

# Using a High-Speed PIV System to Study the Transient Processes in Superfluid Helium

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## Abstract

Superfluid helium, a unique fluid system occurring in liquid helium below 2.2 K, is interesting for studying the fundamentals of quantum turbulence and the related heat transport processes. Unique to superfluid helium are the processes of second-sound thermal shock and non-linear heat diffusion. Since their generation and development are intrinsically associated with the dynamics of superfluid turbulence, the study of these processes enable us to further understand the fundamentals of turbulent state. In previous research, the second-sound shock and heat diffusion processes have been studied only through the measurements of the heat pulse induced temperature profile. These have given quantitative agreement with theory; however, models used to understand these

processes predict an internal convective fluid motion of the two separate fluid components (superfluid and normal fluid). While this “Two Fluid Model” forms the basis for understanding the behavior of thermal processes in superfluid helium, to date actual measurements of the associated velocity profiles have never been observed. In the present study, the PIV technique, taking advantage of its ability to quantitatively measure the global flow field with high spatial resolution, is used to quantitatively characterize the convective velocity field during these two transient heat transport processes.

A second-sound shock wave is usually generated by applying a short heat pulse of width less than several milliseconds, which is transported through the superfluid helium at a speed of around 20 m/s. This process has a characteristic development time on the order of several milliseconds. By comparison, the heat diffusion process develops relatively slowly with a characteristic time on the order of several hundreds milliseconds. For such processes with short characteristic development times, it is generally not possible to use the conventional DPIV system in the continuous mode because of the low-speed CCD camera and pulse laser generator used, which have a typical operating rate at 15 Hz. To overcome this problem, a high-speed DPIV system developed by IDT Inc. has been used in the present study. The system includes an X-Stream VISION high-speed camera featuring a CMOS sensor capable of supporting triggered double-exposure mode with 100 nanosecond inter-frame time interval, and an infrared continuous wave laser generator that can also be operated at pulse mode. The operating rate of the camera can be set at a rate of 628 Hz with full resolution (1280 H  $\times$  1024 V pixels), or as high as 30 kHz with partial resolution (e.g. 1 kHz at 1280 H  $\times$  640 V pixels resolution). These

characteristics make the system suitable for the PIV measurements of most transient processes in fluid dynamics.

Using this high-speed PIV system, the propagation of second-sound shock wave in superfluid helium was successfully detected. Results from PIV measurement confirm that the second-sound shock wave propagates at a theoretical second-sound speed of around 20 m/s. In addition, the relatively slow heat diffusion process was also observed. With the high-speed camera operated at 1200 Hz, the flow velocity was measured in a continuous mode with a time increment of 0.83 ms. A complete picture of the evolution of heat diffusion process has been successfully visualized, from which much more details of the heat diffusion process can be obtained. These results shows that the high-speed DPIV system might be applied usefully in the study of superfluid turbulence, and become a powerful technique to quantitatively investigate the heat diffusion process and second-sound shock wave in superfluid helium.