EXPERIMENTS ON FLOW DUE TO OSCILLATORY MOTION OF A CYLINDER OF RECTANGULAR CROSS-SECTION AND VIBRATING QUARTZ TUNING FORK

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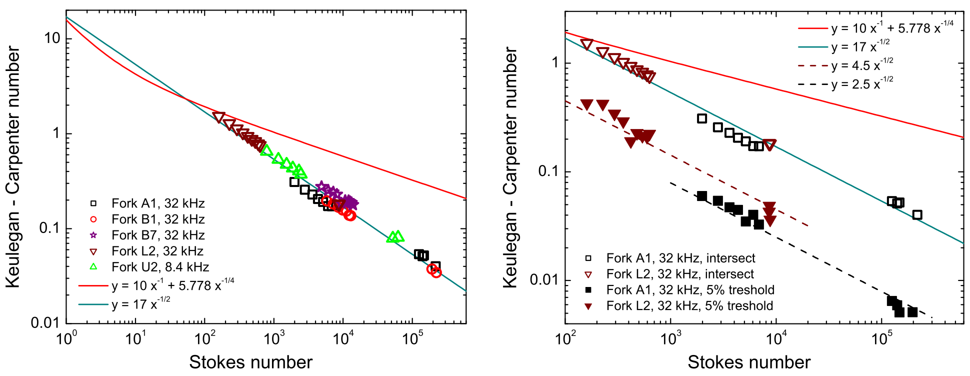
Introduction

We extend our previous experimental studies [1, 2] of flow of gaseous and normal liquid cryogenic helium due to vibrating (angular frequency ω, amplitude a) quartz forks. Measurements of the drag on prongs of the forks of different sizes and oscillation frequencies are analyzed and discussed together with the complementary Baker pH technique [3] and Kalliroscope visualization technique of room temperature water flow due to oscillatory motion of cylinders of square cross-section.



Obrázek 1: The cryogenic helium K_C versus β plots with K_C determined as a cross-section of limiting laminar and turbulent drag behaviour (left) and, for selected forks, using the criterion of 5 per cent deviation from linearity (right). The curved solid line represents expected instability for round cylinders.

Results and discussion

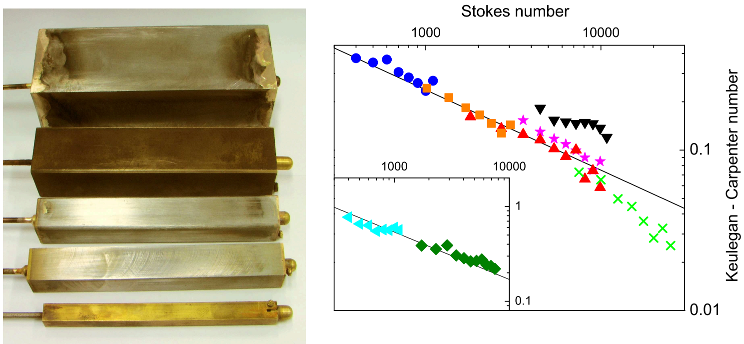
The experimental parameters, ω and d, and the critical amplitudes, a_c, were used to calculate the Stokes number, β, and the critical value of the Keulegan-Carpenter number, K_C, defined as: $\beta = \frac{\omega d^2}{2\pi\nu} = \frac{1}{\pi}\frac{d^2}{\delta^2}; K_C = \frac{2\pi a_c}{d}$, where δ is the viscous penetration depth given by $\delta = \sqrt{2\nu/\omega}$.

Fig. 1 shows the cryogenic helium critical $K_C(\beta)$ for all quartz forks determined as a cross-section of limiting laminar (velocity $\propto$ drive) and turbulent (velocity $\propto \sqrt{\text{drive}}$) drag behaviour. One can get better physical insight on instability of the laminar flow if another criterion is used - we have chosen as a point of 5 per cent deviation from the drag vs. drive linearity. Data obtained using this criterion are shown for selected forks on the right in Fig. 1. It is clear that neither set follows the expected behaviour established for round cylinders, as discussed in [4].

In order to better understand the underlying physics of the transition from laminar to turbulent drag flow due to oscillating cylinder of square cross-section, we have substantially extended our visualization approach (see preliminary results reported last year [5]) using two visualization techniques (pH Baker technique and Kalliroscope technique) in water at room temperature.

We use four different metallic cylinders with sharp edges (see Fig. 2), discuss the consequence of successively trimming the sharp edges of one of them and roughening the surface of another.

The Baker pH technique gave results shown in Fig. 2 for four cylinders of square cross-section with smooth surface (surface roughness $\ll \delta$). These data represent a visual observation of first instability in the flow in a form of columnar vortices streaming from the surface. Except perhaps for the largest 5 cm cylinder (for which 3D effects might start to play a role), the data sets confirm the experimental cryogenic $K_C \propto \beta^{-1/2}$ functional dependence.



Obrázek 2: Left - a photograph of cylinders of square cross-section. Right – The K_C versus β plot of the critical velocity determined visually, using the Baker pH technique (from left, cylinders of square cross-section d^2 =1 (•), 2 (squares), 3 (Δ), 5 (×) cm^2). Stars and ∇ indicate changes in critical K_C due to subsequent trimming the originally sharp edges of the 3 cm^2 cylinder (Δ). The inset shows the analogical visualization data obtained using the Kalliroscope visualization technique for 1 cm^2 cylinder with sharp edges - left-cylinders and 2 cm^2 cylinder with rough surface - diamonds.

Moreover, a subsequent trimming of the originally sharp edges for the 3 cm^2 cylinder shifts the data series up and convincingly shows the tendency of the data to eventually join the expected behaviour for round cylinders.

We attempted to investigate also a possible influence of roughness on the critical $K_C(\beta)$ behaviour and prepared an additional 2 cm^2 cylinder with gold-plated rough surface (estimated rougness of order 1 mm). As the Baker pH technique failed to provide the desired data, we utilized the Kalliroscope visualization instead. The instability is (barely) visible there, but due to the difference in the technique the data might not be directly comparable and we show them separately in the inset of Fig. 2 together with the complementary set obtained for 1 cm^2 cylinder with smooth surface. One obvious conclusion is that the $K_C \propto \beta^{-1/2}$ is for the rough surface not substantially altered. The detailed analysis of all our data will be published elsewhere.

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References

[1] M. Blažková, D. Schmoranzer, and L. Skrbek, Phys. Rev. E **75**, 025302, (2007).

[2] R. Blaauwgeers *et al.*, J. Low Temp. Phys. **146**, 537 (2007).

[3] D.J. Baker, J. Fluid Mech. **26**, (1966).

[4] L. Skrbek and W. F. Vinen, *The use of vibrating structures in the study of quantum turbulence*, Progress in Low Temperature Physics, vol. XVI, Elsevier (2008).

[5] V. Pilcová, D. Schmoranzer, L. Skrbek, Proc. of the Colloquium Fluid Dynamics, ISBN 978-80-87012-14-7, October 22-24, p. 143-44 (2008).