

# Gas and plasma dynamics of RF discharge jet of low pressure in a vacuum chamber with flat electrodes and inside tube, influence of RF discharge on the steel surface parameters

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**Abstract.** Researches results of the characteristics of the RF discharge jet of low pressure and the discharge influence on the surface modification of high speed and structural steels are introduced in the article. Gas dynamics, power and energy parameters of the RF low pressure discharge flow in the discharge chamber and the electrode gap are studied in the presence of the materials. Plasma flow rate, discharge power, the concentration of electrons, the density of RF power, the ion current density, and the energy of the ions bombarding the surface materials are considered for the definition of basic properties crucial for the process of surface modification of materials as they were put in the plasma jet. The influence of the workpiece and effect of products complex configuration on the RF discharge jet of low pressure is defined. The correlation of the input parameters of the plasma unit on the characteristics of the discharge is established.

## 1. Introduction

Metal cutting tool is widely used by enterprises and ordinary customers. For this reason, very high demands on quality are required, work safety and ergonomics, that in turn forcing manufacturers to create more and more sophisticated types and forms of the instrument.

Metal cutting tools - equipment for different types of work with metal parts. In most cases, these include equipment for various metal-cutting equipment, such as milling cutters, taps, metal knives, saws and drills. Currently, consumers are often faced with a difficult choice to buy an expensive tool under the well-known trademark or cheaper by a little-known manufacturer. In recent years there has been a consistent trend of changing preferences of customers who refuse to buy cheap domestic instrument in favor of more expensive imported. What is the reason? First of all, the fact that the domestic manufacturer is not able to produce a tool that is comparable in quality to foreign analogues, but the lowest price is not so attractive for buyers, because then this advantage is lost because of the need of constant repair, the appearance of injuries and so on.

Manufacturers of cutting tools, feeling the intense competition in the market, introduce more and more new achievements in science and technology to improve productivity, quality and safety of its product. Constructive view of machines and mechanisms is being changed, new alloys for the production are being applied, very actual now is to improve the current cutting properties to improve cross-metal, the possible shortcomings of the current tool are extremely well-calculated to remove them and make it even more perfect.



Milling is one of the most common methods of processing of flat and shaped surfaces. The grooves, ledges, edges, profiles, grooves in the wood products, metal, plastic, acrylic and other materials are carried out with this type of method.

The milling process is characterized by a set of several factors: the rapid rotation of the tool around its axis and the slow translational, rotational or screw sideways movement of feeder. The rectilinear motion of feed is used for the treatment of different types of cylindrical surfaces: planes, all kinds of slots and grooves, shaped cylindrical surfaces. The rotary motion is used for milling surfaces of revolution. Screw traffic flow is handled for screw surfaces such as chip flutes tools, depression helical gears and others.

As the objects of study disk, corner, end mills and drills were chosen.

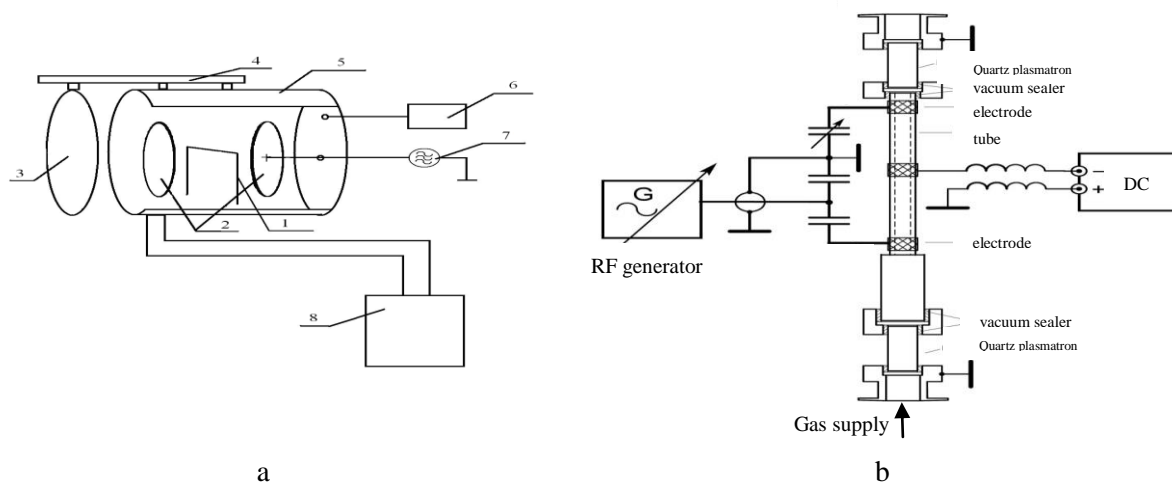
The technologies currently used in the tool industry and mechanical engineering, have led to the development and wide application of concentrated energy flows such as Plasma Technology. The advantages of these methods are: high density of energy flows; possibility of reactivity and pressure regulation; possibility of ionization of inert and reactive gases for direct modification of the surface layers [1-13].

Analysis of studies on surface modification of metals and alloys shows that the formation of the set of physical and mechanical properties most advantageous to use particles with an energy of 50 - 100 eV. Currents with such energy of ions are formed in jet of radio-frequency (RF) discharges of reduced pressure. In this paper as a high-frequency low-pressure discharge using a capacitive discharge.

Currently, gas and plasmodynamic processes of interaction of plasma flow of RF capacitive low-pressure discharge with metals and their alloys and the effect of reduced pressure RF capacitive -setting on the formation of diffusion coatings on the products are not enough studied [14-16]. Properties of RF capacitive jet discharge with flat electrodes are studied very poorly.

## 2. Results and discussion

For the purpose of steel processing with flow of radio-frequency (RF) discharge of low pressure and the discharge flow studies plasma unit was used. Experienced RF capacitive plasma installation for modification of materials is shown in Fig. 1a.



**Figure 1.** Scheme of the experimental radio-frequency capacitive setup (a), Scheme of tube processing (b). 1 - frame for the installation of the workpiece; 2 - high-frequency electrodes, 3 - the door of the vacuum chamber; 4 - console for opening the door of the vacuum chamber; 5 - vacuum chamber; 6 - supply system and regulation of plasma-forming gas; 7 - RF generator; 8 - vacuum exhausts posts.

*RF generator.* For studies of different types of RF discharges the creation of RF generators, collected in a single-circuit tuned to the capacitive load on the permitted frequency of 13.56 MHz was required. Consumed power generators range is from 0.5 to 3 kW.

*RF plasmotrones.* Plasmatron for producing of a plasma flow capacitive type with flat electrodes consists of two water-cooled copper plates. The electrodes are placed in a vacuum unit. Means for fixing samples are located between the electrodes.

*Vacuum chamber* constructed in a cylindrical design. The door pulls back in a special console with a grounded electrode. Loading is carried into the chamber through the face door in the chamber. When the lid of the vacuum chamber are closed plates are installed in the operating position. Feed through rotation is provided for rotatable products in-chamber volume on the door.

The base of the vacuum unit mounted in a welded frame. Vacuum pumps and water cooling plant components are arranged at the frame unit.

*Vacuum exhausts posts* consist of two pumps: fore vacuum pump AVZ-20D and twin-rotor pump DVN-150, respectively, with a pumping speed of 50 l / s and 150 l / s. The pressure in the vacuum chamber is controlled by membrane capacitance sensor MKS 627B.

*Supply system and regulation of plasma-forming gas* consists of a compressed gas cylinder, a reducer for reducing the pressure, manometer, mass flow controller MKS 1179A and a needle valve to regulate flow and a device for producing a mixture of gases.

*Water System* of Installation BMT-20 serves to provide a set thermal regime of parts and assemblies, the most loaded thermally. The water supply to the installation and removal of it is carried out with rubber hoses.

*Control equipment* is used to control the input parameters of installation: RF voltage, generator frequency during all experiments for materials processing.

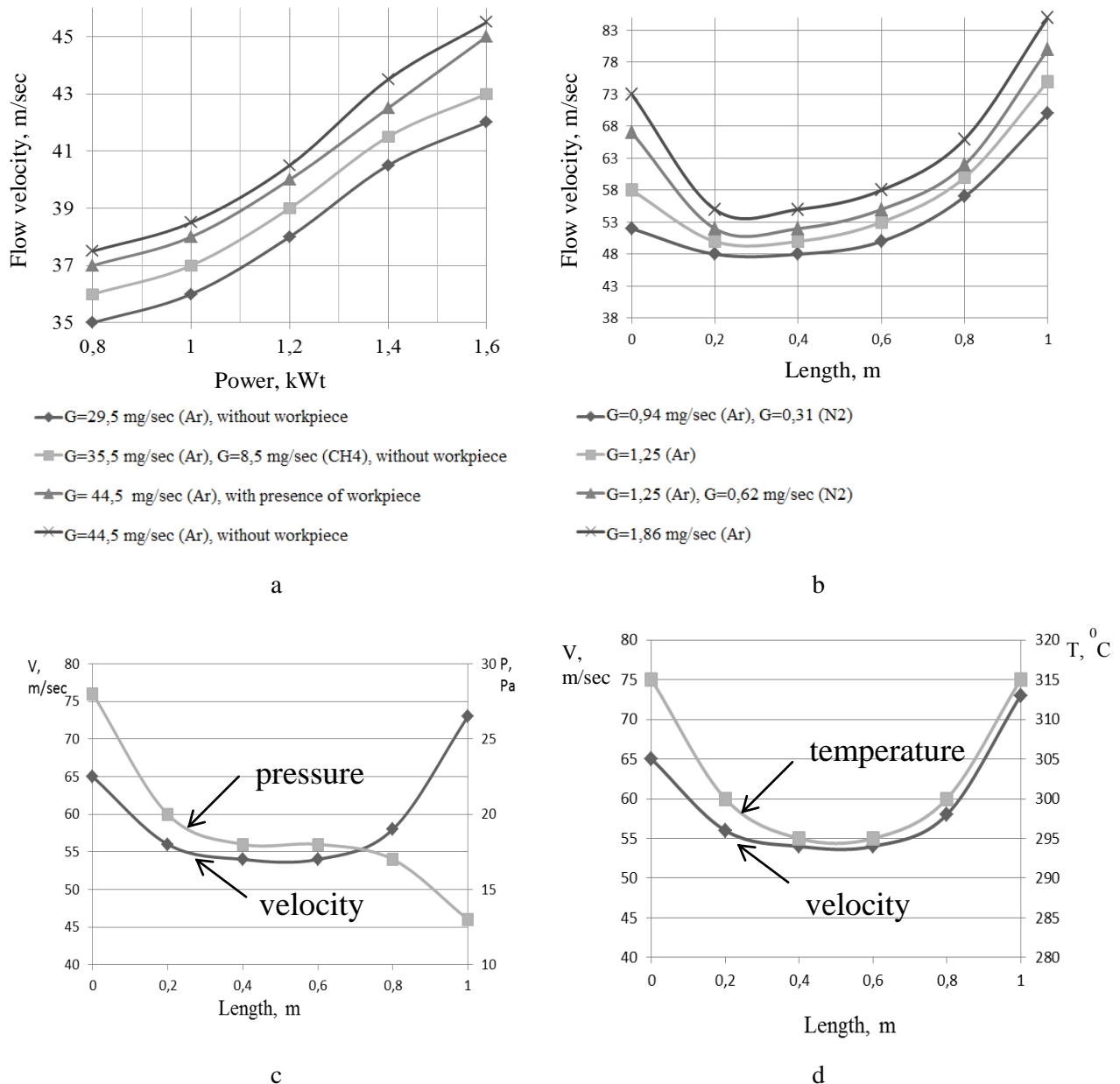
The definition of plasma flow rate, discharge power, the concentration of electrons, the density of RF power, the ion current density, and the energy of the ions bombarding the surface materials and sample processing itself is performed as follows: Samples are hung on the frame (1) and installed between the RF electrodes (2) in a vacuum chamber (5). As the door of the vacuum chamber hanging on the console (4) is closed electrodes are installed in the operating position. Further, the vacuum chamber is pumped using the pumping system (8), built on the basis of a vacuum unit AVR-50. Then, discharge chamber is filled with the plasma gas through the feed system (6) RRG-10. A predetermined gas flow rate is set, voltage is applied from the RF generator (7). The electromagnetic field from the electrodes make a partial ionization of the gas in the chamber, i.e. plasma formation.

Generation of plasma jet inside the tube was carried out according to the scheme shown in Fig. 1b. The tube was set between upper and lower vacuum sealers. The tube is a part of LC-contour and represent the analogue of inductance.

Measurements of plasma in the discharge flow rate of the vacuum chamber with planar electrodes have shown that with increasing gas flow rate increases approximately linearly. The speed of the plasma in the gas mixture on average 5% less than the velocity of the argon plasma. With the increase of the power discharge the flow velocity increases (Fig.2a). A similar dependence occurs with a decrease in pressure in the vacuum chamber. Flow velocity decreases near the metal surface when the article is introduced into the plasma jet. This happens due to the fact that when the body is introduced into the plasma flow in the surface layer flow temperature partially drop due to the difference arising plasma column and the sample temperature. With the same power input to the discharge temperature of the atoms and ions in the gas mixture is smaller than in an argon plasma. Thus, the kinetic energy of the particles significantly affects the discharge flow rate.

The gas-dynamic characteristics of plasma flows in a tube with a diameter ratio to the length of the tubular article 1: 100 were investigated. Fig. 2b shows the dependence of the plasma stream velocity according to the length of the tube in the gas flow rates range  $G_{Ar} = 1,25-1,86$  mg / sec in argon and a mixture of inert and reactive gases (argon + nitrogen). The flow rate along the length of the product increases, because gas pressure in the pumping zone is significantly lower than the inlet zone (Fig. .2c)

Electron density studies revealed that the pressure is increased in the range of 10 to 40 Pa electron concentration in the jet RF discharges of low pressure increases. According to the declining of pressure loss of charged particles is reduced due to their diffusion and increasing of the frequency of ionizing collisions with heavy particles. Analysis of ion energy is shown that 10-60 eV is enough for the surface modification.



**Figure 2.** a) dependence of power discharge on the flow velocity in the range of gas flow rates  $G_{Ar} = 29.5-41.1$  mg / sec in argon and a mixture of inert and reactive gases (argon and methane) in the presence of the workpiece and without the workpiece; b) dependence of gas flow rates according to the length of tube on the flow velocity in argon and a mixture of inert and reactive gases (argon and nitrogen),  $P=20$  Pa,  $N=1$  kWt, c) Correlation of flow velocity and pressure according to the length of tube,  $0m$  – gas supply area,  $N=1$  kWt,  $G=0.001$  g/s, Ar; d) Correlation of flow velocity and temperature according to the length of tube,  $0m$  – gas supply area,  $P=20$  Pa,  $N=1$  kWt,  $G=0.001$  g/s, Ar

To investigate the effect of the interaction of low pressure RF plasma to the surface of the material experiment with the plasma of an inert gas, argon, and mixture of plasma-chemical gas, methane and argon, was carried out.

Parameters of treatment and results of the experiments are presented in the table 1 and table 2 respectively.

**Table 1.** Parameters of treatment

N, Watt	Q1, cm <sup>3</sup> /min	Q1, mg/sec	Q2, cm <sup>3</sup> /min	Q2, mg/sec	P, Pa	Time, min
900	1500	44,4	-		22	20
900	1500	44,4	150	1,8	21	20

**Table 2.** Results of the experiments

Workpiece (material)	Hardness of untreated work pieces, GPa	Hardness of treated work pieces, GPa
side milling cutter (R18)	13,19±1,93	15,08±0,9
face milling cutter (R18)	14,90±1,02	15,82±1,26
drill (R6M5)	22,5±1,07	30,62±18,53
side milling cutter (R18)	20,87±0,98	20,25±0,87
face milling cutter (R18)	13,28±0,50	23,32±3,97
drill (R6M5)	18,87±0,79	21,42±4,39

Microhardness and roughness measurement was applied to determination of physical mechanical properties. The relief and surface structure at a submicronic and nanometer scale was investigated by means of the scanning nanohardness gage «NanoScan-3D». On the «NanoScan» base the method of measurement of the hardness, based on measurement and the analysis of dependence of loading at indentation of indenter in a material surface from depth of introduction of an indenter is realized. This method is a cornerstone of the standard of measurement of hardness ISO 14577. The indenter of Berkovich type is applied to mechanical tests. It represents a trihedral diamond pyramid with a corner at top near 142°. The method of a measuring dynamic indentation consists in the following: the indenter is pressed into a sample surface with a constant speed, at the achievement of the set loading the indenter is taken away in the opposite direction. In the course of such test record of values of loading and shift of an indenter corresponding to it is made. Feature: pezozezonanse cantilever tuning fork construction with high bending resistance ( $\sim 2 \cdot 10^4$  N/m).

For quality control of convex surfaces the device on the basis of nanoskan hardness tester was designed determined specifically for the study of the quality system by the non-destructive methods of physical and mechanical properties of the surface of the pipe.

### 3. Conclusions

Thus, it revealed that the physical and mechanical characteristics of metal cutting tools treated with capacitive radio-frequency plasma discharge, have a high technological and operational characteristics. Gas saturation (carbonizing) of surface layers of metals and alloys at a depth of 1 micron during processing to 40 minutes was obtained, resulting in an increase of strength properties, durability and lifetime of the products. The advantage of ion implantation over other methods of introducing other impurities in solids is the versatility of the process which allows introducing any element of any material in strictly controlled quantity, as well as setting its depth distribution.

Research of wear resistance was carried out by experimentation way on field trials of "Northwest trunk pipelines." They showed that lifetime of all treated mills increased in the range of 140 to 230%.

The complex approach to the study of surfaces with the use of methods to measure topography, roughness, hardness, wear resistance, modulus of elasticity, elastic recovery coefficient and the thickness of the modified layer in a single instrument was studied and mastered.

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