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EXPERIMENTAL RESEARCH OF THE GLOW DISCHARGE ELECTRON GUN FOR METAL HEATING[1])

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Technological exploitation of electron beams for annealing copper and aluminium wire is described. The beams are extracted from the glow discharge cathode. The principles of operation are discussed and some results of measurement of heating efficiency are given.

ЭКСПЕРИМЕНТАЛЬНОЕ ИССЛЕДОВАНИЕ ТЛЕЮЩЕГО РАЗРЯДА ЭЛЕКТРОННОЙ ПУШКИ ДЛЯ НАГРЕВА МЕТАЛЛА

В работе описана технологическая эксплуатация электронных пучков для отжига меди и алюминия. Пучки экстрагированы из катода тлеющего разряда. Обсуждаются принципы работы и приведены также некоторые результаты измерений темплового коэффициента полезного действия.

I. INTRODUCTION

Technological exploitation of electron beams has been used for many years. This applies for electron beam welding, brazing, melting, machining and sintering of materials.

Further possibilities appear in the use of high accelerated electron beams for rubber vulcanization, polyethylene cross-linking, and for similar industrial applications.

The basis of the technological arrangement for the exploitation of the heat effect of an electron beam is the electron gun generating, forming and accelerating an electron beam. There are two types of electron guns according to the way of the electron emission: 1. electron guns with a hot cathode, 2. electron guns with a glow discharge cathode.

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In the initial phases of the electron technology introduction electron guns with a hot cathode were almost exclusively used, in recent years glow discharge cathodes have been used for certain applications.

II. PRINCIPLE OF THE GLOW DISCHARGE CATHODE

For industrial applications it is necessary for the cathode to be a source of electron current of about 1 Amp. This requirement can be also met by a glow discharge through high current density is not its outstanding feature. But with respect to the very large emitting area, the total current which can be gained from the cathode meets our requirements.

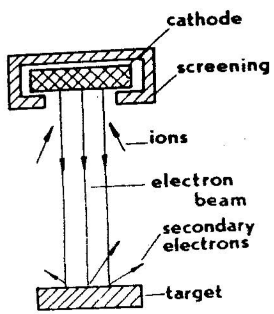

Fig. 1.

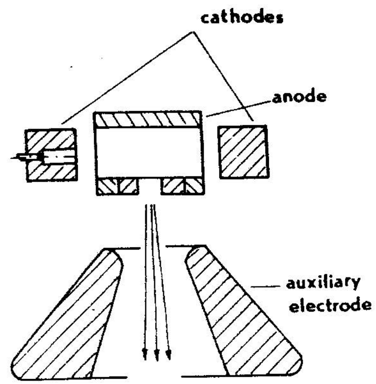

Fig. 2.

The electron beam can be obtained from a plasma generated by a glow discharge in two ways, differing in the voltage connected to the electrodes. When using the so-called high-woltage discharge, the glow discharge is operated on the left-hand branch of the Paschen curve at voltages from 2 to 30 kV and at pressures from 10 Pa to 10^{-1} Pa. Schematically the eletron gun of this type is illustrated in Fig. 1.

The electron paths with an energy higher than 2 keV are not practically influenced by collisions with gas and depend only on the form of the electric field near the cathode. It is therefore possible to form the shape of the beam by the shape of the cathode.

The second system (Fig. 2) is based on a low-voltage glow discharge, the ignition voltage of which corresponds to the minimum of the Paschen curve. For this system the principle of the Penning gauge was used. The gauge consists of three electrodes, two interconnected target cathodes, which operate also as magnet poles, and a cylindrical anode, located between them [1].

Through the combined operation of magnetic and electric fields the paths of electrons are lengthened and the number of ionization collisions increases. The electron beam is obtained from the plasma through the hole in the anode.

An auxiliary electrode, to which the accelerated voltage is connected, supplied the required kinetic energy for the electron beam.

III. EXPERIMENTAL DEVICE

The requirement of continual wire annealing, for which the electron gun is intended, was solved by means of a high voltage type of the glow discharge cathode in the cylindrical design.

The wire, having the function of a central anode, passes through the centre of the hole of a cylindrical cathode, surrounded by screaning, which also serves as an auxiliary anode.

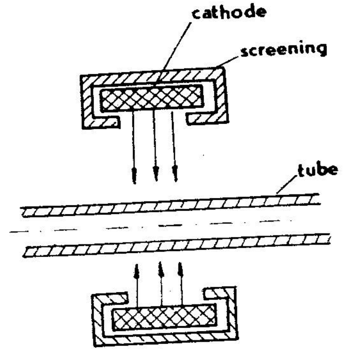

Fig. 3.

In Fig. 3 there is the same arrangement of the system, only the wire is substituted by a tube with flowing water. This arrangement was used to watch the effectivity of the central anode heating.

For supplying the cathode with high voltage (approx. 15 kV) a regulating autotransformer with a high-voltage transformer and a six-phase rectifier were used. For smoothing the output voltage a filter with a condenser and a choke were used. The inductivity of the filtration choke influences positively the discharge stability. Against the overcurrent during the striking of the arc the source was protected by a series resistor. This arrangement cannot be used for industrial aplIication, as the total efficiency of heating would decrease considerably.

The equivalent discharge resistance is not constant. It considerably depends on the gas pressure and on the connected voltage (see Fig. 4). For a uniform heating of the wire it is therefore necessary to maintain the pressure in the discharge area with considerable accuracy. With regard to unavoidable leakages of the chamber with the drawing wire and owing to a certain impurity of the wire surface, rapid variations of the discharge resistance during heating can result. These variations of the source must be compensated to keep the discharge efficiency constant.

This can be achieved only by a controlled source of a short response time of a regulator and power unit. This requirement can be fulfilled for example by a pulse converter with a higher operating frequency. Fig. 5 illustrates the block diagram of the source provided with the converter.

An alternating supply voltage from the network S is supplied to the rectifier U, further to the converter M, then to the rectified filter F and finally the cathode K. The central anode (heated wire) is connected through the current shunt RB to the positive pole of the source.

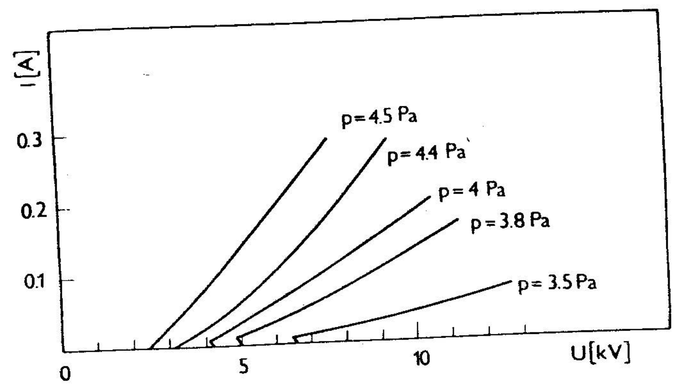

Fig. 4.

The converter regulator RM evaluates the actual values of the output current (from RB) and the voltage (from RU) and the required wire temperature. The vacuum regulator RV controls an air-inlet valve EV according to the measured pressure (gauge VM) and to the requirements of the converter regulator (voltage and current work region). The rotary pump operation is uninterrupted and pumping is not regulated.

IV. WIRE ANNEALING BY THE ACCELERATED ELECTRON BEAM

One of the prospective possibilities of the glow discharge cathode utilization is the annealing of copper and aluminium wires. When using the normal method of wire annealing by Joule's heat the surface is damaged and moreover the wire is annealed irregularly. Other methods, e.g. in furnaces or in resistantly heated tubes are considerably uneconomical. Therefore electron beam heating seems to be more advantageous, owing to contactless heat transmission not damaging the wire

surface. This process is carried out in vacuum, which retards oxidations of the surface. The device is also considerably smaller than other annealing equipment.

Annealing is performed continually and therefore the output of the annealing arrangement must correspond to the speed of the wire drawing machine, which in modern devices reaches almost 40 m/s. The output of the annealing arrangement corresponding to this speed is about 30 kW.

V. EFFICIENCY OF THE CENTRAL ANODE HEATING BY THE ELECTRON BEAM

When applying the glow discharge cathode in annealing devices the most important parameter is the efficiency of energy transmitting into the heating wire. To reach a high degree of efficiency is important not only for the proper energy exploitation, but also because of difficulties, arising from the cooling of electrodes, differing in potential from that of the ground.

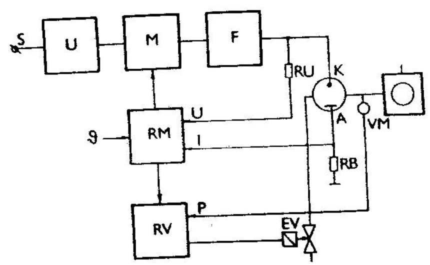

Fig. 5.

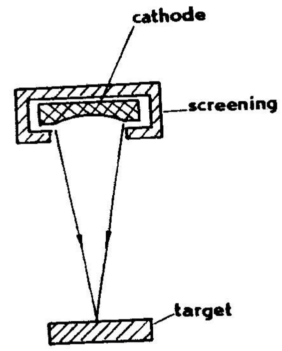

Fig. 6.

The measurement of heating efficiency in an arrangement in which moving wire is used is technically difficult, therefore the wire in the measured arrangement was replaced by a copper tube and the obtained efficiency was determined according to the temperature of flowing water.

In practice the measurements were effected in such a way that by means of thermocouples the difference in the copper tube temperatures in front of and behind the annealing chambre was registered. This method was verified by the direct measurement of the increasing temperature of water passing through the tube.

From the efficiency measurement the following information was obtained: 1) Efficiency does not depend on the pressure in the measured range of pressure 2—10 Pa. 2) Efficiency changes considerably with voltage, increases from the value of 30 % for the discharge voltage of 2 kV up to approx. 70 % for voltages higher than 5 kV and this value does not change by a further voltage increase. 3) Efficiency does not depend on the magnitude of the electron current.

This conclusion was verified during experiments with the glow discharge cathode up to an output of 3 kV. Similar results were obtained also for a flat cathode with an applied focused beam (Fig. 6).

V. CONCLUSION

Experimental results obtained up to now prove that there are many possibilities of the exploitation of the glow discharge cathode for annealing devices. Moreover, the experiments accomplished with focused beams also prove the possibility of using the glow discharge cathode for welding.

We are convinced that with respect to the further development and optimalization of glow discharge cathodes, they may replace hot cathodes in a lot of industrial applications.

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