Some Questionably Useful Comments on the Requirements for a Magnet Power Supply for G_E^n

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Abstract

To make a long story short, I think that the Agilent 6675A should be okay for G_E^n as long as you don't need to rotate the field or change the polarity of the field.

1 Old Requirements

Traditionally a power supply (PS) is used to power a pair of Helmholtz (HH) coils. In the past, from my understanding, these HH coils in conjunction with the PS had to perform the following tasks:

1. Generate a "stable" holding field ≈ 25 G
2. Provide a linear sweep of output current controlled by a linear input voltage sweep over two ranges of field (for water and ^{3}He)
3. Be smoothly variable from positive to zero to negative output current and vice versa in order to rotate the main holding field
4. Be "stable" during a ^{3}He NMR polarization measurement
5. Be "stable" during a ^{3}He EPR polarization measurement
6. Be "stable" during a ^{1}H NMR polarization measurement

2 New Requirements

I am assuming that for G_E^n NMR will be performed using a frequency sweep and that the field angle and magnitude will never be varied. If this is the case, then the ability for the power supply to react to a changing input control voltage is greatly reduced. Therefore all "dynamic specifications" for the power supply (such as bandwidth, slew rate, rise time, and fall time) are more or less irrelevant. This reduces the requirements for a G_E^n power supply to

1. Generate a "stable" holding field ≈ 25 G
2. Be "stable" during a ^{3}He NMR polarization measurement
3. Be "stable" during a ^{3}He EPR polarization measurement
4. Be "stable" during a ^{1}H NMR polarization measurement

In each case, "stable" refers to the root mean square (RMS) variation of the power supply output current over some relevant time scale. I will refer to the RMS power supply output current as "current jitter." I will try to estimate our sensitivity to current jitter as best as I can, but when all else fails, we can compare the specs for the Agilent 6675A against the Kepco BOP 36-12M (which is what we use for the HH coils). I do this in table (1)

Specification	Agilent 6675A	Kepco 36-12M
Power	2000 W	400 W
Output Voltage	0–120 V	±36 V
Output Current	0–18 A	±12 A
Noise Bandwidth	20 Hz to 20 MHz	20 Hz to 10 MHz
Noise V_{rms}	1.9 mV	typ < 1 mV, max = 3 mV
Noise V_{pp}	16 mV	typ < 10 mV, max = 30 mV
Noise I_{rms}	12 mA	typ < 1.2 mA, max = 3.6 mA
Drift Bandwidth	DC to 20 Hz	DC to 20 Hz
Drift (over 8 hrs) Voltage	3.6 mV + 0.02%$\cdot V$	typ < 1.8 mV, max = 3.6 mV
Drift (over 8 hrs) Current	6.0 mA + 0.02%$\cdot I$	typ < 1.2 mA, max = 2.4 mA
Temperature-Voltage (per 1^{o}C)	2.4 mV + 50 ppm	typ < 1.8 mV, max = 3.6 mV
Temperature-Current (per 1^{o}C)	2.0 mV + 75 ppm	typ < 1.2 mV, max = 2.4 mA

Table 1: Aglient numbers are quoted from the manual. Kepco numbers are quoted from the catalog.

3 Polarimetry Requirements

I have no idea how the current jitter affects the orientation of the target spin angle, so I won't comment on it. The drift specs for the two power supplies are comparable, so I'm not worried (with respect to target depolarization) about the field drifting during the experiment.

For EPR, the output current jitter translates into noise in the EPR frequency of the alkali metal atom. The absolute size of the holding field jitter is proportional to the relative current jitter:

$$\sigma_B = B_0 \frac{\sigma_I}{I} \tag{1}$$

assuming that the field and current are proportional. This can be converted into absolute EPR frequency jitter (at low field, $B \ll 0.1$ T) by:

$$\sigma_\nu = \sigma_B \frac{\partial \nu}{\partial B} \tag{2}$$

where at $B_0 = 25$ G:

$$\begin{aligned}
\frac{\partial \nu}{\partial B} &= 485\ \frac{\text{kHz}}{\text{G}}\ \left(\text{for } ^{85}\text{Rb}, m_J = -3 \leftrightarrow -2\right) && (3)\\
&= 449\ \frac{\text{kHz}}{\text{G}}\ \left(\text{for } ^{85}\text{Rb}, m_J = +2 \leftrightarrow +3\right) && (4)\\
&= 878\ \frac{\text{kHz}}{\text{G}}\ \left(\text{for } ^{39}\text{K}, m_J = -2 \leftrightarrow -1\right) && (5)\\
&= 558\ \frac{\text{kHz}}{\text{G}}\ \left(\text{for } ^{39}\text{K}, m_J = +1 \leftrightarrow +2\right) && (6)
\end{aligned}$$

Typical EPR shifts (relative to the zero-field value) for a large pumping chamber G_E^n style cell operated at ≈ 250 ^{o}C with about 30% polarization are $\Delta\nu = 16$ kHz, 15 kHz, 28 kHz, and 18 kHz depending on the alkali metal and the transition. Our relative EPR frequency jitter due to power supply current jitter under these conditions would be:

$$\frac{\sigma_\nu}{\Delta\nu} \approx 800 \frac{\sigma_I}{I} \tag{7}$$

I don't know what voltage you would run the G_E^n power supply at. For the JLab HH coils, assuming they have a resistance that is close to what we have ($R \approx 3\ \Omega$), the voltage is about 24 V. Using the maximum V_{rms} noise for the Kepco, I estimate that the relative current jitter is about:

$$\frac{V_{rms}}{V} \approx \frac{\sigma_I}{I} \approx \frac{3\text{ mV}}{24\text{ V}} = 0.0125\% \tag{8}$$

This gives a relative frequency jitter of about 10%. In absolute terms, this conservative estimate gives about 1–2 kHz, which is larger than but on order of the kind of frequency jitter that I recall seeing at JLab. Note that the final statistical uncertainty is much lower than this because of averaging.

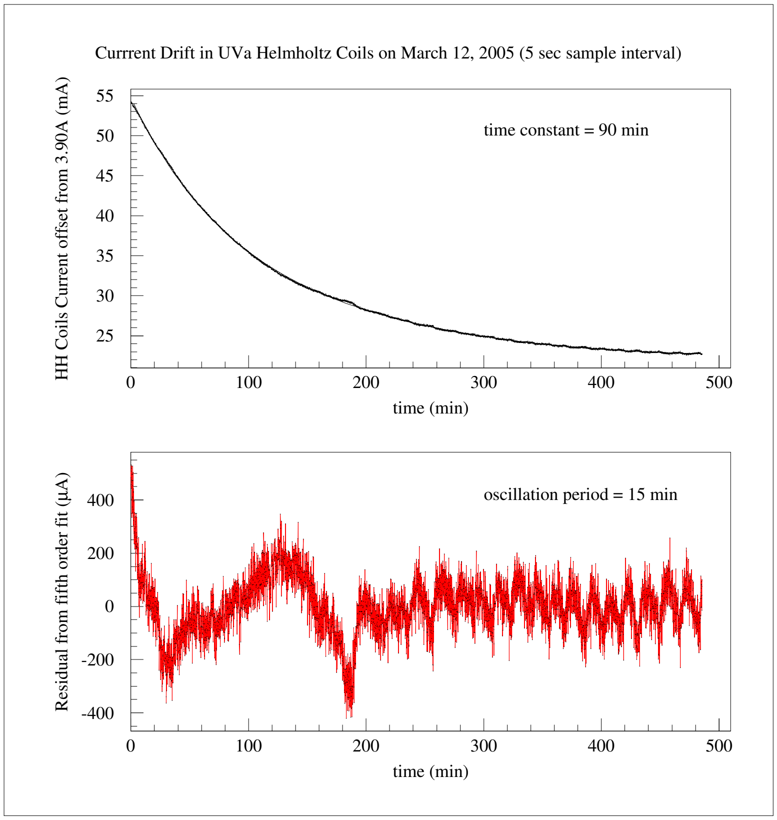

Figure 1: This is typical behaviour of our KEPCO (72-6M) which is in the same family as the KEPCO used at JLab (36-12M). I set the current to 3.95 A, which corresponds to a field of about 12.95 G. At $t = 0$, the KEPCO is turned on after being off for a long time. We run in constant voltage mode. This means that as the coils warm up, the resistance increases, and consequently the current must decrease. The current eventually stabilizes at about a percent less than the original current with a time constant of about 90 min. The fit is an exponential added to a 5th order polynomial. Note the weird things in the residual.

As for NMR, I am not at all worried about the field drifting during a single NMR measurement. However, for multiple successive NMR measurements over a long period of time (water calibration), a drift in the field could result in an artificially broadened averaged signal. This is only true if the drift in the field is not removed by actually measuring the field during each NMR measurement. Traditionally the field is measured and it has been taken into account in past water analyses. I'm not worried about it too much because the level of drift according to the specs is at the hundreds of ppm level.

4 UVa HH Coil Performance

The HH coils and KEPCO (BOP 72-6M) in our lab drifts on a day to day basis (peak to peak) on order of a percent and (rms) on order of a tenth of a percent, fig 1. Our KEPCO does weird things at a level of ppm over a time scale of minutes. These weird things include but are not limited to oscillations with a period of minutes. I'm not worried about a field drift even at the levels that I've measured in our lab.