# Ultrasonic Doppler Velocimetry Measurements on the Madison Dynamo Experiment

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In the summer of 2004, I began work at the Madison Dynamo Experiment alongside Professor Cary Forest, engineer Roch Kendrick, and graduate students Mark Nornberg and Erik Spence. The primary goal of my undergraduate research was to prepare an Ultrasonic Doppler Velocimetry (UDV) system for use and take measurements of velocity on the Madison Dynamo Experiment.

The experiment seeks to understand how magnetic fields can be modified by and generated from flows of a conductive metal (liquid sodium) driven by two counter-rotating propellers inside a spherical shell. To create a dynamo, the magnetic field of the system must be stretched sufficiently by the motion of the liquid sodium such that the field becomes self-sustaining. This condition requires that the magnetic Reynolds number, a dimensionless product of conductivity, velocity, and size, is above a critical value. In the experiment, the liquid sodium flows need to be not only sufficiently fast, but also of the right shape. Therefore the velocity field of the liquid sodium should be well known in order to fully understand the experiment.

A full-scale water version (Fig. 1) of the sodium experiment is used to measure a velocity field very similar to that of the sodium experiment. Laser Doppler Velocimetry (LDV) can be used to measure the toroidal and polodial velocity components of a transparent liquid as in the water experiment. UDV can measure velocity components along a chord even in an opaque liquid, and is thus suitable for use on both the water and sodium experiments.

High-temperature (150 °C) ultrasonic transducers used in UDV have a diameter of 27 mm and operate at a frequency of 0.5 MHz, allowing for velocity measurements up to 10 m/s at a depth of 30 cm within the experiment. In order to provide valid UDV velocity measurements, suitable seed particles particles needed to be found. The particles had to be neutrally buoyant in water and also have a diameter at least one-quarter wavelength of the ultrasonic beam (740 micron). Polystyrene beads (Fig. 1) with a diameter of approximately 840-915 micron and a density of nearly 1 g/cm$^3$ were ultimately used.

To shield the ultrasonic transducer from the harsh chemical environment in the sodium experiment, a protective enclosure that allows transmission of the ultrasonic beam needed to be developed. Initially a thin stainless steel plate, cut to a thickness of one half wavelength was to be used to protect the transducer face. However, after several failed attempts, this approach was abandoned as transmission was poor. An improved probe was designed that used silicon rubber to cover the transducer face. Silicon rubber has an acoustic impedance nearly the same as water, which allows for good transmission independent of thickness. These probe designs were evaluated using a small test flow in a water tank. The probe was installed in a hole located at the equator of the water experiment and secured using Grayloc and Swagelok fittings.

The first ultrasonic measurements were taken on a radial chord at the equator in the water experiment. Problems arose as the probe was pointed normal to the far wall of the sphere, resulting in strong reflections that distorted the velocity profile. To remedy this, either an absorptive material needed to be installed on the opposite wall of the sphere, or the probe needed to be pointed on an off-radial chord. An absorptive pad was first used to reduce reflection but prooved inadequate.

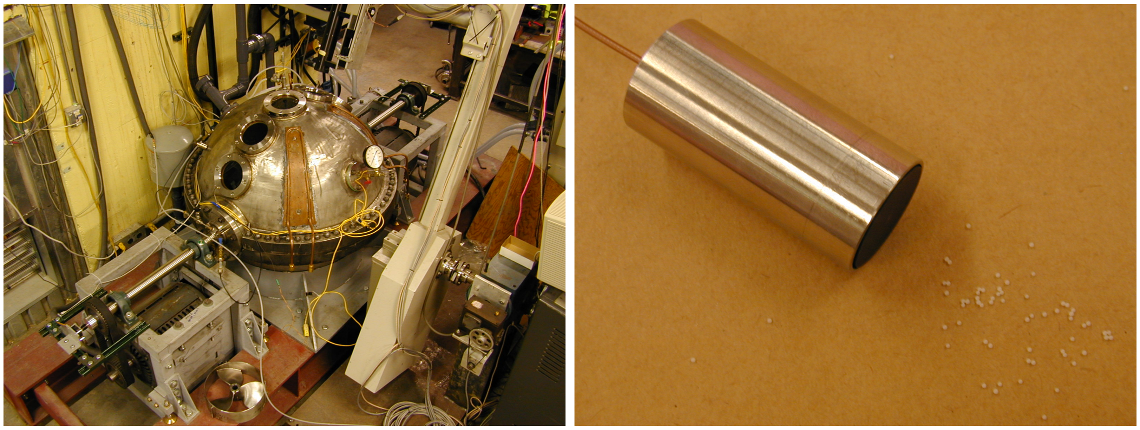

Figure 1: A photo of the water experiment (left) and the ultrasonic transducer and polystyrene beads (right)

Instead, probe orientation was changed to a fixed angle of 17.5° from the normal vector of the sphere. Inconsistencies in the measured profile as measurement depth is varied are currently being addressed. A sample UDV measurement is shown in Fig. 2. Positive velocity values correspond to inward flow. Error bars represent RMS fluctuations of the time-averaged velocity values (58 second sampling time) resulting from a 200 RPM shaft rotation rate. Note that since the transducer cannot measure velocity near its face, the first 10 profiles do not represent accurate fluid velocity.

The water experiment has also been extensively modified. The experiment is now remotely operated via National Instruments Lookout and Fieldpoint control. More diagnostic instruments have been added, such as thermocouples, a pressure transducer, motor shaft speed encoders, and an ultrasonic cavitation detector. A water cooling system, including a large water chiller and heat exchanger, was also added.

I also assisted others in alignment and operation of LDV measurements on the water experiment and construction of magnetic coils for use on the sodium experiment.

I attended the American Physical Society Division of Plasma Physics in November 2004, where I presented preliminary results during a poster session exhibiting undergraduate research[1].

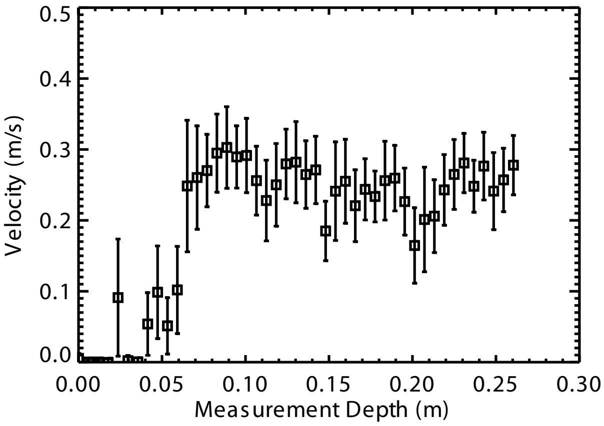

Figure 2: Velocity measurement from the water experiment

Future work includes an overhaul of the water experiment to replace its propellers so that they are identical to those in the sodium experiment. Additional ultrasonic probes will be added to the water experiment. An adjustable angular probe will be developed. Problems regarding inconsistent velocity profiles will be addressed. UDV probes will be added to the sodium experiment.

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[1] http://www.aps.org/meet/DPP04/baps/abs/S1010015.html