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Quantification of the effect of inhomogeneous magnetization or irregularity in shape on the measurement of remanent magnetization with a high-sensitivity multifunctional spinner magnetometer

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Quantitative assessments of the effect of inhomogeneous magnetization or irregularity in shape on the measurement of remanent magnetization were made experimentally and theoretically. Experiments were performed on artificial and natural samples, using a novel type of high-sensitivity spinner magnetometer (Kodama, *G-cubed*, 2016). The spinner has a wide dynamic range from 10^{-10}–10^{-4} Am^2 and a resolution of 10^{-11} Am^2, incorporating two unique functions: a mechanism for adjusting flexibly the spacing between the sensor and the spinning axis, and a capability of measuring not only the fundamental component (5 Hz) but also the second (10 Hz) and the third (15 Hz) harmonic components. The former enabled the measurement of samples in any shape sized 10–50 mm, and the latter allowed the measurement of waveforms containing the harmonics leading to the analyses of their FFT spectrum. Numerical simulations using finite element method (FEM) were performed for assessing the effect of shape irregularity on the measured remanent magnetization.

The effect of the heterogeneous magnetization was evaluated using a small dipole-simulating coil and a mini-core specimen of volcanic rock, and measured their magnetization by repositioning at different distances off the spinning axis. The effect of the offset was assessed in terms of the amplitude of the fundamental wave and the harmonics versus the amount of the offset. The measured amplitudes, without exception, increased with the amount of the offset, and their relationship was well approximated by a polynomial curve consisting of the second- to forth-order terms. This suggests that the contribution from the higher-order harmonic components could be represented in the form of a non-linear function of the offset distance. Measurements by a conventional spinner also demonstrated a similar increasing curve, but in association with a smaller increase rate and relatively large errors. The smaller increase rate is most likely due to its high-order low-pass filter and the large sensor distance for isolating only the fundamental wave component. However, the systematic increase with the offset, regardless of the type of spinner used, is contrary to the expectation that, given the same sample with the same magnetic moment, the magnetization measured for the offset and non-offset samples will be identical. This finding suggests that the intensity of magnetization measured with a spinner may include a systematic bias, particularly when samples contain a large amount of harmonic component that can be represented by an offset dipole. Theoretical analyses based on multipole expansion have revealed that the systematic relationship between the amplitude and the offset can be explained quantitatively in terms of the dipole and higher-order multipole and their varying contributions dependent of the amount of offset. Results from the FEM calculations were consistent with the experimental data from samples with the same properties as used in the model calculations.