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EXPERIMENTAL SETUP FOR GENERATING AND PROBING He II FLOWS[1]

T. V. Chagovets[*,†], L. Doležal,[*,†], J. Dupák,[‡] A. V. Gordeev [†], J. Prachařová[*], M. Rotter [†], F. Soukup [*], J. Šindelář [†], L. Skrbek[2,*,†]

[*] *Institute of Physics ASCR, Na Slovance 2, 182 21 Prague 8, Czech Republic*

[†] *Faculty of Mathematics and Physics, Charles University, V Holešovičkách 2, 180 00 Prague 8, Czech Republic*

[‡] *Institute of Scientific Instruments ASCR, Královopolská 147, 612 64 Brno, Czech Republic*

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A flexible experimental setup for the investigation of He II flow and turbulence generated by (i) thermal counterflow, (ii) thermally-induced pure superflow in channels of various crossections, (iii) between counterrotating discs with blades and (iv) due to a torsionally oscillating cylinder has been designed and constructed. The flows (iii) and (iv) are driven via a shaft by the PC controlled DC motor placed on the top flange of the cryostat. Our principal method of probing the flow is second sound attenuation; thermally-induced flows can additionally be probed by measuring the temperature difference along the channel.

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1 Introduction

Quantum turbulence (see, e.g., [1, 2] and references therein) — i.e., the turbulence in quantum fluids such as He II, superfluid ^{3}He-B or BEC of alkali atoms-involving a tangle of quantized vortex lines becomes increasingly more attractive to fluid dynamicists, as it might hold the key to solve a long lasting puzzle — the fluid turbulence. Among quantum fluids, He II is the most common one, representing an outstanding working fluid with extraordinary but well known and tuneable physical properties and quite naturally serves as a playground for many interesting experiments [3].

A great advantage of using He II is that one can obtain the vortex line density by measuring the attenuation of second sound [4–7]. The sensitivity and dynamic range of this technique are enormously large corresponding to up to 8 orders of magnitude of the turbulent energy [5] that is clearly an impossible goal for any classical experiment. We have, therefore, developed a flexible experimental setup, allowing us to generate and probe various types of He II flow. Our working fluid is natural He II, and using a simple open bath stainless steel HK 150 cryostat (in some cases even a glass cryostat) we can explore a temperature range down to about 1.2 K. As the generation of highly turbulent He II flows results in dissipation typically of order of 1 W we have to use a powerful pumping unit based on CIT Alcatel RSV 350 roots pump.

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[2] E-mail address: skrbek@fzu.cz

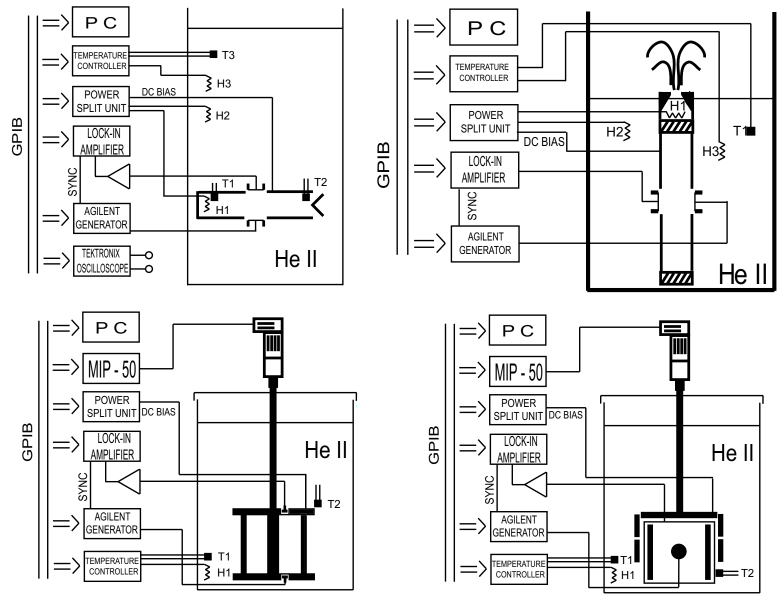

Fig. 1. Schematic block diagram of the experiment, showing the main components used in measurements with different cryogenic inserts. For a more detailed description of used components, see the text.

2 Cryogenic inserts for generating various kinds of He II turbulence

Quantum turbulence in He II was discovered [4] in a counterflow channel where it is easily generated by applying a heat pulse. We have utilized this method (Fig. 1, top left) and constructed three counterflow brass channels (Fig. 2, middle) about 12 cm long; one of a circular crossection 9 mm in diameter [6] and two of square crossection 6×6 and 10×10 mm^2 [7].

The vortex line density is deduced from the amplitude of the standing wave of second sound generated and detected by two identical plane gold-plated membranes acting as a transducer and receiver, placed opposite each other across a channel in the middle of its length (see Fig. 1, top left). The channel — a space between transducer and receiver — acts as a second sound resonator. One side of the standard Nuclepore membrane used to fabricate these sensors has to be conductive (by covering it with $\simeq$ 100 nm layer of gold) and serves as one electrode of a capacitor; the dc bias (typically 100 V) being used to press it against a brass electrode beneath. The capacitance of the sensor (10 mm in diameter, see Fig. 2 bottom right) reaches typically 60 pF, while our sensitivity threshold at working frequency of order 1 kHz is about 1 fF. The closed end of the channel includes a manganin wire heater ($\simeq 50\ \Omega$) wound on a conical surface. The channel is open to the He II bath and covered by another cone, in order to reduce coupling of the generated second sound signal with longitudinal modes on the channel along its length. Thermometers T1 and T2 are placed in the opposite sides of the channel and allow the direct measurement of the temperature gradient along it due to thermal counterflow; thermometer T3 and heater H3 are used to control the bath temperature.

Recently we have designed and utilized an insert where He II turbulence is generated by a pure superflow (Fig. 1, top right) [8]. Both conical ends of the channel (Fig. 2, middle) are smoothly connected (via a thin In o-ring) to sintered silver superleaks (Fig. 2, top right) about 2 mm thick and 16 mm in diameter. They have been sintered *in situ*; their large diameter and filling factor about 1/2 ensure that superfluid can freely penetrate through such superleaks and through the channel. The He II turbulence is thus generated by a pure superflow through the channel; there is no net normal fluid flow trough it. This superflow is set by applying the heat input into the heater H1. The upwards moving superfluid is partly converted into the normal fluid above the channel and leaves the heater volume as a fountain streaming into the helium bath.

As for the mechanically generated flows of He II, we have developed a cryogenic insert for investigation of the flow of He II due to torsionally oscillating cylinder (Fig. 1, bottom left). The stainless steel cylinder of 20 mm in diameter torsionally oscillates and generates the flow of He II inside the outer cylindrical wall of 70 mm in diameter. This experimental volume is limited by the stainless steel bottom and top plates which are 56 mm apart. The bottom one contains fine ceramic bearing that supports the inner cylinder during rotation. There is a plastic bush in the top plate though which the inner cylinder is fixed to a long shaft made of thin wall stainless steel tube 9 mm in diameter. The shaft includes stainless steel bellows in order to allow an extra lateral elasticity and passes through the top flange of the cryostat via two rubber O-rings. The space between them can be overpressurized by the helium gas in order to prevent contamination of the helium bath during experiment. A computer controlled Maxon DC motor and a gear box to smoothen its motion are mounted to the top flange of the cryostat. Requested values of the period and amplitude of oscillation are set up by MIP-50 board connected to the PC COM port.

Following the influential work [9] where He II turbulence (He I and cold helium gas can be used as well) is generated between counterrotating discs, we have designed and tested the multi-purpose turbulent box $9 \times 9 \times 9$ cm^3 in size. Turbulence is again driven by the Maxon DC motor, but the motion of the shaft is transmitted via a system of transmissions to two counterrotating discs (2R=8 cm in diameter) equipped with blades inside the box (Fig. 2, left). We have successfully tested this box in He II up to 5 revolutions of discs per second, what corresponds to superfluid Reynolds number of order 10^6.

3 Electronics

All our standard devices such as the Conductus LTC 21 cryogenic temperature controller, SR 830 dual phase lock-in amplifier, TD 2000 Tektronix oscilloscope and Agilent 33250A function generator are controlled via GPIB bus card by PC using LabView software.

To generate the heat-induced He II turbulence we had to develop the power split unit. It contains two voltage-to-current convertors capable to deliver up to 200 mA into 50 Ω load. In order to keep the bath temperature stable (it is monitored and controlled by the LTC 21 temperature controller with Cernox sensors), the total heating power applied to the system by heaters H1 and H2 (see Fig. 1) ought to be approximately constant. This is achieved by feeding two voltage inputs of the power splitter by the appropriate signals from the PC digital/analog convertor computed to be proportional to the required power ratio. In some cases it was favourable to use the home-made low-noise current to voltage converter (based on the TI OPA 121 FET input amplifier or OP 27 bipolar operational amplifier) as a preamplifying stage to the SR 830. It eliminates the

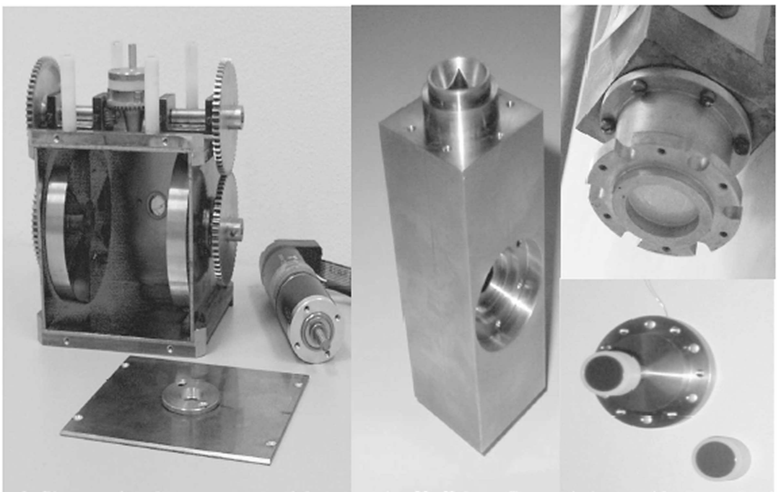

Fig. 2. Photographs of components used for generating He II flow. Cryogenic insert with counterrotating blades and the dc motor (left); one of the brass counterflow channels of square crossection (middle); also shown is the silver superleak covering its end (top right) and the second sound transducers (bottom right).

parasitic capacitance of the coaxial cable, while keeping the current noise level at 0.1 pA/$\sqrt{\text{Hz}}$. We use a high quality Lake Shore cryogenic coaxial cable with no appreciable microphone effect and miniature LEMO coaxial connectors (these have been made leak-tight by sealing them with Stycast 1266 compound).

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