# VISUALIZATIONS OF VARIOUS MHD PHENOMENA CAUSED BY INTERACTION OF THE DC AND AC MAGNETIC FIELDS WITH THE LIQUID METAL FLOW

*A. Bojarevičs, Yu. Gelfgat*
*Institute of Physics, University of Latvia, Miera 32, LV-2169 Salaspils, Latvia*

**Introduction.** Any means of direct monitoring of the flow phenomena in the volume of the oblique media like liquid metals remain limited and partial. Properly set experiment never has failed to bring forward the unexpected, but crucial details of the physical phenomena. Quite interesting fluid flow phenomena often are recognized only after visual observations of the associated behaviour on the "free surface" of the liquid. Current presentation would present video demonstrations of some physical phenomena as observed "in situ" on the "free surface" of the liquid metal under impact of DC and/or AC magnetic fields.

**1. Audio frequency AC magnetic field induced liquid metal flow.** The room temperature model of the melt dynamics in a crucible induction furnace demonstrates the extremely unstable fully three dimensional nature of the liquid metal flow while the dimensionless frequency is of order of magnitude $10^2$ [1]. The convective mixing is very intense and in industrial furnaces at high temperature of the melt may cause the erosion of the crucible walls and undesirable interaction with the surrounding gas on the free surface. During semi-levitation melting such very strong convective heat transfer may cause unacceptably high heat losses into the cooled bottom plate.

**2. Two-phase high frequency traveling field as a tool to control the convective transfer.** During melting of the oxide materials in high frequency induction furnaces the convective heat and mass transfer often is insufficient for fast homogenization of the melt. The current video clip presents how efficient may

*Fig. 1.* The free surface deformations during an unstable AC field induced liquid metal flow.

be the introduction of the "traveling" magnetic field in this kind of furnaces. The inductor coil in model setup has been split into two parts and the high frequency current phase in one of the parts was shifted by 90°C. The action of the additional tangential component of the time-averaged electromagnetic force, besides increasing the intensity of the convective mixing, permits to control the direction of the averaged meridional flow. Depending on the sign of the introduced phase shift the meridional circulation flow may be driven in required direction, permitting to control the convective heat and mass transfer. The video clip also shows that axial asymmetry of the low inductivity coils, inevitable in high frequency applications, result in markedly asymmetrical melt flow.

**3. The audio frequency AC field driven flow under impact of an superimposed DC magnetic field.** When it is desirable to damp the unstable velocity fluctuations of the AC field induced flow in the liquid metal the DC magnetic field may serve as a highly efficient tool. The video clip presented in this section illustrates the unisotropic interaction of the DC magnetic field with the liquid metal flow. At sufficiently high MHD-interaction parameter values the mean flow and velocity pulsations in the inductively stirred melt may be effectively damped when the DC field direction is normal to the vorticity of the AC magnetic field induced flow. The unstable free surface deformations, like those shown on Fig. 2, and associated vorticity, parallel to the DC magnetic field induction, may persist in the liquid metal flow even at quite high values of MHD-interaction parameter [2].

**4. Gravity wave damping by DC magnetic field.** Inadvertently excited gravity waves occurring in finite depth pools may be very persistent and at large wave numbers very weakly damped by viscosity. The DC magnetic field efficiently damps all the surface waves with wave vectors normal to the direction of the applied DC magnetic direction, Fig. 3.

The video clip demonstrates that any surface waves in liquid metal pool are efficiently damped by DC magnetic field normal to the free surface. The DC magnetic field coplanar with the free surface of the liquid metal transforms the surface waves leaving pronounced surface waves with wave vector directions parallel to the DC magnetic field direction.

**5. Thermo-capillary convection of a Lead doped liquid Gallium.** During experiment attempting to realize thermo-capillary convection in an axially symmetric layer of high purity liquid Gallium the resulting melt flow exhibited unpredicted behaviour – the direction of the flow was opposite to the expected. It was explained when analysis of the Gallium after experiment showed 120 ppm Pb content. The most probable source of contamination may have been the Lead from

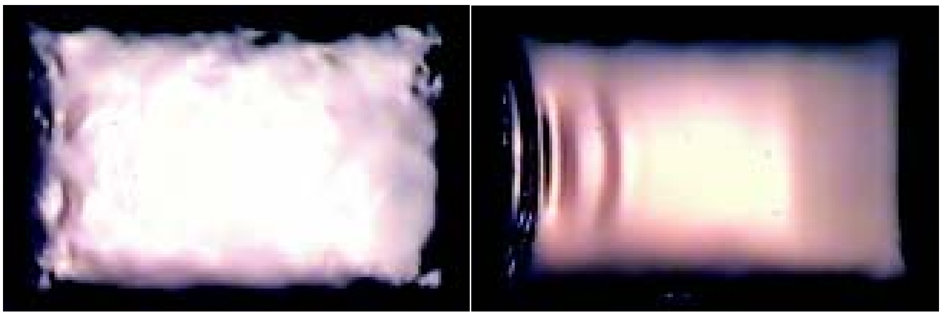

*Fig. 2.* AC field induced flow in liquid metal. The video frame on the right side illustrates the effect of the superimposed DC field normal to the longer side wall of the rectangular crucible.

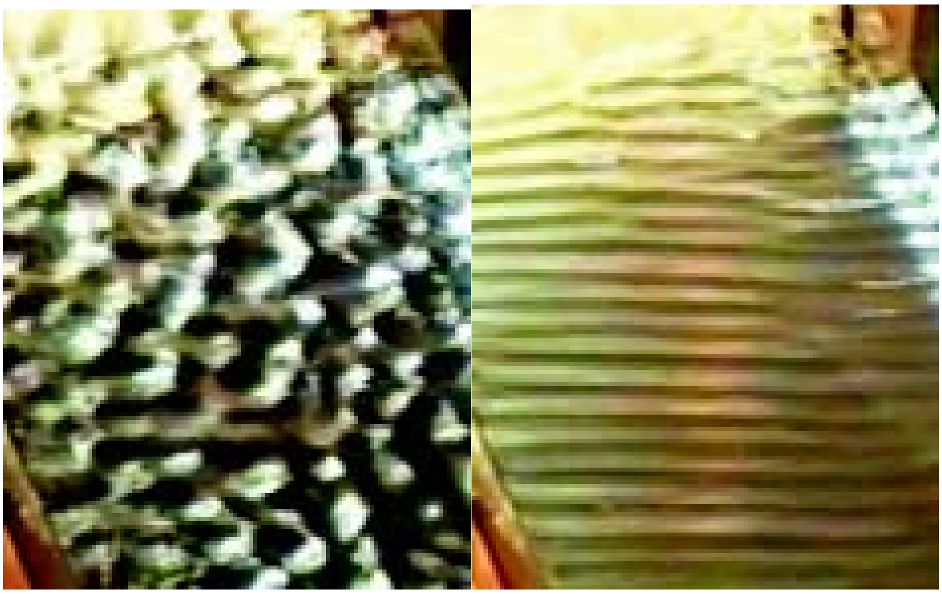

*Fig. 3.* The chaotic surface waves in liquid metal pool are ordered by DC magnetic field.

the solid Lead vacuum seal transferred to the bottom of the empty pool by surface diffusion during 72 hour long degassing prior to filling it with liquid Gallium. While the applied axially symmetrical heat flux was not too high the axially symmetric flow was directed along the direction of the gradient of the temperature – from the cold to the hottest region of the free surface. Such anomalous flow was explained in a paper [3] by surface activity of Lead I liquid Gallium. Even more unexpected flow pattern was recorded on video, when the heat flux was increased. The axially symmetrical flow was replaced by unsteady bipolar flow. The presented video clip (Fig. 4) shows how the asymmetrical flow develops while the heat flux increases.

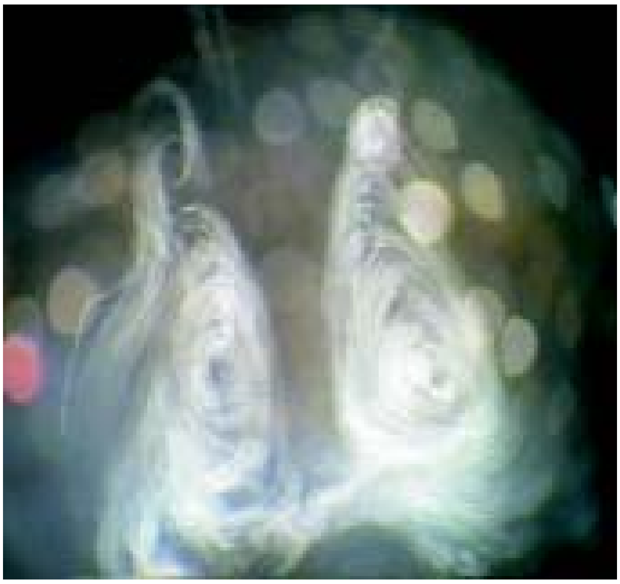

*Fig. 4.* The pattern of the tracer particle motion on the free surface during bipolar unsteady thermo-capillary convection.

*Fig. 5.* The deformations of the Gallium melt region due to intense flow induced by thermoelectric current interaction with DC magnetic field: axially symmetrical video frame (left) and transverse one (right).

**6. Thermo-electro-magnetic convection in a container.** Very intensive liquid metal flow has been demonstrated in an axially symmetrical container with liquid Gallium, when tangential gradient of temperature along the Cobalt bottom was causing thermoelectric current in the melt. Thermoelectric current interacting with axially symmetrical magnetic field induced very intense azimuthal motion of the melt. The magnetic field, transverse to the axis of symmetry, induced intense bipolar motion. The current video clip demonstrates that thermoelectromagnetic convection could not be neglected considering the actual unisothermal liquid metal flows at electrically conducting boundaries if there are intense heat flux along the liquid-solid interface, electrical conductivity and the relative thermoelectric power of both media is high.

**7. Video recordings of crystallization and melting of Gallium.** The current video clip demonstrates some peculiarities of solid-liquid phase transition in a 2 mm thick axially symmetrical layer of Gallium. The axially symmetric heat flux occurred through the thin stainless steel bottom of the vacuum container to the copper rod which was heated or cooled. Fig. 6 is a still frame of a video clip showing very slow crystallization of Gallium with large single crystal blocks. While the radial extent of the solid-liquid boundary increased, the heat flux density decreased inversely. The surrounding liquid Gallium became significantly undercooled. Spontaneous super fast crystallization happened at this stage, when crystallization front advanced for approximately 1 cm with the speed of order of magnitude 25 cm/s ( Fig. 7).

When the heat flux direction was reversed in the same setup, the oscillatory melting instability behavior was observed Fig. 8.

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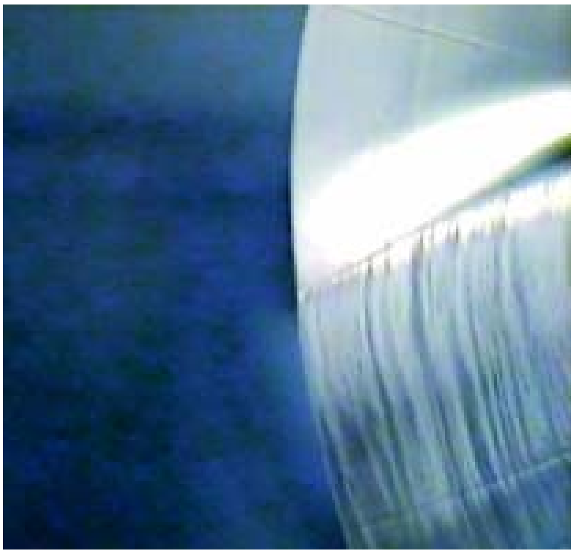

*Fig. 6.* Crystallization of Gallium.

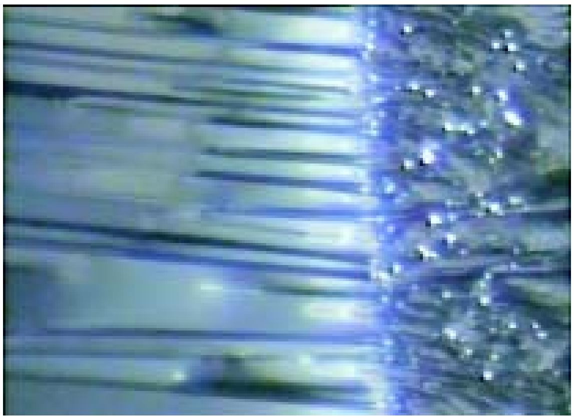

*Fig. 7.* Super fast crystallization of Gallium.

*Fig. 8.* Oscillatory melting of Gallium.