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RTD Fluxgate Behavioral Model For Circuit Simulation

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Abstract

SPICE simulation is universally recognized as a powerful tool in the field of electronic engineering. Simulations are strategic when dealing with a strong non-linear behavior that cannot be easily handled analytically. Magnetic hysteresis is one example of non-linearity that founds many practical applications, especially in the field of magnetometers and magnetic sensors. The aim of this paper is to present a behavioral model of RTD Fluxgate magnetometers easy to implement and adaptive with respect to the dynamic of the driving signal. Even if the whole work is focused on a specific magnetometer, the developed methodology can generalized to the wide class of hysteretic devices.

Keywords: Type your keywords here, separated by semicolons ; hysteresis, modelling, simulation, magnetometers

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1. Introduction

Magnetic hysteresis is probably one of the most fascinating and complex physical phenomena. Linear magnetic material found many practical applications (linear inductors, power transformer etc.). However, several examples are available where the exploitation of non-linear magnetic material is dramatic. Such a case is the operation of RTD Fluxgate magnetometers that present an hysteretic input-output relationship, due to the presence of a soft ferromagnetic core [1-5].

Despite of its importance, the native support for ferromagnetic hysteresis of the available circuit simulators is very limited or, more frequently, not present. Modern SPICE simulation packages, such as ORCAD (Cadence, CA, USA) include a non-linear magnetic core model that is based on the Jiles and Atherton (JA) model [6]. Sometimes the JA parameters are supplied by the vendor. However, when dealing with non-commercial magnetic materials, as in the case of our magnetometers, the development of a dedicated model is mandatory.

Fluxgate magnetometers are suitable to sense low magnetic fields or magnetic field perturbation, at room temperature. In particular, the Residence Times Difference (RTD) Fluxgate magnetometer represents an innovative solution to detect quasi static magnetic field. The authors have proposed RTD fluxgate as competitive devices to the traditional second harmonic architectures [1-5]. Low cost, small dimension, high sensitivity, low noise floor, low power consumption and an intrinsic digital form of the output signal are the main advantages of this innovative strategy. The prototype considered through the rest of the paper is based on a filiform ferromagnetic core that exhibits very interesting magnetic properties, such as a sharp hysteresis loop and low coercitive fields value. The “wire core” material has a 100 µm diameter (FeSiB Amorphous magnetic microwire). A simplified construction

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description can be summarized by the following steps: a two coils structure (excitation coil and pick-up coil) is wound around a plastic support, where the 100µm ferromagnetic amorphous wire is hosted (Fig. 1).

A brief description of the sensor operating principle can be summarized as follows (for a more accurate description see [1-5]): a periodic driving current is forced in the excitation coil thus generating a periodic magnetic field, parallel to the geometry of the core, high enough to saturate the core alternatively in the two verses. The induced voltage at the pick-up coil, being proportional to the time derivative of the magnetic flux, is a train of impulses. The time position of the impulses are related to the intensity of a DC target magnetic field.

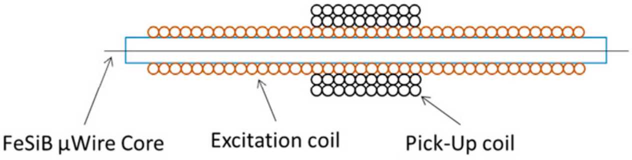

Fig. 1: Cross-section of the wire-core RTD Fluxgate (not in scale)

2. The proposed model

The proposed approach is based on a nonlinear differential equation implementing the model schematized in Fig 2. The basic model adopted to describe the nonlinear behaviour of the ferromagnetic material is based on a bistable potential energy function (for details see [1]). It is a strictly mathematical model of magnetic hysteresis because the parameters are not physically meaningful. However, a physical interpretation can be still given as the parameters are related to the macroscopic magnetic quantities (coercitivity, remanence, saturation) of the material [1]. The parameter *d* has been introduced to fit the normalized output of the bistable model to the experimental behaviour of the device.

The operating condition of the magnetometer is defined by the amplitude and the frequency of the periodic excitation current [1]. It is well known that the "shape" of the hysteresis loop changes with the operating conditions. In particular, the coercive field value, the remanent magnetization and the saturation magnetization grow as the amplitude and/or the frequency of the driving signal increase.

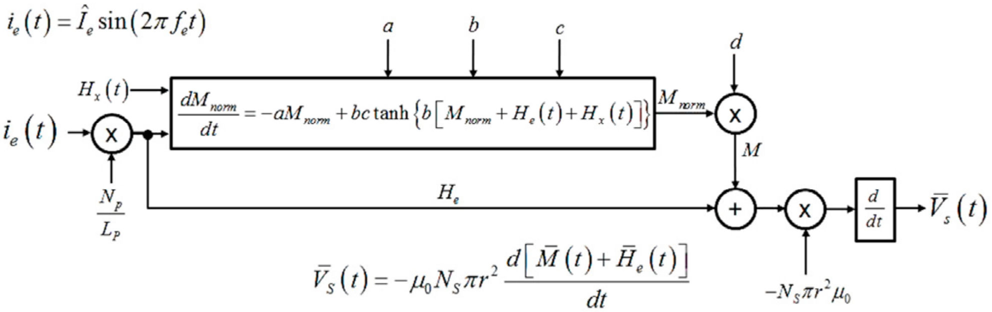

Fig. 2: Flow-chart of the proposed RTD Fluxgate behavioural model .

$I_e(t)$= excitation current, $H_x(t)$ = target magnetic field, N_p = number of turns of primary coil, L_p = length of primary coil, $H_e(t)$ = excitation magnetic field, N_s = number of turns of secondary coil ,r = radius of secondary coil, M(t) = core magnetization, $V_s(t)$ = output voltage at secondary coil. [a,b,c,d] = model parameters

2.1. Data Acquisition and parameters identification

Starting from a large set of real input-output measurements, a suitable nonlinear optimization has been performed to identify the model parameters in each operating condition. In order to simplify the acquisition procedure, a LabVIEW-based automatic measurement system has been implemented (Fig 3). For each operating condition, the LabVIEW tool fixes the amplitude and the frequency of the sinusoidal driving signal, through a GPIB communication with an arbitrary function generator (Agilent E33250A). A voltage to current converter is then used to drive the primary coil of the fluxgate sensor; the RMS value of the driving current is constantly monitored through a digital multimeter (Fluke 45) connected to the automatic system . This operation is crucial because the accuracy in the estimation of the driving current amplitude influences the whole successive elaborations. The output voltage at the secondary coil is amplified and filtered before being conveyed to the data acquisition board (NI PCI 6132). It must be highlighted that both the output voltage and the driving voltage are simultaneously acquired. The latter allows for the estimation of the driving current evolution.

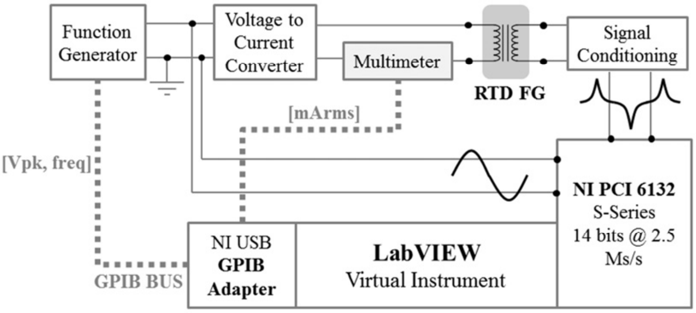

Fig. 3: A simplified block-diagram of the automatic measurement system used for the data acquisition procedure.

During the acquisition procedure, the magnetometer is placed inside a suitable magnetic shield in order to protect the sensor from environmental electromagnetic noise sources that could otherwise modify the normal operation of the device. Data acquired are used to identify the model parameters by a Matlab routine. Actually, a non-linear, unconstrained optimization algorithm (Nelder-Mead simplex) has been used to identify the model parameters value for each operating condition.

For the sake of implementing a model valid in the whole range of the explored operating condition, the dependence of each model parameter to the driving signal has been also investigated. For each parameter, a 5th order bivariate polynomial function has been used thus making the model adaptive to the amplitude and the frequency of the driving signal.

2.2. Implementation and validation

Multisim[7] (National Instruments) has been chosen among the available SPICE packages for its strong support for behavioral modeling. The magnetometer model can be easily implemented as a hierarchical block by the proper use of the control function blocks and Analog Behavioral Model (ABM) sources, resembling the schematization shown in Fig. 1. As an example, Fig. 4 shows the behaviour of the model and its performances in fitting a real data set for a specific operating condition (4.5 mApk @ 320 Hz). As can be observed the model properly fits real data thus providing a realistic description of the device behaviour. The same behavior has been observed in the whole range considered (0.5 to 20 mApk for the amplitudes and 50-1000 Hz for the frequencies).

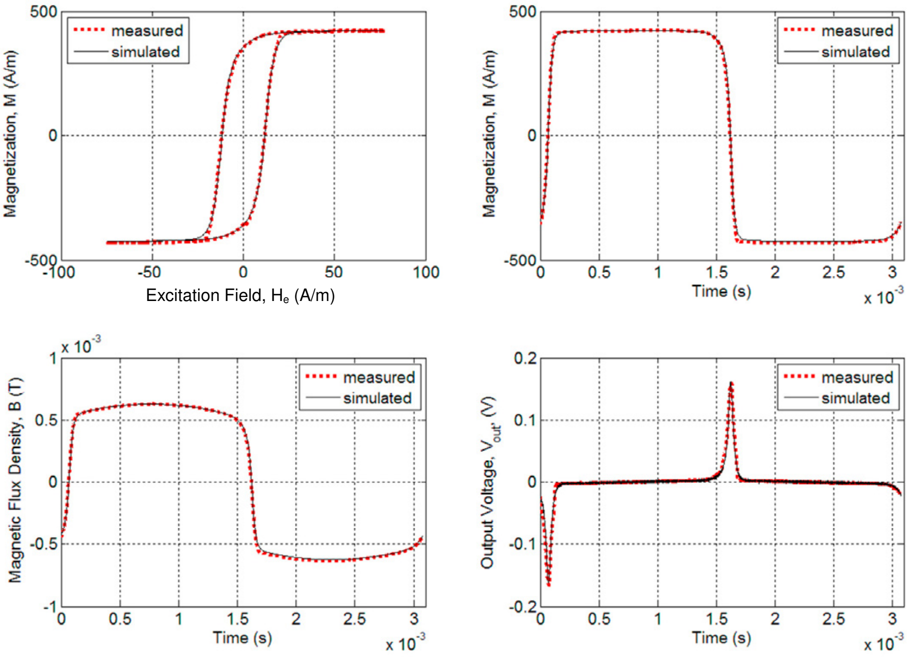

Fig. 4: Model validation, example for a driving current of 4.5mApk @ 325 Hz
Top-left = MH hysteresis loop, Top-right = core Magnetization, Bottom-left = Magnetic Flux Density, Bottom-right = Output Voltage

3. Conclusions

The proposed RTD Fluxgate behavioral model allows the simulation of the sensor behavior including also the driving section and the conditioning and readout electronics. The proposed approach represents a general method to overcome the limitations of SPICE simulators when dealing with magnetic hysteresis. The values for the model parameters can be easily determined starting from input-output measurements, thus the apriori knowledge of the physic properties of the magnetic core is not strictly necessary. This represents an advantage over traditional approaches to magnetic hysteresis modeling (i.e. the Jiles-Atherton model) in particular when dealing with non-commercial materials.

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