VISUALIZATION OF SECOND SOUND RESONANCE WAVES IN HE II USING PARTICLE IMAGE VELOCIMETRY

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ABSTRACT

This paper discusses the obtaining of standing waves of second sound in a rectangular cavity. Resonant waves are created in a rectangular cavity using thin-film nichrome heaters and thin-film graphite thermometers. The resonant frequencies are found using a waveform generator and a lock-in amplifier. Particle image velocimetry (PIV) was attempted in order to visualize the second sound waves. The channel was too short for PIV measurements and needs to be lengthened before more work is done.

INTRODUCTION

At 2.17K, liquid Helium undergoes a phase transition from a normal fluid which follows ordinary fluid-mechanical laws to a superfluid which behaves very differently. This superfluid (also known as Helium II) displays many unique properties, including extremely high thermal conductivity, almost zero viscosity, and zero entropy. These properties allow the liquid to support more than one type of wave propagation or sound. First sound (normal acoustic sound), can be excited using a speaker and detected with a michrophone. It is a wave of alternating high and low pressure regions. Second sound, which is a wave of temperature, can be excited using a heater and detected with a thermometer. It is a wave of alternating high and low temperature regions. It can also be thought of as alternating regions of high concentration of normal fluid (the warm regions) and superfluid (the cold regions). When the heater is on, the superfluid heats up, changes to a normal fluid, and is transmitted across the channel where it is detected by a thermometer. As with acoustic waves, second sound standing waves can occur. In this experiment, the goal was to visualize second sound standing waves using a technique called Particle Image Velocimetry (PIV).

Recently work has been done using PIV to visualize thermal counterflow in He II [1]. PIV is a valuable technique because it allows the experimenter to determine the velocity field of a large area of interest. To do PIV, the experimenter first seeds the fluid with small particles of neutral buoyancy. The particles are illuminated by a laser beam and a picture is taken by a camera. After a short time elapses, the camera takes another picture. From these two pictures, the displacement of the particles can be seen and, since the time between pictures is known, their velocities can be calculated. In this experiment, PIV was used to visualize second sound standing waves.

CHANNEL DESIGN

For this experiment, an optical cryostat was used which has three fused silica windows—laser in, laser out, and camera. The experiments took place in a G-10 channel inserted into this cryostat. The channel was 10cm long and had a 3cm x 2cm interior rectangular cross-section. It was painted black with a graphite spray paint so that when doing PIV, the laser light would illuminate only the area of interest and not reflect off the walls of the channel. The bottom of the channel was affixed to a larger G-10 plate. This plate helped support the channel in the cryostat as well as housed the main thermometer.

On one side of the channel was a window made from fused silica for the camera. On the two adjacent sides were small windows for the laser to enter and exit. To the left and right of the small windows were either two small heaters or two small thermometers.

The main heater was made from a fused silica substrate which measured 20mm x 34mm x 0.84mm. On the upper face, a 30mm x 20mm x 22nm thin film of nichrome (80%Ni/20%Cr by weight) was deposited by physical vapor deposition. Nichrome was chosen for its nearly constant resistivity following the work of Hilton [2]. The resistance of the nichrome on the heater is 60Ω. On the edges a 150nm thin film of silver was deposited to make electrical contact. The resistance of the nichrome and silver is 200Ω. Brass plates were screwed in at the sides of the heater. Between the brass plate and the silver edge, a piece of indium was crushed to make electrical contact. Indium was chosen because it superconducts at liquid Helium temperatures. The purpose of the main heater is to lift fallen particles through counterflow or to induce vertical second sound pulses.

The main thermometer was a bare chip Cernox CX 1030 from Lake Shore Cryotronics, Inc. affixed to a peg 8cm from the bottom which jutted into the center of the channel. The purpose of this thermometer is to detect pulses coming from the main heater.

The small heaters were made by depositing a 13mm x 15mm x 30nm thin film of nichrome on a 13mm x 15mm x 0.84mm fused silica substrate. The resistance of these heaters is 40Ω. Contacts were made to these heaters using the indium method described above, though in this case, contact was made directly to the nichrome, not to a silver edge.

The small thermometers were made by abrading a thin sheet of G-10 with sandpaper and then rubbing it with Pentel 1.5mm hardness B pencil lead. The resistance of these thermometers is about 600Ω and 900Ω at room temperatures and 1.3kΩ and 3.1kΩ respectively at 1.85K. This method was again chosen in accordance with the work done by Hilton [2]. The resistance of graphite changes dramatically with temperature, thus making it a sensitive as well as inexpensive thermometer. Contact was again made using the aforementioned indium method.

EXPERIMENTAL SETUP

In order to determine the resonant frequencies of the channel, one small side heater was connected to a function generator (see Fig. 1). Only one heater was used to minimize noise. Sinusoidal waves of frequencies ranging from 460Hz to 3000Hz with amplitudes of 4Vpp were sent through an amplifier which increased the signal tenfold and then to the heater. The thermometer which displayed the least noise had a constant current of 10μA from a battery-powered current supply through it and was connected through a preamplifier to a lock-in amplifier. The preamplifier provided a bandpass filter as well as increasing the signal strength. The reference frequency for the lock-in was provided by the function generator. This reference frequency had to be doubled as the heater will heat when the incoming signal is at its peak, but it will also heat when the signal is at its trough, hence making the frequency of the signal in the channel double that of the input signal.

The output amplitude from the lock-in was plotted versus frequency in Fig. 2. The resonance peaks correspond to the theoretical values given by $\nu = \frac{nc_2}{4L}$ where ν is the resonant frequency, n is the normal mode number, c_2 is the speed of second sound, and L is the width of the channel. In this case, c_2=21m/s and L=0.02m. All experiments were performed at 1.85K. From this equation, resonances are expected at 250Hz, 500Hz, 750Hz, etc. Low frequency data was not taken, as second sound does not exist there.

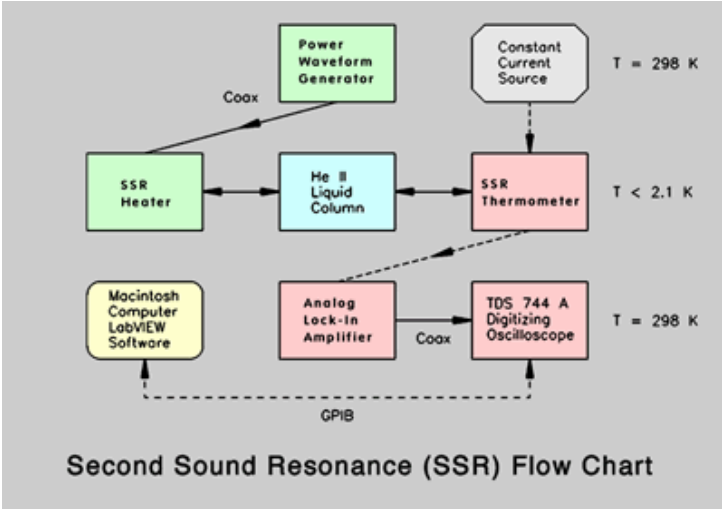

Fig. 1 Second sound resonance flow chart [2]

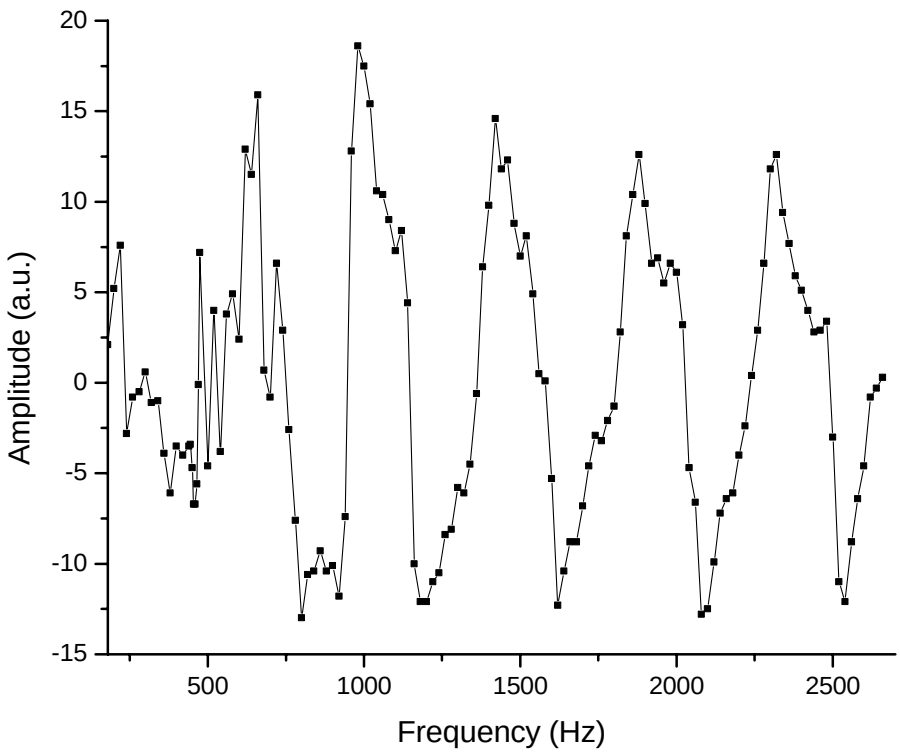

Fig. 2 Resonant frequencies of the channel

PIV MEASUREMENTS

To do PIV measurements, the lowest frequency available is desirable in order to allow the particles to track the flow accurately. The experiment was performed at two different frequencies, 460Hz and 1000Hz. The particles were seeded successfully and had good separation and small size, but did not stay in the viewing window. The end of the seeder was quite close to the window and the particles left the seeder with a high momentum, causing them to exit the channel without tracking the second sound resonance wave. The larger particles did fall to the bottom of the channel and were lifted with the main heater, but they were too large for PIV.

To remedy this problem, the channel should be lengthened so the seeder will be further away from the area of interest. This would allow the particles to slow down before reaching the resonance wave and hopefully stay long enough to track the flow.

CONCLUSION

In this experiment, a rectangular channel was built to produce standing waves of second sound. The resonant frequencies of this channel were determined and corresponded well to the calculated values. PIV was attempted in order to visualize the second sound wave, but the particles left the channel without tracking the resonance wave. Modifications to the channel need to be made before more experiments are attempted.

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