Miniature velocity probe for Superfluid Turbulence

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Experimental setup

Liquid helium (superfluid or not)

Cantilever tip

\( l \approx 300 \mu m \)

Arm

\( \Phi = 2.4 \text{ cm to } 9 \text{ cm} \)

Measurement principle

- The cantilever tip is deflected by the flow
- Known to be effective in air and water (Barth et al., 2005)
Probe Geometry

Specifications for the probe geometry

- The cantilever tip must be inserted in the bulk of the flow
- The arms have to be as transparent as possible for the incoming flow especially near the measured volume
- The mountings have to fit in the room available outside the flow inside the cryostat
Probe Geometry

Cantilever

Arms

Mounting

100 µm

300 µm

200 µm to 150 µm

3 mm

8 mm

11.2 mm

14.8 mm
Measurement techniques

Desired specifications for the deflection measurements

- Large frequency range, typ. DC to 50 kHz
- High signal dynamics
  In turbulence, the power of the fluctuating signal scales like $f^{-5/3}$, ie. if power $P_0$ at $f_0$, then $P_0/50$ at $10f_0$
- Working temperature range: 1.1 K to 4.2 K

Possible solutions

Optical detection, Strain gauges, LC resonator, ...
Measurement techniques

Chosen technology: RF superconducting resonator

Pros:
- Well known technology for fine measurements (e.g., NIKA project)
- Fast dynamics
- Multiplexing perspectives
- Easy to micro-machine

Cons:
- Oxides introduce phase noise ⇒ proscribe SOI solutions
- RF circuitry and electronics
Superconducting $LC$ Resonator

- **Inter-digital capacitor**
- **Inductance**
- **RF feedline**
- **Bounding port**
At first order, we expect:

\[ f_0 = \frac{1}{2\pi \sqrt{LC_0}} \left(1 - \frac{\Delta \ell}{2\ell}\right) \]

Mechanics says:

\[ \frac{\Delta \ell}{\ell} \sim \frac{P \ell^2}{E e^2} \]

where

\[ P \sim \rho v^2 \]

We expect:

\[ \frac{\Delta \ell}{\ell} \sim 5 \times 10^{-5} \]
Cryogenic Cantilever Anemometer
First prototype

First approach

RF source

−20 dB

IQ-Mixer

G = 10

ADC

G = 10

Room temperature

Cryostat

Nb

Source RF: Agilent N93A10A, Splitter: ATM, IQ-Mixer: Miteq
ADC: VXI + cartes Agilent E1437A
Amplification RF: 38dB + 18dB \( (G = 10^{(18+38)/20} = 631) \)
We have a prototype working and its dynamics is comparable to the best anemometers known to work in He II

**BUT**

1. Quality factor very low
   \( \approx 10^3 \) versus \( 10^5 - 10^6 \) expected
2. High low frequency noise
3. Many peaks for \( f > 3 \text{kHz} \)
**First prototype**

- **RF source**
  - FM in
  - RF out

- **Splitter**
  - -20 dB

- **Mixer**
  - LO
  - RF

- **Lock-in**
  - Osc
  - A

- **ADC**
  - G = 10

**Room temperature**

**Cryostat**

- -20 dB
- +20 dB
- +30 dB
- Nb
Calibration \textit{versus} Mean velocity

![Graph showing the relationship between signal in mV and \( \langle v \rangle^2 \) in \( m^2/s^2 \)]
Conclusion

- Validation of the principle of cantilever anemometry He II
- Validation of the principle of a superconducting resonator sputtered on a cantilever to measure its deflection
- FM technique allows to get rid of phase noise problems

Perspectives

- Understand why $Q$ is so low should greatly improve sensibility
  - Residual aluminum on the circuit?
  - High temperature and gradients during plasma somehow changes niobium properties?
  - Problems with Nordiko 2550 sputtering machine?
- Replace Nb with NbN to get a higher $T_c$. Possible with Nordiko?
- Improve resolution (at least down to 50 $\mu$m)
- Array of probes multiplexed on a single RF line
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