Reduction of Low-Frequency Temporal Field Fluctuations in Powered Magnets

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Introduction

Powered magnets such as the 25 T Keck and the 36 T series-connected-hybrid (SCH) require cooling systems that introduce undesirable low-frequency field fluctuations in the magnetic field [1]. It is desirable to use field frequency lock (FFL) technology designed for compensating the slow-drift observed in permanent and self-persistent magnets, as it is well developed and readily available. Surprisingly, this well-known technique is not effective for powered magnets, and this work aims to understand why this is the case.

The most common FFL technique assumes that the dispersion component of the NMR measurement is directly proportional to the undesirable field drift. The FFL cancels the magnetic field drift by generating a magnetic field that drives the dispersion component to zero. A first principle analysis reveals that the dispersion component is proportional to the field disturbance only when the time-scale of the field fluctuations is significantly larger than the spin-lattice relaxation constant (T_1) of the lock sample. This assumption holds in all self-persistent magnets and many permanent magnet systems, but not in powered magnets. In the latter case, where field fluctuations occur on a time scale close to, or shorter than, T_1, the dispersion signal becomes a dynamic, nonlinear function of the field fluctuation. As a result, the FFL compensation signal does not cancel the temporal field fluctuation. This reasoning leads to the hypothesis that the conventional FFL approach is only applicable when the time-scale of the field fluctuations is much larger than T_1.

Experimental

We test our hypothesis using the NHMFL 800 MHz superconducting magnet and a Bruker console employing a digital FFL. A solenoidal coil surrounding the NMR probe introduces a 20 mG triangle wave disturbance. Measuring the current in the correction coil provides a record of the FFL compensation field. To investigate the effect of T_1 on the FFL compensation system, we record the response of the FFL using a doped deuterium sample with a T_1 value of 376 ms.

Results and Discussion

Fig.1 compares the applied disturbance and FFL compensation fields when the period of the disturbance is significantly larger than T_1. In this case, the FFL generates a correction field that closely matches the applied disturbance. Within the magnet, these two fields are in opposition and effectively cancel each other. In contrast, Fig. 2 reveals that when the period of the disturbance is smaller than T_1, the correction field no longer matches the disturbance field. As the fields no longer cancel, the NMR sample experiences a strong temporal fluctuation. We have previously shown that rapid field fluctuations can be estimated using inductive detection [1], and that both fast and slow fluctuations can be corrected using a combination of inductive detection and direct estimation of the Larmor frequency [2].

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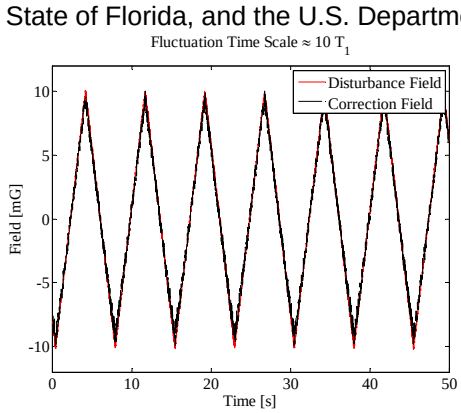

Fig.1 Field fluctuation time scale larger than T_1

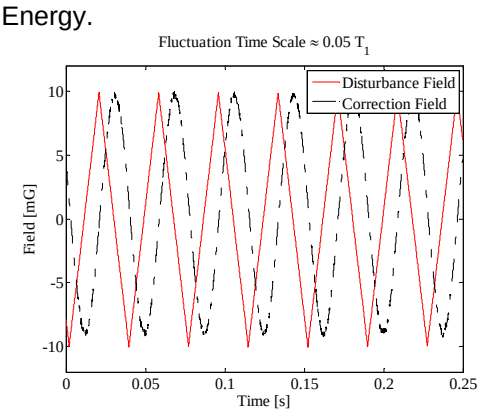

Fig.2 Field fluctuation time scale smaller than T_1

References

[1] Li, M., *et al.*, J. Magn. Reson., **212**, 254-264 (2011).
[2] Thomson, B.F., *et al.*, NHMFL Res. Rep., **407** (2013).