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Standing twin peaks due to non–monotonic dispersion of Faraday waves

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Abstract

We report on a Faraday experiment with magnetic fluid in a DC magnetic field, which is driven externally by accelerative modulation. A novel pattern of standing twin peaks is found. It has its origin in the simultaneous excitation of two different wave numbers in the non-monotonic regime of the dispersion relation. © 1999 Elsevier Science B.V. All rights reserved.

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The Faraday instability has been frequently investigated in water or silicon oil. It is a popular experimental system for the study of parametrically excited instabilities, pattern formation and spatio-temporal chaos [1]. The excitation of magnetic fluids offers in addition the possibility to tune the dispersion relation by an external magnetic field. Especially, the advent of the Rosensweig instability [2] is accompanied by a non-monotonic dispersion relation [3]

$$\omega_D^2 = gk - \mu \frac{(\mu_r - 1)^2}{\mu_r + 1} \frac{1}{\rho} H^2 k^2 + \frac{\sigma}{\rho} k^3. \tag{1}$$

Here ω_D denotes the driving frequency, k the wave number, H the strength of the external magnetic field, μ_r the relative magnetic permeability, $\mu = \mu_r \mu_0$ the magnetic permeability, $\mu_0 = 1.257 \times 10^{-6}$ Vs(Am)$^{-1}$ the magnetic field constant, σ the surface tension, and ρ the density of the magnetic fluid.

Although experimental studies of externally induced surface waves have been published previously [4,5], it was only recently that experimental evidence for a non-monotonic dispersion relation was given for locally excited travelling waves in an annular channel [6].

In a new approach we are now investigating the dispersion of globally excited standing waves in an annular channel situated in-between a pair of Helmholtz coils. Details of the experimental setup are given in Ref. [7]. However, instead of a periodic modulation of the magnetic field we utilize here

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a mechanical exciter, which is shaking the vessel in the vertical direction. A tungsten bulb, placed in the center of the annulus, projects the shadow of the standing wave patterns on to a conical screen. The screen is scanned in a circular manner by a CCD–camera mounted above the center of the channel. A computer-controlled synchronization between the driving and sample frequency permits a stroboscopic image acquisition. Thus, by sampling only every second driving period we are able to record the long-time behaviour of the spatio-temporal dynamics. Keep in mind that this type of Poincare section suppresses the familiar subharmonic response of the surface waves in the space–time plots.

A space-time plot of the standing wave patterns recorded in this way is shown in Fig. 1a. For a fixed value $H = 0.98\ H_c$ of the magnetic field the oscillation amplitude has been switched on at $t = 0$ s. The blurred horizontal bar originates in the relaxation time of the system. Eventually, dark and bright vertical stripes evolve. They characterize the temporal evolution of wave crests and wave troughs, respectively. Here a novel pattern of oscillating twin peaks can be observed. Its structure can best be resolved in Fig. 1b which gives the harmonic interpolation of the brightness profile of the last recorded line of Fig. 1a. The twin-peak pattern seems to be accompanied by an increase of the fourth harmonic in the power spectrum in Fig. 1c.

Next we present in Fig. 2 the dispersion relation. The circles denote the wave number at the onset of the surface instability. The two squares mark the two dominant wave numbers of the twin-peak

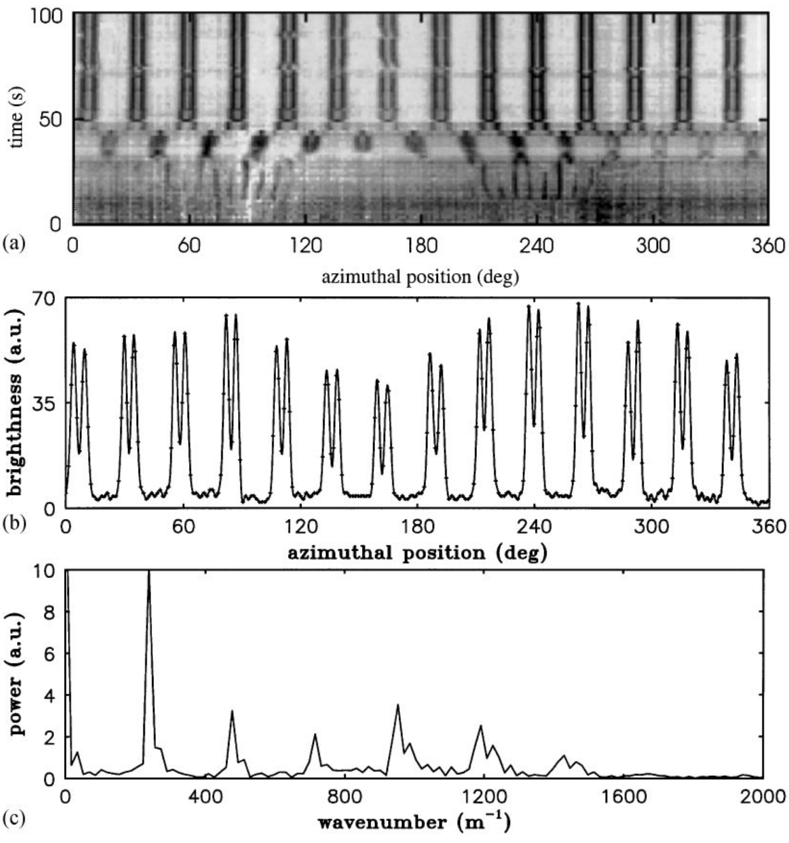

Fig. 1. Twin-peak pattern recorded at a driving frequency $f_D = 9.615$ Hz at $H = 98H_c = \ = 1.88 \times 10^{-4 \cdot}$ A/m. The fluid is EMG 909 from Ferrofluidics Corporation. (a) Space–time plot, (b) profile of the brightness at $t = 100$ s, (c) powerspectrum of (b).

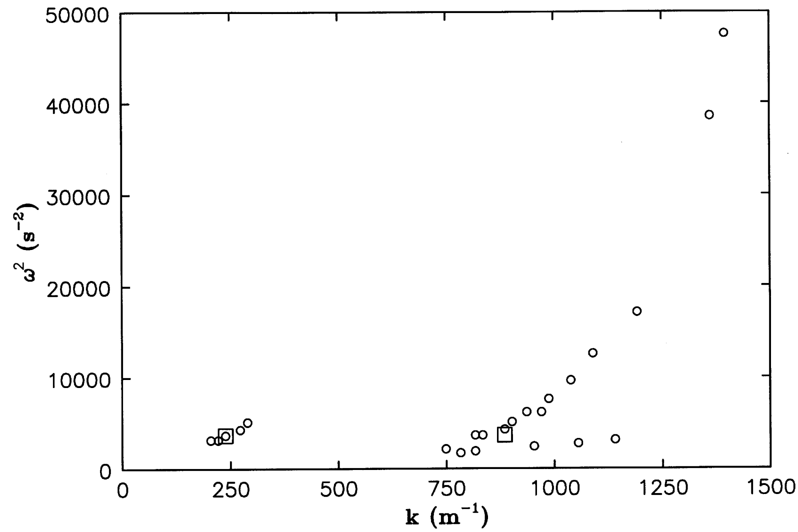

Fig. 2. Dispersion relation at the onset of the Faraday instability for subharmonic standing waves at $H = 0.98H_c$, $H_c = 1.88 \times 10^{-4}$ A/m indicated by circles. The squares mark the position of the stable twin-peak pattern.

pattern situated at a common driving frequency. This might be a direct outcome of the non-monotonicity of the dispersion relation.

Our measurements might be explained in part by a model taking into account the viscous dissipation in the bulk and in the bottom layer of the fluid, which has been developed in the meantime [8,9]. This model, which is based on a linear stability analysis, would rather suggest a ratio $\frac{1}{3}$ for the locked wave numbers for a similar driving frequency [10]. Keep in mind that this ratio describes the pattern at onset only, whereas our twin-peak pattern occur at large amplitude of the waves.

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