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Flux density waveform control based on Newton-Rhapson method

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Ensuring sinusoidal flux-density waveforms is a very challenging prerequisite of repeatable magnetic characterizations. A novel type of iterative feedback is presented, based on Newton-Rhapson zero-finding algorithm. It benefits from its lack of parameters, and theoretical good properties of convergence. The experimental implementation shows some encouraging results, yet with sizeable limitations.

Keywords: Flux density control, Characterization of magnetic materials, Digital Feedback algorithm.

1. Introduction

To compare magnetic properties of different materials, one has to impose the same experimental conditions. For iron losses measurements, identical flux density waveforms have to be set. The historical analog feedback gave way to digital means along the development of numeric capabilities (acquisition, computing...) [1], which while slower ensure better stabilities in advanced conditions [2]. Therefore, a great variety of digital feedback principles arose. This paper present a new type of digital feedback, characterized by a low number of parameters and a good theoretical basis.

2. Concept and validation

2.1. Innovative controller

The new type of feedback we developed is akin to the Newton-Rhapson method for zero-finding, adapted to iterative regulation of periodic signals. For each iteration i , an unknown and anhysteretic function F is considered as linking the flux density at one point k of the period $B_k^{(i)}$ to the voltages at each point $V_1^{(i)}, V_2^{(i)}, \dots, V_k^{(i)}, \dots, V_n^{(i)}$. Combining both the hypothesis of iterative process and periodic waveform, we identified a circulant Jacobian matrix, and apply it to compute the excitation $V^{(i+1)}$ for the next iteration.

The main benefit of this feedback is the absence of any setting. Furthermore, the property of quadratic convergence of the Newton-Rhapson algorithm (in the vicinity of the solution) raised expectations about the convergence speed, especially for the last iterations which are usually quite slow for classical controllers based on proportional error correction [3]. Three different applications of this principle were defined : control of the flux density B , control of its derivative dB/dt , and a mixed version using less-square method to solve the Jacobian.

2.2. Method and experimental setup

The assessment of the capabilities of our controller asked for a comparison to the most common form of flux density

feedback, shown in Eq. 1.

$$V^{(i+1)} = V^{(i)} + \alpha (B_{ref} - B^{(i)}) + \beta \left(\left(\frac{dB}{dt} \right)_{ref} - \left(\frac{dB}{dt} \right)^{(i)} \right) \quad (1)$$

We tested the performance of our feedback against this one with several physical setups to ensure its adaptability : some toroidal samples, an Epstein frame, and a C-yoke. Moreover, we characterized different types of magnetic materials (FeCo, FeSi, FeNi, nanocrystalline) to evaluate the area of performance displayed by our controller, that is which magnetic behaviour it can compensate.

3. Results

The operation of this new method was first ensured in simulation, then with the experimental setups. Convergence was achieved in most cases with frequency above 10 Hz, with a convergence time of the same order of magnitude as the classical feedback, albeit longer for all materials. However, some iterations involved heavily distorted waveform, which may adversely affect the magnetic state of the sample.

4. Conclusion

The method we presented displays a great ease of use, with good results in some cases. However, it still presents substantial drawbacks, hence more work, both experimental and theoretic, is ongoing in order to reduce them. More development about the algorithm and detailed results would be included in the final paper.

References

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