NON-AXISYMMETRIC RESONANT MODES UNDER OSCILLATING MAGNETIC FIELDS FOR VERY LOW INTERACTION PARAMETER VALUES

CORTÉS-DOMÍNGUEZ Iván[1], BURGUETE Javier[2]
Department of Physics and Applied Mathematics, C/ Irunlarrea 1, University of Navarra, E-31008 Pamplona, Spain
[1]icortes.1@alumni.unav.es, [2]javier@unav.es

Abstract: In this work we present results related to instabilities created into a disk shaped conducting fluid layer. No external forces are applied. Only a zero-mean time-dependent magnetic field parallel to the disk axis. The experimental setup allows very fine determination of the amplitude of possible instabilities. We show different azimuthal wavenumbers and we are studying their dynamics. The axisymmetric fluid layer destabilizes even for very small values of the interaction parameter.

1. Introduction

The action of external magnetic fields that evolve in time can produce surface waves or instabilities in conducting fluid layers [1]. There are a few experimental works related to the study of instabilities in fluids under the action of external magnetic fields [2,3,4]. This effect depends on two sets of parameters, the fluid layer characteristics (electrical conductivity, layer depth, diameter) and the magnetic field (frequency and intensity). When the magnetic field frequencies are large, the instabilities grow due to forces localized near the surface. On the other hand, for low frequency ranges, those forces may penetrate and produce bulk forces. Many experimental works have been developed for the large frequencies regime but there is a lack of results in the domain of low frequencies because of its limited potential applications. We want to study the low range of frequencies (0.1Hz to 10Hz).

Following the previous work of J.Burguete et *al.* [4] we will focus in a configuration where a thin axisymmetric conducting fluid layer with free surface is forced through a time-dependent magnetic field parallel to the axis of a circular cell. In Burguete's work, the magnetic field had always the same orientation: the magnetic field was $B_0+B_1\sin(\omega t)$, being $B_1<B_0$. In our experimental setup, we work with a zero mean magnetic field, so it oscillates between both possible orientations in a cycle. This field generates in the fluid an azimuthal current due to Lenz's law that interacts again with the magnetic field producing a radial force (Lorenz's forces). Due to the nature of the external magnetic field applied the oscillatory component of the Lorentz force's will have a frequency twice the frequency of the magnetic field [5]. Assuming that the system is axisymmetric, any perturbation that deviates the system from the axisymmetry can produce an azimuthal force that can destabilize the fluid and a flow can be created.

There are some measurements in a strongly non-linear regime [6,7] and in low frequency regime [3,4] but our system allows a much more precise study of the dynamics of the pattern close to the threshold, so we can compare with the theory that predicts an instability without threshold [2,4].

2. Presentation of the problem

We have developed an experimental setup that allows us a fine adjustment of the main control parameters (magnetic field amplitude and frecuency) to study the dynamics of these patterns and a precise observation of any deviation from axisymmetry. Our experimental setup consists of three parts, the experimental cell, magnetic field and optical system (fig1).

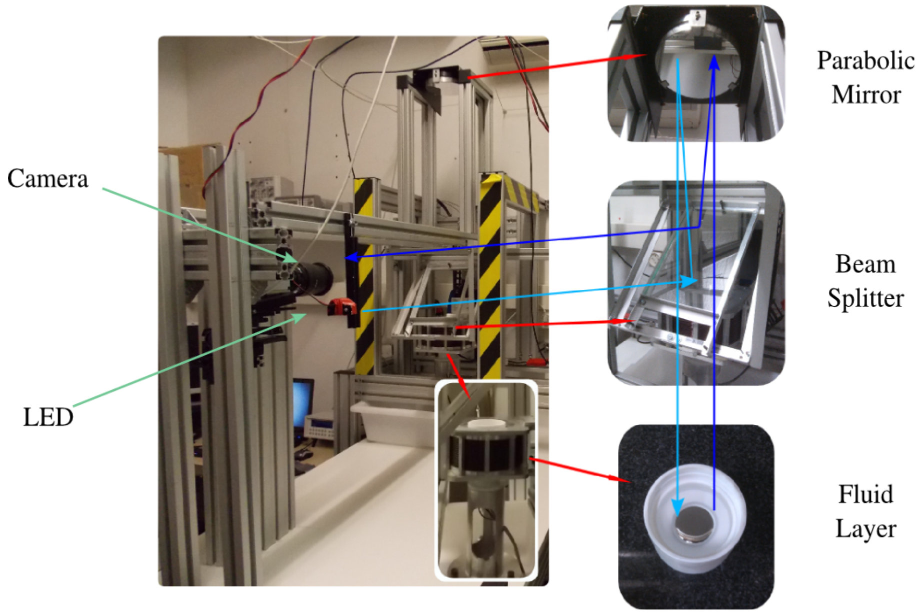


Figure 1. Experimental setup

Experimental Cell

An eutectic InGaSn alloy (liquid at room temperature) is placed on a Teflon® cylindrical cavity which a diameter of 84mm. There is a depression at the bottom part of the cell that allows to center the liquid. The alloy adopts the form of a thin circularly shaped fluid layer (a large drop of fluid) on the bottom of the container, with free surface. The drop remains centered on the cell. The InGaSn drop is up to 20mm depth. An upper layer of HCl (1%) has been placed to prevent oxidation of the eutectic alloy.

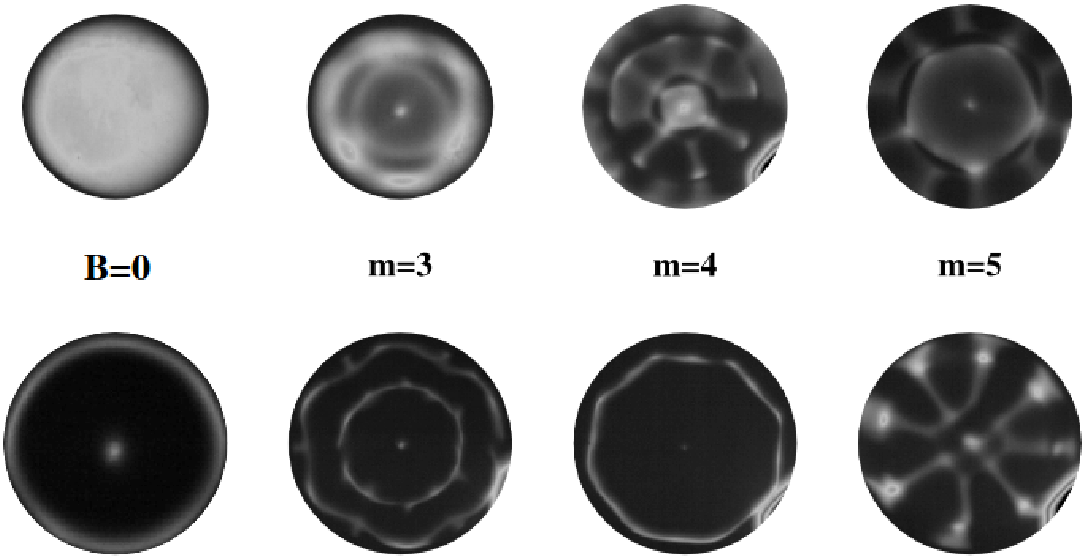
Magnetic field

No external current is applied on the fluid. The force only appears through a purely vertical time dependent magnetic field perpendicular to the free surface. This field evolves harmonically with frequencies between 0.1Hz to 10Hz. The field evolution is slow enough to avoid skin effects. The magnetic field is induced by modulating an electric current on an external coil. The power source that drives the coil can deliver up to 60A producing magnetic fields up to 70mT. This electrical current can be modulated in an extremely low frequency range. Once the experimental cell is placed inside the coil, the axis of this magnetic field is parallel to the axis of the cylinder (perpendicular to the free surface of the liquid metal layer).

Optical System

The optical system is based on the method developed by Foucault [8]. A beam of light is redirected using a mirror and a beam splitter. This configuration will allow us the direct observation of the free surface of the fluid layer (a top view). In the top view of the fluid the liquid metal remains as a mirror when the system is at rest and there are no instabilities. Any instability produces small deviations from the equilibrium position. A camera placed to record the top view allow us to study the deflections of the surface (any deflection will appear in the camera as a bright or dark region). Therefore we can record the dynamical behaviour of the system.

Our experimental setup has allowed us to observe spatial patterns (fig. 2) that appear in the phase-space between 0.4 Hz and 10Hz. An axisymmetric pattern (m=0) appears in all the phase-space. We observe very restricted windows where different patterns (m=2,3,4…) are very close and can even coexist as was noted by J. Burguete et *al.* [4].



B=0 **m=3** **m=4** **m=5**

m=0 **m=6** **m=8** **m=8**

Figure 2. Different azimuthal wavenumbers (top view)

Using Fourier analysis tools it is possible to study the dynamics of the patterns. The evolution of the resonance frequencies with the intensity reveals that these patterns are not pure modes. For example, in the case of a 35ml InGaSn drop, we observe three restricted windows in wich more than azimuthal wavenumber appear simultaneously (fig. 3). If we further increase the magnetic field intensity, a cycle is established between different patterns.

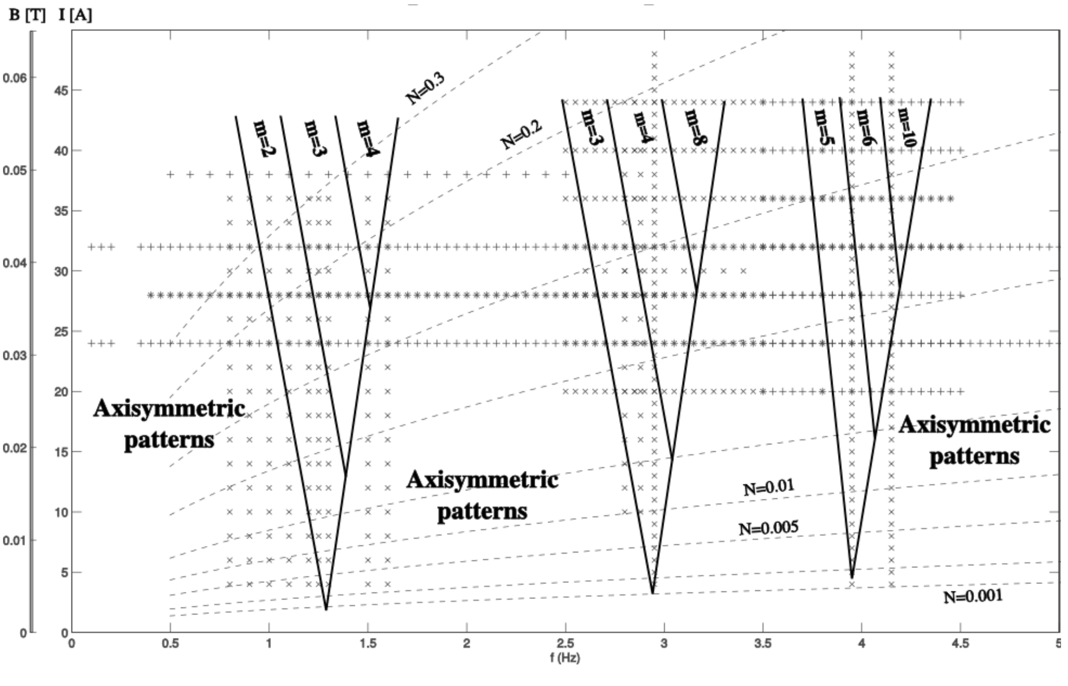


Figure 3. Phase-space of the different patterns. Dashed line : isocontours of the interaction parameter N. Each mark represents an experimetnal run.

Focusing our attention in the third restricted window of the phase-space shown in fig. 3 we can observe how in 3.95Hz frequency a dynamical behaviour alternating between modes 5, 6 and 10 has been detected. If we study the extended FFT at this frequency, we can isolate the different modes that appear simultaneously (fig. 4). We can study their growth rates and we can show how different families of harmonics grow slaved. The amplitude of this modes change with **B** for a given frequency, and different growing rates that tend to fill can be determined for different modes (fig. 5).

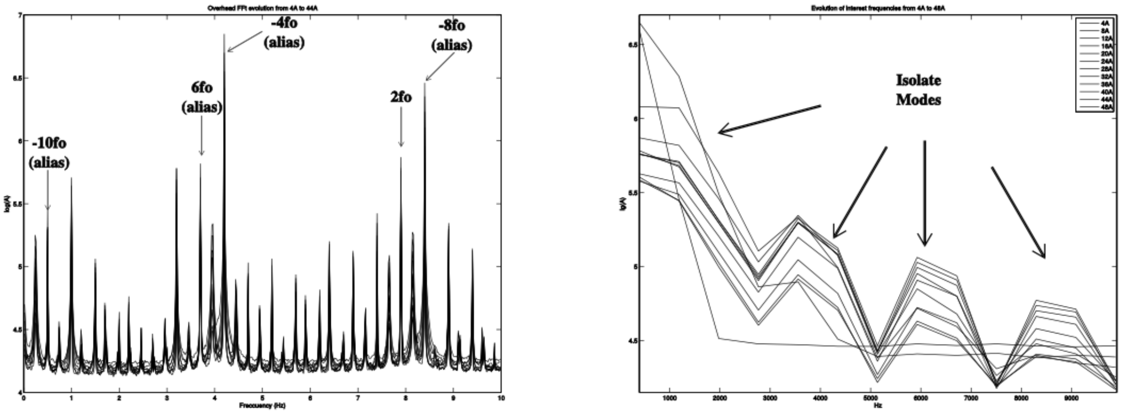


Figure 4 . Overhead and extenden FFT for increasing values of magnetic field at 3.95Hz

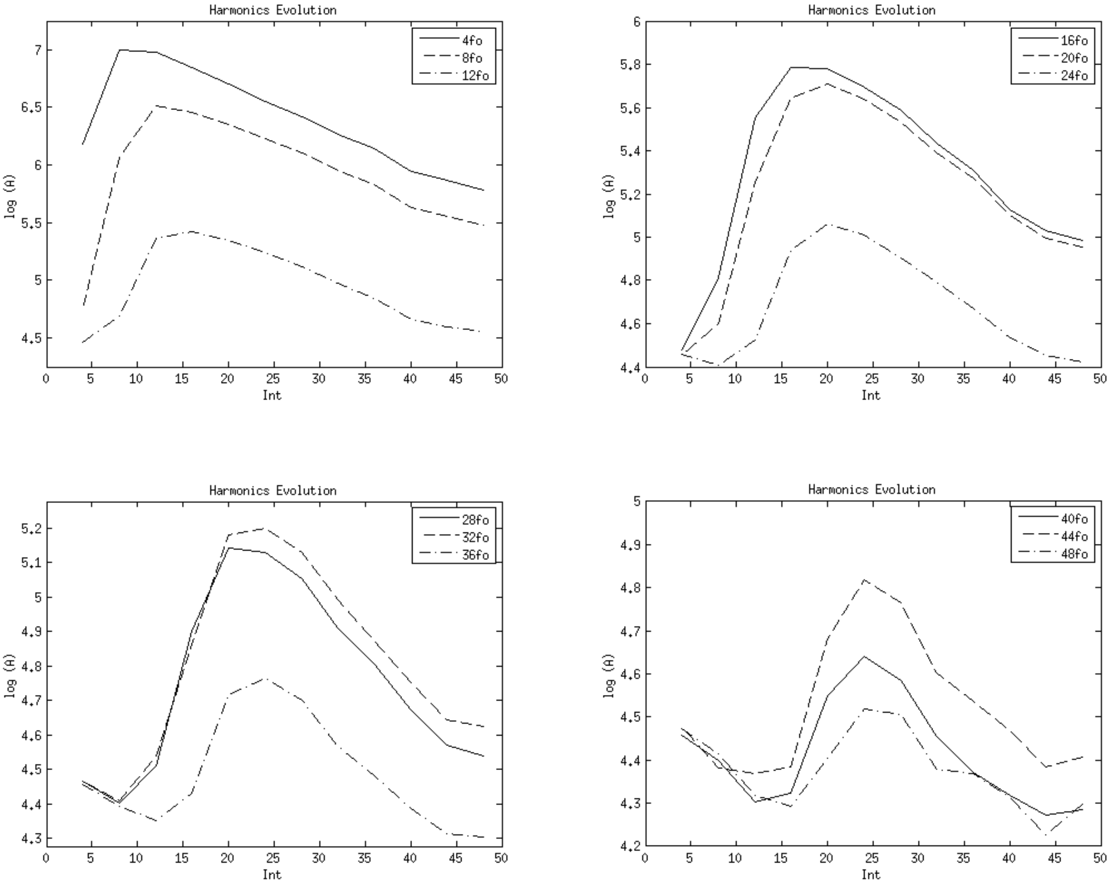


Figure 5. Grow rate of different families of harmonics that form isolated modes for increasing values of magnetic fields at 3.95Hz

3. Conclusions

Our experimental setup allows the characterization of spatial patterns very close to any potential threshold. Different symmetry breaking patterns have been found with different azimuthal wavenumbers m = 0, 2, 3, 4, 5, 6, 8, 10. For the same parameter values, the azimuthal wavenumbers can even coexist and we have identified various sets of harmonics that evolve slaved. These patterns appear for parameter values in very restricted windows and for very small interaction parameters. These instabilities have been observed for interaction parameters as low as N=0.002, and up to now we have not detected any threshold. Radial wavenumbers have been observed. So, the magnetic field can induce patterns even for very small forcings.

4. References

[1] R. Moreau, Magnetohydrodynamics, Kluwer Academic Publichers, Dordrecht, the Netherlands (1990).
[2] Fautrelle, Y.; Sneyd, A.D.; Surface waves created by low-frequency magnetic fields. European Journal of Mechanics B/Fluids. Vol.24, pp.91-112 (2005).
[3] Galpin, J.M.; Fautrelle, Y.; Liquid-metal flows induced by low frequency alternating magnetic fields. J. Fluid Mechanics, vol. 239, pp. 383-408 (1992).
[4] Burguete, J.; Miranda, M.A.; Instabilities of conducting fluid layers in cylindrical cells under the external forcing of weak magnetic fields. Magnetohydrodynamics. Vol.48, No.1. Pp.69-75 (2012).
[5] Galpin, J.M.; Fautrelle, Y.; Sneyd, A.D.; Parametric resonance in low-frequency magnetis stiring. J. Fluid Mechanics, vol. 239, pp. 409-427 (1992).
[6] F. Debray and Y. Fautrelle, Adv. in Turb. IV, in: Appl. Sci. Res., vol. 51, Kluwer (1993) p 31.
[7] F. Ingwiller, F. Bonnel, Y. Fautrelle, S. Daugan, and J. Etay Actes du 9eme FLUVISU (2001) p 18.
[8] L. Foucault, Comptes rendus de l'Academie des Sciences, Paris, vol. 47, pages 958-959 (1858).