CU-09. Suspension Force Modeling and Electromagnetic Performance Analysis on the Integrated Five Degrees of Freedom DC Four-Pole Hybrid Magnetic Bearing.

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Modern ultra-high speed power transmission system puts forward new performance requirements for magnetic suspension motor [1], such as high power density, high suspension force density and high critical speed. The existing magnetic suspension motors usually use 1-DOF axial magnetic bearings, 2-DOF radial magnetic bearings and 3-DOF radial-axial magnetic bearings to form a 5-DOF magnetic suspension support system to support the rotor [2], which results in the longer axial length, lower critical speed, lower power density and suspension force density. Moreover, compared with AC HMB, DC HMB are uncoupled in every direction and easy to control. Therefore, to solve the above problems, an integrated DC HMB which can achieve 5-DOF stable suspension is proposed in this paper. The proposed 5-DOF DC HMB integrates the functions of two radial magnetic bearings and one axial magnetic bearing. It can realize 5-DOF stable suspension in one unit, which is of great importance to improve the critical speed, power density and suspension force density of magnetic suspension motor. Firstly, the structure and suspension mechanism of the integrated 5-DOF four-pole DC HMB are analyzed. Then, the mathematical models of suspension force are deduced by the equivalent magnetic circuit method. Thirdly, the three-dimensional finite element model is established according to the prototype parameters, and the three-dimensional magnetic circuit is analyzed. The relationships between the suspension forces and the control currents are calculated, and the experimental prototype has been manufactured. The simulation and experimental results verify the correctness of the suspension mechanism and the mathematical models. The structure of integrated 5-DOF DC HMB is shown in Fig. 1(a). Fig. 1(b) shows the magnetic circuits. Fig. 2(a), Fig. 2(b) and Fig. 2(c) show the distribution of bias flux density. Fig.2(e), Fig.2(f) and Fig.2(g) show the distribution of resultant magnetic flux density. The force-current relationships are shown in Fig. 2(h). It can be seen that the calculated values of the finite element method agree with those of the mathematical models.

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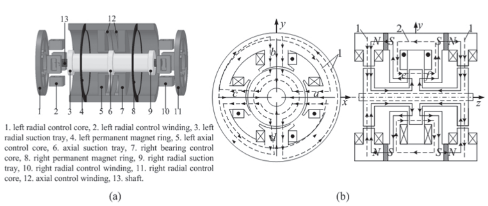

Fig.1 Structure and magnetic circuits

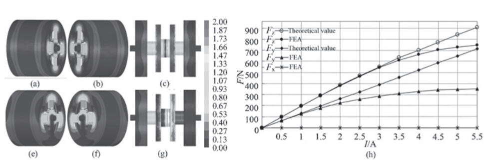

Fig.2 Simulation results

CU-10. Effects of an external magnetic field on the hyperfine parameters in RE_2O_3 (RE = Gd, Er) nanoparticles measured by perturbed angular correlation spectroscopy.

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The RE_2O_3 (RE = rare-earth) oxides present three different structures depending on the RE ionic radii: hexagonal (A-type), monoclinic (B-type) or cubic (C-type). In the latter, RE ions occupy two non-equivalent cation sites: asymmetric 24d sites and symmetric 8b sites. Gd_2O_3 and Er_2O_3 crystallize in this structure and have a paramagnetic behavior, although Er_2O_3 also orders antiferromagnetically below 4 K. Due to the high magnetic moment of Gadolinium ions, Gd^{3+} chelates have been used as a contrast agent for magnetic resonance imaging[1]. An investigation of the localized magnetic moment behavior on Gd and Er sites in Gd_2O_3 and Er_2O_3 nanoparticles (NPs), within an atomic resolution, under the influence of an external magnetic field (EMF), is very necessary mainly because the high neutron absorption cross-section of Gd prevents the use of neutron diffraction[2]. In this paper, hyperfine interactions, measured by Perturbed Angular Correlation (PAC) spectroscopy using $^{111}In \rightarrow ^{111}Cd$ as probe nuclei, were used to investigate the behavior of each RE site in Gd_2O_3 and Er_2O_3 NPs with and without the application of an EMF of 0.5 T. NPs were synthesized by thermal decomposition and characterized by transmission electron microscopy and X-ray diffraction. Results show that the contribution of RE atoms at 24d sites is invariant with temperature whereas the contribution from RE atoms at 8b sites is so that the hyperfine magnetic field (B_{hf}) increases in Er_2O_3 and decreases in Gd_2O_3 when temperature decreases indicating an opposite alignment of Gd magnetic moments at the 8b symmetric sites.

[1] M. Absinta et.al., Neurology, 85, 18-28 (2015). [2] B. J. Kennedy, M. Avdeev, Aust. J. Chem. 64, 119–121 (2011).

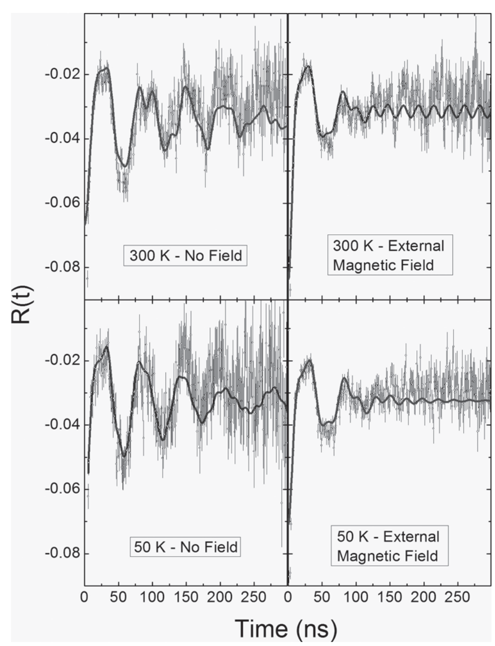

Fig.1 - Perturbation functions of Gd_2O_3 sample with and without the application of an external magnetic field

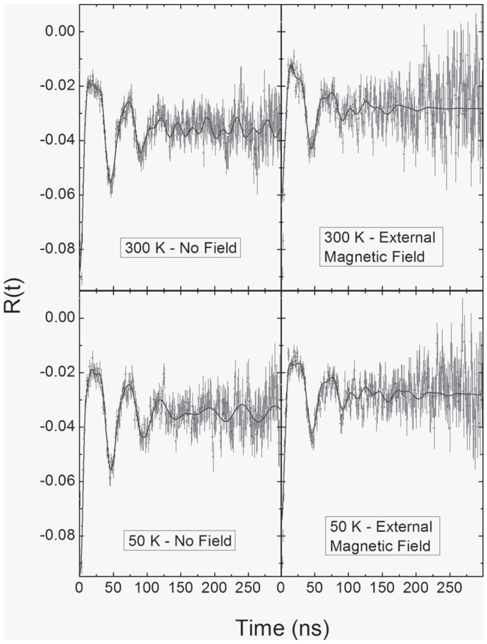

Fig.2 – Perturbation functions of Er_2O_3 sample with and without the application of an external magnetic field

CU-11. Macroscopic magnetization tunneling in the Josephson φ_0 junction.

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A quest to understand the quantum tunneling of magnetization(M) in nanomagnets has been a topical issue of intensive theoretical and experimental studies. At extremely low temperature the magnitude of M is frozen out and its orientation becomes an interesting dynamical variable. Since the direction of M is intrinsically determined by the anisotropy energy, there are two or more equilibrium orientation of M. Many studies have focused on the switching rate of individual nanoparticles for observing magnetic tunneling in the magnetic field. In recent years special interest has emerged in the tunneling rate manipulated by a Josephson current. As is well known, an influence of ferromagnetism on superconductivity is much stronger than the opposite one of the superconductivity on the ferromagnetism because the exchange interaction for ferromagnet (~100 K) is much larger than the order parameter for conventional superconductor (~ 1K). However, relativistic interactions responsible for the direction of M in nanomagnets (~ 1 K or less) are expected to be of the same order as the superconducting order parameter. Such a possibility was recently studied by Chudnovsky[1] who investigated the tunneling rate of M in the Josephson φ_0 junction. In fact, such a junction was proposed by Buzdin[2] who studied the Josephson junction between superconductors with a weak link formed by a noncentrosymmetric magnetic metal, and present the current-phase relation, $j=j_c\sin(\varphi-\varphi_0)$ where the phase φ_0 is proportional to M perpendicular to the gradient of the asymmetric spin-orbit potential. However, in the previous works they considered the spin dynamics controlled only by the bias current. In this work we consider quantum tunneling of M in the Josephson φ_0 junction with an external magnetic field as well as the bias current, and present diverse features of the tunneling rate which depends on two external controlling parameters. Spin-coherent-state path integrals are used to obtain analytic expressions for the tunneling rate for various crystal symmetries, with special attention to the field effect of currents. We will discuss optimal conditions giving the possibility of observing quantum tunneling of M coupled with Josephson current.

[1] E. M. Chudnovsky, Phys. Rev. B 93, 144422 (2016). [2] A. Buzdin, Phys. Rev. Lett. 101, 107005 (2008); F. Konschelle and A. Buzdin, *ibid.* 102, 017001 (2009).

CU-12. Research on High Frequency Magnetic Properties for Nanocrystalline Alloys Under Alternating and Rotational Magnetizations.

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Compared with silicon steel sheets, nanocrystalline alloys have higher permeability and lower conductivity, and it can be made into thinner strips, which makes it more easily magnetized and have lower eddy current loss. Therefore, nanocrystalline alloys have great high frequency performance. Compared with ferrite, nanocrystalline alloys have higher saturation magnetic density, which can further reduce the volume of electrical equipment and effectively improve power density. The rotating magnetic field will exist at the corner joint of laminated and blocky cores, and the rotating loss will be quite different from the alternating loss. In order to improve the accuracy of loss prediction, it is necessary to measure the rotational magnetic properties of related core materials [1]. At present, electrical equipment is gradually developing towards high frequency and miniaturization, and the application of novel materials such as nanocrystalline alloys is more extensive. In order to widen the application of nanocrystalline alloys in engineering practice, it is necessary to measure and analyze the magnetic properties of these materials and to make their physical properties clearer so as to give full play to their application value [2]. In this paper, a novel high-frequency 2-D magnetic tester for nanocrystalline alloy is proposed. The alternating and rotating magnetic properties of this material are studied from 1 kHz to 20 kHz. And the differences of magnetic properties between easy and difficult magnetization directions of nanocrystalline alloy in alternating magnetic fields are systematically investigated, and combined the experimental data of 2-D rotating magnetic properties, the macroscopic phenomenon of the magnetic anisotropy is analyzed from the view of the microstructure of the material. The relationship between rotation loss and alternating loss of nanocrystalline alloys under different axial ratios of elliptical magnetic field excitation is analyzed.

[1] S. Yue, Y. Li and Q. Yang, IEEE Transactions on Magnetics., Vol. 55, p.1-5(2019) [2] L. Chen, Y. Wang and Z. Zhao, IEEE Magnetics Letters., Vol. 8, p.1-5 (2017)

CU-13. Independent Control of Anti-parallel and Parallel State Thermal Stability Factors in Magnetic Tunnel Junctions for Telegraphic Signals with Two Degrees of Tunability.

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Magnetic tunnel junctions (MTJs) with low thermal stability at room temperature have been proposed as read units in probabilistic-bits, or p-bits [1]. However, networks of multiple interconnected MTJs may be particularly sensitive to device-to-device variations of thermal stability from design targets [2]. Recently, we generated tunable telegraphic signals using a thermally stable MTJ through proper control over an external bias field and a DC voltage bias [3], which is illustrated in Fig. 1. Not only does this provide a solution to issues associated with device to device variations, but it also introduces the possibility of p-bit designs that are compatible with state of the art MRAM technology. Furthermore, our results demonstrated that the average anti-parallel (AP) and parallel (P) state dwell times could be tuned independently, giving a second degree of tunability to the signals generated. In this work, we expand on this method in two important ways. First, we demonstrate the applicability of our method to p-bit designs by modelling the transfer function using existing p-bit models. Fig. 2 shows that the device's transfer function can be adjusted with slight modifications to the bias field, where the bias voltage is treated as the input and the percentage of time that the MTJ spends in the AP-state (referred to as the AP-rate) is treated as the output. This allows for the possibility of p-bit circuits capable of on-chip