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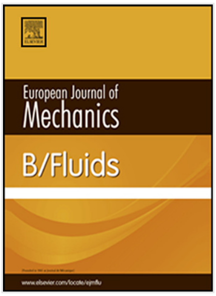

Instabilities and pattern formation in rotating spherical cavity with oscillating inner core

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INSTABILITIES AND PATTERN FORMATION IN ROTATING SPHERICAL CAVITY WITH OSCILLATING INNER CORE

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Abstract. The flows in a rotating spherical cavity with liquid and a free solid core in the center are experimentally investigated. The core performs small amplitude circular oscillations in the cavity frame due to a static external field. It results in the excitation of a lagging differential rotation of the core and a two-dimensional axisymmetric azimuthal motion of the fluid with several points of inflection in the velocity profile. The flow has the form of nested columns, one of which is formed on the geometrical continuation of the inner core (Taylor column). With an increase in the differential rotation rate of the core the axisymmetric fluid flow becomes unstable and several modes of instability manifest themselves. First, two-dimensional vortices appear inside the Taylor column. After it, an azimuthal wave appears, which manifests itself in the deformation of the tangent cylinder and has a retrograde phase velocity. A new mode of instability manifests itself outside the Taylor column with an increase in steady flow intensity: a regular system of 2D rolls, parallel to the cavity axis, which propagate in the prograde direction. The discovered modes are characterized by different phase velocities, the dispersion relations are determined experimentally. It is shown that for small Ekman numbers the thresholds of instabilities are determined by the critical values of Reynolds number calculated on the differential rotation rate of the core.

Keywords: rotation, circular oscillations, differential rotation, steady flow, pattern formation, flow instability

I. INTRODUCTION

Investigation of flows in the liquid cores of planets is of great interest in connection with the problem of magnetic dynamo [1]. The fluid motion in planet cores is known to be determined mainly by the thermal convection [2]. Along with the thermal convective mechanism, the oscillations of liquid could result in the excitation of steady flows. This actual problem is now attracting attention [3] due to the fact that the fluid oscillations in the cores are common and can be caused, in particular, by tidal deformations of rotating planets [4], librations [5, 6, 7] and precession [8, 9, 10, 11]. In all cases, the steady azimuthal flows have the form of nested columns rotating with different speed. It is known that one of these columns, namely the tangent cylinder, is spawned by the Ekman layer on a spherical core, at a critical latitude [12]. The dynamics of the Ekman layer remains an actual problem, see for example theoretical results giving an extended description of the Ekman layer in the equatorial region of the sphere [13]. The mechanism of steady flow generation on the one hand is connected with nonlinearities in the Ekman boundary layer [5, 6, 7], and on the other – with a nonlinear self-interaction of inertial waves in the interior fluid [14, 15]. The authors of recent numerical [16] and experimental [16, 17] studies investigated the flow in a spherical shell excited by differential rotation at negative Rossby numbers. They showed that the generation of inertial waves and azimuthal flows occurs only at a relatively large magnitude of the Rossby number. The recent experimental [18] and numerical [10, 11] studies showed that the steady flows generated by harmonic forcing might experience a shear instability. A similar result was obtained in the calculations [15] for a spherical layer.

Oscillations of the inner solid core also cause the fluid oscillations. An example is the free oscillations of the inner core of buoyant nature with the natural frequencies named “Slichter triplet” [19]. As has been found in [20, 21, 22], the circular oscillations of the inner core relative to the cavity under the action of a perturbing external static field, i.e. with frequency Ω_{osc} equal to the cavity rotation rate Ω_{rot}, result in the excitation of intensive steady flows accompanied with the lagging differential rotation of the core. As follows from [23] the nonlinear effects in