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Dynamical behavior of digitations state in Faraday waves with a viscoelastic fluid

Cecilia Cabeza[a], Marta Rosen[b],*, Gabriel Ferreyra[b], Gustavo Bongiovanni[b]

[a]*Instituto de Física, Facultad de Ciencias, Universidad de la República, Iguá 4225, Montevideo 11400, Uruguay*
[b]*Grupo de Medios Porosos, Facultad de Ingeniería, Universidad de Buenos Aires, Argentina*

Abstract

Parametrically excited surface waves, well known as Faraday waves, are studied when finger structures are generated on the free surface. In this state, the surface breaks and ejects droplets from wave peaks when the applied force exceeds an acceleration threshold. In this work, both the chaotic and turbulent bifurcation behaviors of Faraday surface waves have been intensively studied and many different transitions have been examined and described. The spatial and temporal finger distribution is studied as a function of external acceleration.
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1. Introduction

Droplet ejection from liquid surfaces is an important phenomenon that is possible to observe spontaneously in the nature. Waves break, for example, on the shores and surfaces of oceans and lakes; the spray from turbulent rivers, resulting in the production of small and energetic droplets. This phenomenon is also a relevant mechanism for both energy dissipation and gaseous absorption. These surface waves receive the energy required to create droplets from sources such as the wind- or gravity- driven flow and require a certain minimum energy flux to produce droplets. The aim of this work is to generate finger structures and droplet ejection through Faraday experiment. The formation of standing waves on the free surface of a narrow layer of liquid when a vertical sinusoidal oscillation is applied was reported by Faraday in 1831 [1] and is one of the classical ways to make patterns of hydrodynamic origin [2]. Vertically oscillated waves experience a number of bifurcations before the transition to a droplet-ejecting state [3]. With increasing control parameter, frequency or acceleration, the initially flat surface wave state will evolve into a periodic standing wave state. When the external acceleration exceeds a well defined threshold, finger formation is developed on the free surface. If we increase this control parameter, surface break leading to droplets ejection. Recently many experiments have been reported using a non-Newtonian fluid [4–7]. The memory of the viscoelastic fluid introduces additional

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*Corresponding author.

E-mail addresses: cecilia@fisica.edu.uy (C. Cabeza), mrosen@fi.uba.ar (M. Rosen), gferreyra@fi.uba.ar (G. Ferreyra), gbongio@fi.uba.ar (G. Bongiovanni).

time scales to the relaxation time. Moreover, the rheological properties of the fluid determine the characteristics of the finger and the droplet ejected. Ejecting states can occur in waves where either surface tension effects or gravitational effects are the primary restoring forces. As we explained earlier, the transition to droplet-ejecting states in capillary surface waves is induced by increasing the applied force until the Rayleigh instability causes wave peaks to break up into droplets. This system presents a great number of technological applications: fuel atomization and injection for engine combustors, mixing processes, ultrasonic emulsification, spray formation, etc.

2. Experimental results

The experimental set-up consists of a square acrylic container (side: 7 cm long), mounted on a Bruel & Kjaer model 4810 vibrator, which allows vertical movements with range amplitudes between 0 and 3 mm. The vibration is driven through a function generator, in order to excite the system by spatially uniform acceleration in a vertical direction. The characteristic length scales in this experiment are the wavelength $\lambda = 2\pi/k$ of the surface patterns, the size of the viscous boundary layer $\delta = \sqrt{\nu/\omega}$ [8] and the capillary length $L = \sqrt{\sigma/\rho g} = 2.4$ mm. In our experiment we have worked with frequency between $15\,\mathrm{Hz} < f < 120\,\mathrm{Hz}$, and the viscous boundary layer varies between $0.27\,\mathrm{mm} < \delta < 0.77\,\mathrm{mm}$. In this work, we use a viscoelastic fluid, in which the elastic effects are predominant in our work range and the viscosity depends on shear rate (shear thinning fluid). We have worked with finite depth and this condition allows us to neglect the influence of lateral boundaries. Fig. 1 shows the rheological properties of the fluid, G' (elastic modulus) and G'' (loss modulus) as functions of frequency. In our work range $G' > G''$, then elastic effects are predominant.

We have used a solution of 2% polyacrylamide of 12×106 Mw, density $\rho = 997\,\mathrm{Kg/m^3}$, surface tension $\sigma = 0.060\,\mathrm{N/m}$. Viscosity and complex modulus were measured using a Physica MCR 300 rheometer, with 2% error. The pictures were recorded using a CCD camera with 200 fps. In order to analyze temporal behavior we used a capacitive method. This method allows making an accurate measurement of point surface displacement [9]. We recorded and digitalized this temporal series and we made a temporal FFT at real time. To investigate temporal response, i.e., harmonic or sub-harmonic regimes, we measured two acceleration thresholds (Fig. 2). First, the transition between flat and squares structures is developed on the free surface. In second place, we measure the transition between regular patterns and finger formation. Moreover, we investigated temporal response, i.e., harmonic or sub-harmonic regimes.

In Fig. 3 we show some pictures of finger formation at $f = 20$ Hz, between threshold finger ($a = 5.26\ g$) and when threshold droplets are ejected ($a = 7.9\ g$).
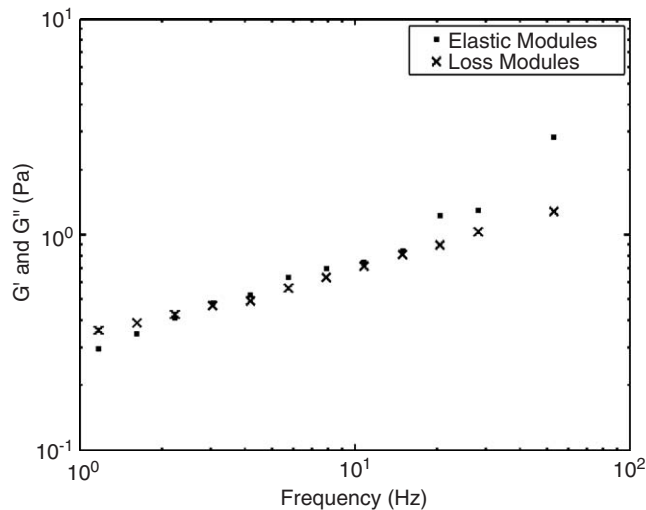

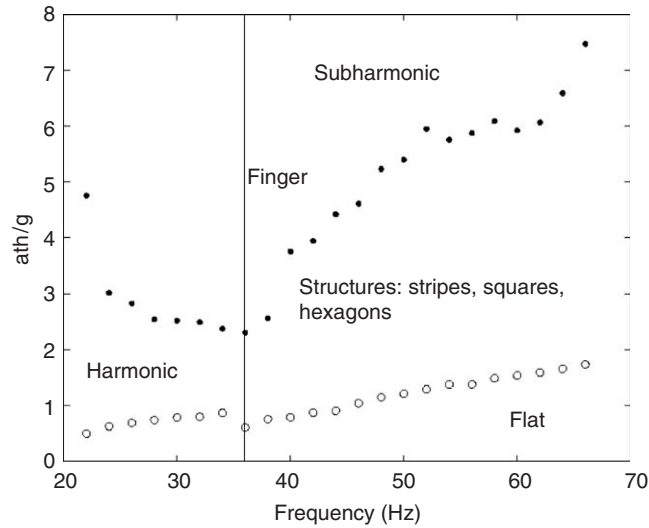Fig. 1. Rheological properties: elastic modulus (G') and loss modulus (G'') vs frequency.

Fig. 2. Acceleration threshold as function frequency. Square represents the transition from flat to square patterns. Circle represents transition between regular patterns to finger formation.
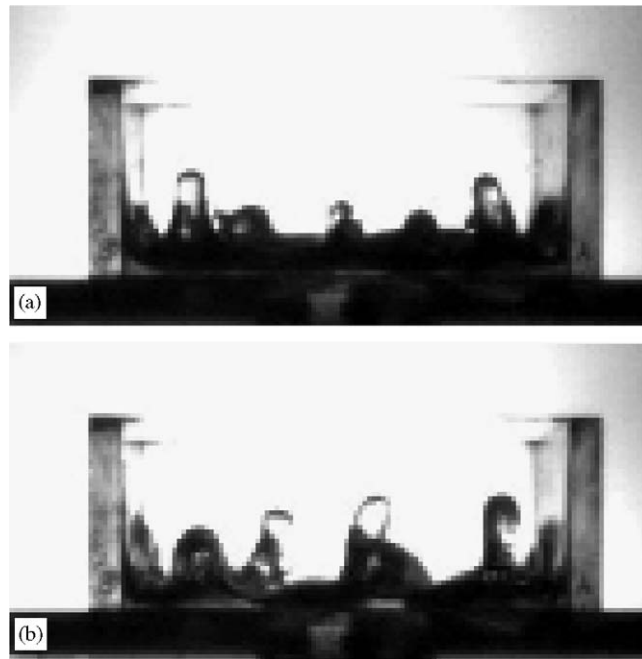

Fig. 3. Finger formation at $f = 20$ Hz. (a) $a = 5.26\ g$, (b) $a = 7.9\ g$.

Fig. 4 shows the droplet ejection at $f = 20$ Hz and $a = 10.5\ g$. The size of droplet has a strong dependence on both frequency and fluid properties. If the frequency increases the droplet size decreases.

In Fig. 5, the spatio-temporal representation is shown. The frequency drive is kept constant at 20 Hz. The disorder of finger increases as the acceleration drive increases. The dark color corresponds to the maximum height of the finger. In Fig. 3(a) the acceleration driving near threshold finger appears. There are three zones where fingers are formed as a function of time. When the acceleration is increased, we can observe that the

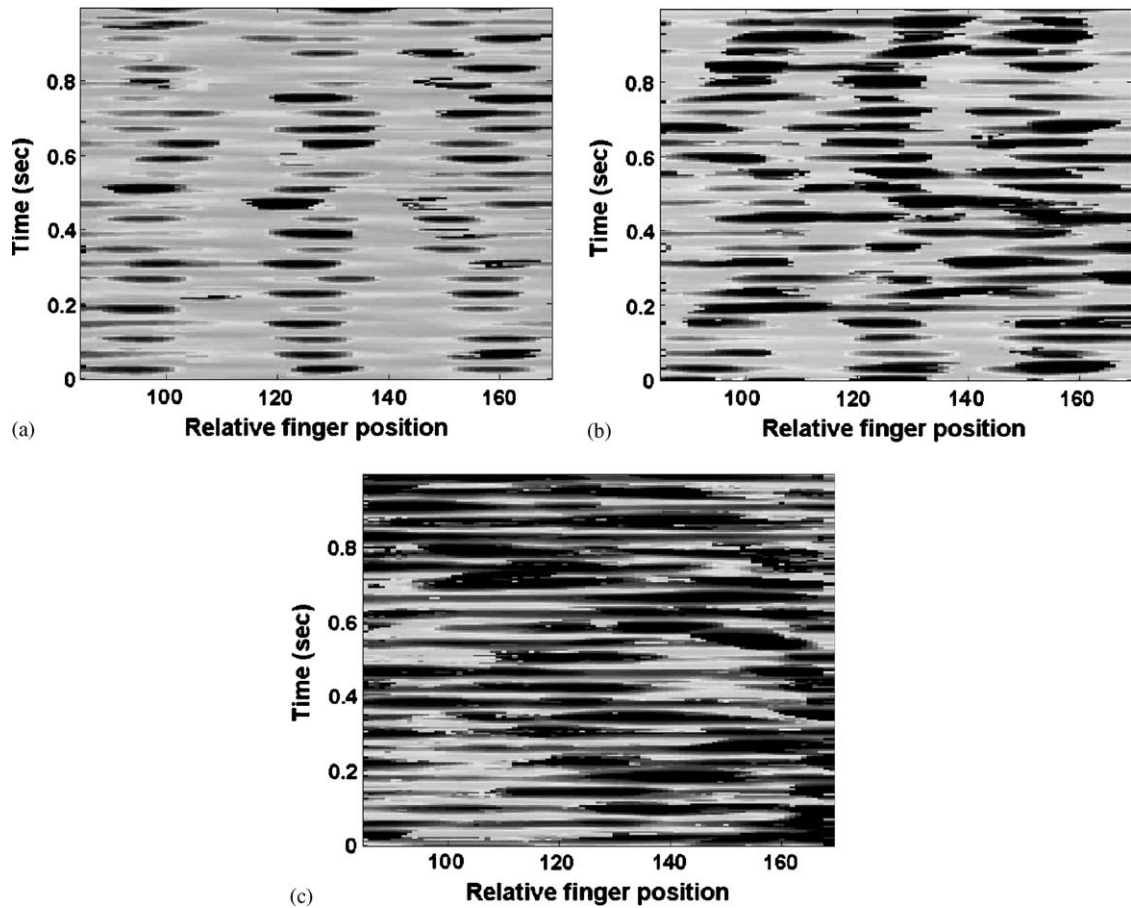Fig. 4. Droplet ejection at $f = 20\,\mathrm{Hz}$ and $a = 10.5\ g$.

(a)

(b)

(c)

Fig. 5. Spatio-temporal diagram at $f = 20\,\mathrm{Hz}$. (a) $a = 5.26\ g$, (b) $a = 7.9\ g$, (c) $a = 9.6\ g$.

zones before loss definition (Fig. 3(b)). Previous to droplet ejection, chaotic behavior on finger formation appears (Fig. 4).

3. Conclusion

In this work we analyzed the intermediate states between regular patterns and droplet ejection in a Faraday instability. In order to control the droplet ejection it is very important that we understand the dynamical

behavior of the previous state. Moreover, we characterized the finger formation and their dependence an control system parameter.

References

[1] M. Faraday, Philos. Trans. Soc. London 52 (1831) 319.
[2] C. Wagner, H.W. Muller, K. Knorr, Phys. Rev. E 68 (2003) 066204.
[3] H.W. Muller, W. Zimmerman, Europhys. Lett. 45 (1999) 2169.
[4] O. Lioubashevski, Y. Hamiel, A. Agnon, Z. Reches, J. Fineberg, Phys. Rev. Lett. 83 (1999) 3190.
[5] F. Raynal, S. Kumar, S. Fauve, Eur. Phys. J. B 9 (1999) 175.
[6] S. Kumar, Phys. Fluid 11 (1999) 81970.
[7] C. Wagner, H.W. Muller, K. Knorr, Phys. Rev. Lett. 83 (1999) 2308.
[8] E. Cerda, E. Tirapegui, Phys. Rev. Lett. 78 (1997) 859.
[9] C. Cabeza C, C. Negreira, V. Gibiat, Meas. Sci. Tech. 13 (2002) 1625.