Fluxgate sensor.

The aim of the case study is to use the unique 3D printing technology DPS (Dragonfly LDM 2.0 by Nanodimension) to print a printed coil with an embedded core. The principle of fluxgate sensor and basic gerber data was prepared in cooperation with FEL CTU, the actual implementation was realized in cooperation with technical support of Nanodimension.

The design of a printed coil can be realized in two ways - by standard design within a specialized eCAD system, using the traditional technology of division into design levels, or by design in a 3D CAD design system, which at the same time allows much greater freedom in the use of the entire 3D space. The implementation of the coil core inside the 3D sensor is possible in two ways:

- Printing using 3D printing technology - which, however, is conditional on the existence of a material suitable in terms of electromagnetic properties and compatible with the printing technology of the next motif; this material is not currently available.
- Insertion of suitable core material during the printing process.

The Dragonfly LDM2 printer, on which the development was carried out, has two printheads and therefore it is not possible to use the direct core printing method and therefore the "embedded parts" technology was developed, which divides the printing into several steps; for each motif the layer thickness in um and the ink used is shown - CI = conductive ink and DI = dielectric/isolant ink, in round brackets is the recipe used for the print job, in square brackets is the information about the print start setting in the Z axisthis:

1. *Before printing in Printer Control Parameters : /Heaters/Tray/Post Print parameter TrayPostPrintTargetCoolTemperatureInC set on 140 °C.*

2. PART1 [Z=0.0] - Printing the bottom of the sensor Part1, so this stackup:
    a. protective bottom layer – 50 um DI (or + CI contacts)
    b. bottom part of the coil turns – 400 um DI+CI
    c. vertical part of coil turnss + protective layer between coil and core – 50 um DI+CI
    d. creation of a cavity for the core, i.e. the vertical part of the coil coils + insulator with the cavity – 100 um DI+CI
    e. creating an increase of the vertical parts of the coil turns to ensure condustive contact of the bottom part with PART3, i.e. the printing of the via – 50 um CI
    f. (recipe = TO-disabled; *MachineConfig.cfg - parametr EnablePostPrintSession, must be "0"*)
3. Bonding the core to the cavity (adhesive with a curing temperature comparable to the temperature of the printing pad – we have selected PERMACOL 2035E/5R)
    a. *pay attention to the temperature of the print item – 140 °C.*
4. PART2 [Z=700.0] (Seal) - Alignment of the surface of the cavity of the cavity with the bonded core to the plane of the upper plane of the already printed motif PART1
    a. *It is necessary to check whether mechanical contact between the print heads and the printed motif can occur*
    b. Motif corresponds to the cavity opening, default thickness 50 um and varies as needed for repeat run – 50 um DI
    c. (recipe = TO-disabled; *Recipe.json: OVEN_TYPE for DI = "UV", EVERY_X_SLICES for DI set to 10*)

5. PART3 [Z=700.0] - Print finishing, i.e. the upper part of the spool threads:
    a. protective layer between the coil and the core – 50 um DI+CI
    b. upper part of the coil turns – 400 um DI+CI
    c. protective top layer – 50 um DI (or + CI contacts)
    d. (recipe = TO-disabled)

Presentation of this result:

1. https://mitnano.mit.edu/events/tool-talks/nano-dimension - Invited presentation at Nano dimension tool talk MIT in Boston (USA), 27.10.2022,
2. https://www.nano-di.com/events/ame-2022-european-user-forum - Workshop European AME User Forum in Munich 14.11.2022
3. https://smm26.cz/images/documents/SMM_26_2023_Program_A5_web.pdf - Poster-session of SMM26 conference, 4-7.9.2023, Prag.

Dimensions:

• Outer diameter	24,9 mm
• Inner diameter	15,1 mm
• Length including connector	29,2 mm
• Thickness	0,74 mm
• Thicknesses of individual layers	see print flow description
• Number of turns	63
• Coil core	Vitrovac 6025, ø out 22 mm , ø in 18 mm, thickness 25 µm

Results:

The resulting functional sample showed very good values during the measurements and therefore the design of a second generation sensor was proceeded with.

Resulting sensor:

Fig. 2 - Fluxgate sensor model crossection

Fig. 1 - Photo of the final printed sensor

Measured values:

The maximum sensitivity at the output was ca. 300 mV/40 µT (vertical component of the Earth's field) which is 7 500 V/T, it was achieved for 29 kHz excitation frequency (Agilent 33120A, 50 Ω output resistance, with 20 Vp-p, f = 29 kHz sinewave) thanks to the parametric amplification. By non-linear resonance of the time-changing pick-up coil inductance and its parasitic capacitance. The sensor characteristics is shown in Fig. 1. With this excitation we measured sensor noise of 14 pT/√Hz using 6-layer magnetic shielding.

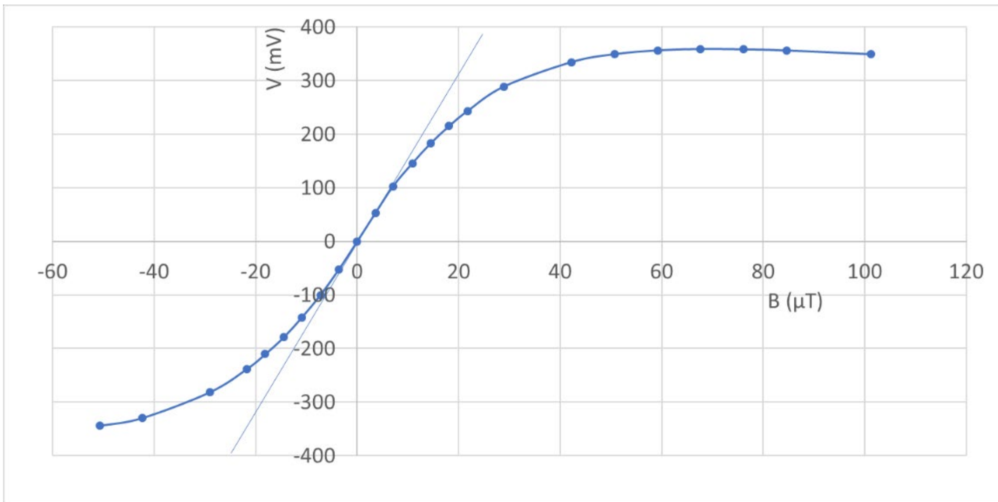

Fig. 3 - 2nd harmonic voltage vs measured field

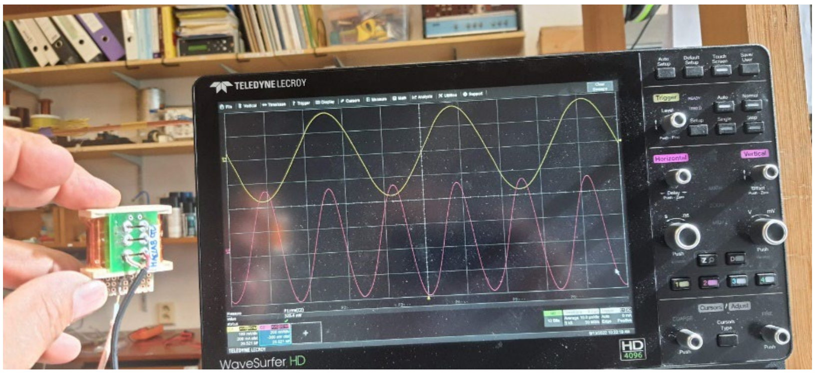

Fig. 4 - 50 µT field - thanks to the resonance tuning the response is quite clean 2nd harmonic voltage

Fig. 5 - 50 µT field for tuned excitation

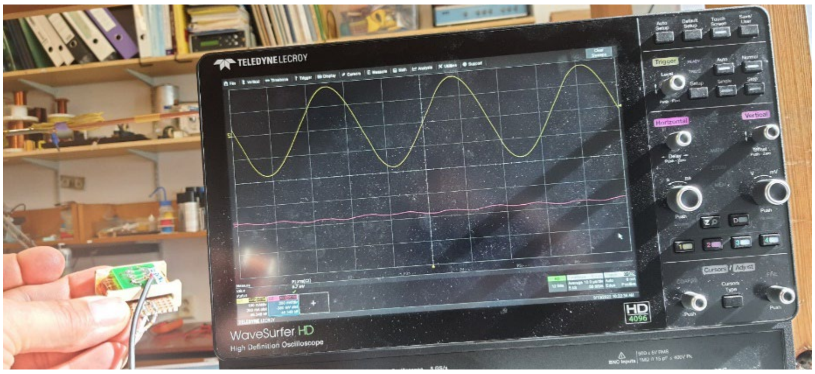

Fig. 6 - Zero field

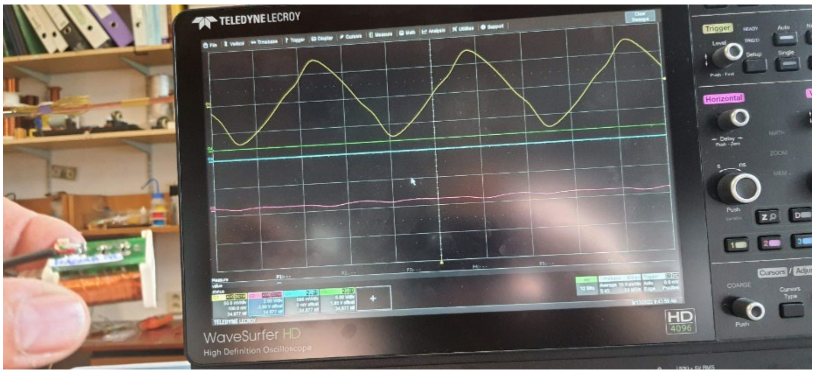

Fig. 7 - Zero field for tuned excitation

Fig. 8 - CT scan motifs (without coil core)