

TRANSITION TO TURBULENCE IN A FLOW DUE TO AN OSCILLATING CYLINDER STUDIED BY BAKER VISUALIZATION TECHNIQUE

V. Pilcová, D. Schmoranzner, L. Skrbek
Faculty of Mathematics and Physics, Charles University, Prague

Introduction

The standard Baker pH technique is used to visualize flows due to an oscillating cylinder of square cross-section in water at room temperature. Transition to turbulence is clearly indicated by the appearance of large flow structures mostly in the form of columnar vortices. The measurements are analyzed in terms of the critical Keulegan-Carpenter number versus the Stokes number and compared with our previous results on the transition to turbulence as detected by vibrating quartz tuning forks in cryogenic helium as well as with available theoretical models.

Experimental technique

The pH Baker technique (1) is a simple and proved method of visualization for low velocity flows. It involves aqueous solution of a pH indicator (thymol blue), an acid (HCl) and an alkali (NaOH). The studied body with its surface made of a conducting material is placed inside the liquid together with a set of metal electrodes located usually at the walls of the tank. When a bias voltage of about 10-15 V is applied between the body (+) and the electrodes (-), the body starts “generating colour”, i.e., local pH in the vicinity of the body changes due to the current of dissociated ions and the pH indicator changes its colour from orange to dark blue. As the pH indicator follows the flow of the water it is dissolved in, this method provides a fairly precise way of studying flow patterns and structures at low velocities of order 1 cm/s.

We have used this technique to visualize the flow due to an oscillating cylinder of square cross-section, $d = 30$ mm, and to study the transition to turbulence. This experiment was devised as a counterpart to our previous cryogenic measurements with quartz tuning forks in cold gaseous and liquid helium (2). The central rod of the cylinder (see Fig. 1) was connected to a loudspeaker, which was driven by a waveform generator at varying frequencies, ω , and voltage amplitudes. The position of the rod was captured by a digital video camera and the recorded files were processed using both commercial and home-developed software, yielding the position of the solid rod with the time resolution of the camera – 40 ms. At the same time, the flow patterns indicated by the Baker solution were observed with the naked eye and an assessment of the critical amplitude at which the transition to turbulence occurs was made based on the occurrence of large structures, mostly of columnar vortices stretching away from the cylinder.

Results and discussion

The experimental parameters, ω and d , and the critical amplitudes, a_c , were used to calculate the Stokes number, β , and the critical value of the Keulegan-Carpenter number, K_C , defined as:

$$\beta = \frac{\omega d^2}{2\pi\nu} = \frac{1}{\pi} \frac{d^2}{\delta^2}; \quad K_C = \frac{2\pi a_c}{d}, \quad (1,2)$$

where δ is the viscous penetration depth given by $\delta = \sqrt{2\nu/\omega}$. These parameters were also obtained from our experiments in cryogenic helium, however, with one important difference. In the measurements with the quartz tuning fork, the critical amplitude of the transition was determined differently – from the fork’s dynamic response. It is known (3) that the dependence of the applied voltage on the passing current, measured with the tuning fork corresponds to the dependence of the force acting on its prongs versus velocity, $F(U)$. This dependence exhibits a transition between linear and quadratic laws

(corresponding to laminar and turbulent drag forces) and the critical amplitude was determined as the point of intersection of the straight lines representing these two laws in a logarithmic plot. For more details, see (2; 4). All of the obtained results are plotted for comparison in Fig. 1.

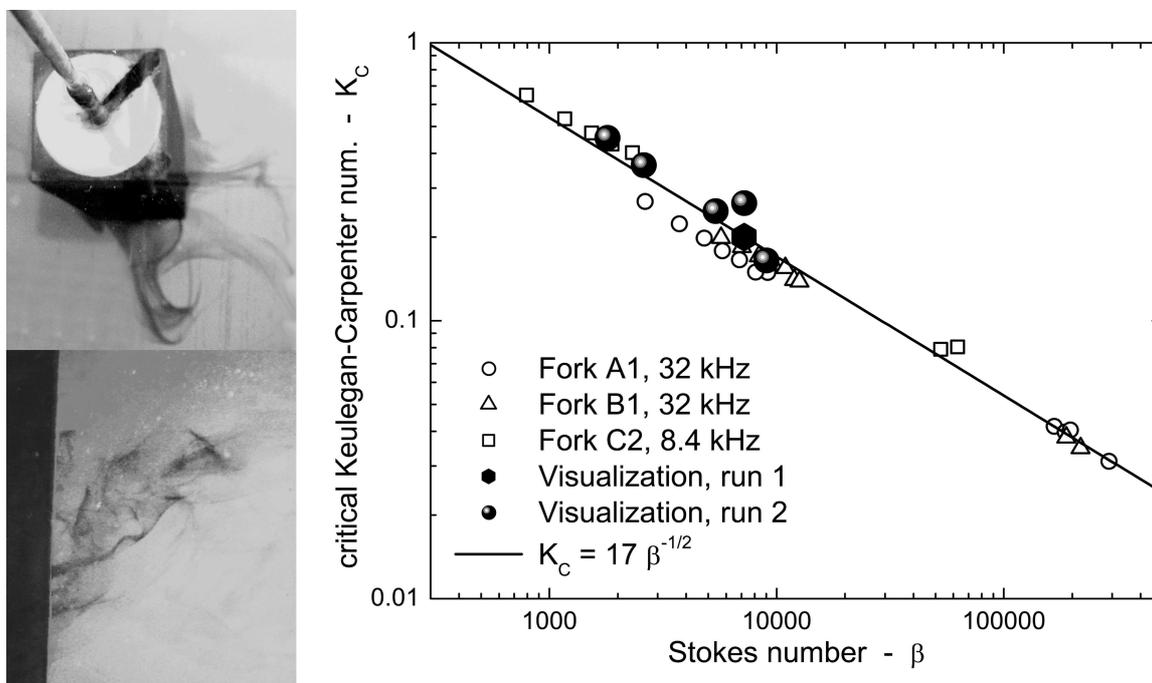


Figure 1: LEFT: The oscillating cylinder in the Baker solution with vortices clearly visible from the side (bottom) and from above (top). RIGHT: The logarithmic plot of the critical Keulegan-Carpenter number versus the Stokes number for both the visualization and tuning fork experiments. The visualization data labeled “run 1” and “run 2” were measured in the Baker solution at different frequencies: 8 Hz for “run 1” and 2 Hz, 4 Hz, 6 Hz, 8 Hz, 10 Hz for “run 2”. The solid line represents a power law fit to the data obtained in cryogenic helium.

As it is evident from Fig. 1, the visualization data are in a very good agreement with our results obtained in cryogenic helium with the quartz tuning forks even though the methodology employed to obtain them was quite different. This result proves that the observed changes in the drag force acting on the fork’s prongs are indeed caused by transition to turbulence as it was claimed previously. All of the experimental data also seem to be described by the $-1/2$ power law, which can be deduced by equating the laminar and turbulent drag forces, with reasonable reliability. This law is hereby confirmed for the cylinder of square cross-section and similarly shaped bodies (such as the tuning fork) over three orders of magnitude of the Stokes number.

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References

- [1] D.J. Baker, *J. Fluid Mech.* **26**, (1966).
- [2] M. Blažková, D. Schmoranzler, and L. Skrbek, *Phys. Rev. E* **75**, 025302, (2007).
- [3] R. Blaauwgeers *et al.*, *J. Low Temp. Phys.* **146**, 537 (2007).
- [4] L. Skrbek and W. F. Vinen, *Progress in Low Temperature Physics*, vol. XVI, in print.