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B. Castaing, Benoît Chabaud, F. Chillà, B. Hebral, A. Naert, et al.. Anemometry in gaseous 4He around 4 K. Journal de Physique III, 1994, 4 (4), pp.671-674. 10.1051/jp3:1994157 . jpa-00249136

HAL Id: jpa-00249136

<https://hal.science/jpa-00249136>

Submitted on 4 Feb 2008

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Classification

Physics Abstracts

7.20M — 47.25 — 47.80

Anemometry in gaseous ^4He around 4 K

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(Received 15 July 1993, accepted 17 November 1993)

Résumé. — Un anémomètre de dimensions microniques et de grande bande passante (~ 1 MHz) a été développé pour des études de turbulence dans ^4He gazeux vers 4 K. Des résultats caractéristiques sont présentés ainsi que des perspectives d'application à la débitmétrie cryogénique.

Abstract. — For turbulent studies in gaseous ^4He at 4 K, a micronic scale anemometer with a broad band (~ 1 MHz) has been developed. Typical results are presented, together with possible extensions to cryogenic flowmetry applications.

Open turbulent flow experiments are governed by the Reynolds number : $Re = UL/\nu$. U is the mean flow velocity measured at the same place as L which is some characteristic length for the energy injection (the diameter of a nozzle in a jet experiment for example) and ν the kinematic viscosity, that is the ratio between the viscosity and the specific mass. Investigations at high Re numbers ($\geq 10^6$) are rather difficult under clean laboratory experimental conditions. The relatively large ν for air (Tab. I) shows that the reaching of these Reynolds numbers needs decametric L sizes, that is windtunnel conditions. Low ν values are of clear advantage. The use of N_2 at 77 K, with a ten times lower ν , has received large attention, despite the technological problems associated with the development of metric cryogenic wind tunnels.

Table I. — Kinematic viscosities.

| Fluid (1 bar) | Air | Hg | N_2 | ^4He |
|----------------------------|----------------------|----------------------|----------------------|----------------------|
| T_K | 300 | 300 | 77 | 4.2 |
| $\nu \text{ m}^2/\text{s}$ | 1.5×10^{-5} | 1.2×10^{-7} | 1.4×10^{-6} | 6.5×10^{-8} |

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We have performed jet experiments at high Re numbers with gaseous ^4He at 4.2 K. Due to the 230 times smaller than air kinematic viscosity, such Re may be obtained in low diameter cells matched with normal laboratory cryostats. Moreover the constant value of νp , where p is the pressure in the cell, gives the possibility to easily adjust the Re value.

At high Re it has been proposed [1] that the energy cascades from the large L scales down to some low ℓ_k dissipative scale where the energy is turned into heat through viscous effects : $L/\ell_k \approx Re^{3/4}$. It immediately appears that the use of gaseous helium which allows to operate with moderate L scales has a counterpart, the corresponding low ℓ_k value (typically : $\ell_k \sim 1 \mu$ at $Re \sim 10^6$). Then any local measurement, in high turbulent conditions, will need the development of micronic size sensors.

Such an anemometer, shown in figure 1a, has been recently developed [2]. A $5 \mu\text{m}$ diameter fiber glass is covered with a 500 \AA Cr film. This resistive film is short circuited by a 2000 \AA superconducting lead-indium film, except on a $5 \mu\text{m}$ central hot spot. The detector is placed in the ^4He turbulent flow. Above some threshold value I_ℓ of the polarization current, the hot spot reaches a high enough temperature ($T \approx 7 \text{ K}$) to turn normal the adjacent part of the superconductor film (Fig. 1b). The I_ℓ current depends on the cooling detector conditions and thus on the local velocity : arise of the flow velocity will increase I_ℓ . The detector is placed in a constant resistance R_ℓ feedback loop, R_ℓ being the sum of the hot spot resistance and that of the short normal Pb-In length. Lock-in detection at 10 Mhz gives an output « dc » current I_{dc} with a bandwidth 0-1 MHz, which is a measurement of the local and instantaneous flow velocity.

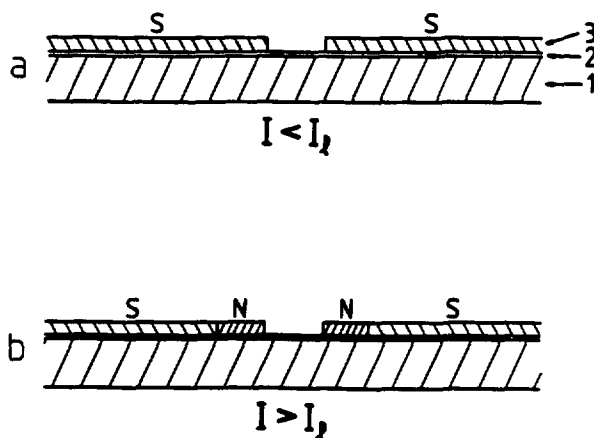


Fig. 1. — Schematics of the anemometer : 1) fiber glass ; 2) chromium film ; 3) lead-indium film.

The anemometer was calibrated at 4.2 K in laminary conditions (3 mm away from a $\varnothing 5 \text{ mm}$ diameter nozzle). As seen in figure 2 no pressure dependence is observed (except very close from $v = 0$, where convective effects are detected and a parabolic behavior for the square of the dissipated Joule power *versus* the square root of the Reynolds number is measured in agreement with thermal exchange considerations [3].

In a second cool-down from room temperature, a new set of results was obtained in fully developed turbulent jet conditions (130 mm away from a $\varnothing 1 \text{ mm}$ nozzle). The same values as in the laminary calibration experiment were obtained despite important fluctuations around the mean jet velocity U . After several months of daily operation, no aging effect has been observed.

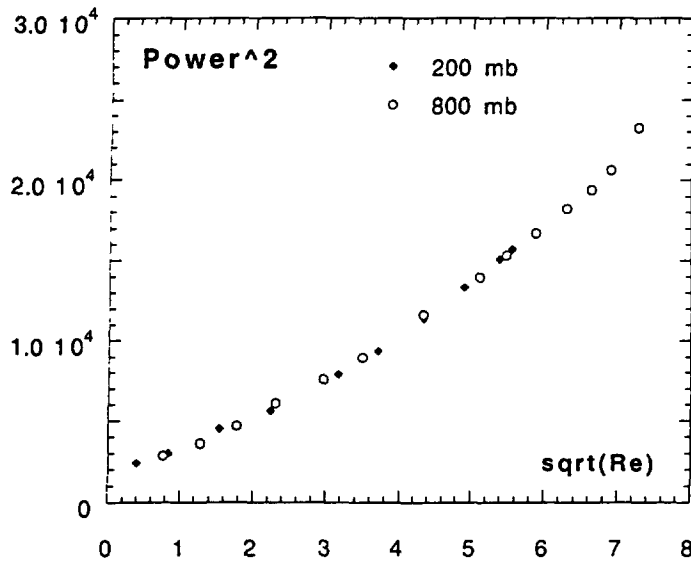


Fig. 2. — Calibration curve.

This detector appears very reproducible and of high sensitivity. In order to study the velocity fluctuations : $\delta v = v(t) - v(t + \tau)$ two series of analysis have been performed. First the histograms of δv are analyzed from files of 10^7 velocity data points recorded in times varying from some hours down to a few minutes depending on Re (note that high Re , that is high velocity jets, correspond to cut off frequencies f_c around v/ℓ_k , namely up to 0.5 MHz in our experiments). In figure 3, for $Re \sim 60\,000$, the normalized histograms for various τ values are presented. The distribution varies from an essentially Gaussian form at high τ to a very different behavior at low τ : enhanced peak at low δv and large tails for high δv . This is the

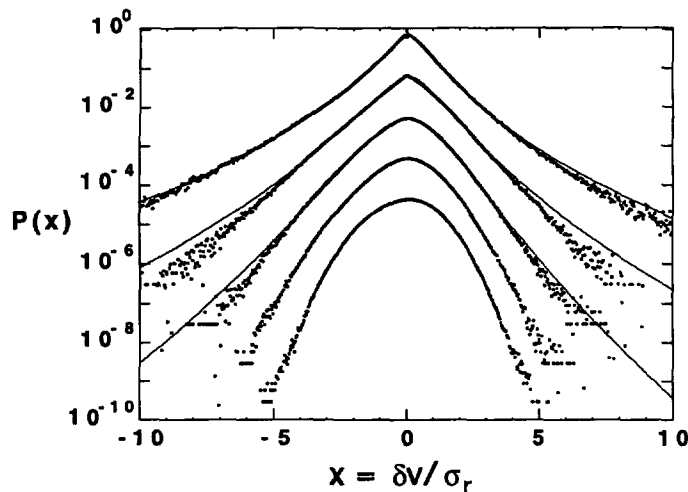


Fig. 3. — Normalized histograms of velocity fluctuations ($Re \sim 60\,000$). Each curve is shifted by one decade. σ_r is the standard deviation at the scale : $r = v\tau$. The lines correspond to theoretical fits. $\tau(s)$: 2.8×10^{-4} · 2.3×10^{-3} · 9.1×10^{-3} · 3.7×10^{-2} · 0.15.

characteristic intermittency of a turbulent flow. This central and heavily discussed phenomenon is taken into account by recent theoretical proposals [4, 5] : some fits are also displayed. The second series of analysis deals with frequency-energy spectra showing the classical $f^{-5/3}$ law up to a value close to f_c .

With a simplified version of this sensor (geometry and electronics), another application is its use as an *in situ* flowmeter in cryogenic conditions. The present developments of large scale refrigeration in accelerators, tokamaks, etc., producing cooling power around 20 kW at 4 K and 1 kW at 1.8 K needs accurate knowledge of the coolant flows. This detector is simple to operate, very reliable and is suited for the range of flows which are needed (up to 10 kg/s).

Acknowledgments.

This work has been partly supported by a DRET contract (n° 92/105) and by the Region Rhône-Alpes. J. P. acknowledges financial support from Deutsche Forschungsgemeinschaft.

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