^{3}He-^{129}Xe NMR Gyro with ^{87}Rb decoupled SERF detection

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We aim to decrease the long-term bias drift and increase the sensitivity of a ^{129}Xe-^{3}He NMR gyro using direct ^{87}Rb detection [1-4]. Our gyro in Fig. 1 uses two spin-1/2 noble gas species, ^{129}Xe and ^{3}He, that each measure the same magnetic field in the same volume, operating as a co-magnetometer and resulting in a measurement that is independent of any external static magnetic fields. A bias field of B_z ~ 0.5 μT results in a detected frequency ratio of $(\omega_{He}+\Omega)/(\omega_{Xe}+\Omega)$, where Ω is a rotation of the apparatus about the z axis; in this way, we can use our technique to create a gyroscope for inertial navigation systems. If apparatus is kept completely still and all systematics are accounted for, a deviation of the frequency ratio from γ_{He}/γ_{Xe} would indicate the ^{129}Xe and ^{3}He nuclei undergoing exotic spin couplings, e.g., a coupling to a gravitational field.

Spin-1/2 noble-gas nuclei have the benefits of long coherence times and high magnetic-field sensitivity. The nuclear-spin shot noise can be achieved if an alkali-metal vapor, such as ^{87}Rb, serves as the magnetometer for the spin-1/2 noble gas baths. This is a result of a Fermi-contact interaction causing an enhanced magnetic field over the classical dipolar field generated by the noble-gas nuclei, characterized by a factor $\boldsymbol{\kappa}_0$ that is ~6 for ^{87}Rb-^{3}He and ~490 for ^{87}Rb-^{129}Xe. While this enhancement improves the ability of the ^{87}Rb magnetometer to detect the noble gases, the ~10^2 difference in $\boldsymbol{\kappa}_0$ causes fields experienced by the ^{3}He and ^{129}Xe due to polarized ^{87}Rb to be significantly different, leading to long-term bias drift instability in the NMR gyro.

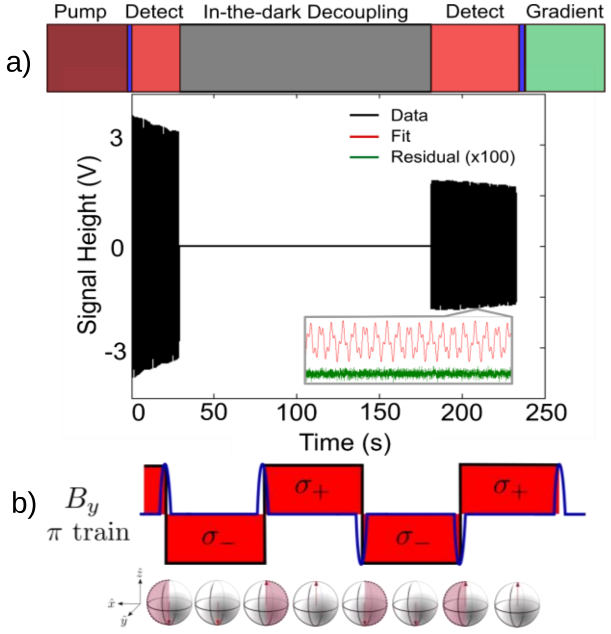

Figure 2. a) NMR gyro data taken using the Ramsey technique described above. ^{129}Xe and ^{3}He are detected via a ^{87}Rb decoupled SERF magnetometer. b) A B_y π pulse train causes ^{87}Rb to be sensitive to fields along the y axis and be decoupled from B_z,

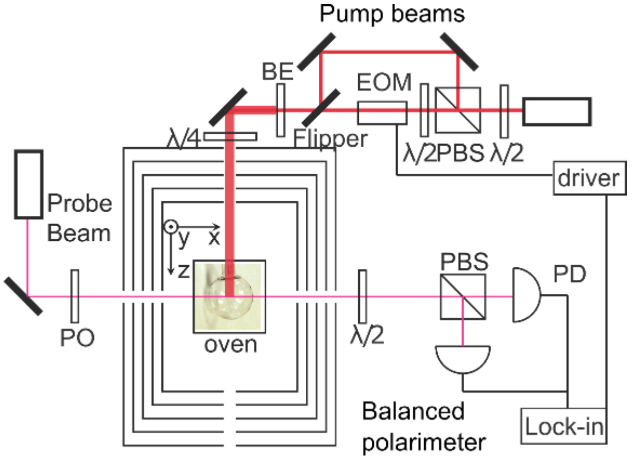

Figure 1. ^{3}He/^{129}Xe is hyperpolarized along B_z. The ^{3}He/^{129}Xe is then placed in the transverse plane, and operates as a co-magnetometer. An EOM for fast σ_+-σ_- switching is used in conjunction with a sequence of ^{87}Rb $\pi_{\pm y}$ pulses, causing ^{87}Rb to be decoupled from B_z, and hence for spin-exchange relaxation free (SERF) operation [2]. The precessing ^{3}He/^{129}Xe causes an over- or under-rotation of the ^{87}Rb during a π pulse, resulting in a projection of ^{87}Rb along x. An off-resonant probe beam and balanced polarimeter is used for Faraday detection of this projection, and fed to a lock-in.

To remove the effect of $\boldsymbol{\kappa}_0$ on the noble gas precession, co-magnetometer phase accumulation can be performed "in-the-dark" without optically pumping the alkali-metal vapor (shown in Fig. 2). However, even in-the-dark, the ^{87}Rb is "backpolarized" by the ^{129}Xe, so the ^{87}Rb-^{129}Xe interaction must be actively decoupled or else ^{87}Rb polarization instabilities manifest and cause uncontrolled noble-gas frequency shifts. During the in-the-dark evolution, we use fast repetition ^{87}Rb π pulses to decouple ^{87}Rb-^{129}Xe interaction by a factor of 10^4. We are also able to rotate the ^{87}Rb π pulses at a frequency that is the sum of the ^{129}Xe and ^{3}He precession frequencies, in order to null out the effect of the π pulses on the ^{129}Xe and ^{3}He frequency ratio.

Our ^{87}Rb decoupled SERF magnetometer has a sensitivity of 40 fT/sqrt(Hz). The decoupling techniques described herein have produced an NMR gyro with a single-shot resolution of ~20 nHz and achieved a long-term bias drift of ~7.7 nHz at 7 h.

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References:

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