LM JET AND FILM FLOWS OVER SOLID SUBSTRATES IN STRONG MAGNETIC FIELDS

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Abstract: Free surface liquid metal (LM) flows in the presence of a magnetic field remain attractive because of a single reason. The workability of such flows is essential for several challenging power transforming and transferring projects. Power load capability should be considered as one of the main parameters determining the usefulness of any of such systems. In this relation a fast moving free surface LM flow stays beyond comparison. However, quite from the beginning of the development attending remain doubts about the spatial stability of such flows. In the presence of up to 4T magnetic fields different versions have been considered how to stabilize a free surface flow by means of solid substrates.

1. Introduction.

Free surface LM flows have been proposed to the role of a working medium in rather specific technologies including exotic future plans. So, in [1] a situation is considered when a LM jet used as a target for a 4MW proton beam at the production of pions. To capture the generated particles a magnetic field is foreseen; also the jet has to penetrate an up to 20T field. However, essentially better investigated are systems proposed for the protection of plasma facing components in fusion devices. Power load capability should be considered as one of the main parameters determining the usefulness of all such systems. A fast moving free surface liquid metal (LM) flow stays here beyond comparison. In this relation enlightening are the results gained on the small scale tokamak ISTTOK [2]. A LM limiter formed by a thin 2.5 mm Ga jet at a rather moderate ($v \approx 2.0$m/s) velocity was able to exhaust 2.4 kW in a 14.5 kW (ohmic) discharge. The corresponding volumetric power extraction capacity reached 2.4 kW/cm^3. The parameters of the discharge remained practically unchanged. However, the discharge caused a small displacement of the free flying flow; as the source floating potential inside the plasma has been assumed [3]. Whatever the reason of the deflection, essentially more stable would be a flow is backed by a solid substrate. We are accentuating here fast flows. It should be remembered that interesting can be also MHD flows at close to zero velocities .So, in [4] an attempt is made to create a creeping ($v \leq$ 1cm/s; thickness$\leq$ 1mm) Li flow over a plate in a strong 4T field. Aim of such a motion in a fusion application – controlling of the tritium dynamics. Because of the small thickness the liquid film will be prevented from overheating and evaporation – the generated heat can be extracted through properly cooled substrate.

2. Flows supported by curved substrates

Intriguing are the results of our recent experiments on jets passing over curved substrates [5].In our superconducting solenoid (up to 5T in a D=30cm; L=100cm.bore) three d=2.14mm InGaSn jets were targeted towards a cylindrical (R=95 mm) wall. The angle of incidence, fixed at 30^0, was rather blunt. The nozzles were made of 40mm long medical needles issuing from a cylindrical Plexiglas container (Fig.1). In the initial version the jets were targeted towards a non- prepared SS wall, it means, practically towards a non-wetted badly contacting substrate. The result was somewhat striking - in up to 4T fields the jets remained stable and well organized over the full length (~200 mm) of their path. The velocities reached 0.59 m/s (Fig.2a) In the next experiment the cylindrical SS wall was covered by a 4mm thick Cu insert, beforehand carefully treated. In this case the substrate should be considered as good wetted and electrically good contacting. As expected, without the field the jets tended to merge, to form a film-like flow. In this case we see a clear competition between the inertial and capillary forces. In the presence of a strong enough magnetic field the induced by the motion electromagnetic forces are dominating. The flow becomes unstable and fragmentary. The induced forces were able even to lift small volumes over the surface (Fig.2b).

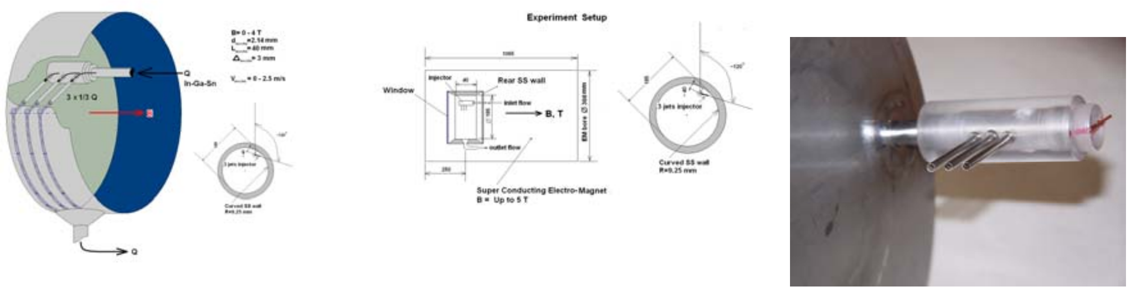

Figure 1: Scheme of the experiment with jets over curved substrates.

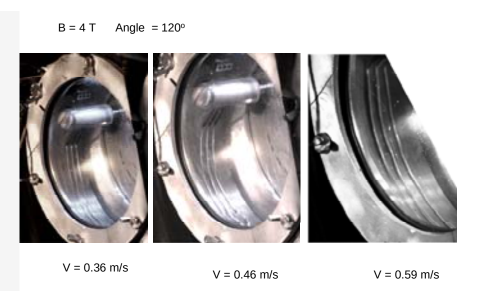

Figure 2a: Flow over non-wetted wall.

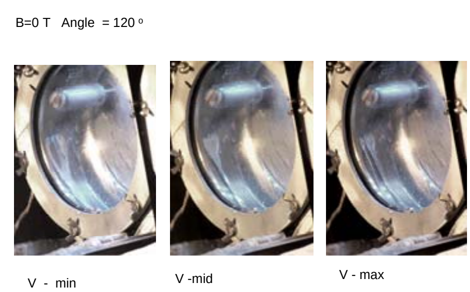

Figure 2b: Flow over a wetted wall.

3. Flows passing over flat plates

Let us start with a simple example. Fig.3 illustrates the situation when a single InGaSn jet is touching to a SS steel plate under small angle. The plate is glued on the surface of a permanent magnet which generates an orthogonal to the plate field with the intensity of order of 0.6 T. In addition to this, the plate is carefully vetted. In such a way a good electrical contact is ensured. Under such conditions the main actors are clearly defined - the inertial, the surface tension and the EM (Hartman) forces. It can be seen that after a definite distance the d=2.5 mm jet equally covers the full 3 cm width of the braking plate. It is a result which could be expected-a transfer of a jet flow into a film flow.

Figure 3: Spreading of a jet over a conducting plate.

In the main part of the experiments the principle scheme, compared with [4], remains unchanged (Fig.4).The magnet can be seen (a), the position of the working chamber inside the bore(b), also the chamber together with supplying lines(c). In Fig.5 an explanatory scheme is presented together with an experimental example. Worth mentioning, the typical to a fusion divertor field configuration was achieved. With regard to the axis of the magnet the container (together with the plate) was turned for 10 degrees. In such a way the typical to divertor topography of the field was approximately reproduced – 90% tangential, 10% orthogonal.

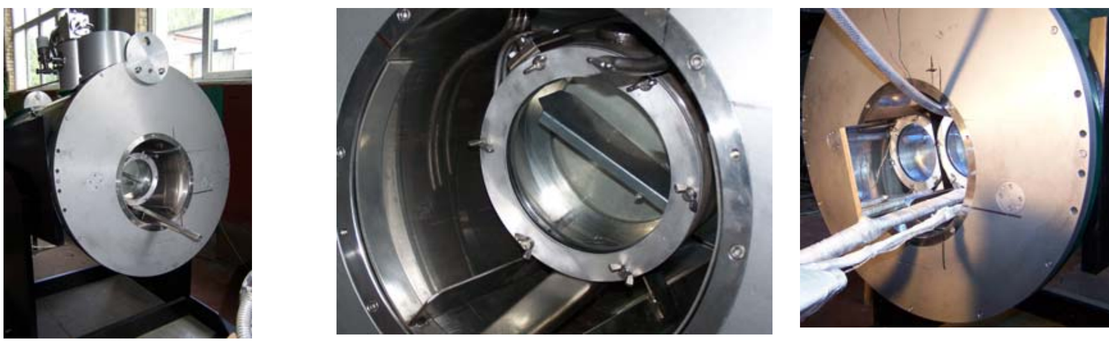

Figure 4: Arrangement of the experiments with flat substrates.

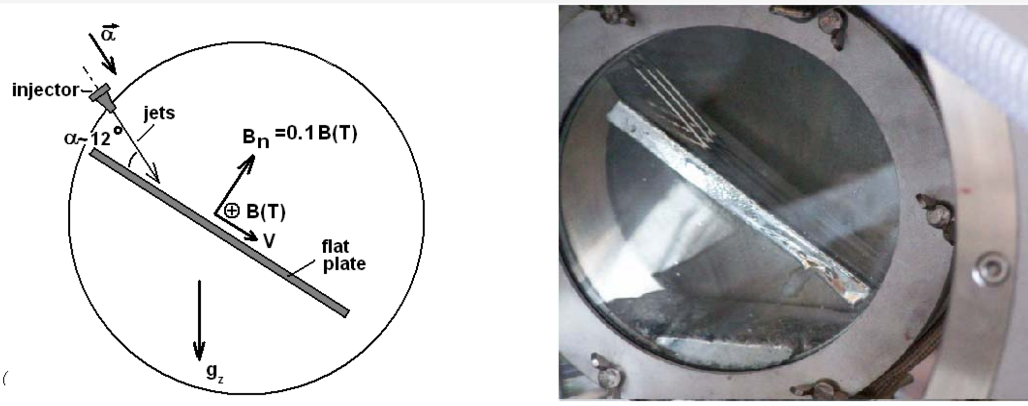

Figure 5: Geometry of the experiments and example of the flow at B = 1T; V = 2.1 m/s

Figure 6: Two running in parallel jets. B = 4T; V = 0.27 m/s.

During the experiments the magnetic field was increased up to 4T, the velocities varied in the range from 0.5 m/s to 2.5 m/s. There were some grounds to expect that the jets will be spread over surface of the plate. Here we can remind on the seemingly similar experiment presented in Fig.3. However, the jets clearly tended to a local compactness, instead of spreading (Fig.6). The conditions were changed -the SS surface could not be properly treated.

In Fig.7 an addition phenomenon can be seen. The jet is bent/deflected deeper into the magnet, even somewhat uphill, since the plate is inclined for approx. 10^0 with regard to the horizon. Attention should be paid to the boundary conditions typical to the described "strange" MHD process. First, the magnetic field was non-uniform.

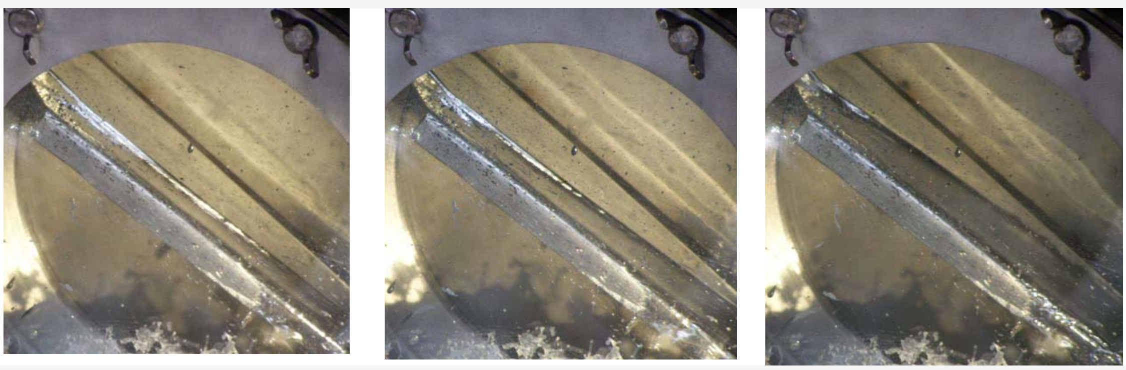

Figure 7: The behavior of a single jet at gradually decreasing velocities: B=4 T; velocity ():373;250;127 cm/s.(from left to right)

MHD experiments on free surface LM flows, it is not an easy task. How attractive and convincing the results will be, it depends on the quality of the photo and video records Objects of interest are the lustrous sharp reflecting liquid metal surfaces, deformed by the motion (characteristic length 10-15 cm, diameter or thickness 2-3 mm). They are located in a confined space inside the D=30 cm.bore of a superconducting solenoid, usually at a distance (~ 50 cm) from the edge of the solenoid. Liquid metal (InGaSn) communications covered by heaters and insulations are significantly overlapping the field of vision. The objects are placed inside a separate vacuum chamber with a window and internal lighting. Delicate handling is needed, particularly during metal injection into the chamber. Errors and carelessness in these moments lead to splashing of metallic droplets, jets; re- opening of the chamber connected with a de-pressurization, cleaning, etc. is inevitable. Another unpleasant moment, it is the presence of a strong magnetic field. This fact leads to the need to shoot objects from a considerable (≈1m) distance, at awkward angles, etc.

Conclusions.

The behavior of free surface liquid metal flows in the presence of a strong magnetic field is influenced not only by the well known boundary conditions (homogeneity of the field, wettability/contactability of the walls. Essential is also the role substrates curvature.

Acknowledgments.

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