Brief Instructions for EPR Measurement

M. Liang

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EPR measurement is the alternative way to measure the polarization of the polarized ${}^3\vec{H}e$ target. The polarized ${}^3\vec{H}e$ will shift the frequency of the Rb Zeeman resonance due to the magnetic field it creates and the Rb-^{3}He spin-exchange. By measuring the frequency shift of the Zeeman resonance of the Rb atom, we measure the absolute polarization of the target.

During experiment E94-010, we inteneded to use NMR measurement for regular target polarization monitoring. Since NMR gives only the relative measurement, it needs to be calibrated against either water signal or EPR measurement. Therefore EPR measurement will be performed in a less frequent basis ($\sim$ once every two, three days?) and will serve as cross check for the polarization measurement.

Based on this consideration and also due to the difficulty and time constrain in the design of the radiation shielding for certain parts needed for EPR measurement, we decided that the photodiode and the fluxgate magnetometer sensor will only be put in place prior to the measurement and be taken out immediately afterwards to limit the radiation damage to them. Therefore we will require access prior to the EPR measurement to put the photodiode in the tube above the target, which has a removable cover where the photodiode and the D2 filter will be attached. The fluxgate magnetometer sensor will be put in the holder located under the target ladder and on the upstream side of the beam line.

Following is the simplified procedure to follow when doing the EPR measurement. Note that here I have assumed most of the equipments have already been setup, except few things I outlined below in detail which requires additional work.

1. Access to the hall:
   Asking MCC for controlled access if the hall is in the beam permit mode, asking for RADCON assistance had the hall not been surveyd after beam being delivered in the hall. Check the things needed: photodiode, D2 filter, fluxgate magnetometer sensor and a scope if you

are going to do the field feedback. Following the general procedure of access to the hall.

2. Install the photodiode and D2 filter:

   (a) Find the black cover with the photodiode holder attached inside. Separate the two-pieced holder, put in the photodiode with the sensor facing outside and the end with the BNC connector stick out through the small hole of the big piece. Put in the D2 filter on top of the sensor and then the cover piece. Screw them together.

   (b) Wear the ear plug, (and the face masker if the target chamber is open) before get close to the target area. Pay attention to the yellow band which marks the boundary of the radiation area. In case of any doubt, consult the RADCON.

   (c) Get a stool if you are not tall enough to reach the pipe on top of the target. Replace the black conver with the one in which the photodiode was installed, connect the BNC cable nearby to the BNC connector of the photodiode, make sure the cable extends out from the hole on the back of the black cover. Check the pipe is covered properly.

3. Install the Fluxgate Magnetometer Sensor if field feedback is needed: If you are not going to use the field feedback, skip the following and step 5.

   The field feedback system includes Fluxgate Magenetometer (power supply, sensor), compensate coil, stable DC power supply to compensate coil, and a field feedback box connect these to the main power supply. Since we decided to do EPR only once in a couple of days, and the field feedback is only needed during the EPR measurement, we will put the sensor in prior to the EPR measurement. This however adds to the overhead of installing and retunning the feedback system. Following is the suggested procedures:

   (a) Before access to the hall, tune the current of the stable DC power supply to the compensate coil to around 150 mA. Make sure that you are in the constant current mode (the ***cc*** indicator should be lit). This is because when you adjust the sensor of the fluxgate magenetometer in the hall, it will be easier that you already have some compensate field and you don't have to readjust it due to the change of the compensate field. Remember we are trying to measure the small change in the field, typically $<10^{-3}$. This will be obvious once we subtract the main compenent. Make sure that the Fluxgate Magnetometer power supply has been turned off.

(b) Find the sensor holder located below the target chamber and towards the upstream side of the beam line. You should find a cable with Hirose connector nearby. Connect it to the end of the sensor, tighten it up. The holder is on a rotatable plate, has compensate coil wired to one end with a hole in the middle of the coil and another small piece of plate with similar size of the hole in the middle. You should stick the sensor through the holes, stop inside the coil, once you felt the stopper, align it such that the z-axis indicator on the sensor is on the top (there is a scratch mark on the side of the coil).

(c) Call Counting House to ask somebody else to turn on the Fluxgate Magnetometer power supply. Thre is a BNC cable near by which is connected to the Vx output of the power supply. Connect it to the scope, set the scope to ***ground*** and find the ground level, then set the scope to ***DC***. Hold one end of the sensor and rotate it a little around the sensor z-axis, you should see the DC level change. Keep adjusting it until you find the position corresponds to minimum DC level on the scope, i.e. minimum Vx . Then tighten the screw on top of the small plate holding the sensor. Typically you should be able to get Vx to be less than $100mV$.

(d) You may want to rotate the whole holder horizontally, especially if you couldn't adjust the Vx to the range mentioned before. There is a screw underneath the holder (you have to stick your hand beneath to feel it). Loosen the screw and you can rotate the plate within small range. If you need a bigger adjustment, unscrew the screw completely, lift the whole plate up and rotate it and put it down. Put the screw back to the corresponding hole. Again watching the scope DC level when you do your adjustment.

4. Check photodiode signal:
   In the counting house, use the scope to check the photodiode signal.

   (a) Disconnect the input to the Lock-In Amplifier and connect it to the scope. You should see $\geq 150mV$ DC signal on the scope. If the signal is smaller and you have hard time to lock the signal later, you may need to check whether the photodiode is OK or whether there is any other problem such as the position of the photodiode, the mirrors, or the focussing of the lense.

(b) Connect the cable back to the Lock-In input.

5. Field Feedback system setup:
   Only the part of the procedure requires your assistence to complete the field feedback loop is presented here. Please follow strictly, since otherwise you may destroy the polarization without notice. Call me if you have any problem or question. Now you should have completed the step 3c. Skip to step 6 if the field feedback is not required.

   (a) Adjust the current of the DC power supply for the compensate coil: In the EPR electronics rack, connect one teed output V_z of the fluxgate magnetometer power supply to the scope, set the scope in DC mode and watching the level change when increasing the current of the DC power supply connected with the compensate coil for the sensor. Change the scale when the DC level is getting close to zero. The output of the fluxgate magnetometer is less than $10V$, and the goal is to adjust the current such that the V_z output is as close to zero as possible.

   (b) Connect one teed V_x output to scope for a check. It should be roughly the one you saw in the hall, see 3c, if it changed a lot, you may need to go into the hall again to readjust the sensor as mentioned before.

   (c) The outputs V_x, V_z from the fluxgate magnetometer power supply should be already connected to the field feedback circuit, which is located in the middle of the NMR electronics rack. There should be six cables connected: four inputs and two outputs. **DO NOT DISCONNECT ANY OF THESE CABLES.** There are seven switches on the front panel of the field feedback box. Check the most left one labelled ***(bypass, active)*** should be in the ***bypass*** mode. If there is any doubt, please page me at 849 7617. Do not touch any of these switches if you are not instructed to.

   (d) There are nine test points and eight hidden adjustment screws on the front panel as well. Use a banana ended cable to connect the ***com*** to the ***ground*** of high resolution HP multimeter. Use another cable to connect the Multimeter V input to one of the test points: ***Xoffset, Yoffset,*** depending on which offsets you are adjusting. There is a small pencil-like screw driver nearby which is used to adjust those hidden screws. Set the multimeter in ***DC, Voltage*** mode, and adjust the screws for ***Xoffset (Yoffset)*** until the test point ***Xoffset (Yoffset)*** readout closest to zero. Normally, you should be able to adjust them within few mV.

(e) Flip the ***(bypass, active)*** switch to ***active*** mode. Watching the KEPCO power supply while you are doing it. You are not expected to see any major change in either current or voltage displays of both KEPCO power supplies. As a matter of fact, you should not see any change at all, since the correction is expected so small that the resolution of the KEPCO display won't be able to distinguish them. If you do see some noticeable changes, flip the switch back to ***bypass*** mode. Check the offsets again, or you can page me.

6. EPR measurement:
   Go to Mac, use the mouse to click the Apple sign on the top left corner and select **EPR Master.** This should start the main program for EPR measurement. It consists several programs written for differenet purposes. For those who knows how to lock the signal and just wanted to do a AFP spin flip, go to step 6c.
   If you are not expert in searching for the resonance line of Rb, following the steps outlined below:

   (a) Frequency Modulation (**FM**) sweep:
   Use FM to find the frequency of the Rb Zeeman resonance. FM scans in frequency and measures the derivative of the Rb lineshape as function of the EPR RF frequency.

      i. Disconnect the cable to the V_{in} input of PI-feedback circuit. This is to disable the feedback of the EPR circuit.
      ii. Click the button next to FM option in **EPR Master** program. Follow the instructions/messages of the program. Had you changed any cable connections for FM sweep, remember to change it back when you finish.
      iii. Changes the parameters to suit your need. If you don't have any idea where the frequency might be, try this: The central frequency f_0 can be calculated from the main holding field B_0,

$$f_0(MHz) = 0.4667 * B_0(Gauss)$$

      and you could try to scan from $f_0 - \Delta f$ to $f_0 + \Delta f$ with $\Delta f = 500kHz$. Note that you may only read the data every $0.5 - 1sec$, therefore the length of the sweep time will decide what resolution you will get. As an example, if you read the data every 1 second, to sweep the total frequency range of 1 MHz over 200 *sec*, you will have data in about 5 kHz step.

iv. Click on ***Update parameters?*** once you are ready, check for messages in ***Status***. After you see the message *waitting for trigger ...* , click on button ***Sweep Trigger*** to ***Start.***

v. When the sweep is complete, you will have a graph of the derivative of the lineshape as function of the sweep frequency displayed in the bottom graph labelled *Lock-in vs. Frequency (Hz)*. You are expected to see a dip and a peak (or a peak and a dip, depending on the phase) next to each other, between them there is a frequency corresponding to lock-in readout (or derivative) *zero*. This is the resonance frequency you are looking for. When you are doing the feedback, you should adjust the carrier frequency anywhere between the dip and the peak, but not at the resonance frequency, since you need the non-zero lock-in readout signal to check whether the feedback is working properly or not.

vi. Once you decided that you find the resonance frequeny, click on ***Return to Main Menu*** button to go back to **EPR Master** main panel. Change the cable connections back. Make log entry, write down the filename, and the resonance frequency.

(b) Lock-in and Feedback:
This is a very important step before you start actual measurement. You may need to repeat few steps outlined below several times to get the desired results.

i. Check cable connections before you start. In particular, the cable to V_{in} input of PI-feedback box should still be disconnected; the wavetek 80 output should be connected with a cable to EPR RF coil, and if it's not, make sure that you set wavetek 80 output in *standby* mode before you make the connection; The sync output of the wavetek 80 should be connected to the Counter input.

ii. Check the parameters set for Wavetek 80: Modulation input mode in ***VCO*** ; Function in ***FUNC*** ; The offset should be at zero; The amplitude is typically between $10 - 16Volts$, we normally use $16Volts$; The frequency should be close but not at the resonance frequency, there will be fine tunning of the frequency outlined at next step. Enable the output of Wavetek, if it is in ***standby*** mode.

iii. You may wish to play with few parameters with the Lock-In Amplifier: the phase, TC, gain or input limit, the sensitivity, etc. Few tips here: the time constant (TC) should be such that it's short but you don't see the fast fluctuation of the output signal; The sensitivity should also be small (in value) but make sure that the output signal doesn't jump around; the gain (or the input limit) should also be set small as far as you don't see the overload sign. The good check of all these parameters is to set the Wavetek 80 carrier frequency near the resonance, see information in 6(a)v, where it's relative easy to lock and it should give a steady non-zero readout. You can also scan the frequency of Wavetek in the last digit to see the change in the output in both the amplitude and the sign (equivalent to what you did in 6a). If you cannot get steady lock at big signal, check or replay your parameters again.

iv. Turn PI-feedback integration switch to ***off***, check the output $Vout$ signal on scope with only $Vmod$ input. Set the scope in DC mode, you should see the nice sine wave centered at zero. If you see either saturation or the sine wave centered at non-zero, adjust the two screws labelled ***absolute gain*** and ***relative gain***. Set Wavetek 80 frequency to near the resonance, where you see small but non-zero lock-in signal. Connect the Lock-in output to V_{in} input of PI-feedback box, check the $Vout$ on scope again, it should still show a nice sine wave. Turn the integration switch of PI-Feedback to ***on***, you may see the jump of the signal. But you should also see the Lock-In signal go to zero, or much smaller than before. Again check the signal on scope, it should be a nice sine wave centered around zero. Any deviations, try to readjust the screws. *Bottom line: when turn on the integration, the lock-in signal should go to zero.* This is the indication whether the PI-feedback is working or not.

v. Once the signal is locked, the frequency you are reading in the counter is the one you are measuring. By recoding this frequency over long time period, you can either monitor the polarization change or measure the pump-up curve, provided that you have a stable main field. Bear in mind that this frequency is the results of combination of both the field and the polarization. And one way to stabilize the main field is to use the field feedback system. A nice way to cancel the field contribution is to flip the ^{3}He spin direction, so only the polarization contributes to the frequency measured, see 6c.

You can record the frequency by clicking on the switch next to the option in **EPR Master**. Either **Counter Readout** or **Lockin & Counter** or **AFP Spin Flip** should do the job. The **Counter Readout** and **Lockin & Counter** both record the frequency, with later records the Lock-in output as well, which has the advantage of monitoring the lock-in signal. The trade-off is the slower data reading. You may want to do this to monitor the frequency change, or to measure the pump-up curve, if the holding field is stable.

vi. You can also use **AFP Spin Flip** to record frequency, but it's not recommended unless you are ready to do AFP spin flip.

(c) AFP spin flip:
The AFP spin flip for EPR is different than for NMR, althogh both are used to flip the spin of ^{3}He. In EPR, we sweep the frequency of the RF coil at constant main field, whereas during NMR, the RF frequency is kept constant and the main field is swept.

i. Due to the particular setup we have right now, we need to skip the capacitor used to enhance the RF field downstairs for NMR measurement. First check the HP Function Generator 3324A, used for RF frequency sweep, if it is not in the condition/parameters described, set it so and in the following order: it should be on already; it should be in ***local*** mode; the amplitude should be $0.4mVrms$; and turn off the signal output (***signal off***): if the light indicator above the output is green, the signal output is enabled, otherwise it's off. Then connect the input and output to the capacitor together with a barrel, i.e. skip the capacitor.

ii. Click the button next to **AFP Spin Flip** option to start the **AFP** program. Follow the instructions in the program. Select the ***Auto*** or ***Manual*** sweep mode. In the ***Auto*** mode, when you click on ***Start Sweep*** button, it will automatically complete the number of cycles of sweeping frequency up and down. In the ***Manual*** mode, every time you click on the ***Start Sweep*** button, it will sweep the frequency up or down, depending on where it was before. Set the parameters for sweep, click ***download parameter*** button. The ***download parameter*** button **only** need to be pushed if you changed the parameters, otherwise the change will not be made. Switch **(*pause, run*)** button to ***run***, it will start to record the data. Wait for few seconds before you start AFP sweep, so you know where you are. Click on ***Start Sweep*** when you are ready to sweep the RF frequency.

iii. You will see the jump of the Counter frequency when RF frequency start to sweep up or down (or in another word, the spin flips). The difference of the frequency between the spin flip states $\Delta\nu$ is propotional to the polarization P_{He} of $\overrightarrow{3He}$:

$$\Delta\nu = 2 * P_{He} * c$$

where $c \sim 1kHz/\%$.

Pay attention to the lower plot which records the lock-in signal. You may see a spike during the sweep, which is normal. But if the lock-in signal doesn't go back to where it was after the frequency sweep (you can tell when the counter frequency flats out), then you should stop the data taking by clicking **(*pause, run*)** button to ***pause***. Go back to check your lock-in and feedback box as the procedure outlined in 6b.

iv. After AFP measurement, make sure that HP Function Generator for RF coil is left at amplitude of $0.4mVrms$. If not, set to *local* mode first, then press *amplitude* button, give the above voltage number. You should also reconnect the capacitor you just bypassed for EPR measurement, once you are done AFP EPR.

v. Make entry in the logbook, write down the data filename and the frequency shift (difference) between the two spin flip states.

7. Access to the hall to retrieve the equipment:
Asking for access to the hall again, to take out the photodiode, flux-gate magnetometer sensor, scope etc, which you brought in at step 1. It should be straight forward. Note that had any of the items been exposed to the beam, you are not allowed to take them out without certification of the RADCON group.

Please be organized and careful about the instruments you are handling. Any thing you take out should be put back in place, except you are told otherwise.