Final Report - Using a Handheld Unilateral Magnet for Fluid Flow Measurements with a Constant Gradient

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Contents

1 Introduction

The purpose of this document is to outline the construction of the fluid flow setup for the SA3 magnet. This document should help with recreating a similar probe for low frequencies, as well as detailing a design for future flow setups that use handheld unilateral magnets. The upside to the SA3 magnet, is that it is relatively small compared to the much larger GARfield magnet (GARfield simply means gradient at right angles to the field). While using a smaller magnet comes with benefits, such as being portable, it also brings with it many problems. Since the frequency is quite low, many scans are needed to acquire adequate signal. This is why using doped water as a sample is a preferable choice when getting NMR data as it will have a much lower delay time.

Also, the SA3's gradient is perpendicular to the surface which means that to have a component of the gradient along the direction of flow, the magnet must be placed at some angle. Because of this angle it's important that any future "unilateral magnet flow designers" keep in mind that it's a trade off; being closer to the magnet gives a larger magnetic field, and thus a larger frequency (which can make probe building easier), but also decreases the maximum possible angle of the magnet since the RF probe is so close to the surface of the magnet.

2 SA3 Characterization

The constant gradient region that's of interest is approximately 150gauss/cm. It extends upwards from the surface of the magnet from 2.0 cm, to 2.5 cm. Within that region, the gradient remains constant. By tilting the magnet at some angle, the constant gradient will have a component that lies in the direction of flow. The magnetic field plotter was used to plot the magnitude of magnetic field as a function of height from the surface of the magnet. With this, a height corresponding to 530 gauss was chosen because it remains within the constant gradient region. This gives a frequency of 2.26MHz.

From the plot in figure 2, a general region where the gradient has constant values with variation in X can be found. If the largest magnitude point is assumed to be the center (This high magnitude region is not exactly center on the X axis because the magnet has to be centered by hand in the magnetic field plotter. Realistically, it's very difficult to place the magnet in the center of the plotter by hand in exactly the same region every time), then the acceptable region would span about +/- 0.5 cm from the center.

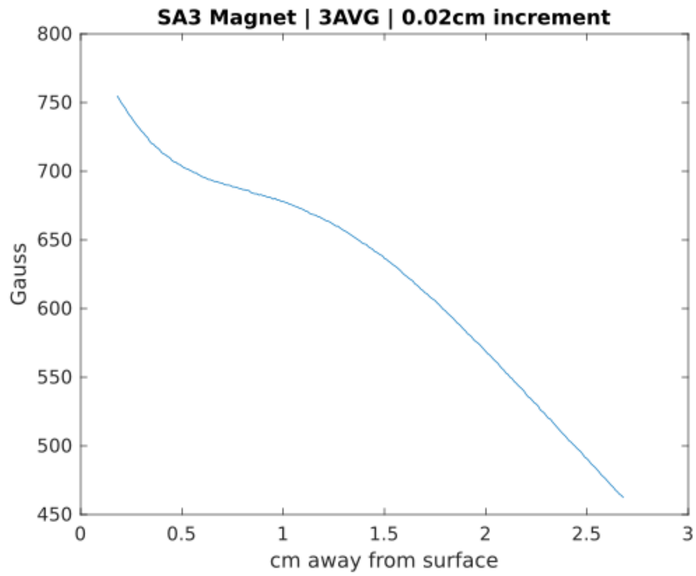

Figure 1: Plot of the magnitude of magnetic field of the SA3 magnet as a function of height from the surface. Notice that the constant gradient region exists from roughly 1.5 cm, to 2.5 cm.

3 SA3 Geometry with Probe at 2.26MHz

3.1 Calculations

Since the SA3 magnet has a 150gauss/cm gradient perpendicular to the surface, at a height of 2.0cm to 2.5cm, the magnet must be tilted at an angle in order to have a component of that gradient along the direction of flow.

In figure 3 it can be seen that the combination of b+a must equal the total height of the gradient region. Thus:

$$0.5 = b + a \tag{1}$$

Then 'b' and 'a' can be described in terms of the horizontal width of the gradient region and θ. Where θ is the angle the magnet will be tilted. Since the inner diameter of the glass tube is 0.66cm, we get equation 2:

$$0.5 = tan(\theta) + \frac{0.66}{cos(\theta)} \tag{2}$$

The angle then works out to -9.6 degrees. The reason for this angle being negative, is because there would be no small positive angle at which the magnet could be oriented and have the gradient region fully enclose the tube (as in figure 3).

3.2 Mount for SA3

Since the RF probe can be difficult to move to a specific angle, a mount was built for the SA3 magnet in order to make the magnet easier to position. The mount was built with a 3D printer that uses PLA as filament material. The setup may not be suitable for long term use but should be acceptable for the beginning stages of this system.

The mount also includes an M5 threaded screw hole at the bottom of the swinging platform to allow for the magnet to be raised or lower.

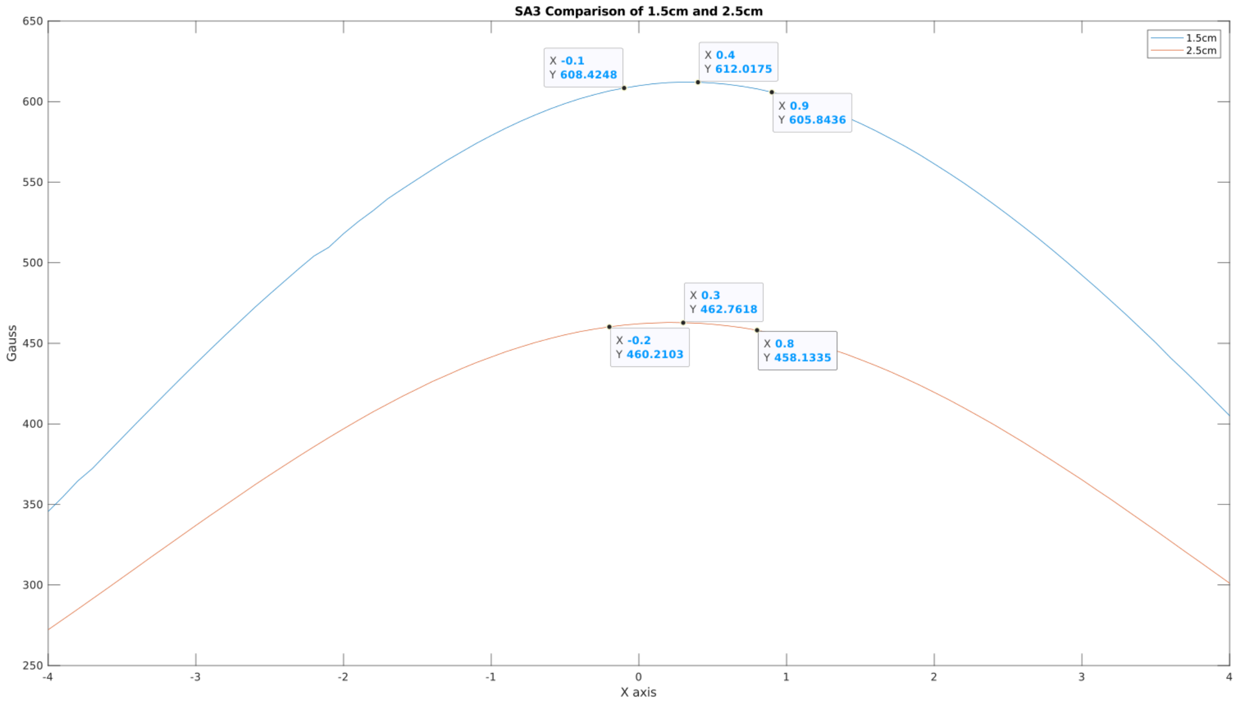

Figure 2: This is a plot of the magnitude of magnetic field in gauss, of the SA3 magnet as a function of X (the flow direction). The red line represents the plot for a height of 2.5cm, and the blue plot represents the plot for a height of 1.5cm. Through this it can be seen that the variation in the gradients strength changes very little with small variations in X position.

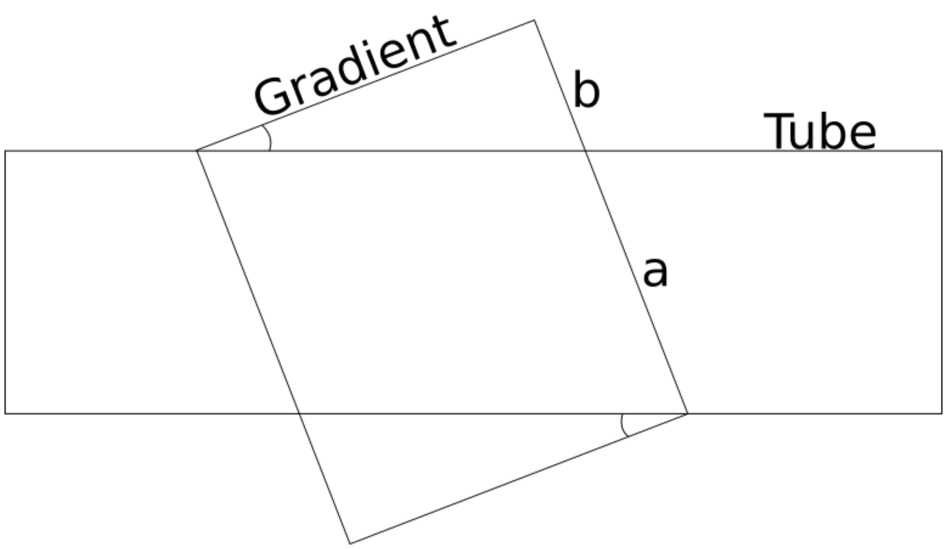

Figure 3: This diagram represents valid gradient region that will be tilted at an angle.

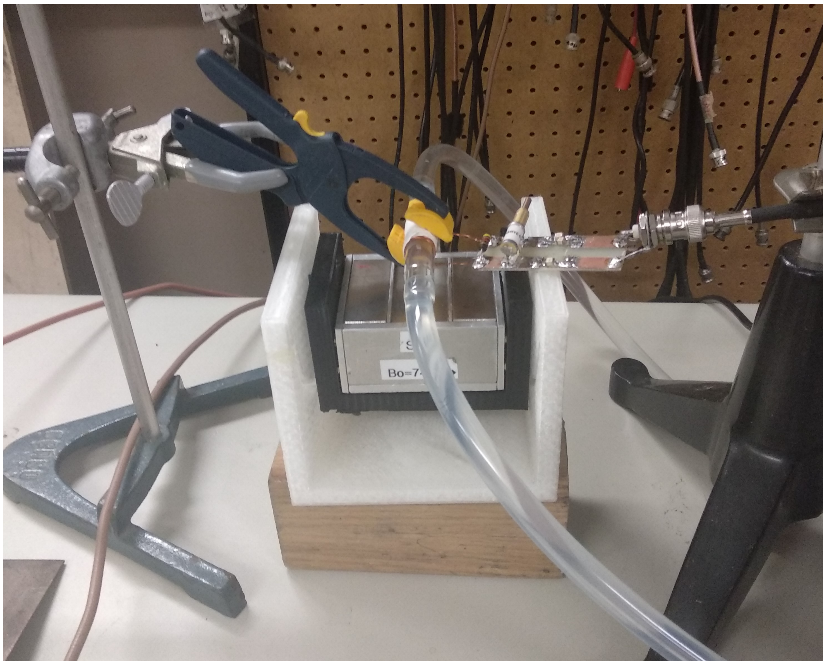

Figure 4: Image of the SA3 mount setup.

3.3 Flow Rig

The "Diener Gear Pump 1500ml/min" pump was used to circulate MnSO4 doped water through the probe. The flow velocity can be calculated by the following equation:

$$FlowVelocity(ml/min) = \frac{Frequency \times 15}{2} \tag{3}$$

The frequency can be determined by attaching an oscilloscope to the BNC connector on the pump, label as Speed Monitor. It should be noted that the frequency displayed on the oscilloscope varies by approximately 5 percent as it fluctuates.

The tube that feeds water into the probes coil is connected to a piece of glass that can slide into the Plexiglas cylinder. The glass has an inner diameter of 6.6mm, and an outer diameter of 10mm. The Plexiglas that surrounds the glass tube (and keeps the RF probes structure) has an inner diameter of 11mm, and an outer diameter of 12.7mm. On the other end of the glass tube, the plastic tubing is connected and fed into a bucket containing the water sample.

4 Construction of 2.26MHz Capacitively Matched RF Probe

Building the probe proved to be quite a challenge, as early complications with its construction encouraged the probe to be inductively matched, rather than capacitevly. Previous inductively matched probes have been used for fluid flow measurements at 33.1MHz. However, with an inductively matched probe, getting to 2.26Mhz proves to be near impossible. The lowest frequency achieved was roughly 8Mhz. To go beyond that would take an inductor which seemingly destroyed the matching entirely. Later on in the probes construction it was discovered that the most likely problem with the capacitevly matched probe was that the Q was too high, and had problems with ring-down. So to decrease the Q from 100 to 20, a resistor of 4.3kΩ was used. The circuit diagram in Figure 5 describes how the capacitevly matched probe was constructed.

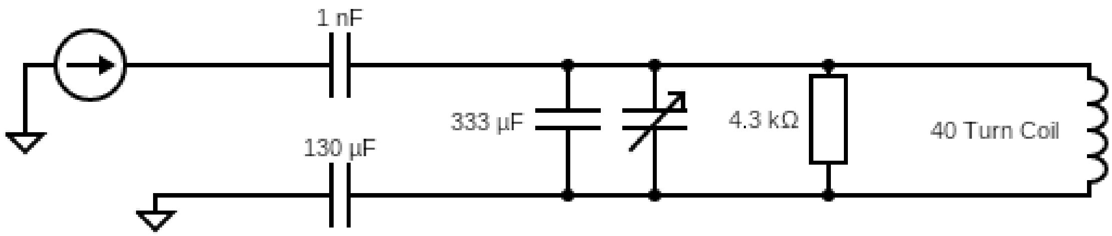

Figure 5: Circuit diagram of the RF probe.

The 40 turn coil had a height of 2.6 cm, and diameter of 1.27 cm. When building a probe, these would all be very important quantities to know since it will influence the strength of the magnetic field. This would in turn influence the pulse width to get a 90 degree tip angle. The coil was wrapped around a Plexiglas former which has an inner diameter of 11 mm, and an outer diameter of 12.7 mm. The length of the Plexiglas tube is not arbitrary, as a second glass tube till be slid into the Plexiglas former. Since the flow setup is going to be attached to the glass tube, be certain that the glass has a longer length than the Plexiglas.

5 Settings for TNMR

5.1 General Parameters

By using a sample of water that is doped, the delay time can be greatly decreased. Since many scans are needed to get acceptable signal, it would be appropriate to dope the water in order to decrease the delay time. With 0.1mM MnSO4 doped water, a delay time of 0.1 second was used.

It was also noted that with a tau time of 80us there seemed to be no difference between flow data and stationary data. By increasing tau to a range between 200us and 3000us, it was noted that the signal changed to indicate that flow was present (”indicate that flow was present” simply means that each second echo had a greatly decreased amplitude).

ACQUISITION	———
Observe Freq.	2.26MHz
Dwell Time	2u
Last Delay	0.1s
SEQUENCE	———
pw	4.1us (With 27dB of attenuation)
tau1	=[tau]-[pw]-5u
tau2	=[tau]-[pw]-[Acq. Time]/2+[rtd]
Acq. Time	64u
Last Delay	0.1s
tau	80

6 Useful Equations

$$B_1 \approx 3\sqrt{\frac{PQ}{Vf_0}} \tag{4}$$

$$Q = 2\frac{f_0}{f_2 - f_1} \tag{5}$$

$$\theta = B_1 t_p \gamma \tag{6}$$

$$attenuation(db) = 10log(\frac{P_1}{P_2}) \tag{7}$$