Research Group for Mechanical Control of Materials and Spin Systems

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The research objectives of Mechanical Control of Materials and Spin System are to develop new methods for controlling spin currents by combining electron spins and mechanical rotation, and/or by coupling spins and nuclear magnetic resonance (NMR) techniques, and to expand a new frontier of spintronics. Spintronics is a subject of great current interest that will be essential in next-generation electronics. Spintronics exploits an electronic charge and spin simultaneously so as to produce novel functional and electronic devices. A central concept of the spintronics is a flow of an electronic angular momentum called spin current. In our research group, a mechanical angular momentum and nuclear angular momentum are focused on as new angular momentum source interacting with spin currents.

Barnett effect of gadolinium in a paramagnetic state

The Barnett effect is a phenomenon that a rotating object is magnetized. The effect was discovered in 1915 [1, 2]. We report the first observation of the Barnett effect in a paramagnetic state by mechanically rotating a gadolinium. We developed a magnetic measurement setup comprised of a high-speed rotation system and a fluxgate magnetometer for the measurement (Fig. 1 left panel). The right panel of Fig. 1 shows the rotational frequency dependence of the magnetization of the gadolinium sample at 300±0.5 K and that of a blank capsule. We estimate the magnetization of the rotating sample, M_{Ω}, from the stray field measured by the fluxgate magnetic sensor using a dipole model. We find that the magnetization is proportional to the rotational frequency and its polarity changes with the rotation direction. For the blank capsule, no rotation frequency and direction dependence are observed. Thus, the magnetization arises from the rotating Gd sample.

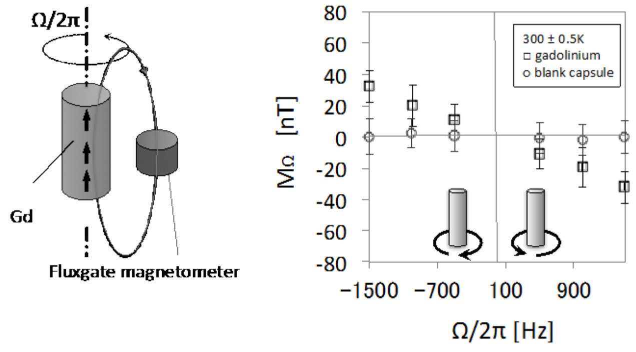

Fig.1 (Left panel) The experimental setup for observation of the Barnett effect.
(Right panel) Rotational frequency dependence of the magnetization observed at 300±0.5K for the Gd sample and the blank capsule. Each data point is averaged over three measurements with the error bar in the standard deviation 1σ including the rotational frequency fluctuation.

Nuclear magnetic resonance (NMR) for a I=1/2 system in an external magnetic field and mechanical rotation

NMR signals are measured under the synchronous rotation of a sample and a detector coil where the rotation axis is perpendicular to the external field. We found that NMR line of spin 1/2 nuclei system (^{31}P in H_3PO_4) splits into two lines despite the system having a single Zeeman level separation and the splitting is given by twice the angular velocity of the rotation (Fig. 2). We analytically calculated the motion of a nuclear spin in mechanical rotation based on quantum mechanics, and showed that the line splitting originates from double precession in the nuclear spin motion and that the splitting is determined by only the angular velocity of the rotation without any material parameters. The result implies that measuring the line splitting can be utilized for precise determination of mechanical rotation frequency [3].

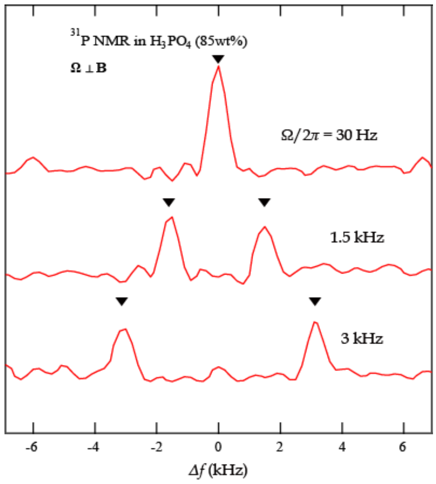

Fig. 2 Resonance spectra at various angular velocities. The red lines are the experimental results. The origin is defined as the center frequencies of the lines. The black triangles indicate resonance peak positions. The unconventional line splitting appears at $\Omega/2\pi$ = 1.5 and 3 kHz.

References

[1] S. J. Barnett, Phys. Rev. **6**, 239-270 (1915).
[2] S. J. Barnett, Rev. Mod. Phys. **7**, 129 (1935).
[3] K. Harii *et al.*, Jpn. J. Appl. Phys. **54**, 050302 (2015).