Towards a Primary Quantum Rotation Standard: Co-Magnetometry with Transversely Polarized Xe

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NMR Gyros (NMRG) have enabled many precision “null” measurements, e.g., upper-bounds on Lorenz violations and dark matter candidates, as well as precision rotation measurements. Next generation experiments require further reduction of systematic errors and, for applications, high detection bandwidth. An ideal primary quantum rotation standard has a unity scale factor (no need to calibrate!), no dead time, and suppresses the leading systematic errors. We are developing a new NMRG that meets these criteria.

Longitudinally spin-exchange pumped NMRG (pump light polarization and bias field oriented parallel to one another) have demonstrated continuous unity scale factor inertial sensing with a bandwidth approaching the NMR frequency [1]. An important systematic error in longitudinally pumped NMRG is the Rb spin-exchange field. This field can shift the resonance frequency by tens of linewidths and depends on cell temperature as well as pump laser power and detuning. We mitigate this effect by pumping the Xe nuclei transverse to the bias field using collisions with synchronously polarized Rb atoms.

We achieve synchronization of the transversely polarized Rb and Xe spins by applying the longitudinal NMR bias field as a sequence of $2\pi$ pulses. Each pulse, a few $\mu$s in duration, causes the Rb electrons to precess $2\pi$ radians and the Xe nuclei to precess only a few milliradians. Resonant spin-exchange occurs when the polarization of the Rb atoms is modulated via optical pumping at the Xe NMR frequency, which is set by the time-averaged pulsed bias field magnitude. For kHz repetition rates and $\sim$1% duty cycle pulsing, the Rb doubles as a SERF magnetometer enabling spin-exchange–enhanced detection of the Xe precession. The precessing Xe field is on the order of 100 $\mu$G and the spin-exchange field is suppressed at least 2500x [2].

We have extended these ideas to simultaneous dual Xe isotope excitation. One isotope is used to stabilize the magnetic field while the other isotope is used as a probe for rotations or other spin dependent interactions. We simultaneously excite $^{131}$Xe and $^{129}$Xe with 50% efficiency (compared with single species excitation) using optimized polarization-modulated pumping waveforms. Lock-in detection is used to measure each isotope’s phase.

The performance of bias field stabilization using one of the isotopes is shown in Fig. 1. Bias field feedback reduces the baseband magnetic field fluctuations by more than 100x to our technical noise floor. After 700 seconds of integration we measure a rotation bias instability of 770 nHz. We note that these results were obtained without any other form of feedback (both pump and probe lasers are free running DFB diodes without optical isolators, the 3-axis shim coils and pulsed bias field are set by hand without active stabilization). Future work includes further reducing technical noise sources and then using the device to measure earth’s rotation as well as set new limits on scalar-pseudoscalar couplings. This work is funded by the US National Science Foundation and Northrop-Grumman Corporation.


Oral Presentation