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SUPPRESSION OF ELECTROMAGNETICALLY INDUCED INTABILITIES OF THE LIQUID METAL DISK

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ABSTRACT

In this work we study a method to suppress the electromagnetically induced free surface instabilities of the free surface subject to a high-frequency magnetic field. The object of our current investigation is a liquid metal disk (GaInSn) exposed to a high-frequency magnetic field (with frequencies in a range of 10*n kHz – 100*n kHz). This simplified configuration can be realized by putting the liquid metal within the thin gap between two horizontal plates, so that gravitational effects can be omitted. This way a 3D liquid metal drop is reduced to 2D model problem. We consider a local inhomogenity of the high-frequency magnetic field as an instrument for the suppression of the instable oscillation modes of the disk.

Index Terms – Liquid metal, Magnetic field, Instability, Stabilization

1. INTRODUCTION

Instabilities of the capillary surfaces of liquid metal subject to high frequency magnetic field can take place in many technological processes like Levitation physical vapor deposition and Laser beam evaporation with electromagnetic shaping [1, 2]. In the current investigation we study a simplified model of such capillary surface - a 2D liquid metal disk of GaInSn (eutectic metal alloy which is liquid at room temperature). This simplified configuration can be realized by putting the liquid metal within the thin gap between two horizontal plates, so that gravitational effects can be omitted. Moreover, we reduce the order of the instable geometries to mode 2 (ellipsoid). The results of the previous investigations [3] allow us to choose the range of the experiment parameters like liquid metal volumes and the excitation magnetic field frequency 31 kHz to reach exactly the 2nd mode of the instability oscillations at the appropriate eigenfrequency.

2. MECHANICAL MODEL

Let us represent the local moving part of the peripheral area of the disk as a harmonic oscillator. Considering the moving volume of the fluid as given in Fig. 1 and taking into account the continuity of the fluid motion, we can assume for the first order approach that the flow is two-dimensional and a mean velocity of the flow can be considered for the given moment of time.

Moreover, there are two halves of the oscillating disk in which the flow has opposite directions. Hence, the symmetrical problem can be formulated in which the impulse in one direction is defined by the half of the disk mass (in case of the 2nd mode of oscillations).

Representation of the moving disk contour as a harmonic oscillator can be given as follows

$$\frac{m}{2}\frac{d^2x}{dt^2} = -kx\,, \qquad (1)$$

where m – effective mass of the disk, x – contour displacement, k – effective elasticity of the oscillating disk.

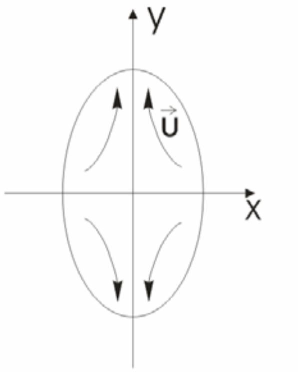

Fig. 1 Geometry of the instable form of the disk (2nd mode of oscillation)

From which the effective elasticity can be found in a form:

$$k = \frac{\omega^2 m}{2}\,. \qquad (2)$$

here $\omega = \sqrt{2k/m}$ is eigenfrequency of the disk.

Considering a potential energy of the disk at maximum displacement *x* from the equilibrium position

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$$E_{p\max} = \frac{1}{2}kx^2, \tag{3}$$

one can estimate a maximum velocity $u_{\max}$ of the disc during the instable azimuthal displacement:

$$u = \sqrt{\frac{2E_{p\max}}{m}}. \tag{4}$$

Using units' analogy from Bernoulli equation, one can finally express the local pressure in the fluid on the disc periphery as follows:

$$p = \rho\upsilon^2. \tag{5}$$

3. ASSESSMENT OF THE ACTUATOR

Using the scaling equation for the magnetic energy density we can estimate the minimal magnetic induction B in a vicinity of the disk surface, which is necessary to counteract the instable deformation. The equation is given as follows:

$$p = \frac{P_M}{A} = \frac{B^2}{2\mu_0 A^1}, \text{ or } B = \sqrt{2\mu_0 p A^1 / A}. \tag{6}$$

Here A^1 – unit area, A – effective area of the free surface of the liquid metal disk, B – amplitude of the magnetic field, μ_0 - magnetic constant.

To obtain the necessary local increase of the magnetic induction in a vicinity of the disk periphery an actuator can be used in a form of the coil fed with AC current.

The schematic diagram for the calculation is given in Fig. 2.

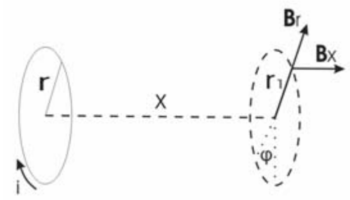

Fig. 2: Schematic representation of the electromagnetic actuator for the calculation of the axial component of magnetic induction.

The axial component of the magnetic induction is given as follows:

$$B_x = \frac{\mu\, i\, N}{2\pi\, r}\int_0^{\pi} \frac{1 - R\cos\varphi}{(X^2 + R^2 + 1 - 2R\cos\varphi)^{3/2}}\, d\varphi \tag{7}$$

The next parameters of typical actuator are used for the calculation using the equation (7):

Parameter name	Parameter symbol/equation
Windings number	N
Peak Current	i
Mean radius of the actuator	r
Absolute magnetic permeability	$\mu = \mu_0\ \mu_r$
Axial coordinate of the view point	x
Radial coordinate of the view point	r_1
View point axial aspect ratio	$X = x / r_1$
View point radial aspect ratio	$R = r / r_1$

4. CONCLUSIONS

In this work we present an example of analytical calculation of the AC actuator for the counteraction to the instable azimuthal motion of the liquid metal disk subject to high-frequency magnetic field. We start with the mechanical model of the disk on the basis of the equation of harmonic oscillator. Further the local magnetic pressure and the necessary local magnetic induction was evaluated. For an actuator in a form of cylindrical coil the magnetic induction near the liquid metal disk periphery can obtained on the basis of Biot-Savart law.

5. ACKNOWLEDGEMENT

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