FREE SURFACE DEFORMATION AND FORMATION OF ELECTRICAL DISCHARGES UNDER CURRENT CARRYING FLUIDS IN MAGNETIC FIELDS

KLEMENTYEVA[1] I.B., PINCHUK[2] M.E., TEPLYAKOV[1] I.O., ABDELLAH KHARICHA[3]
[1]JIHT, 13/2 Izhorskaya str., 125412 Moscow, Russia
[2]IEE, 18 Dvortsovaya nab., 191186 St.-Petersburg, Russia
[3] University of Leoben, Franz-Josef-Straße 18, 8700 Leoben, Austria
E-mail: ira.klementyeva@mail.ru

Abstract: Results of investigations of high current discharges formation under liquid metal free surface deforming due to interaction of passing through it electric current with current's own magnetic field are described in the paper. Discharge characteristics and parameters of its ignition are presented here. Visualization pictures of free surface deformation and electrical discharge formation are shown in the paper. Processes taking place in the system are considered. Mechanism of formation of the discharge over the liquid metal surface is discussed.

1. Introduction

The significance of these investigations is in solving of the fundamental problems of magneto-hydrodynamics and discharge physics and also in solving of the application problems related to improving the performance of technical devices in power engineering and industry. The investigations are relevant and caused by the need to create energy-efficient technologies. The electrical discharge under the liquid metal surface appears in different technological processes. One of the applications of research results is in metallurgy. With the use of magneto-hydrodynamics methods of control [1, 2] of electrical discharges and electro-vortex flows it is possible to successfully improve many electrometallurgical processes – welding, melting, melt purification. Another important application of the received results is in nuclear and thermonuclear power engineering for intencification of mixing of plumbum and lithium for creation of eutectic alloy [3] planed to be used as a heat transfer agent. The investigations of processes in current-carrying fluids with high current electrical discharges under free surface of liquid metals are of fundamental interest.
Two types of liquids were use for experiments in the work – plumbum (Pb) and eutectic alloy indium-gallium-tin (In-Ga-Sn) (weight content: Ga – 67%, In – 20.55%, Sn – 12.5%, +10.5C). Pb and eutectic alloy plumbum-lithium are planned to be the heat transfer agent in modern reactors on fast neutrons. Whereas In-Ga-Sn are sutable for modeling of the system under interest due to low melting point and no hazard to health. The investigated processes are complex and comprise deformation of the free surface of the liquid metall, electrical discharge ignition and electro-vortex flows formation. Deformation of the free surface and formation of electro-vortex flows are caused by interaction of electric current running through the electro-conductive liquid with current's own magnetic field. Then the electrical discharge ignites influencing hydrodynamics and heat-exchange processes in the system.
Tasks of current work are: to reveal causes and conditions of electrical discharge ignition; to determine parameters of the electrical discharge.

2. Presentation of the problem

The base element of the experimental setup is a test section (fig 1) that is a steel or copper rod electrode with hemispherical edge (diameter – 20mm or 5mm) and a cylindrical or hemispherical [4] container (diameter – 10cm and height – 5cm or diameter – 18.8cm) filled with the melted metal (plumbum Pb or eutectic alloy In-Ga-Sn) playing role of another electrode. The rode electrode is dipped initially into the melted metal. Electric current in the circuit is organized by accumulator power source or three phase power source with open circuit voltage U_{oc} up to 13V or 20V correspondingly.

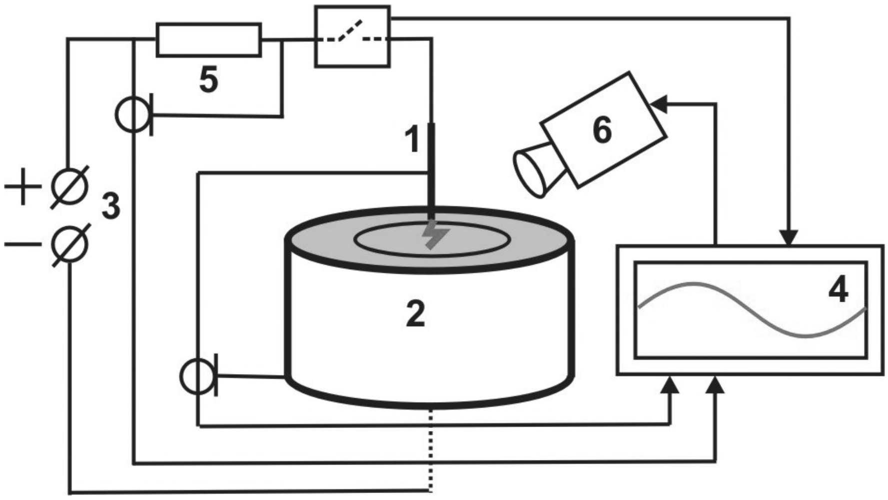


Figure 1. Scheme of the experimental setup. 1 – rod electrode, 2 – cylindrical or hemispherical container, 3 – accumulator power source or three phase power source, 4 – oscillograph, 5 – electric current shunt, 6 – high speed digital photo camera.

Synchronization scheme gives required time sequence and time intervals between switching on of electric current and triggering of recording equipment. Electric current runs an oscillograph generating pulse signal to trigger video camera. The oscillograph and camera record processes before and after electric current switching on.
Electrical parameters, circuit current I and voltage U measured between the electrode and the free surface of the liquid metal, are registered with four-channel digital recording ocsillograph Tektronix TDS 2014.
Electric current is defined through voltage drop on current shunt (0.2mOhm or 0.05 mOhm).
Processes visualization is performed with high speed digital photo camera Citius Imaging C10 of following specification: maximum matrix resolution – 652×496, pixel size – 10mkm, maximum registration rate – 10000 frames per second, time of exposure – from 6mks, synchronization accuracy – 1mks.
Experiments were carried out in air and argon at P – 1Atm.

3. Results and discussion

Fig 2 and fig 3 represent processes in the system through voltage U measured between the electrode and the liquid metal and voltage drop measured on the current shunt that reflects electric current I in the circuit in experiments with melted Pb [5].
It is seen that at initial stage after switching on of electric current U ~ 2V and I ~ 500A and there is no any discharge in the system. Then U and I start to rise and falls correspondingly due to free surface deformation under action of electro-motive body force that is a result of

interaction of passing through the liquid metal electric current with its own magnetic field. After that there is rapid increase of U getting its maximal value in the experiment that reflects reduction of contact area between the electrode and the liquid metal. Following oscillogram ranges demonstrate ignition and evolution of the electrical discharge in the system with parameters: $U_{arc} \sim 10V$, $I_{arc} \sim 100 - 200A$ (fig 4).

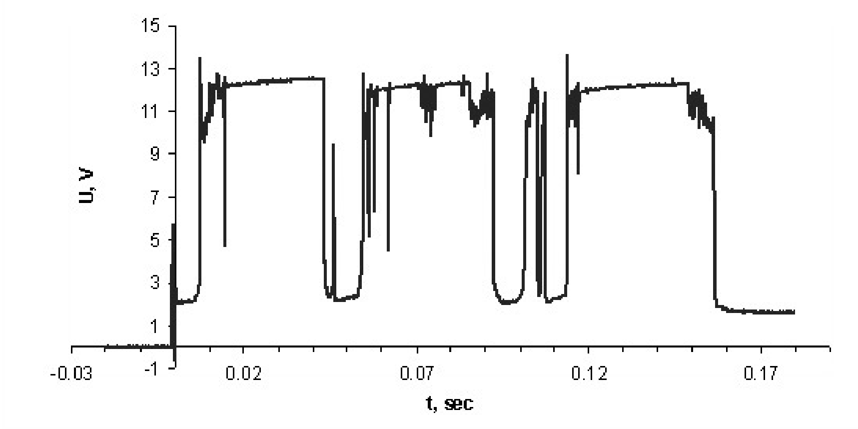


Figure 2. Voltage U measured between the electrode and the cylindrical container with melted Pb

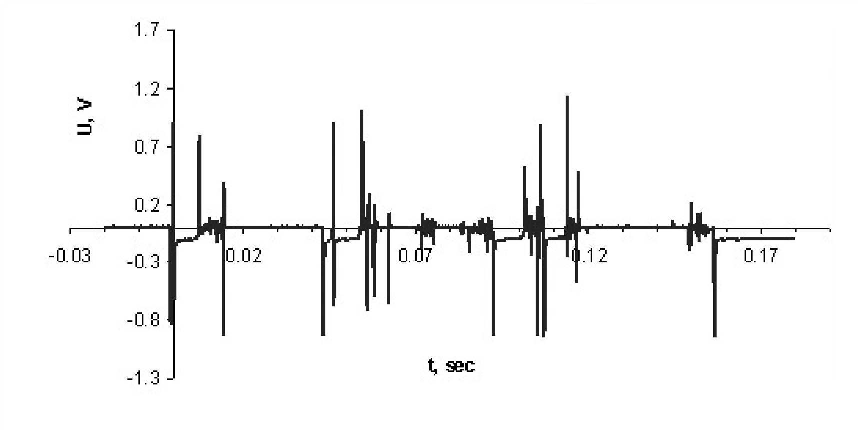


Figure 3. Voltage drop measured on the current shunt that reflects electric current I in the circuit in the experiments with melted Pb.

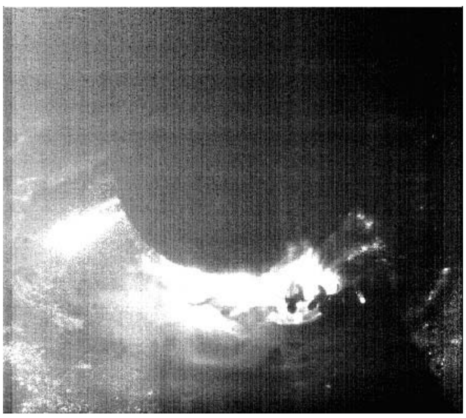
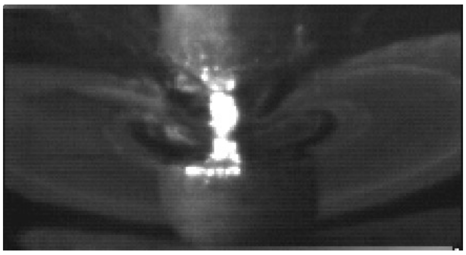
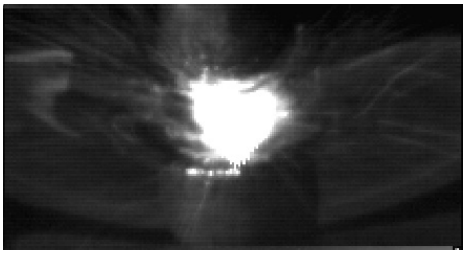


Figure 4. Image of the electrical discharge in the experiments with Pb.

High-speed videos confirm the picture of processes development described above. Free surface deformation and discharge ignition repeat during the run of the experiment with following parameters: frequency of discharge ignition due to deformation of the free surface ~ 30Hz, time of discharge evolution ~ 7ms, and frequency of discharge pulsations ~ 0.5ms. As the rod electrode is an anode the pulsations of the discharge reflects movement of a discharge attachment point to the electrode along it [6, 7].
Estimations of breakdown voltages approve that the cause of discharge ignition is deformation of the free surface due to action of electro-motive body force.
High-speed video frames of the experiments with In-Ga-Sn demonstrate deformation of the contact surface, its detachment from the rod electrode (fig 5 a) and ignition of the electrical discharge (fig 5 b).



a



b

Figure 5. a) Deformation of the contact surface, its detachment from the rod electrode, b) ignition of the electrical discharge in the experiments with In-Ga-Sn.

Character of the processes in the experiments with Pb and In-Ga-Sn are the same qualitatively. Fig 6 represents voltage drop measured on the current shunt that reflects electric current I in the circuit in the experiments with In-Ga-Sn. Electrical discharge paramrters for the case are: U_{arc} ~ 0.24V, I_{arc} ~ 520A.

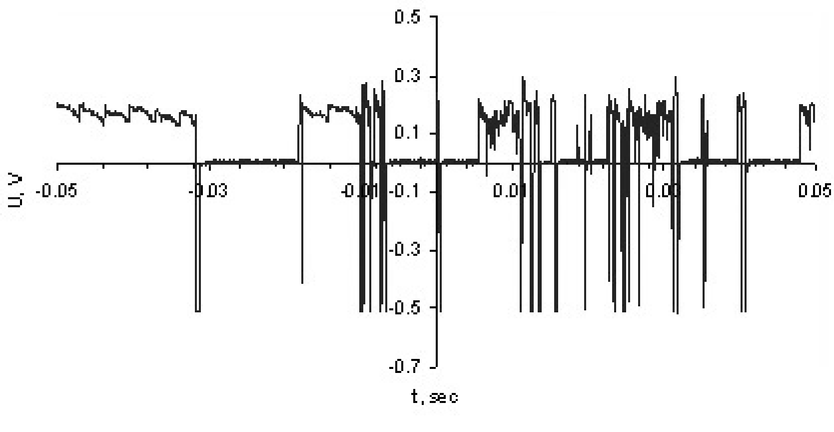


Figure 6. Voltage drop measured on the current shunt that reflects electric current I in the circuit in the experiments with In-Ga-Sn.

4. Conclusion

Experimental studies of formation of the electrical discharges over the surface of the liquid metal were carried out. Discharge characteristics and parameters of its ignition were determined. Wave form, free surface deformation and discharge evolution were visualized. It was confirmed that the cause of discharge ignition is deformation of the free surface due to action of electro-motive body force. The results will be used for investigations and estimations of influence of pinch-effect on vortex structure and velocity field in liquid metals at MHD method application for intensification of mixing and heat transfer in technical devices.

5. Acknowledgements.

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6. References

[1] Klementyeva I.B., et al.: Interaction of electrical discharge with gas medium in external magnetic field and influence of the interaction on flow structure and mixing. High Temperature. V.48 No.1 (appl.) (2010) 132-137.
[2] Klementyeva I.B., et al.: Peculiarities of interaction of electrical discharge with gas flow in external magnetic field. Letter Journal of Technical Physics. V.33 No.22 (2007) 16-22.
[3] Freibergs J., Klavins J., Lielausis O., Mikelsons A., Zandarts J. MHD technology for the production of Pb-Li eutactic alloys. The 15th and 6th PAMIR conference on fundamental and applied MHD fusion. 259-262.
[4] Ivochkin Yu.P., et al.: Investigation of deformation of free surface and its influence on intensity of electro-vortex flows of liquid metal. Thermal Processes in Engineering. V.4 No.11 (2012) 487-496.
[5] Klementyeva I.B., Pinchuk M.E.: Formation of electrical discharges under free surface of current carrying fluids. Physics of extreme states of matter. (2014) 192 – 193.
[6] Klementyeva I., Moralev I.: Electrical discharge interaction with gas flows in external magnetic field. IEEE Transactions on Plasma Science, Special Issue – Images in Plasma Science. (2011) 2144-2145.
[7] Klementyeva I.B., et al.: Experimental investigation of electrical discharges in gas flows in external magnetic field. High Temperature. V.49 No.6. (2011) 816-825.