fluxes.

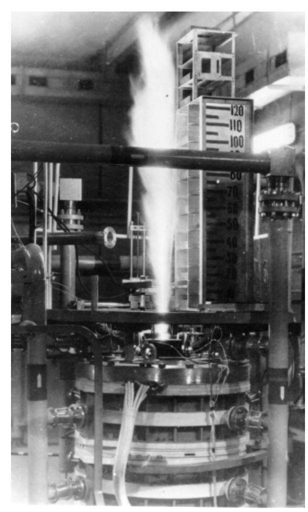

Fig. 1. Electron-beam relaxation in the atmosphere

2. CLEANING EXHAUST GASES OF THERMAL POWER STATIONS OF TOXIC IMPURITIES

One of promising methods for the waste gases cleaning of gaseous impurities is a method of electron beam cleaning

(EBC) on the basis of radiation-stimulated fixing the harmful gaseous impurities to solid easily-removed compounds (ammonium and potassium salts) [2].

The results of home and foreign researches of EBC processes allow it to draw a conclusion that the reached level of the method indexes can meet the requirements for gas cleaning of thermoelectric plants and is quite competitive both with traditional, and new developing technologies of gas cleaning. The wide introduction of the method is restrained by some circumstances among which the most important are as follows:

1. By the electron-beam cleaning the power consumption of the accelerating complex and the auxiliary equipment comprises 2-5 % of the power generated by a power unit. According to the current standards of power requirements this quantity is considered significant. It is to be decreased by a factor of 4-5 (down to level of 0.5-1 %).
2. At present the home industry does not fabricate specialized accelerating complex for solution of EBC problems. The endeavors to use available plants on pilot-industrial scales do not permit it to draw a conclusion on potentialities of these plants.

One of lines of the efficiency rise is realization of chain mechanism of oxidation [3] that must be accompanied by a sharp increase of radiation efficiency and appropriate decrease of power consumption for cleaning. For this purpose, judging from the authors' estimations, the gases to be cleaned must be exposed to radiation of 100 Mrad/s power (or 10^3 kW/kg). By conversion to electron beam parameters, it corresponds to a current density at the level of about 1 mA/cm^2. The foil windows withstand such currents only in pulsed operation or in a regime of beam sweep across a large section. In a stationary operation a current of such a density may be ejected to the atmosphere only with help of the concentrated beam ejection systems.

The second factor restraining the introduction of the EBC method for waste gases is an absence of industrially-fabricated equipment providing necessary parameters of electron beams.

The evaluations performed in [2] reveal that the exhaust gases cleaning for large power units (300-800 MW of power generated) requires an electron beam power at a level of 5-20 MW). This circumstance stipulates the need of development of next generation of industrial accelerators with 0.5-5 MW power. A few accelerators with so individual power can provide gas cleaning for a power unit with an acceptable reliability rate.

For accelerators of this category, the problem of electron beam ejection out of the high vacuum field where an electron beam is formed and accelerated into gaseous atmosphere with pressure of one atmosphere arises. On the operating pilot EBC plants applied is a foil outlet permitting the output of high- power beams with a mean current density of 0.1-0.15 mA/cm^2 into atmosphere resulting in the requirement to foil windows of 1-5 m^2 area at an electron energy of 0.5-1 MeV. The establishing of vacuum-dense foils of so large dimensions involves essential technological complexities. The reliability of these devices is also problematical, especially, under conditions of contact with chemically corrosive medium of a waste gas in a radiation-and-chemical reactor.

The alternative for a dispersed foil output is a concentrated electron beam ejection through a system of differential pumping. In this case a beam is carried to a dense gas through a set of sluice chambers pumped out independently. In spite of relative complexity of a design when compared to foil windows, the concentrated ejection offers a number of advantages:

- absence of limitations on power and energy of an ejected beam;
- low level of radiation owing to use of a low accelerating voltage;
- effective radiation protection of the accelerator cavity against the braking X-radiation;
- feasibility for performance of repair and preventive maintenance at isolated modules without stop of the whole EBC-system.

At present the electron accelerator with concentrated beam ejection to the atmosphere is developed and manufactured for the first full-scale pilot-industrial home plant for the waste gases cleaning of nitrogen and sulphur oxides, that is being constructed for the Cherepetskaya thermoelectric plant. The plant is designed to be operated at a waste gases flow rate as high as 10,000 m^3/h at the initial concentration of $S0_2$ - 0.75-3.5 g/m^3, NO_x - 0.55-1.1 g/m^3, ash - up to 2.0 g/m^3. The used reagents - aqueous solutions of NH_3 and KOH. The accelerator parameters - 200 keV/80 kW. The design rate of cleaning of $S0_2$ - 90-95 %, of NO_x - to 85 %.

3. SURFACE HARDENING OF METALS

From a number of electron beam technologies used in industrial purposes, let us set off the surface thermal hardening of materials.

To conduct investigations in extra-vacuum electron beam technologies, the small-scale plant generating in the atmosphere electron beams with an energy from 60 to 100 keV and a power up to 40 kW in continuous operation was made. For electron-beam ejection from vacuum to the atmosphere the differential pumping system consisting of 5 sluice chamber is used. A linear dimension of the electron-beam module incorporating the electron accelerator and the device for beam ejection amounts up to about 1 m. The appearance of the plant is presented in Fig. 2.

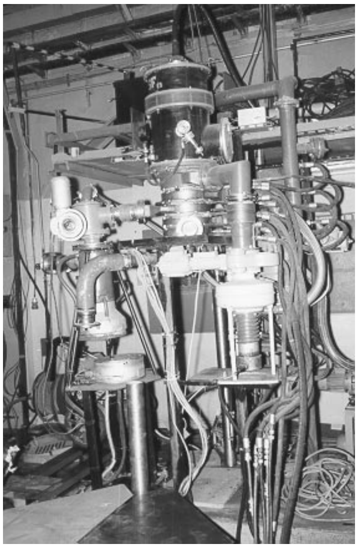

Fig. 2. The small-scale electron-beam plant with the concentrated beam ejection to the atmosphere.

Shown in Fig. 3 is the pattern of microstructure of 14X2H3MA steel treated by electron beam in the atmosphere. The beam parameters: electron energy - 90 keV, beam current 60 mA, diameter - 3.5 mm, specific power - 5.10^4 W/cm^2. A piece moved under a beam with a linear velocity of 0.5 m/s, which allows it to evaluate the time of action as high as 7 µs.

In the experiment conditions the hardening of a surface layer through a depth of 0.2 mm took place, the layer hardness increased about two times: the initial material has hardness of 1.3-1.4 GPa, the hardened layer - 2.0-2.6 GPa. At the same time the material strength increased from 0.7 to 0.8 GPa, the wear resistance growth by a factor of 4 is predicted. The carried-out test for corrosion resistance has revealed that the resistance of treated zones does not practically differ from the resistance of the initial material.

The specific power contribution of the process comprises 350-400 J/cm^2 , which permits the treatment of surfaces

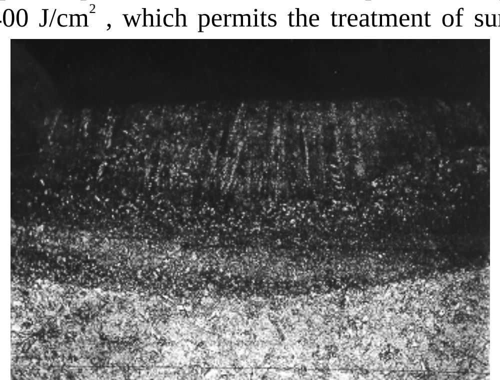

Fig. 3. The pattern of 14X2H3MA steel microstructure after electron-beam treatment.

with a speed of 25-250 cm^2/s (or 9-90 m^2/h) at the typical beam powers of 10-l00 kW.

4. CONCLUSION

Concentrated electron beams ejected into the dense gas atmosphere can serve effective instrument for implementation of some beam technologies.

For the more than 25 year period of working in this field Keldysh Research Center has gained the experience in development of electron accelerators with ejection of a concentrated electron beam to the atmosphere through the differential pumping system. Accelerators of this class may be used, in particular, in systems for gas cleaning of toxic impurities as well as for the surface hardening of steels in the atmosphere.

For the full-scale pilot-and-industrial plant (the first in Russia) for cleaning stack gases of sulphur and nitrogen oxides the electron accelerator with electron energy up to 200 keV and and a beam power up to 80 kW has been developed, manufactured and delivered to the Cherepetskaya thermal power station.

For finishing development of technology of the electron-beam hardening of materials in the atmosphere, the small-scale plant is made. The investigations carried out on this plant for surface hardening of 14X2H3MA steel allow it to consider the extravacuum electron-beam hardening as one of promising technologies for some branches of machine-building (shipbuilding, transport etc.).

Since November 1997, the research in technology of extra-vacuum metal hardening with a powerful electron beam are being carried out with the financial support of the International Scientific and Technical Center within the context of Project ¹ 580.

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