Registration of vortex motion in the bulk of superfluid helium by injected charges

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Abstract. We developed a technique for studying the vortex motion created by waves on the surface of superfluid helium-4 using charges injected into the bulk of the liquid. The charges move from the source to the five sectional collector mounted on the opposite side. The interaction of charges with vortices formed by the waves on the surface leads to a change in the distribution of currents recorded by the collector segments.

1. Introduction
Vortex motion can be created by waves propagating on the surface of a liquid. Two no collinear waves form a vortex lattice with period equaled to the wave length [1]. Initially, experiments on the generation of vortices by waves were performed on water. However, in the nature, in addition to classical liquids, there are also quantum liquids in which vortex motion is quantized. Such liquids include helium -4 at temperatures below 2.17. In the temperature range near 2.17, vortex motions in both the normal and superfluid phases coexist in the volume of liquid helium-4. At temperatures around 1.3 K, the motion of the superfluid component dominates. Injected charges are good test particles for studying vortex flows in a superfluid, since they interact with quantum and normal vortices [2].

The main purpose of this work is to study the formation of quantum vortex flows by surface waves in a wide range of temperatures, and to study the evolution of vortex structures under changes in wave pumping conditions.

2. Experimental procedure
The experimental studies of the interaction between injected positive charges and vortex motion in superfluid helium were performed in an experimental cell placed in a container. The container was located in a vacuum cavity of a helium cryostat and was connected to a liquid helium vessel by means of a copper cold finger.

The experimental container was a cylinder with a built in it experimental cell. The experimental container was a cylinder with an experimental cell built into it. Six metal faces of the experimental cell, which are not in contact with each other, form a cube. A charge source (Usours) was installed in one of the vertical faces. Helium was condensed to the cell from a high-pressure tank with gaseous helium through a capillary. The charge source was located beneath the surface. On an opposite face there is a 5-segment collector, (-2,-1,0,1,2) is in fig. 1. Each segment was connected to an amplifier. The voltage is applied to the faces of the cube so that the injected charges move from the source to the collector. The
output lines of the amplifier were connected to an ADC. The signal was digitized and written to a computer. The upper segment was a semitransparent glass.

![Figure 1](image.png)

**Figure 1.** Top view of the experimental cell. Plungers are shown by green lines. The collector segments are marked with yellow lines.

Generation of waves on the surface of liquid helium was carried out by two plungers which were mounted perpendicularly to each other [3] (Fig. 1). The plungers were set in motion independently of each other using an electromagnetic drive. In the experiments, pumping was carried out at a frequency of 1-30 Hz, wave amplitude up to 0.1 mm, and phase difference from -90° to 90°.

Positive charges (He+ ion) were used in our investigations. The experiments were carried out at the following operating voltages: \(U_{\text{sours}}=300-400\) V, \(U_{\text{side1,2}}=6-100\) V, \(U_{\text{up}}=5\) V, \(U_{\text{down}}=25-100\) V. Approximately 100 points (~5 min) were measured during the experiment. This is due to the fact that low current (fA) were measured. After measurement, the received signals from the receiving collector were wired, then subjected to averaging. Fourier filtering was performed at low frequencies in order to measure the DC component of the current. The average value over the entire time interval was also found.

3. Results

In the experiments, current was measured on the receive collectors before pumping and during excitation of waves on the superfluid helium surface. An electrical circuit of the experiment was as follows: voltage \(U_{\text{sours}}=400\) V was supplied to the source, voltage on the lateral faces was \(U_{\text{side1,2}} = 6\) V, \(U_{\text{up}}=5\) V was supplied to the upper face, and \(U_{\text{down}}=25\) V was supplied to the lower face. Before switching on the pump, the central collector current was at the level of 88 fA. The currents at collectors -1 and 1 were equaled 21.8 fA and 24 fA respectively (blue histograms in Fig. 2). Then, pumping at a frequency of 13 Hz was switched on at the phase difference of the electric signals supplied to the plungers \(\Delta\phi=90\). After several minutes in a stationary state, currents were redistributed: on the central
segment current decreased to 4.5 fA, at the left segment (1) the current increased up to 96 fA, at right segment -1 current left at the level of 17 fA (pink histograms in Fig. 2).

To estimate the behavior of vortex system after switching off pumping we measured the time dependence of the value of total current coming to all 5 segments. In 5 minutes after switching on excitation of waves on the surface the total current on the collectors was equaled to 99 fA. The points in Fig. 3 demonstrate the results of measurements performed 0, 5, 10, 15, 35, 45 minutes after switching off pumping. One can see that the total current is increased linearly with time approximately by 30%. We can propose that approximately the same fraction of charges did not reach the collectors due to the interaction with vortices. The charges apparently could deviate from a straight trajectory and move to the lateral faces as a result of the interaction.
It is assumed that waves form a vortex lattice during pumping which evolves into a complex structure with vortices of different sizes with time. After switching off pumping, the vortex structure decays with low damping approximately by the linear law. This dependence differs from Vinen’s predictions for total length of quantum vortex $L \propto t^{-3/2}$. The interaction of charges with vortices system weakens which leads to an increase in the total current.

4. Conclusions

We developed the method for investigation of behavior of vortex system in superfluid helium-4 with help of injected charges. The first experiments show that waves on surface of superfluid helium generate vortices that penetrate into the bulk. In future experiments we plan to study in more detail the interaction of charges with quantum vortices.

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