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FLOW MODES SELECTION AND TRANSITION IN CONICAL CYLINDERS SYSTEM

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Abstract

This paper is concerned with an experimental study of the flow mode selection in the system formed by two truncated conical cylinders. The inner conical cylinder is rotating and the outer one at rest. The rotation of the inner conical cylinder, controlled by a computer, was accelerated linearly from the rest until the chosen final speed was reached. Flow visualization permitted to draw a map of the different flow modes observed according to the Reynolds number Re and the acceleration rate β. Furthermore, the use of the electrochemical method (polarography) allowed to study the characteristics of the time dependent structures.

Introduction

The occurrence of Taylor vortices in systems other than a circular cylinders system has been subject of many investigations. Recently, a growing interest has been devoted to the flow system formed by two rotating conical cylinders [1][2]. Wimmer [3] discussed in a recent survey the occurrence of Taylor vortices between the conical cylinders and the dependence of the apex angle on these vortices. The transition from Taylor vortex type flow to cross-flow instabilities occurs when the apex angle increases. On the other hand, the effect of the initial conditions on the onset of the Taylor vortices is quite important since for different acceleration rates, different flow modes can be obtained marking the non-uniqueness of the hydrodynamics of this flow system. In the present work, an experimental investigation has been carried out to give a clear understanding of the acceleration effect on the occurrence of Taylor vortices and the characteristics of the different flow modes observed. For this purpose the inner rotating conical cylinder acceleration was controlled by the use of a computer and only linear paths were followed with a constant acceleration rate β.

Experimental setup

The experimental setup, shown in Figure 1, consists of a rotating inner cone made of stainless steel with an upper radius R_{ih}= 42 mm and a transparent stationary outer cone of plexiglas with an upper radius R_{oh} = 50 mm. Both conical cylinders have the same apex angle, ϕ= 16 degrees, so that the gap width is kept axially constant d = 8 mm. At the top of the flow system, the radius ratio is then: $\eta = R_{ih} / R_{oh} = 0.840$. Both top and bottom plates are fixed to the outer cone. The fluid column height is L=125 mm, which gives an aspect ratio $\Gamma = L / d = 15.62$. The Reynolds number was defined as: $Re = \frac{R_{ih}\,\Omega\, d}{\nu}$, Ω is the angular velocity of the inner conical cylinder and ν the kinematic viscosity.

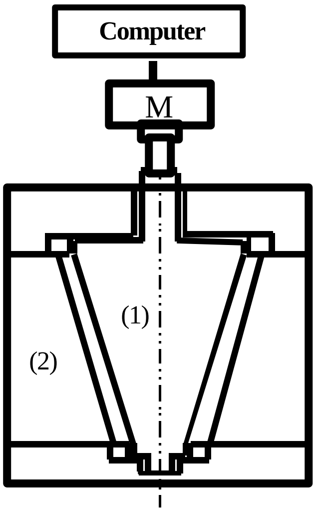

Figure 1: Experimental apparatus and arrangement
(1) inner cone stainless steel,
(2) outer cone of Plexiglas;
(inside wall: conical, outside wall: rectangular).

For flow visualization, the working fluid was an aqueous solution of 66 vol% glycerol, with 2 % of Kalliroscope AQ1000 added for flow visualization.

The fluid temperature was measured by the use of a thermo-couple of Copper / Constantan, with an accuracy of 0.1 °C. The kinematic viscosity was then 14.81 cS at 25 °C. The visualized flow structure was recorded with a high resolution video camera. Two illumination techniques were utilized: (i) Argon laser sheet illumination for observing a cross section of the gap and (ii) reflected white light illumination for the observation of the front view of the flow system. The rotation of the inner cone was controlled by the use of a computer. In the start-up operation, the rotation was accelerated linearly following: $\Omega(t) = \beta t$, where t is the time until the final speed for the specified steady state is reached. After the Reynolds number to be reached had been fixed, the inner cone was slowly accelerated from rest with a constant rate β up to the terminal rotation for steady state. The visualization recordings of steady-state flow were done after a time equivalent to over hundred times the acceleration time, i.e. when the flow was steady.

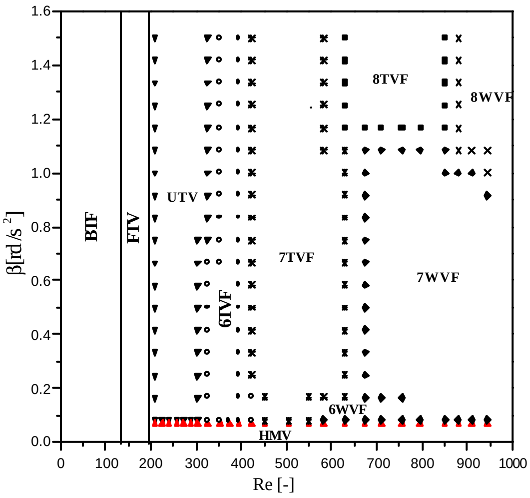

Figure 2: Flow modes in the β-Re plane.
(BTF: Basic flow, FTV: first vortices, HMV: helical motion, UTV: Upward motion, 6TVF (6pairs), 7TVF (07 pairs), 8TVF (08 pairs), WVF: Wavy vortex flow).

The acceleration rate range β was varied between 0.06 rad / s^2 and 1.32 rad / s^2 and the Reynolds number range was Re < 1000. The time-dependent instabilities were also studied by the use of an electrochemical method (polarography). For this purpose, a battery of electrode probes were implemented on the inner wall of the outer fixed conical cylinder. The electrolyte was an aqueous solution of 66 vol% glycerol, ferri-ferro potassium cyanide (10^{-2} mol/ l) with an excess of potassium nitrate (1 mol/ l). The signals collected were treated with a DSP software.

Experimental results

The different flow states observed in the β-Re plane are summarized in Figure 2. After the basic laminar flow, at the Re_c = 132, the first vortices appear at the top of the flow system. These vortices occupy more and more the fluid column as the rotation of the inner conical cylinder increases. For increasing Reynolds number, two scenarios can take place depending on the acceleration rate β.

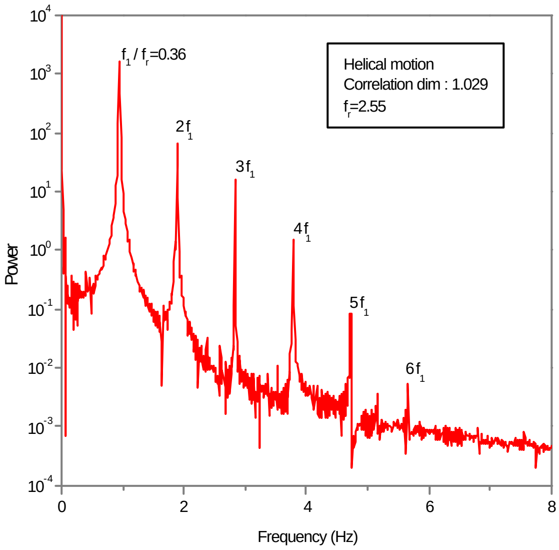

Figure 3: Power spectrum for helical motion

As showed in Figure 2, the first bifurcation branch occurs for very low acceleration rates and gives birth to a downward helical motion. The power spectra obtained for this flow motion show a constant ratio between the frequency of the helical motion and the frequency of rotation of the inner cone (Figure 3). This is found to be 0.36 in all the Reynolds number range investigated. The second bifurcation branch occurs when the first observed vortices begin to move upwards. This upward motion slows down with increasing Reynolds numbers until it stops and steady Taylor vortices are observed. From the power spectra obtained for the upward motion (Figure 4), the decrease in the main frequency can be followed when Re increases. When the upward motion stops, according to the value of β and following Figure 2, three modes of Taylor vortex flow can be obtained.

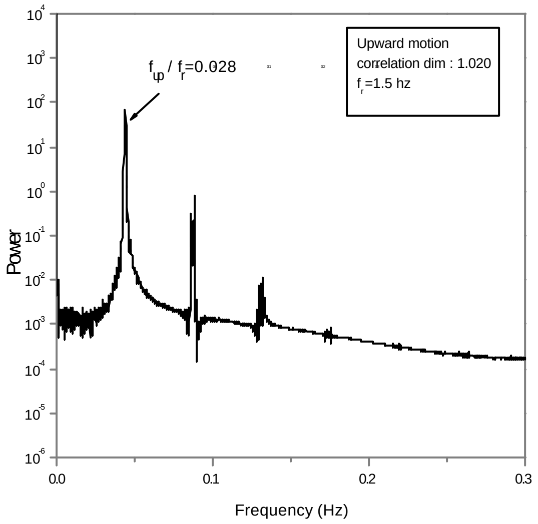

Figure 4 : Power spectrum for Upward motion

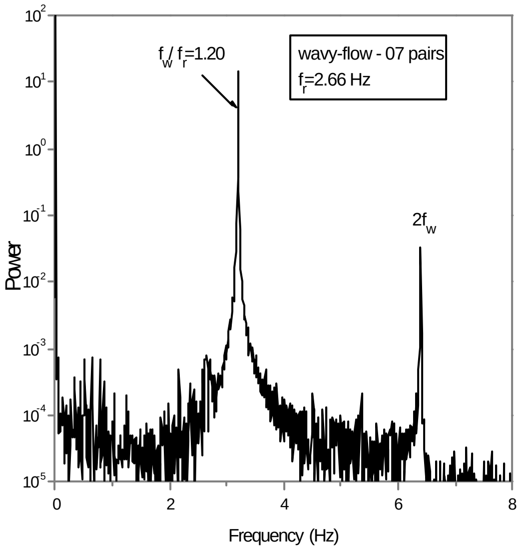

Figure 5 : Power spectrum for 07 pairs of WVF

For each mode when the Reynolds number increases, wavy vortex flow takes place.

The frequencies related to the azimuthal waves have in all cases ratios to the frequency of rotation greater than 1, as remarked in Figure 5. In the range of Reynolds number investigated, single periodic wavy vortex flow was only observed.

Conclusions

This flow system shows many scenarios of bifurcation and transition routes. The control of the acceleration rate of the inner conical cylinder can be quantified and then the desired flow mode can be reached for the geometrical and dynamical conditions imposed. These hydrodynamic properties are of fundamental importance for the comparison and classification with regards to the different rotating flow systems studied.

References

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