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Test case for the verification and benchmarking of coupled electromagnetic field and circuit simulation

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***Abstract*— For the verification of coupled electromagnetic field and circuit simulation, a well defined test case is required. Therefore, this paper proposes a test case, which consists of a C-core in conjunction with a reluctance rotor. Due to the simple geometry, independent comparison of individual approaches to the coupled problem are possible. The test case is designed to work in static operation and with velocity induced voltage.**

I. Introduction

The design of electromagnetic systems, such as electrical drives or switch-mode power supplies, increasingly focus on the interaction between magnetic components and electrical circuitry. The magnetic behavior is governed by the field equations, where as the properties of the electric circuit are determined by Kirchhoff's laws and the current/voltage characteristics of the individual components.

To evaluate the effects of interaction, it is necessary to solve the physically coupled problem. This can be done using numerically weak coupled or numerically strong coupled simulations. There exists several approaches to do so.

As the coupled simulation is often applied to the area of electrical machinery in conjunction with power electronic converters. A good example for this may be a brushless dc motor drive, a switched reluctance machine or a claw pole alternator. Most authors are using applications of physical and technical importance of that area [1], [2].

This, however, has two significant drawbacks: First, the chosen geometries are, in general complex, which makes it hard to exclude inaccuracies in modeling the structure. Second, most authors do not publish all details of the components of the magnetic and the electric circuit, and therefore no independent comparison and benchmarking of the individual approaches is possible. On the other hand, existing test cases to verify and benchmark electromagnetic field computation, such as the series of TEAM workshops by the International Compumag Society, do not provide a possibility to intensively study the field circuit interaction [3].

The test case proposed in this paper tries to overcome these fundamental drawbacks. Therefore, a simple geometry of the magnetic circuit is chosen and all dimensions of the test cases are given.

II. Proposal of Test Case

The first requirement for the design of the test case is a simple and well defined geometry. Second, in the operation of the test case, a significant field circuit interacting should be considered for the operation without power electronic switches.

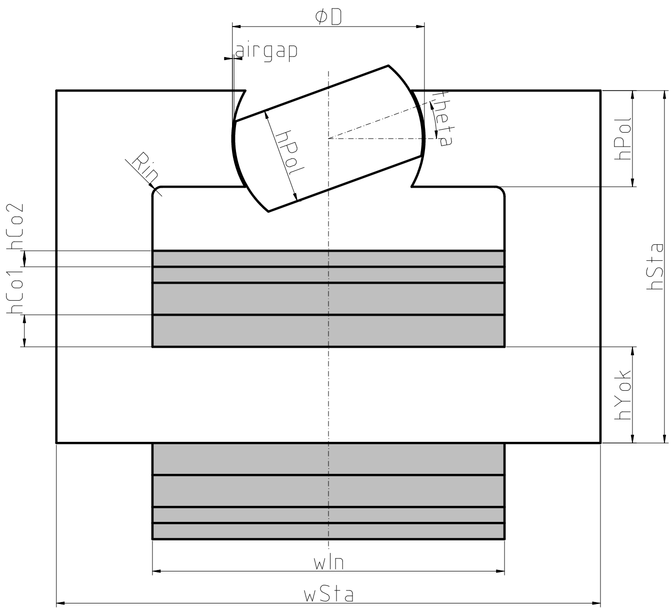

Fig. 1. Test-case geometry.

TABLE I
Dimensions of the test-case geometry.

Dimension	Value	Dimension	Value
h_{Sta}	110 mm	w_{In}	110 mm
h_{Pol}	30 mm	w_{Sta}	170 mm
h_{Yok}	30 mm	w_{Spa}	2 mm
h_{Co1}	10 mm	w_{Yok}	30 mm
h_{Co2}	5 mm	D	60 mm
thickness	35 mm	R_{in}	3 mm
airgap	0.5 mm		

The C-core, one of the most fundamental magnetic circuits serves as a basis for the development of this test case. Since velocity induced voltage has to be investigated, a reluctance rotor is placed into the airgap of the core. This allows for mechanically static and dynamic experiments. Due to an excitation winding residing on the same yoke, the excitation mmf can be adjusted very accurately and no slip rings are required. The geometry of the developed test case is shown Fig. 1. Table I gives the numerical values of its dimensions.

Dividing the primary and secondary winding into two partitions each, allows for a variety of different connections on the test bench. The layout of the test case is done according to the standard design procedure of electrical machines [4].

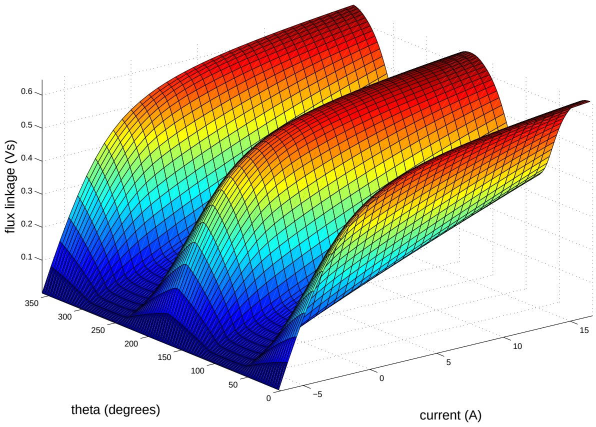

Fig. 2. Flux linkage from static 3D FEM.

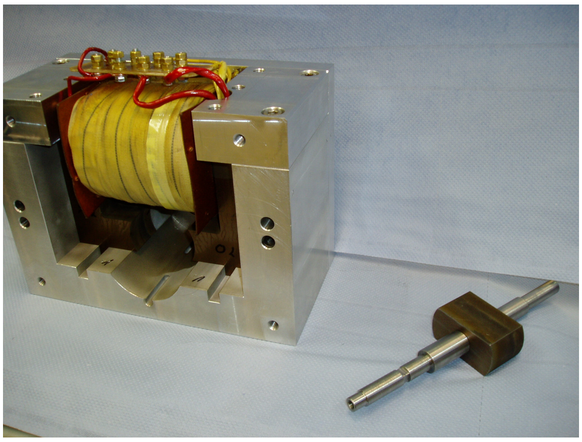

Fig. 3. Photograph of C-core with winding and reluctance rotor.

III. Results

A. Numerical Simulation

To demonstrate the effectiveness of the proposed test case, a series of three-dimensional magnetic field analyses are performed using the Finite Element (FE) method. Assuming a constant dc excitation of 2000 Ampere turns in the primary winding, the secondary current and the rotational angle of the rotor are used as parameters for the simulations. The computed flux linkage of the secondary winding is shown in Fig. 2. Strong non-linearities with respect to angle and current can be observed. This data also serves as a lookup table to a system simulation of the test case, which provides an additional method of validating coupled simulations.

B. Experimental Realization

The proposed test case is implemented as a prototype and set-up on a test bench. A photograph of the C-core together with housing and rotor is shown in Fig. 3. Part of the shaft is equipped with a rectangular cross-section, which is aligned with the rotor to lock it for static tests.

C. Comparison of Numerical Results and Measurements

The first tests are static measurements, in which the test case is working as transformer. Fig 4 and 5 show the comparison

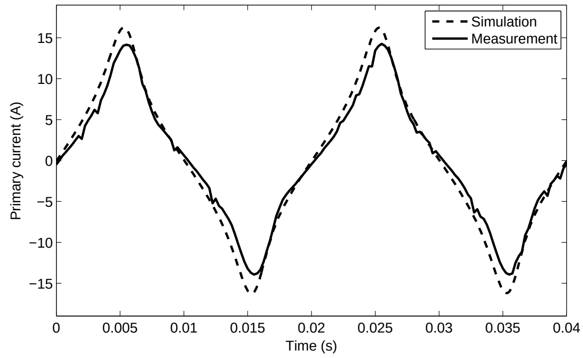

Fig. 4. Comparison of waveform from measurement and simulation.

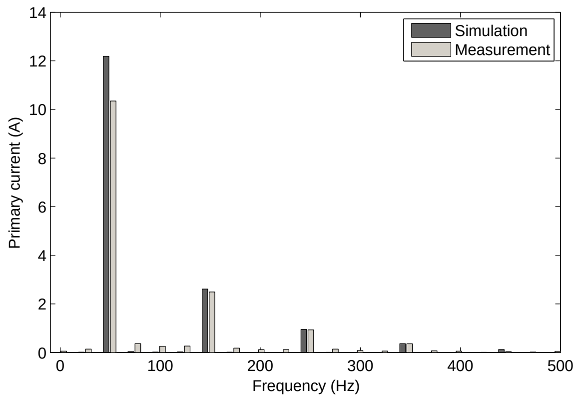

Fig. 5. Spectral comparison of measurement and simulation.

of primary current waveforms obtained from measurement and from coupled simulation using the approach proposed in [5]. The applied voltage is 90V on the primary side, the secondary side is open circuit. Significant harmonics due to saturation can be observed.

IV. Summary and Conclusions

This paper proposes a test case for the verification and benchmarking of coupled electromagnetic field and circuit simulations. A prototype of the test case has been constructed and first simulation results, compared to measurements are presented and show good agreement. More detailed results of the static case and measurements of the rotating case will be presented in the full paper.

References

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