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Implementation and Applications of a 3D-sensitive Giant Magnetoresistance (GMR) Sensor

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Abstract

We report the implementation and applications of a GMR commercial magnetic sensor, capable of measuring simultaneously the three cartesian components of a magnetic field, either DC or AC. After calibration procedure, basic tests are made by mapping the magnetic field around a small solenoid. The response of the sensor to a vibrating magnetic sample is then studied in various situations of resonance: (a) continuous vibrating sample; (b) sinusoidal amplitude modulated motion; (c) squared amplitude modulated motion and (d) modulated pulsed signal. This last experiment is rather similar to what is done in the well known technique of Nuclear Magnetic Resonance (NMR). The sensor response in this case resembles the Free Induction Decay, the signal observed in usual NMR experiments. The Fourier transform of such signals reveals the response of different vibrating modes of the system. The high sensitivity of the sensor is tested for mechanical noise, what entitles it to be used in various applications. Computer interfacing is made through the parallel port, and experiments were automated through a LabVIEW routine. Details on the built circuitry for reading from and writing to the sensor are also presented.

Magnetic sensors are one of the main industrial applications of new magnetic materials [1, 2]. The recent literature of magnetic sensors has been focused rather in sensors based on the so-called Giant Magneto Impedance (GMI) phenomenon [3, 4, 5]. On this paper we report the implementation and applications of the Giant Magnetoresistence (GMR)–based sensor HMC2003 from Honeywell. These are made from thin films of Nickel-Iron deposited on Silicon substrate. Three mutually perpendicular stripes of the film, each one arranged in a Wheatstone bridge configuration, are capable of measuring simultaneously the three cartesian components of a magnetic field. The saturation field for this model is 2 G, and its resolution 40 μG. Further technical details of the sensor can be found in [6]. The chip containing the sensor is mounted in a board with approximate dimensions 2×2.5 cm, which in turn is mounted in a box of $4.4 \times 3.5 \times 1.6$ cm. The communication with the sensor is made through a PC (Personal Computer) parallel port, and the circuitry to perform this task is shown in Figure 1.

Reading the sensor is carried out through a circuit containing the AD974 Analog to Digital Converter (ADC), from Analog Devices. This acquisition system makes use of four channels for serial communication and presents high sampling speed (200 kHz) and 16 bits resolution. The data acquisition software was developed using the graphical programming package LabVIEW. The values of the measured magnetic field were acquired individually for each spatial direction (x, y and z), through one of the input channels of the A/D converter. Due to the high sampling rate, there was no significant change of the magnetic filed during the data transfer. Furthermore, since the converter A/D resolution is of 16 bits, and it was possible to measure very low values of magnetic fields ($\tilde{}$ 60 μG), using the developed acquisition system, described in this paper. For digital filtering process, a subroutine was created, which averages several measured values, in order to eliminate the random white noise.

The HMC 2003 sensor can be affected by large fluctuating magnetic fields which lead to degradation output signal. In order to eliminate this effect, and maximize the output signal, a magnetic switching technique can be applied to the bridge using the SR+ and SR- pins that eliminates the effect of past magnetic history. Then a Set/Reset control circuit was built using the HEXFET IRF7105, from International Rectifier. These circuits are also controlled through the parallel port.

Calibration and linearity tests were carried out through the comparison of the HM2003 sensor to a non-directional commercial Hall effect-based sensor. The directional property of the sensor was verified using a Helmholtz coil, with the field applied along the three directions, although attaining good alignment along the thin edges of the sensor was not simple. Figure 2 exhibits the mapping of the static magnetic field around a solenoid with dimensions $R = 1$ cm, $L = 20$ cm. Two peaks are observed at the extremities of the coil, region where the field is more intense. Due to the size of the sensor box, as compared to the size of the solenoid, measurements between the two peaks inside the solenoid could not be taken.

In order to test the response of the sensor to AC fields, samples of ferrite with different masses were mounted in a glass rod (≈ 6 cm of length and radius $R \approx 0.5$ mm) and made to vibrate directly above the z-face of the sensor. Data acquisition was automated through a LabVIEW routine. Figure 3(a) shows the response to a simple sinusoidal signal and its Fourier transform, and Figures 3(b) and 3(c) show the response to amplitude modulated signals, with the respective Fourier transforms. By varying the (unmodulated) frequency, resonance curves can be observed, as in Fig. 4.

From the information of resonance peaks, it was possible to test the sensor in an experiment rather similar to what is done in Nuclear Magnetic Resonance: the carrier was modulated with a square pulse at the resonance frequency of a particular sample (in the case shown, 33 mg), and applied to the system. Separation between pulses was chosen to be a few times the linewidth ($\Delta\tau \approx 20$sec.), and pulse width was varied around $\tau = 1/\Delta f_0 \approx 5.5$ sec, where $f_0 \approx 22$ Hz is the resonance frequency. The results are shown in Figure 5. We observe that the time response is very similar to the so-called Free Induction Decay (FID) of a NMR experiment [7]. As the pulse width is narrowed, the spectra become more complex. This can be attributed to the excitation of different vibrating modes of the rod, as the effect of narrowing the pulse is the broadening of its Fourier components. Of course, this information does not appear in the "continuous wave" experiment, in which a single vibrating mode of the rod is excited.

The above results show the excellent time response of the HM2003 sensor to AC fields. This opens up many possibilities of applications. As an example, Figure 6 shows the detection of a mechanical noise applied to the workbench where the sensor was mounted. The setup can be easily extended to operate as a motion sensor of bridges, building, earthquakes, etc. Furthermore, by adapting the data acquisition program and inserting a Global Positioning System (GPS) to the basic setup, a portable device for mapping magnetic fields can be easily mounted.

Figure Captions

1. Figure 1 – Circuit board to communicating to the Honeywell HMC2003 sensor.
2. Figure 2 – Mapping of a static field around a solenoid with radius $R = 1$ cm and lengh $L = 20$ cm. The two peaks correspond to the extremeties of the solenoid. The region in between them was not mapped.
3. Figure 3 – (a) Response of the sensor to a single sinusoidal signal applied to an oscillating glass rod containing 33 mg of ferrite, and its Fourier transform. (b) and (c) Response to amplitude modulated signals, sinusoidal and square, respectively, and their Fourier transforms.
4. Figure 4 – Resonance curves, varying the excitation frequency point-by-point, for different masses of ferrite samples.
5. Figure 5 – Response to squared modulated pulses for various pulse-widths applied to the sample of 33 mg. The experiment is similar to what is done in Nuclear Magnetic Resonance.
6. Figure 6 - Detection of mechanical noise in the workbench.

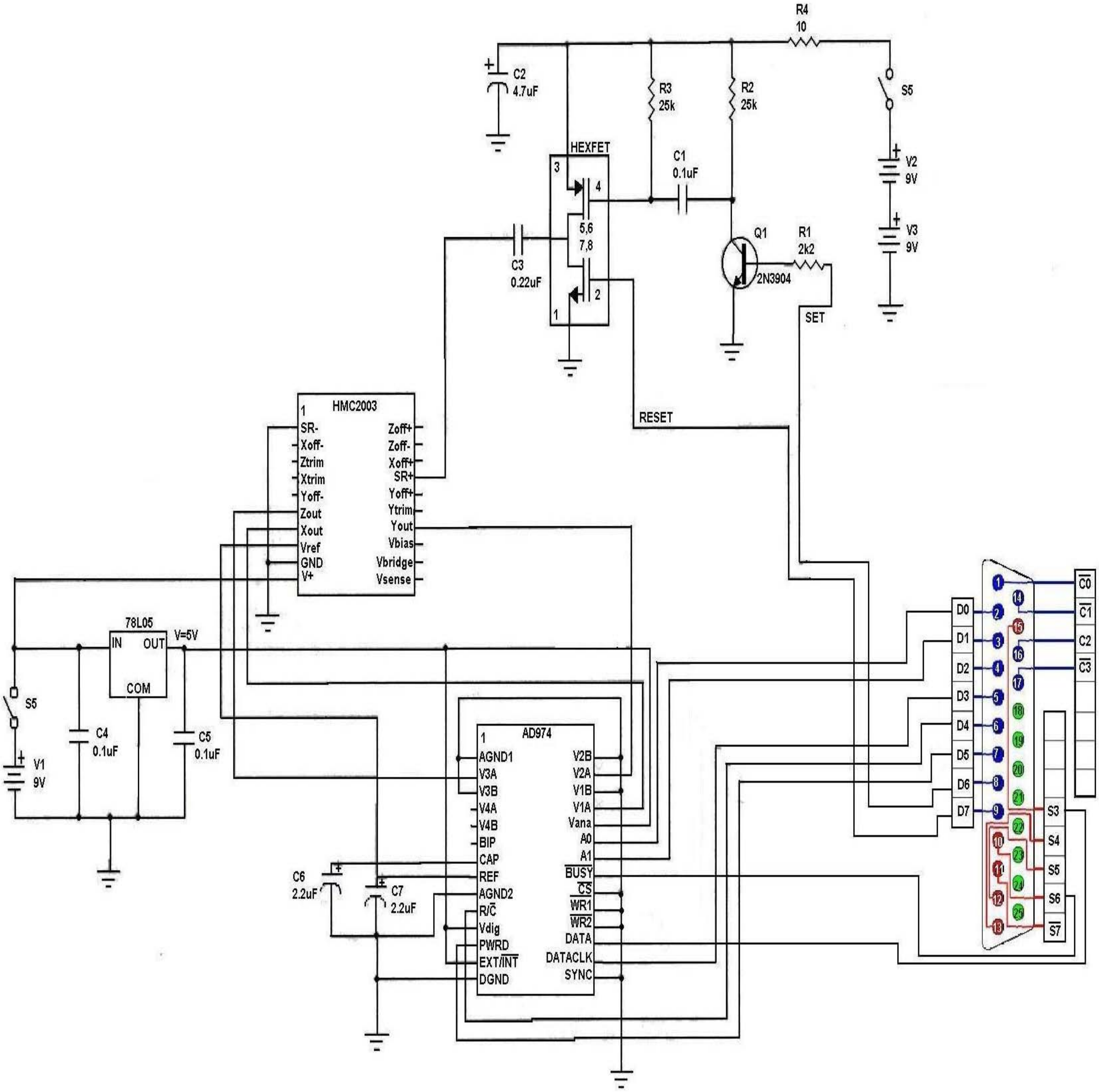

R4
10
C2
4.7uF
R3
25k
R2
25k
S5
HEXFET
3
4
5,6
7,8
2
1
C1
0.1uF
V2
9V
V3
9V
Q1
2N3904
R1
2k2
C3
0.22uF
SET
RESET
HMC2003
1
SR-
Xoff-
Ztrim
Xtrim
Yoff-
Zout
Xout
Vref
GND
V+
Zoff+
Zoff-
Xoff+
SR+
Yoff+
Ytrim
Yout
Vbias
Vbridge
Vsense
78L05
IN
OUT
V=5V
COM
S5
V1
9V
C4
0.1uF
C5
0.1uF
AD974
1
AGND1
V3A
V3B
V4A
V4B
BIP
CAP
REF
AGND2
R/C̄
Vdig
PWRD
EXT/INT̄
DGND
V2B
V2A
V1B
V1A
Vana
A0
A1
BUSY̅
CS̄
WR1̄
WR2̄
DATA
DATACLK
SYNC
C6
2.2uF
C7
2.2uF
D0
D1
D2
D3
D4
D5
D6
D7
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
C̄0
C̄1
C2
C̄3
S3
S4
S5
S6
S̄7

Fig. 1

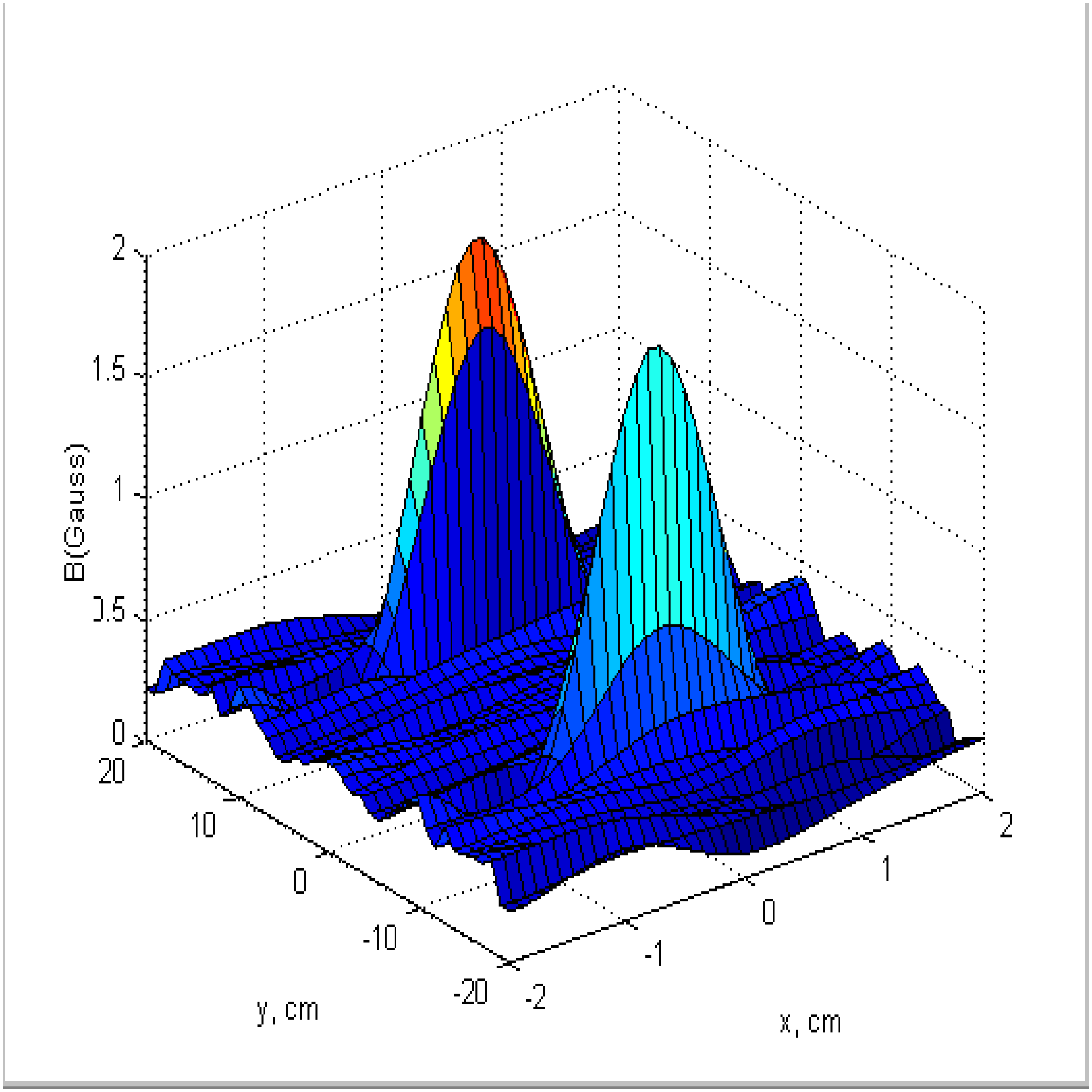
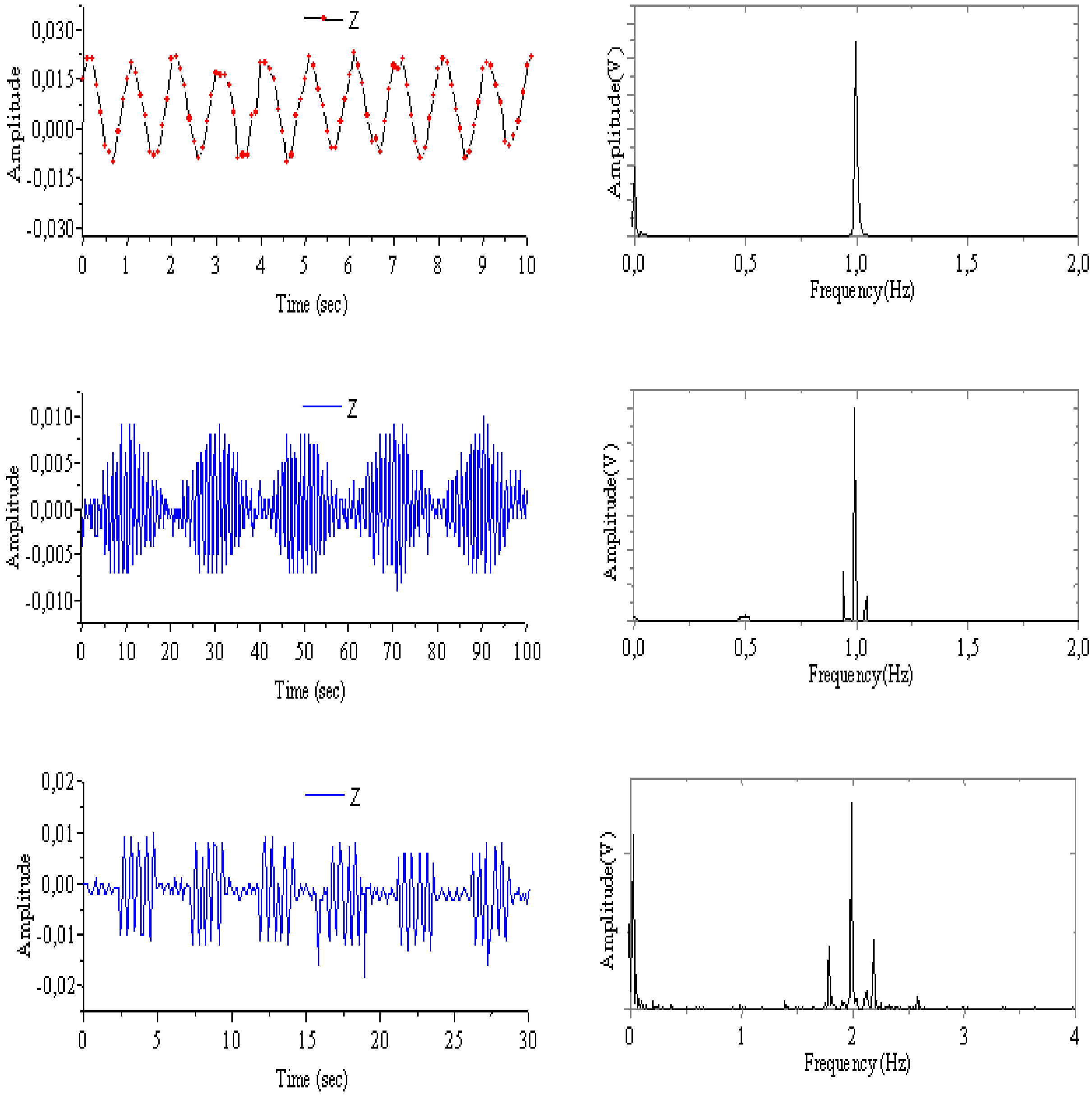


Fig. 2


Z
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0,015
0,000
-0,015
-0,030
Amplitude
0 1 2 3 4 5 6 7 8 9 10
Time (sec)
Amplitude(V)
0,0 0,5 1,0 1,5 2,0
Frequency(Hz)
Z
0,010
0,005
0,000
-0,005
-0,010
Amplitude
0 10 20 30 40 50 60 70 80 90 100
Time (sec)
Amplitude(V)
0,0 0,5 1,0 1,5 2,0
Frequency(Hz)
Z
0,02
0,01
0,00
-0,01
-0,02
Amplitude
0 5 10 15 20 25 30
Time (sec)
Amplitude(V)
0 1 2 3 4
Frequency(Hz)

Fig. 3

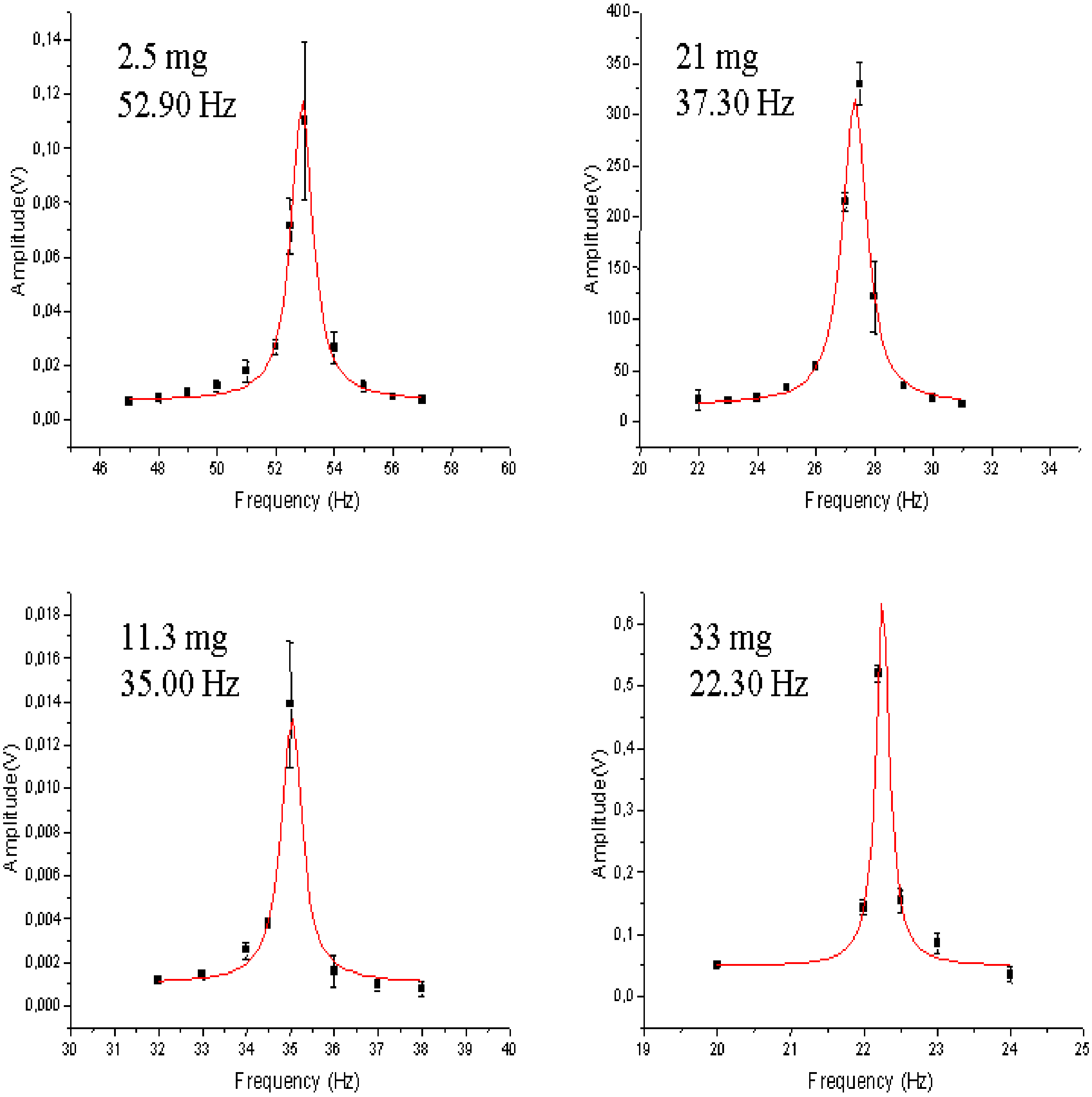
2.5 mg
52.90 Hz
Amplitude(V)
0,00
0,02
0,04
0,06
0,08
0,10
0,12
0,14
Frequency (Hz)
46
48
50
52
54
56
58
60
21 mg
37.30 Hz
Amplitude(V)
0
50
100
150
200
250
300
350
400
Frequency (Hz)
20
22
24
26
28
30
32
34
11.3 mg
35.00 Hz
Amplitude(V)
0,000
0,002
0,004
0,006
0,008
0,010
0,012
0,014
0,016
0,018
Frequency (Hz)
30
31
32
33
34
35
36
37
38
39
40
33 mg
22.30 Hz
Amplitude(V)
0,0
0,1
0,2
0,3
0,4
0,5
0,6
Frequency (Hz)
19
20
21
22
23
24
25

Fig. 4

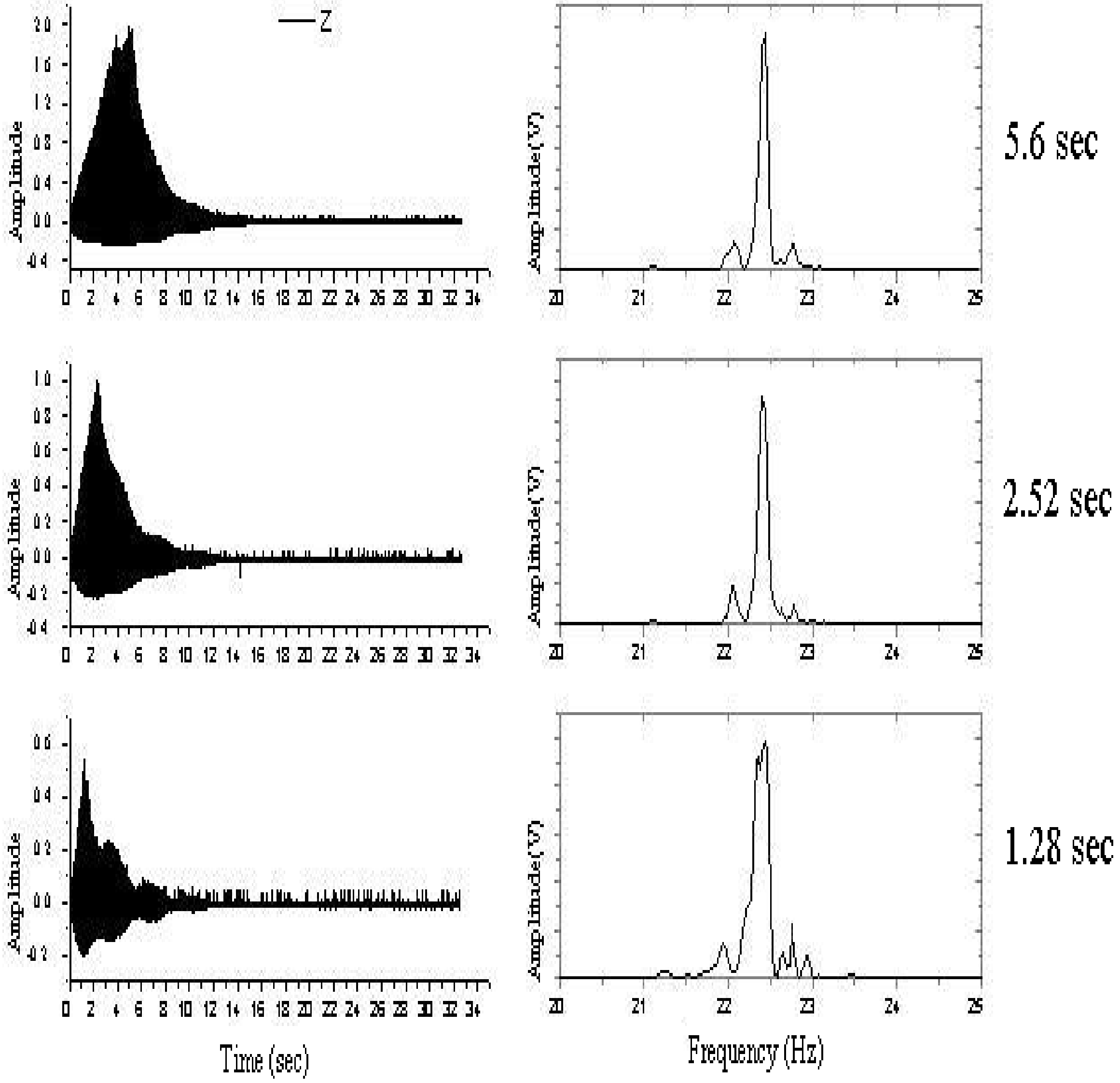
Z
Amplitude
2.0
1.6
1.2
0.8
0.4
0.0
-0.4
1.0
0.6
0.2
-0.2
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34
Time (sec)
Amplitude('V')
20
21
22
23
24
25
Frequency (Hz)
5.6 sec
2.52 sec
1.28 sec

Fig. 5

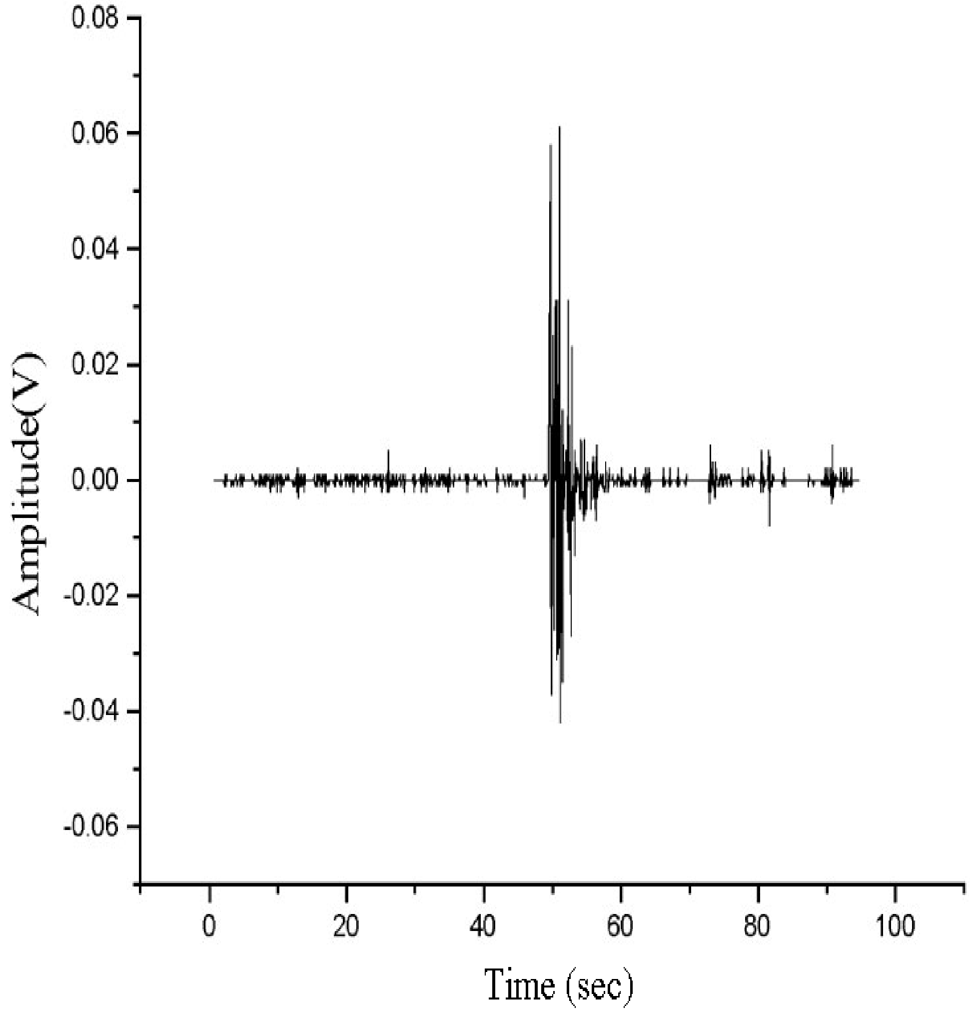
Amplitude(V)
0.08
0.06
0.04
0.02
0.00
-0.02
-0.04
-0.06
0
20
40
60
80
100
Time (sec)

Fig. 6

References

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