

## FORMATION OF TECHNOLOGICAL PLASMA EFFECT OF VACUUM-ARC DISCHARGE ON INNER SURFACE OF METALLIC PIPES AND DEPOSITION OF PROTECTIVE COATS ON THEM

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### 1. Introduction

In many cases of industrial applications it is economically profitable or technically necessary to combine bulk features of one material with surface features of another one in a single material. Vacuum-arc treatment of products from inexpensive materials to form new required features of surface layers is more perspective owing to its unlimited feasibility in process efficiency. Pipes are in great demand in oil-gas industries and power engineering. But there are no effective methods for pipe inner surface treatment and pipe coating deposition, which makes it impossible to use inexpensive steel pipes under conditions of aggressive liquids, high temperature, high pressure and other parameters leading to oxidation, erosion and pipe life. Therefore, development of plasma-arc technologies of pipe inner surface treatment and pipe coating deposition is very topical and actual. A specific effect of vacuum-arc discharge on material surface is due to high concentration of energy in a chaotically rapidly moving cathode spot, short-term local heating of surface and its rapid cooling. The technological effect of cathode plasma on surface is based on cathode spot movement. The effect of a plasma flow of cathode spots formed on the outer surface of a pipe cathode and controlled by a system of vacuum-arc cathode spot fixation with magnets placed inside an electrode has been considered.

A great number of studies [1,2,3] have been devoted to explaining and investigating “anomalous” movement of the cathode spots. It has been shown [2] that the cathode spot moves in the direction of the greatest action of discharge’s own magnetic field and outer magnetic field. The magnets initiate an arc magnetic field [4] that confines the cathode spots and makes it possible to scan (control) them on the electrode-cathode surface and act with a plasma flow and deposit coats on inner surface of a coaxially placed pipe-product. The high efficiency of the plasma vacuum-arc method for pipe inner surface treatment and coat deposition has been found.

### 2. Experimental

To realize the controlled technological action and coat deposition by vacuum-arc cathode plasma flows onto the pipe inner surface in a system of coaxial electrodes, it is perspective and promising to use magnetic stabilization and cathode spot movement control. In this case the regularities of cathode spot movement in outer non-uniform magnetic field are applied. The studies of magnetic field action onto cathode spot motion along the cathode surface have shown that for the optimal ratio of magnetic field induction and distance between the magnetic system and surface the cathode spot motion into the zone of maximal magnetic field is directly restricted. The field lines are over the cathode and have the shape of arcs with their ends resting on the cathode. The cathode spot moves inside such an arc in the region where the magnetic field component perpendicular to the cathode is equal to zero (arc top). The motion takes place perpendicular to the arc plane in the direction opposite the Ampere strength. The controlling action of the arc-configuration magnetic field on the cathode spot is observed for magnetic field induction over the cathode surface  $B > 5 \cdot 10^{-4}$  Tl. The magnetic system for creating a zone of restricted motion of cathode spots makes it possible to control the cathode surface to be treated.

For the pipe inner surface to be treated by vacuum-arc discharge within the range of small diameter 30-60 mm, an electrode system “pipe-inside-pipe” is realized (Fig. 1).

A system of magnetic confinement of the cathode spots for such configuration of the electrode system is created by constant magnets magnetized in the axis direction and located along the same axis to each other with like poles inside an elongated cylindrical cathode.

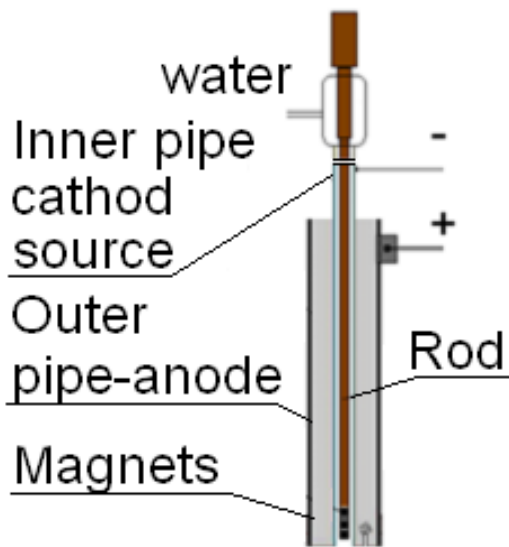


Fig. 1

one in the direction of current supply (random) and an azimuthal one ensuring cathode spot rotation around the cathode axis under “arc” of the magnetic field system. To form an ion-plasma flow to be deposited on the inner surface of the outer pipe-product the magnetic system is displaced inside the cathode along the length of the product surface. A magnetic holder is shifted with a speed ensuring, on the one hand, effective containment of the cathode spots and, on the other one, homogeneous coat deposition and influence on the inner surface of pipe-product. To treat the pipes of average or large diameter it is possible to create a system of the back-to-back solenoid pairs placed along the whole length of pipe under treatment.

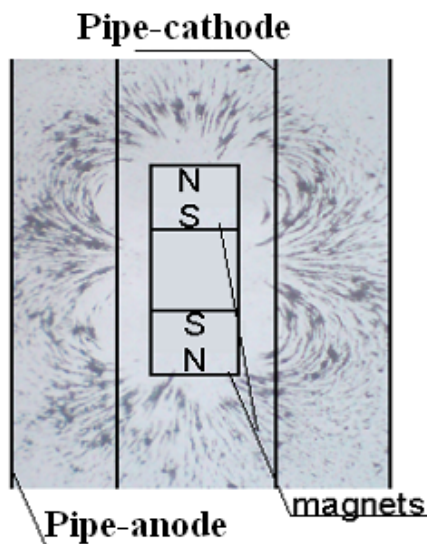


Fig. 2.

perpendicular to the cathode axis the cathode spots move along the cathode from the initiating electrode to the opposite end in order and along a straight-line trajectory. This condition keeps the cathode spots from azimuth motion on the cathode surface.

When the magnetic field is applied an orthogonal component of magnetic field induction keeps the cathode spots from azimuth motion and a tangential one allows their lengthwise ordered motion along the straight-line trajectory.

Effective localization of the cathode spots by magnetic fields of two back-to-back solenoids or constant magnets is achieved by selecting a current in solenoids or constant magnets. The magnet system moving along the pipe inner surface scans the cathode spots on the outer surface of the cathode working zone. There is an arc-initiating electrode. Current is applied to the cathode-pipe at the pipe end and a product-pipe is an anode.

The magnetic cores located on the same axis between the magnets are used to strengthen the “arc” effect of the magnetic field. While arc burning both the magnetic field of the constant magnets and the magnetic field of the plasma and cathode current have an influence on cathode spot motion. The cathode spots move from the initiating electrode to current supply, having the two components of their motion – a lengthwise

The computer programming of solenoid displacement will allow diverse variants of controlled cathode spot motion between the “arc” magnetic fields, for example a travelling wave. If the magnetic field length under the “arcs” is the same the cathode spots move from one zone into another provided that the neighboring magnets have the same value of magnetic field induction. However, a chaotic component of cathode spot motion in the regions between the trapping magnets causes some heterogeneity of the influence on the cathode surface.

The system of “arc” magnetic containment of the cathode spots and cathode surface scanning forms an intensive plasma flow for coat deposition or inner surface treatment of an external pipe (Fig. 2).

If the magnetic system is such that the vector of magnetic field induction along the length of the cathode working zone is in the plane

Changes in orientation of the magnetic system relative to its axis and accordingly the cathode lead to cathode spot trajectory displacement on the cathode surface in accordance with the magnetic field pattern. For relatively small gradients of the electric field the charged particles of the plasma flow move along the magnetic lines of the outer magnetic field. Thus, the applied magnetic field specifies the direction of plasma flow motion over the cathode surface.

In any case the parameters and sizes of the magnetic system depend on a design of the vacuum-arc device and a required character of the cathode spot motion.

A design of the vacuum-arc device with the elongated cylindrical cathode 600 mm in length was developed and tested for pipes of 38 mm in diameter and 600 mm in length. Coat non-uniformity both in length and in outer side did not exceed several percents.

The experiments were carried on in the indicated electrode system in a pulse mode; the duration of vacuum-arc discharge was 1 s. It was shown that when the distance between the magnetic system axis and the cathode surface is increased the track length ( $L$ ) of the cathode spots being formed on the cathode surface increases (Fig. 3). The magnetic induction values of the magnetic field on the cathode surface with distance from the magnetic system are given in Table. The magnetic induction values at  $B_1$ ,  $B_2$ ,  $B_3$  of the cathode surface distant from the magnetic system are presented in Fig. 4.

Table

$R$ (mm)	$B_1$ (mTl)	$B_2$ (mTl)	$B_3$ (mTl)	$L_{cp}$ (mm)
7	0.20	0.35	0.40	6
10	0.15	0.23	0.25	9
15	0.14	0.20	0.17	15
17	0.13	0.175	0.15	20

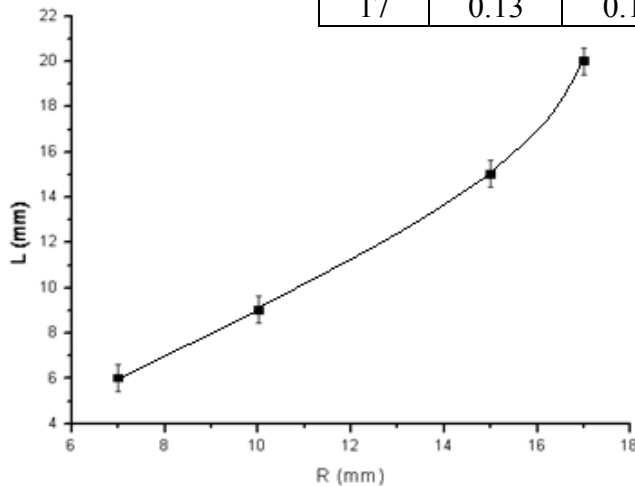


Fig.3

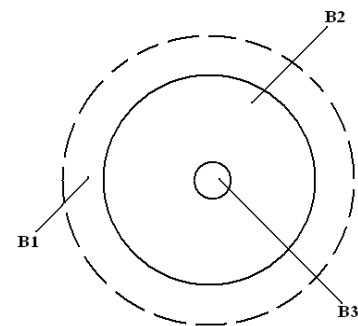


Fig.4.

### 3. Conclusion.

An original system of vacuum-arc cathode spot scanning on the cathode surface in a coaxial electrode system has been proposed. A magnetic field for cathode spot confinement and control on the outer surface of a cathode-pipe is created by two constant magnets magnetized in the axis direction, set coaxially relative to electrode and opposing to each other with like poles inside a cylindrical cathode. Cathode spot containment on the outer surface of the cylindrical cathode is realized by an “arc”-shaped magnetic field. The magnetic cores located between the magnets were used to enhance the “arc” features of the magnetic field. The magnetic field is oriented so that the induction vector components of the magnetic field are in the plane parallel to the cathode axis. A system of the two magnets with like poles along the cathode surface allows the cathode spots in the zone of “arc” magnetic field to be scanned on the cathode surface,

thereby ensuring plasma flow formation and cathode material deposition on the inner surface of pipe.

The proposed design of the vacuum-arc device with the elongated cylindrical cathode 600 mm in length was tested for cleaning and coat deposition on the inner surface of pipes of 38 mm in diameter and 600 mm in length. The coats have necessary density and the coat non-uniformity does not exceed 2-3 percents.

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### Figures:

Fig. 1. The electrode system for technological treatment of the inner surface of pipes with small diameter of about 30-60 mm by vacuum arc discharge

Fig. 2. The system of cathode spot scanning on the cathode surface

Fig. 3. The dependence of cathode spot track length on cathode-magnet distance

Fig. 4. The lines of magnetic induction in the magnetic system