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REPORT ON FG-3+ FLUXGATE SENSORS TESTING

FG-3+ is fluxgate magnetic field sensor has rectangle wave output signal with period, directly proportional to magnetic field strength along its axis (fig.1). So we should only provide each time direct measurement of period in time units (e.g. microseconds or MCU clocks) and convert it to magnetic field units (nT, Gauss, etc.).

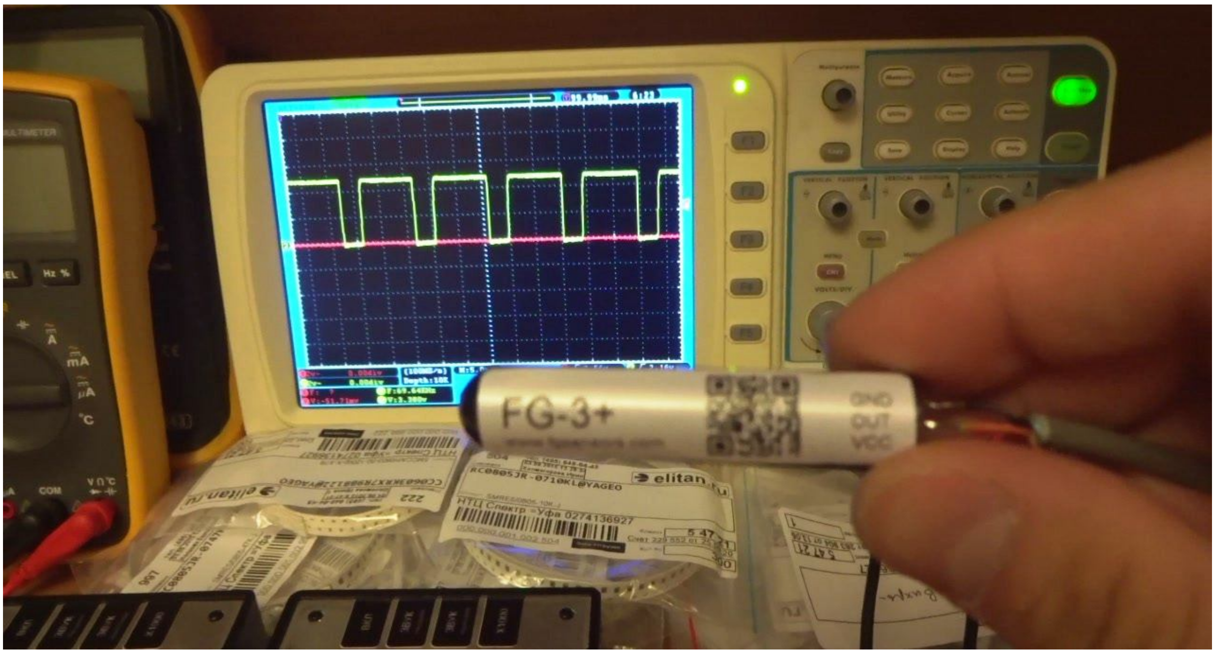

Fig.1. FG-3+ output signal

According to the datasheet there is almost linear relation between period of the output signal and magnetic field strength applied along axis of the sensor. In order to verify it, I placed each FG-3+ sensor into solenoid creating known magnetic field when known current passed over the solenoid (fig.2).

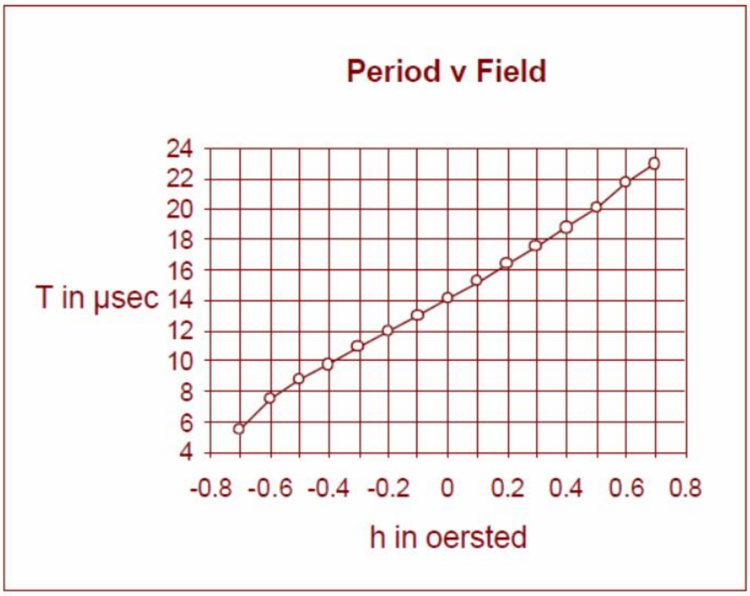

Fig.2. A solenoid to calibrate magnetic field sensors and FG-3+ characteristic from datasheet

Regulating current passed over the solenoid I observed changes of FG-3+ output signal period in the oscilloscope. I acquired my measures to the graphs for each of three my sensors (fig.3), but they turned out very not linear: there is some laydown between –10000 and +40000 nanoTesla (–0.1 and +0.4 Oersted respectively).

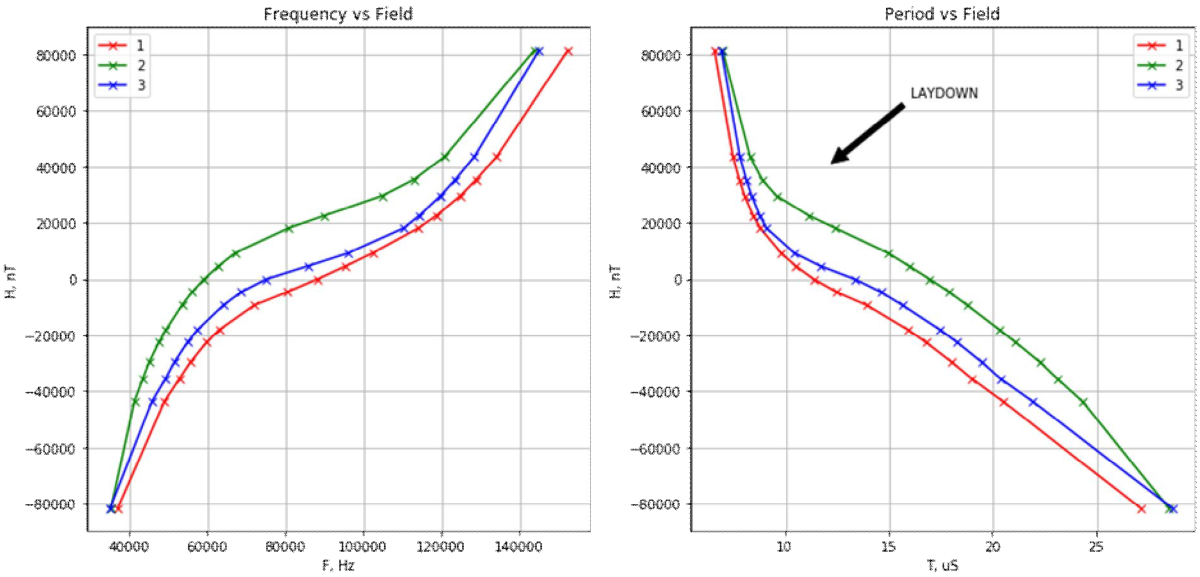

Fig.3. Typical FG-3+ characteristic curves measured (there Period = 1/Frequency)

Since the shape of characteristic curves shown in the figure 3 is too complicated to be approximated by simple linear function $H = \alpha T + \beta$, I tried to pick up transcendent function and high-order polynomial to approximate it (fig.4 and fig.5).

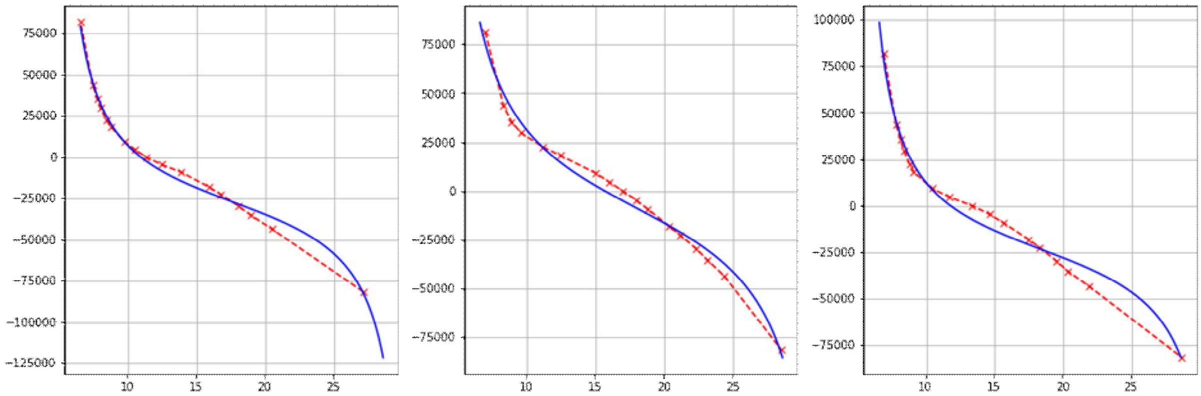

Fig.4. Approximation by function $H(T) = \alpha + \beta \times \tan(\gamma T + \delta)$

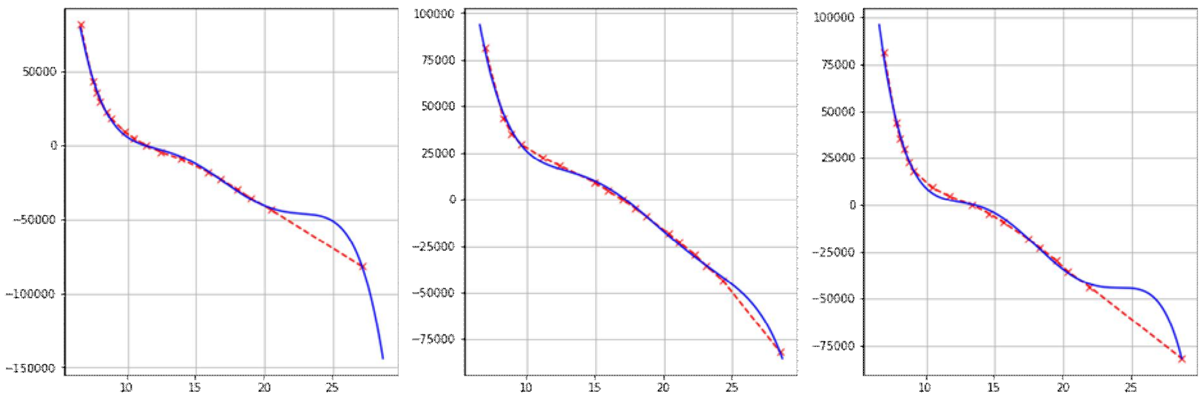

Fig.5. Approximation by function $H(T) = \alpha + \beta T + \gamma T^2 + \delta T^3 + \omega T^4 + \lambda T^5$

In order to linearize period vs field relation the datasheet recommend to calculate period from frequency with some small bias by the formula: Period = 1/(Frequency + Bias). I tried to set different bias values, including recommended, but I could not linearize it, just succeeded to make curves more symmetrical and easier to approximate when bias set to 90 kHz (fig.6).

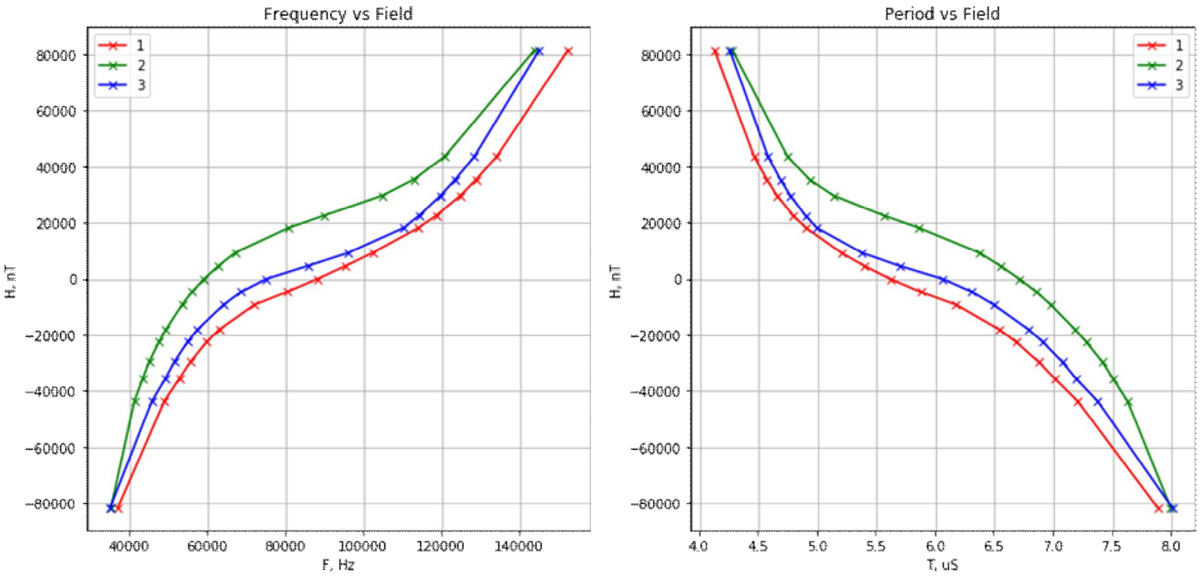

Fig.6. Recalculated FG-3+ characteristic curves (Period = 1/(Frequency + 90 kHz))

Below the results of three recalculated FG-3+ characteristic curves approximation by transcendent function (fig.7) and high-order polynomial (fig.8) presented. It may be observed that approximation got better than without bias.

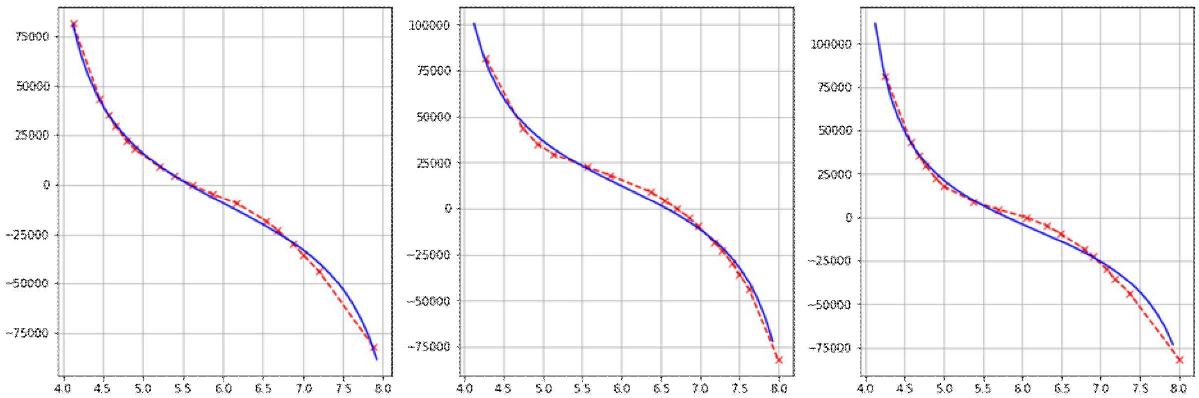

Fig.7. Approximation by function $H(T) = \alpha + \beta \times \tan(\gamma T + \delta)$

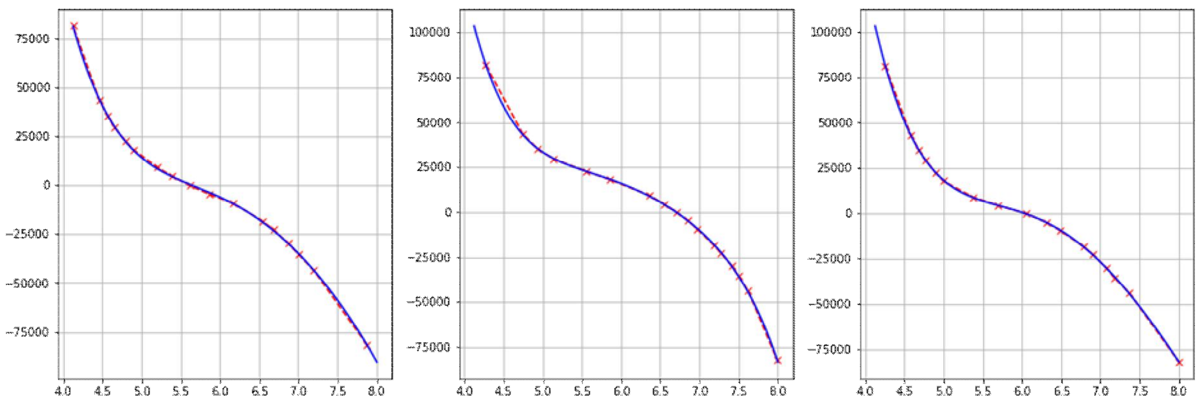

Fig.8. Approximation by function $H(T) = \alpha + \beta T + \gamma T^2 + \delta T^3 + \omega T^4 + \lambda T^5$

Approximations above described and others calculations written in Python 2.7 into Jupyter Notebook file. To open this file you should download and install Anaconda Python 2.7 version from here: https://www.anaconda.com/download/.

But these approximations including biasing and 5th order polynomial or tangent function are too slow and difficult to be implemented in MCU program. In my 3-axial fluxgate magnetometer still under development I used STM32F205RET6 general purpose MCU (fig.9).

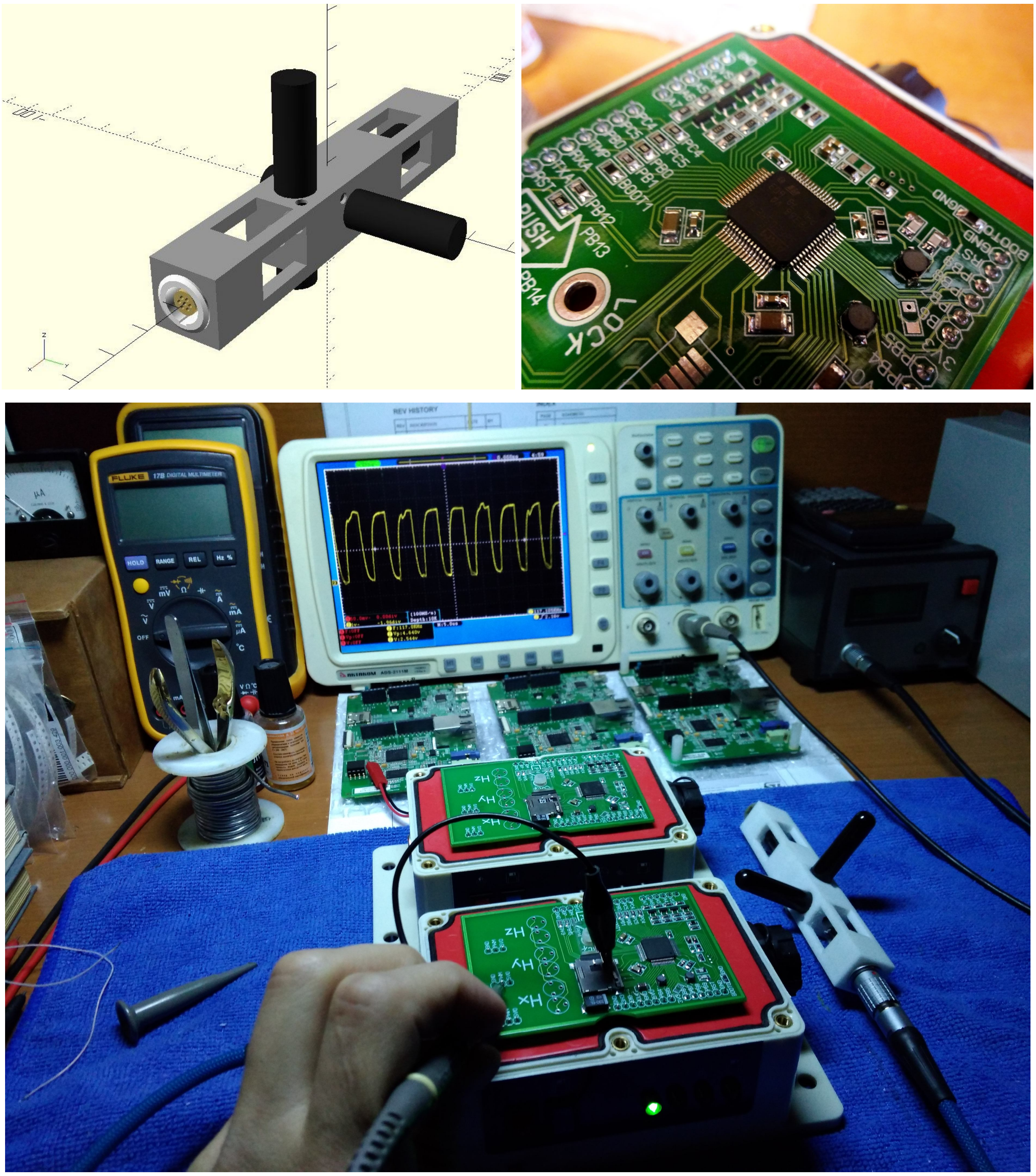

Fig.9. Development of 3-axial fluxgate magnetometer

The measurement of FG-3+ output signal implemented in two ways:

1. The output signal frequency transformed to analog value through LM2917 frequency-to-voltage converter and sampled by ADC built-in. Since STM32F205RET6 ADC resolution is limited by 12 bits, I made circular buffer with length of 8192 samples and oversample it to get

required 1 nT resolution. Such a strong oversampling results to significant delay and averaging on each measurement point. So I can not provide 3-component measurements, because of geometric sum of components measured depended on the speed of each component changed when sensor assembly rotated.

Each component of magnetic field calculated from frequency value measured by characteristic function H(F) = α + β × tan(γF + δ), which provide suitable level of approximation of frequency vs field characteristics we can see on the fig.3.

In figures below the effect of oversampling delay shown when sensor assembly rotated around each axis in one point of space. The figures 10 and 11 obtained with rate about 10 three-component samples per second. When magnetometer mounted to drone I increase it 2 times to get 20 three-component samples per second. As we can see, the faster I rotate sensor assembly, the greater full magnetic field vector value calculated deviates from true constant value.

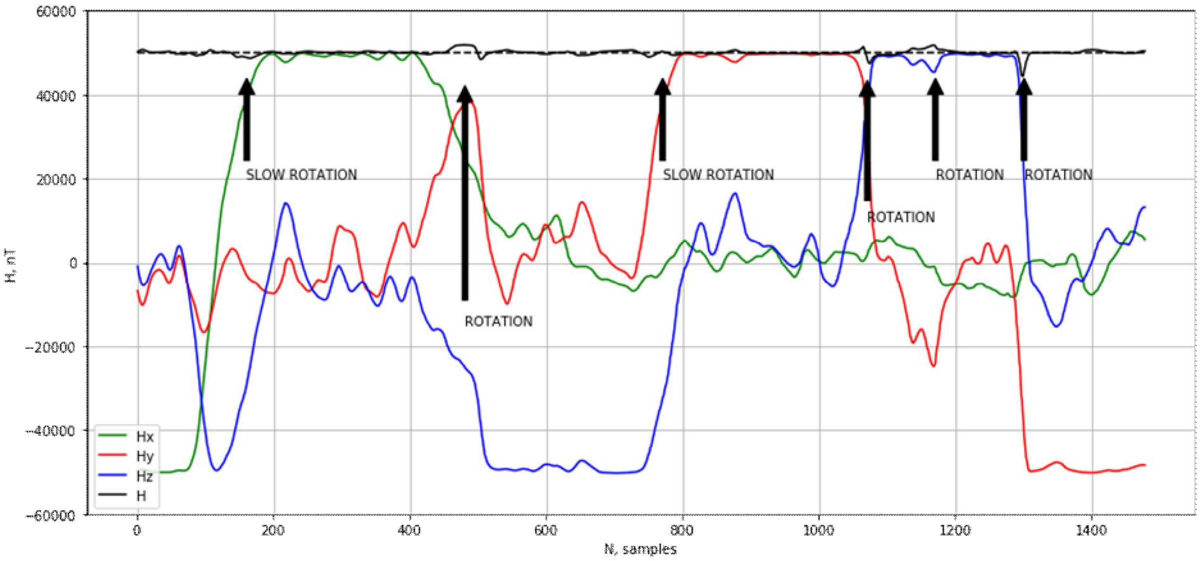

Fig.10. Rotating the sensor assembly calibrated (oversampling factor is 8192)

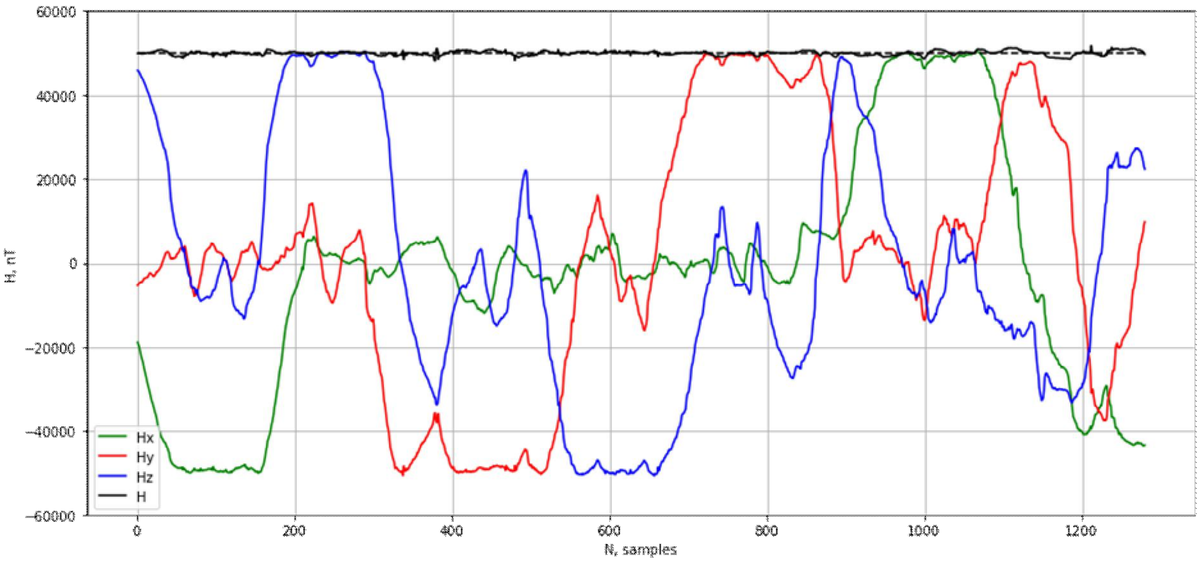

Fig.11. Rotating the sensor assembly calibrated (oversampling factor is 32)

To eliminate effect of speed of rotation on measurements the oversampling delay should be minimized by reducing the oversampling factor from 8192 to 32 (fig.11). But it results to lose of ADC resolution for 256 times, which is not enough to get required 1 nT resolution.

2. The output signal period on each of sensor captured directly by interruption of 32-bit timer on ascending or descending front of rectangle wave. Direct time measurements turned out much faster than ADC and it relieves us from another analog error.

Each component of magnetic field calculated from frequency value measured by characteristic function $H(T) = \alpha + \beta \times \tan(\gamma/T + \delta)$ already used to calculate magnetic field components from frequency measured, since $F = 1/T$.

In figures below we can with the naked eye observe some small changes of full magnetic field vector value when sensor assembly rotated around each axis in one point of space. This is not due to 5 times much fast rotation of sensor assembly I did, but due to approximation of true H(T) characteristic by $H(T) = \alpha + \beta \times \tan(\gamma/T + \delta)$ function became not ideal (see fig.7).

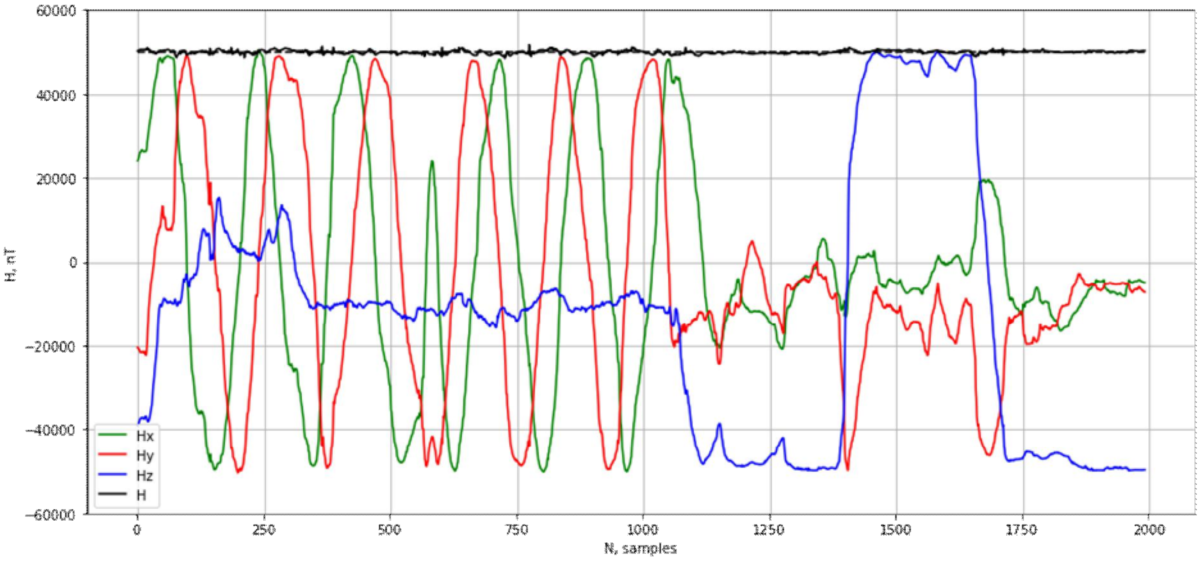

Fig.12. Rotating the sensor assembly of 1st magnetometer

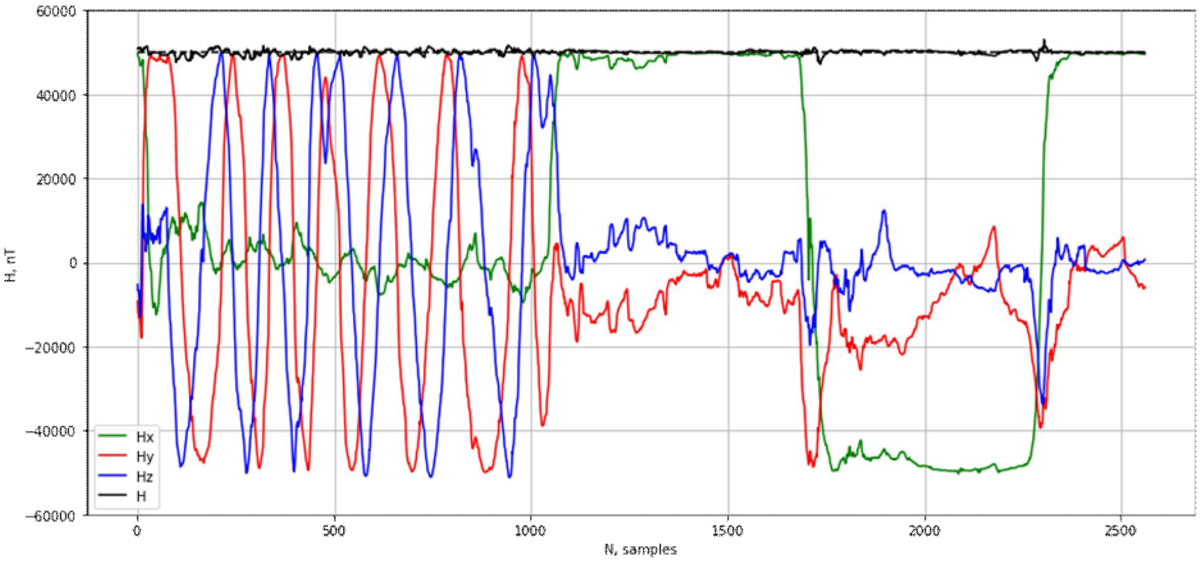

Fig.13. Rotating the sensor assembly of 2nd magnetometer

As we can see comparing figures 12 and 13, first magnetometer calibrated a little better than second, but also not ideal.

Now we have fast and useful, but not ideal function $H(T) = \alpha + \beta \times \tan(\gamma/T + \delta)$ with 4 unknown parameters to calibrate true H(T) characteristic of each FG-3+ sensor, and slow function $H(T) = \alpha + \beta T + \gamma T^2 + \delta T^3 + \omega T^4 + \lambda T^5$ with 6 unknown parameters. The second potentially can provide an ideal approximation of H(T) characteristic, but unfortunately it converged badly during calibration because of too much unknown parameters.

FG-3+ sensor have enough sensitivity to measure magnetic field of buried steel pipelines. The measures in fig.14 obtained by walking with magnetometer across 530-mm pipeline buried to the depth of 2 m under ground. There is some ripple on graphs due to regular rotations of sensor assembly while walking. They will be eliminated when magnetometer will be installed on the drone or airplane or airship.

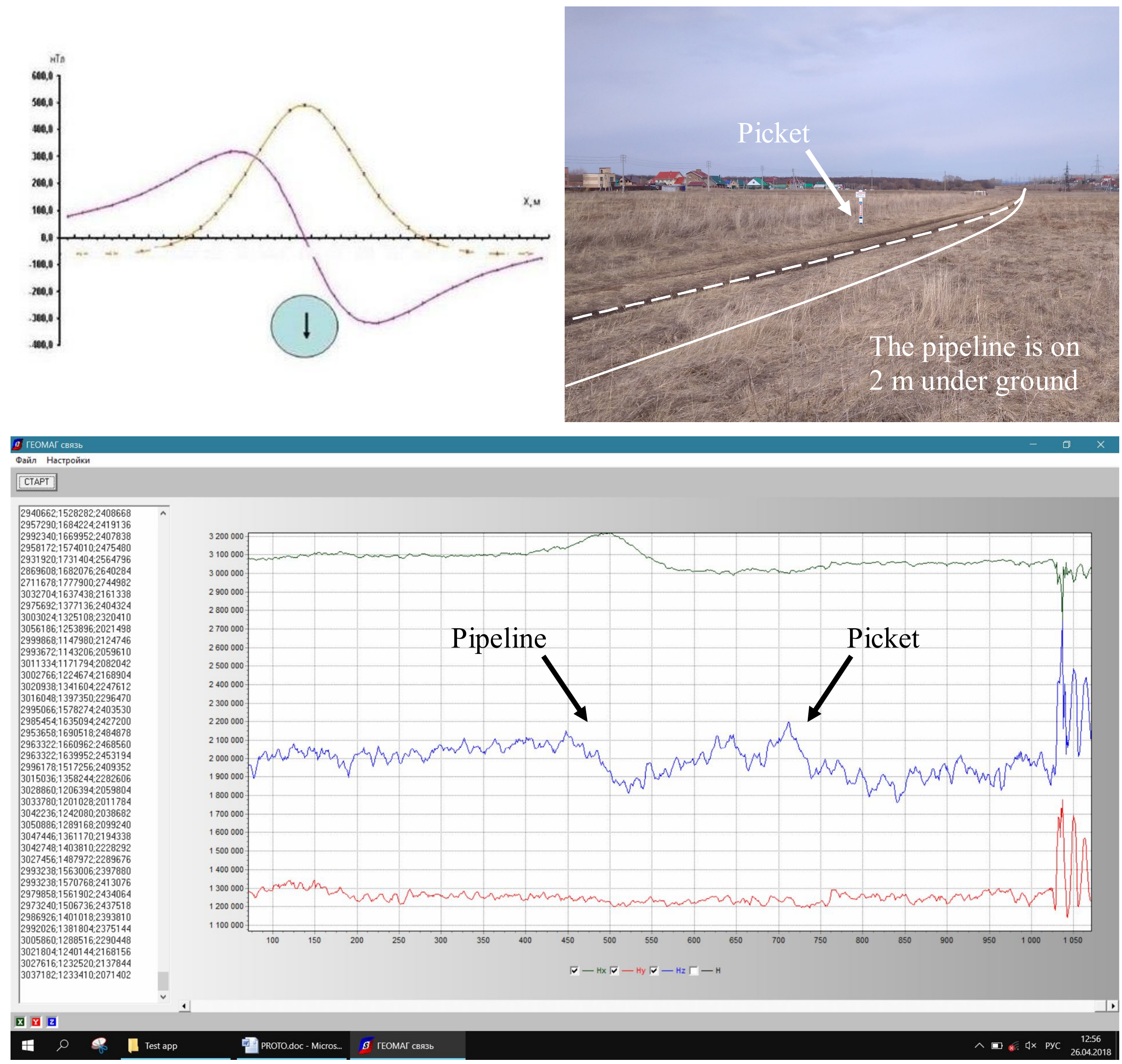

Fig.14. Measuring magnetic field across pipeline

The conclusion is such that in order to achieve resolution of 1 nT from FG-3+ sensor the more appropriate function should be found to approximate true H(T) characteristic of sensor, or, conversely, FG-3+ characteristics should be provided more linear in the manufacture.