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ELECTRON-BEAM PLASMA SYSTEMS IN INDUSTRIAL AND AEROSPACE APPLICATIONS

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Abstract. Compact multipurpose experimental complex for the study of Aerosol Electron Beam Plasma generation and applications is described. The advantages and novel functional abilities of the experimental complex are demonstrated in comparison with the prototypes. Examples of new facilities for both physical and technological experiments are given. Perspectives of further setup modernization, in particular, the development of the beam-plasma unit for experiments on board the air- and spacecrafts are considered.

1. INTRODUCTION

The Electron–beam plasma (EBP) is generated by injecting the electron beam (EB) into a dense medium that could be atomic and molecular gases, vapors of organic and non-organic substances, gas-vapor mixtures. Practically there are no restrictions as to the chemical composition of the plasma-generating medium and the ratio of its components, and the pressure range in the plasma generating zone can be quite wide –from $\sim 10^{-2}$ Torr up to atmospheric and the plasma bulk does not contract even at high pressures. The EBP composition is complex: molecules, atoms, ions and radicals in the ground and excited states, and electrons of the degrading EP and secondary plasma electrons. At moderate gas pressure (P_m lower than 10^2 Torr) the EBP is strongly non-equilibrium and chemically active even at low (about 300 K and lower) temperatures. To generate the EBP of aerosols the dispersed particles as solid powders or liquid drops are added into the plasma bulk in a particular way. Since the EBP can be injected into both still gases and gas streams (sub- or supersonic) the dispersion of the injected condensed phase can be produced via the pneumatic spraying of the liquid jet (sheet) or solid particles by a preliminary formed EBP flow (Mahir et al. 2004). Still plasma formations containing the condensed dispersed phase are formed by means of the mechanical spraying of the liquids and powders throughout the EBP cloud. In addition, gas discharges of various kinds (for example: spark, barrier, high frequency), can be initiated in both still and moving plasma aerosols. This fact, as it is given bellow, is extremely important for the applications of the EBP.

Activities to develop the beam-plasma systems based on the EBP of aerosols and dust plasma, studies of generation, properties and applications of this plasma have been carried on in MIPT for a long time. A complete modernization of the exper-

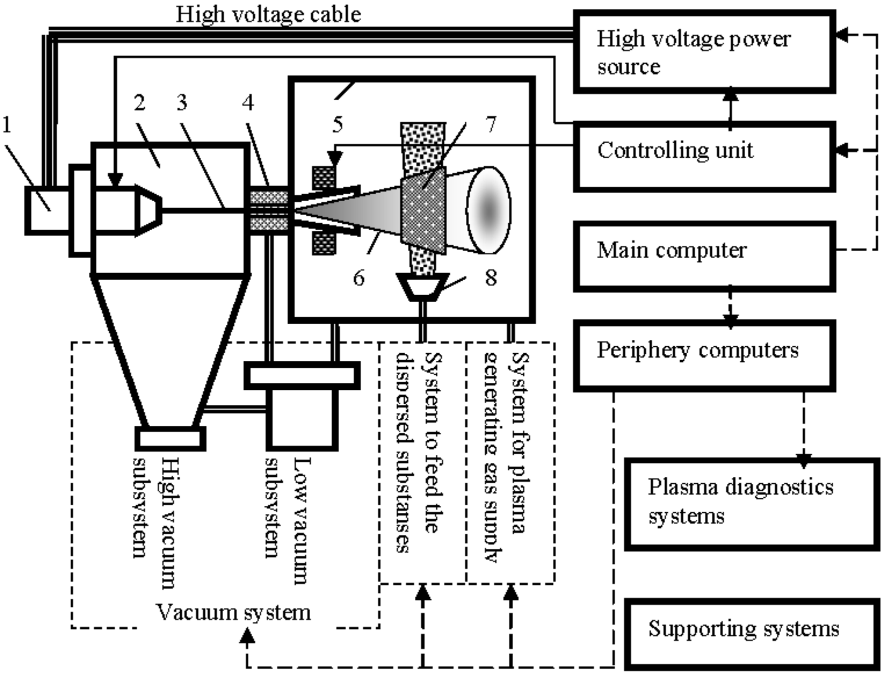

Figure 1: The scheme of the experimental complex EBPG-3.

imental facilities of the MIPT Training & research complex "Beam plasma systems and technologies" at the Department of the aero physics and space research has been made recently. The present paper considers new potential of the complex and the first results, obtained with the new experimental equipment.

2. GENERATORS THE AEROSOL EBP

Fig. 1 presents the scheme of the aerosol EBP generator for physical and technological experiments. The generator is a complicated system consisting of the following subsystems:

- The injector of the EB (electron gun 1 with controlling electrode to adjust the EB current value) equipped with the electrostatic and electromagnetic lenses to form the beam 3 in the high vacuum chamber 2 and to position the beam at the inlet of the injecting unit 4 (see bellow);
- The high voltage source generating the accelerating voltage to feed the electron gun; it is connected to the gun with a high voltage cable;
- The beam control unit to vary and monitor the operation performance of the electron injector and high voltage source and to maintain specific operating regimes of the EBP generator, for example: pulsed-intermittent regime, modulation or the EP scanning regimes and so on;

- The injection window 4 to transport the EP out of the high vacuum chamber, with the gun in it, into the working chamber 5 where the EBP cloud 6 or plasma flow is generated;
- The vacuum system responsible for maintaining the required rarefaction in the high vacuum chamber, the injection window operation, and preliminary evacuation of the working chamber;
- The plasma generating gas supply system that adjusts and maintains required gas pressure in the working chamber (or fractional pressures of the mixture components if a gas mixture of given composition is used as plasma generating medium);
- The system to supply the dispersed substances into the reaction chamber;
- The internal equipment of the working chamber containing elements and units to deflect or scan the beam injected into the working chamber, nozzles to form beam plasma jets, proper dispersing devices 8 to form aerosol particles cloud (flows)[1], electrode systems to initiate and sustain combustion of the additional gas discharges and other elements;
- The system to control the unit as an integral complex on the basis of a local network of a few computers that obtain the data from the sensors which record the working parameters of all subsystems of the complex and give the commands to executive elements of the subsystems;
- The supporting systems to ensure the reliability of the complex (cooling system, radiation protection, emergency cut off in case of hazard threat and some other supporting systems);
- Plasma diagnostics systems (they are not considered in this paper);

Characteristics of the compact generator of EBP aerosols (EBPG-3) as compared to the previously used complex EBPG-2 are given in table 1. This table shows that the modernizations have improved the performance and characteristics of the EBP generator, while the weight and size have been reduced more than tenfold. The radical change of weight and size was made thanks to complete modification of the high voltage source and the beam control unit. The onboard aerosol plasma generator (EBPG-4) with the weight less than 50 kg and the same power 6,0 kW is under development now to prepare experiments in space flights.

[1] It is in this zone of the working chamber 5, where the dispersed phase particles flow is inside the beam plasma cloud (flow) 6, that the formation of the aerosol EBP 7 takes place.

Table 1: Operation performances of the compact generator of the EBP of aerosols (EBPG-4) in comparison with the prototype (EBPG-2).

Characteristics	**EBPG-3**	**EBPG-2 (prototype, (Mahir et al. 2004))**
Accelerating voltage, kV	20-50	25-30
Power, kW	6,0	6,0
Minimal diameter of the EB, mm	0,8	1,0
Gas pressure, Torr	10^{-2}-$2{\cdot}10^{2}$	10^{-2}-10^{2}
System to maintain the gas pressure	Automatic	Manual
Plasma generator operating modes	Continuous, pulsed with the count of the pulse number, scanning.	Continuous, pulsed pulse without the count of the number, scanning.
Pulse frequency	0-1000	0-200
Generators to control the scanning of the EBP cloud	Located inside the main controlling unit.	External, manually controlled.
Modes of the EBP cloud scanning	Linear in x and$y$ raster, directions, rectangular circular scanning.	Linear in x and$y$ directions.
Mass, kg	≈ 100	≈ 2000

3. PHYSICAL AND TECHNOLOGICAL EXPERIMENTS WITH THE EBP OF AEROSOLS

The research teams of the Training & research complex "Beam plasma systems and technologies" continue the experiments in the following fields of the aerosol EBP generation and applications.

- Fundamental study of the EB propagation in aerosols:
  - The EB scattering and absorption in aerosols;
  - Spectral and energetic characteristics of the aerosol radiation stimulated by the EB propagating through it;
  - The abnormally high charging of the aerosol particles caused by the EB, the electrostatic fly-out of the aerosol cloud;
  - The formation of the dust-plasma structures in plasma traps by means of the condensation of organic and inorganic substances preliminary evaporated by the EB, the control of the dust-plasma structure properties by means of the EB action (Fortov et al. 2007).

- Production of powder semi-products for compound materials, including nano-materials, with unique physical-chemical properties and performance:
  - Low-temperature plasma-assisted synthesis and plasma-assisted deposition of functional layers (nitride, carbide, oxide, boron-containing, and others) on surfaces of dispersed powder particles;

- Production of ultra-dispersed powders by condensing vapors of various substances (for example polymers, carbon) in plasma traps.

- Medical and biological applications of the aerosol EBP (Vasilieva 2007):
  - Production of effective agents for novel drugs by means of the beam-plasma treatment of native and artificially synthesized peptides, amino acids, and polysaccharides;
  - Beam-plasma technologies of nano-complexes formation for the addressed drugs delivering to organs of the human and animal organisms.
- Aerospace technologies, experiments on board the aircrafts and space vehicles, experiments in the terrestrial outer space:
  - Physical and technological experiments with the aerosol EBP under low gravity conditions;
  - Air pre-ionization in the intakes of ramjets;
  - Plasma generation in the vicinity and far from aircraft surface;
  - Plasma-assisted combustion of propellants.

In the latter case the supersonic flow of the air-fuel mixture is preliminary activated by the EBP and then ignited by the additional spark discharge, i.e. hybrid plasma, rather than simple gas-discharge or electron-beam plasmas, is generated in the ignition zone. Gas discharges of other types (especially RF-discharges) are successfully used in combination with the EBP to modify various dispersed materials, for example preliminary ground carbon, ceramics, natural biopolymers.

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