FLUXGATE SENSOR AND REAL OPERATING–MODE B-H CURVE

Antonín Platil* — Pavel Ripka*

1 INTRODUCTION

As published earlier, classical fluxgate sensor of ringcore (Aschenberger-Goubau) type was constructed using stack of rings etched from nanocrystalline material (Vitroperm by VAC) supplied by VAC Vacuumschmelze Hanau. The construction was described in detail earlier [1], including the heat treatment of cores for inducing perpendicular field anisotropy and thus lower noise. (Indeed, noise was thus reduced from more than 1000 pT/√Hz@1Hz to 641 pT/√Hz@1Hz.) Interestingly, dynamic hysteresis loops of fluxgate cores (such as those used here) are rarely measured in conditions close to real operating mode. B-H curves of core materials are typically acquired in sinewave H or better in sinewave B conditions as required by IEC standard [2]. These loops do not represent well the real situation, especially where capacitive tuning is used for obtaining high excitation current peaks. Of interest for us are dynamic hysteresis loops acquired in representative conditions, as they exist in fluxgate sensor operating mode. Such B-H curves can be recorded using dynamic hysteresis loopgraph developed earlier [3]. They can be used to find parameters for core model [4] in order to find formulas for sensor parameters such as sensitivity.

2 THE EXPERIMENT SETUP

The cores consisting of several layers of etched rings in a plastic holder were equipped with 125 turns of primary winding (N1, the same as fluxgate excitation winding) and 10 turns of secondary winding (N2, not used in fluxgate mode). The complete core was inserted in another coil (N3, 1000 turns) normally serving as fluxgate pick-up and compensation feedback field generating coil. The excitation current in primary winding was sensed using frequency independent resistor 0.1 Ω (Vishay VCS). The sine excitation voltage was supplied from generator and the excitation winding was optionally tuned into resonance with parallel variable capacitor (typically 3.16 μF) in order to achieve high current peaks (with modest RMS value). The value of H was calculated directly from current (measurement on closed ring specimen), value of B was integrated in software from induced voltage across secondary winding. The whole setup in typical configuration is schematically shown in Fig.1. However, it should be noted that some experiments were conducted also in modified configurations — eg using current clamps instead of RS or using swapped windings N1 and N2.

3 THE MEASURED DATA

The typical waveforms of electrical and magnetic quantities and hysteresis loop derived from the measurement are shown in Fig. 12 at the end, in this case for core annealed without perpendicular field. The loop slopes at peaks do not fully saturate to flat line, as there is non-negligible uncompensated air flux (metallic core – the “iron” – is very thin and occupies relatively small percentage of the coil cross section).

Figures 2 to 5 show waveforms of excitation current and induced voltage and corresponding hysteresis loops for excitation at 10 kHz and 20 kHz frequencies and relatively small amplitude. (Due to a scaling error the loop graphs are shown without the labelled axes, but true peak values are included in the figures.) For both frequencies the coercivity is about 100 A/m, slightly increasing.

* Czech Technical University in Prague, Faculty of Electrical Engineering, Department of Circuit Theory, Technická 2, 166 27 Prague 6, Czech Republic, antonin.platil@fel.cvut.cz

ISSN 1335-3632 © 2012 FEI STU
As shown, in these cases (Fig. 2 and Fig. 4) the excitation current is practically sinewave. For adequate saturation of the fluxgate core, the peak value of $H$ must be much higher in order to suppress perming.

For higher amplitude the current becomes deformed with the onset of saturation effects (drop in incremental permeability) as in Fig. 12. In that case the high current amplitude was achieved with the aid of tuning capacitor set to 3.16 $\mu$F.

Similarly, in Figures 6 and 7 are shown current and induced voltage waveforms and resulting hysteresis loop in tuned mode for excitation amplitude of 2000 A/m.

For comparison, let us consider the case without tuned excitation coil. With the same applied voltage from the generator, the achieved excitation amplitude is approximately one half of that for tuned circuit (ie 1000 A/m) – see Fig. 9 and Fig. 10.

For achieving original amplitude of the excitation (2000 A/m) in untuned mode, higher voltage from generator must be applied. The higher current peak can be achieved but with much higher RMS value and thus higher energy consumption.

4 THE NOISE ANALYSIS

When the fluxgate pick-up coil ($N_3$) was used as intended, ie to collect induced fluxgate output voltage, noise parameters were measured using SR 830 lock-in amplifier and SR 770 spectrum analyzer, both by Stanford Research Systems.
Fig. 6. Excitation current and induced voltage at 20 kHz at higher saturation, tuned mode excitation

Fig. 7. Hysteresis loop at 20 kHz for excitation 2000 A/m, tuned mode excitation

Fig. 8. Hysteresis loop at 20 kHz, tuned mode, fluxgate core saturated by applied external field

Fig. 9. Excitation current and induced voltage at 20 kHz, unturned mode excitation yields about half the H amplitude

Fig. 10. Hysteresis loop at 20 kHz for excitation 1000 A/m, untuned mode excitation

Fig. 11. PSD of fluxgate observed in magnetic shielded chamber, the noise: 6mV/√Hz@1Hz, ie about 690 pT/√Hz@1Hz
The sensor was put into 6-layer permalloy shielded chamber. The instrument’s internal generator was used as the excitation source in tuned mode – in this case $C_T$ was 2 µF. By tuning the excitation coil we can achieve reduction of perming and improvement of offset stability and reduction of energy consumption. In a similar fashion, tuning can also be used for pick-up coil [5].

With untuned pick-up, the sensitivity at lock-in output was 8.7 mV/nT. Tuning to the predominant $2^{nd}$ harmonic component in the output with parallel capacitor 1200 pF provided maximum sensitivity of 83 mV/nT, i.e. tenfold increase in sensitivity. However, in this case the observed noise increased similarly, so the tuning of output had not improved the noise characteristics. In Fig. 11 is shown the power spectral density and corresponding pre-processed time record measured by SR770 analyzer for untuned output. The measurements were taken in open loop, i.e. without operating compensation feedback. The spectrum analyzer used linear average of 100 samples with 97% overlap and Blackman-Harris window.

5 CONCLUSIONS

Experiments were conducted with the aim of characterizing fluxgate core in conditions close to the real operating mode. Included are $B$-$H$ loops of nano-crystalline fluxgate core at 10 kHz and 20 kHz with small excitation amplitude and sinewave $H$. For higher excitation pronounced non-linearity effects and deformed excitation waveforms are observed. Excitation can be enhanced by parallel tuning – shown here is the corresponding $B$-$H$ loop and also for comparison the $B$-$H$ loop in untuned case.

The noise was measured on completed fluxgate sensor in magnetically shielded chamber using lock-in amplifier and spectrum analyzer. The noise here is about 690 pT/√Hz@1Hz. Parallel tuning of pick-up coil in this case improved sensitivity (almost 10x) but not the observed noise. We have earlier observed decreasing the noise with tuning [5], while others reported the opposite [6]. The achieved noise is similar as results reported for Fe-based nanocrystalline alloy fluxgate in [7].

REFERENCES


Received 8 September 2012
Antonín Platil (doc, Ing, PhD), biography not supplied. Pavel Ripka (Prof, Ing, CSc), for biography see page 137 of this issue.