

Monitoring Earth's Magnetic Field Using Magnetoresistive Sensor ZMY20M

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Abstract - This paper describes an effort to design a system using magnetoresistive sensor ZMY20M and its implementation in monitoring earth's magnetic field. Attention is given to the sensor's strong reliance of offset and sensitivity upon temperature and a correction by compensation method and software correction is described. Experimental data, both raw and corrected, is provided.

Keywords – magnetic field, magnetoresistive, temperature, compensation, coil

I. INTRODUCTION

Earth's magnetic field is a physical phenomenon, the monitoring of which could help interpreting certain atmospheric processes and physical parameters as well as some solar activities. There are two main sources of magnetic fluctuations-natural, which is due to the very nature of the field and an external one caused mainly by the planet's revolution around its own axis and sun influence. The system described in this paper strives to achieve accurate monitoring of the second type of field varying. As mentioned above the sun's activity is the main cause for a day regular change of the field's magnitude, which varies with 0.1÷1% of it's regionally established value (between 0.3 and 0.6 G). During the day hours the upper layers of the atmosphere are heated, due to sun's radiation, thus this side's ionosphere is more conductive than the night side which causes a time varying component in the inducted ionosphere currents. More so, any strong fluctuations in temperature and pressure, on a more global size, can cause further change in the atmospheric current profile of scale similar to that of day to night variations. Finally the most drastic fluctuations are caused by solar flares, which precede the so called “magnetic storms”, and streams of charged particles (solar wind), which interacts with the magnetosphere, modifying both its shape and magnitude (up to 1% of its established value) . Some of the most common types of magnetometers, which operate in the range of the earth's magnetic field, are: flux-gate magnetometers, faradey magnetometers, hall-effect

magnetometers and magnetoresistive magnetometers. Of the aforementioned, flux-gate and faradey magnetometers base their operation on specific feromagnetic materials, accurate pick-up coils or moving parts and common hall-effect sensors, despite their wide operation zone, does not have sufficient sensitivity to register earth's magnetic field fluctuations. This leaves the magnetoresistive sensors as the authors' preferred choice, providing the advantage of high sensitivity, solid state device technology and an easy build, low cost implementation. ZMY20M [1] is a permalloy based magnetic sensor. Its structure is that of a Wheatstone bridge consisting of four, trimmed, etched stripe structures. Due to the magnetoresistive effect of the used material the bridge is unbalanced in the presence of an external magnetic field. Information about the field's magnitude and direction can be obtained by measuring this differential voltage.

II. STATEMENT

The output of ZMY20M is strongly dependent on temperature [2]. The three, most affected by it, parameters are the temperature coefficient of offset voltage TCV_{off} , the temperature coefficient of bridge resistance TCR_{br} and the temperature coefficient of open circuit sensitivity TCS . The first one is highly linear, contributing a stable value of $-45\mu V/V^{\circ}K$ to the sensor's output as shown later on, but the latter two are both nonlinear (respectively $0.3\%/^{\circ}K$ for the TCR_{br} and $-0.3\%/^{\circ}K$ or $-0.1\%/^{\circ}K$ for TCS dependent on the type of the sensor's power supply-constant current or constant voltage). Another parameter which dampers sensitivity is the hysteresis of output voltage V_{oh}/V_b being approximately 23% of the estimated output value due to earth's magnetic field. Compensating each of these parameters requires measures that exclude to some degree the compensation of others. The influence of the temperature coefficient of offset voltage, which adds an error of absolute type, is easily lowered by correcting the output of the system via software means thus leaving the other two coefficients open for correction by hardware design. The null compensating method [3] is applied, by which the operating point of the sensor must be kept near its zero output level (balanced bridge), so that the sensitivity differential value is kept at its maximum (near the zero point) with the benefit of excluding any temperature reliance. More so, because of the fixed operation point, the hysteresis of the output voltage is removed as long as the sensor's input (magnetic field) is kept at zero. For the implementation of the method the system needs an error amplifier and a summing device. The summing device's role is practically given to the sensor ZMY20M-a coil is wrapped around it, which, when connected properly, establishes a negative electromagnetic

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feedback from the output of the error amplifier. The error amplifier itself is implemented as an analogue integrator [4] as shown on the block diagram (fig. 1)

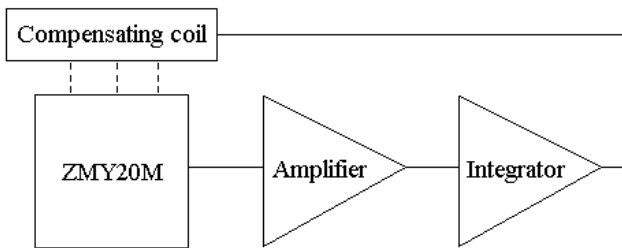


Fig. 1

Thus, closing the electromagnetic loop, any change in the sensor's output would result in an equal and opposite response in the coil so that the error amplifier (the integrator) retains zero at its input. The magnitude of the magnetic field could be acquired by measuring the current through the coil, which is directly proportional to it. The process is governed by a simple differential equation whose solution with respect to the field being applied across the sensor is (1):

$$Hs(t) = He \cdot e^{-k \cdot t} \quad (1)$$

where H_s is the field applied across ZMY20M, H_e is the external field and k is a parameter dependent on the time constant of the integrator, the sensitivity of the sensor, the amplification factor, the size of the compensation coil and the number of windings on it. ZMY20M has one sensitive axis therefore three sensors and coils are needed for acquiring the field vector's components-northerly intensity, easterly intensity and vertical intensity. The other parameters by which the magnetic field is described-total intensity, horizontal intensity, inclination and declination-can be derived by simple calculation from the main three components.

To achieve maximum response to the magnetic field it is desirable for the sensor to be operated at its maximum sensitivity value, which is reliant on the voltage drop across the permalloy bridge. With the temperature reliance of sensitivity compensated it becomes irrelevant, to the sensor's output, which type of power supply to choose though the constant voltage type is preferable. That is because the bridge resistance still rises with temperature and, if supplied with constant current, the voltage drop across the bridge could exceed the maximum safe value. A stable voltage with a much lesser temperature drift, than that of the bridge, is acquired by amplifying the output of a shunt regulator. The signal obtained from the sensor is being amplified by an instrumentation amplifier thus escaping the problem of asymmetrical loading and reducing the anisotropy offset caused by it [5]. The instrumentation amplifier is implemented, as the common three operational amplifier circuit with amplification factor of $A=100$, with A distributed evenly among the two stages. The resulting signal is strong enough to drive the integrator circuit while keeping the noise amplification to a reasonable level. The integrator is implemented as an inverting operational amplifier circuit with a time constant of a value such that

any changes of the magnetic field faster than the ones, that are being monitored, should be omitted. Increasing this time constant makes the system more inert and slower at reaching its balanced state but also increases its stability. For the described system a value of $\tau=10$ ms has been chosen. The integrator circuit's output signal is a voltage potential thus the compensation coil needs a voltage to current converter. The operational amplifier circuit shown on fig. 2 is being used.

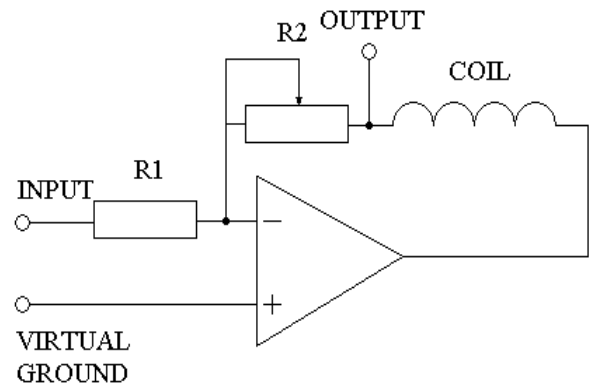


Fig. 2

The resistor R1 determines the voltage to current ratio of the U-I converter. While it is possible to extract the signal from the voltage drop across R1 it is more convenient to get it from the trimmer resistor R2. By adding it, some degree of amplification could be accomplished as an addition to the added stability to the feedback loop of the operational amplifier. This also leaves open the possibility to vary the value of R1 and respectively the time constant $R1-L$, thus changing the coefficient k in equation (1). If the ratio R2 to R1 is being held constant the system could be made more inert without changing its output by raising the resistance of R1 and vice versa. The values of R1 and R2, at a given ratio, though, will be limited by the ambient magnetic field and the power supply voltage.

The number of windings and size of the compensation coil, which govern its field factor, should be chosen with regard to two aspects - compensating current through the coil and uniformity of the produced field. Due to the nature of the monitored field, the current needed to produce its opposite value is rather small compared to the driving currents of the operational amplifiers. Thus, employing a large coil with many windings would result in a very small current through it, the variations of which would not be sufficient enough to be registered with respect to the ambient environment and inner circuit noise. Furthermore it will be difficult to drive accurately this current without special measures. On the other hand if the coil is made sufficiently small, so that the current driving it is of big enough scale, the uniformity of the produced field suffers thus adding a significant error to the output. A compromise should be made when choosing the coil parameters. The coils being used in the system have 26 uniformly spaced windings each, length of four times that of the sensor's one and height (hollow space) equal to that of ZMY20M. The resultant inductance of the coils has been measured at frequency $f=1000\text{Hz}$ and current $I=10$ mA to be $L=8.9\mu\text{H}$.

Due to the circuit's unipolar power supply (12V and 5V), to ensure that a current of both polarities could flow through the coil, a virtual ground circuit has been implemented. The final output value with respect to true ground is then (2):

$$V_{out} = I_c \cdot R_2 = (-H_e \cdot R_2) / A \quad (2)$$

or

$$H_e = V_{out} \cdot A / R_2 \quad (3)$$

where I_c is the current through the coil, H_e is the intensity of the field being measured and A is the field factor of the coil. It should be noted here that every offset and drift of the sensor, amplifier, integrator or the voltage to current converter will be compensated by the coil as though they were an ambient magnetic field additive and thus add an error of absolute type to the output. Therefore values in the outputs of the aforementioned blocks would differ from the ideally established.

As already mentioned, as the temperature reliance upon sensitivity of the sensor is compensated by design means the offset temperature coefficient should not be corrected on sensor level. If the chopper method [6] is applied (the chopper method is used to remove an offset, which is independent of the information signal, by subtracting the output of the sensor of two consequent measurements in which the inputs, polarity of power supply, physical orientation etc. are reversed.), for example, by reversing the polarity of the bridge power supply the current fixed operating point is abandoned resulting in an output error caused by hysteresis (here it should be noted that a strong change in the ambient magnetic field, during a time period much smaller than the system time constant k , causes the operating point of the sensor to shift on the other end of the hysteresis curve). For that reason the offset of the sensor is compensated by means of software. It's drift by temperature has been determined by several times heating the body of ZMY20M and leaving it to cool in a short period of time (tens of minutes to 1 hour) at a supply voltage $V_s=10V$.

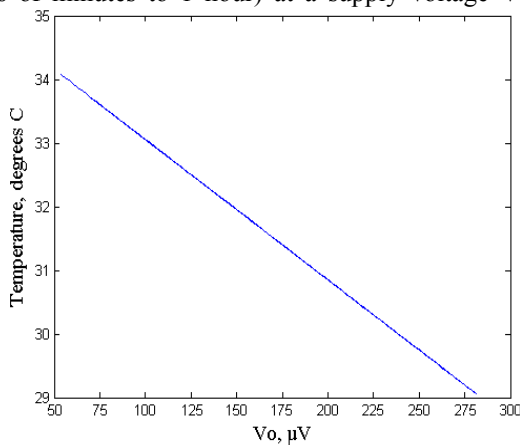


Fig. 3

The time constant is chosen such as to omit any parasitic change of the field but in the same time be small enough as to register the changes due to temperature. That way the output of the sensor and the temperature should have close second derivatives making it easier for processing the obtained data. The ambient temperature is measured by a

system employing Pt100 as a sensor element through the three wire method. Because the temperature drift of sensitivity is compensated by the coil and the time period of the experiment is short enough, no real magnetic fluctuations are detected, i.e. the ambient magnetic field does not change, the drift in the output is ought to be due to the offset temperature reliance. The results are shown on fig. 3 and the experimental setup is given on fig.4 The sensor shows very good redundancy through the several courses of heating and cooling with a steady value of $-45\mu V/^{\circ}K$.

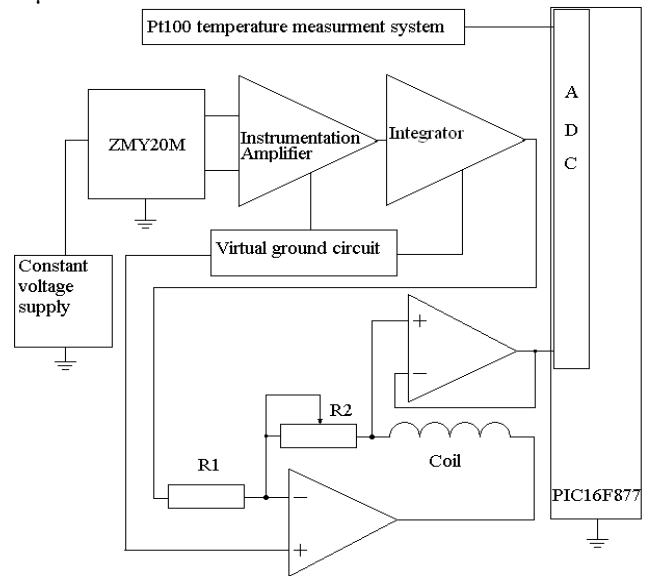


Fig. 4

The setup for the main experiment is the same as the one shown on fig.4. The sensor encased in the compensating coil has been aligned with the magnetic north thus ensuring that maximum output signal is obtained. A suitable way to get a reference point for the sensor output caused by the magnetic field is by rotating the sensor at 180 degrees and measure its output. The average of the two obtained values should be used as a reference point for the field fluctuations. Only one sensor is used so the data isn't

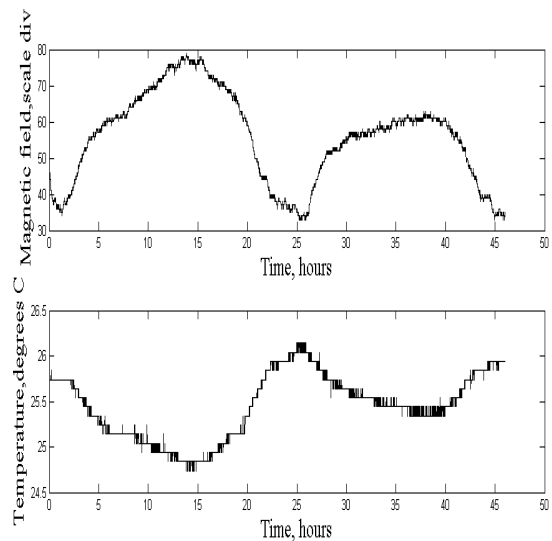


Fig. 5

sufficient to monitor the magnetic field vector. The raw data, system output and temperature versus time of a two-day period of recording, is presented on fig.5.

III. DISCUSSION

Fig. 6 shows the still strong reliance of the sensor's output on temperature. The corrected data shows a clear daily fluctuation of the magnetic field though the exact value of the field cannot be determined at the time due to the lack of calibration tools and the setup which uses only one sensor. The fact that earth's magnetic field varies in direction as well as magnitude furthermore omits any decisive deductions about the magnetic field based on the results. Nevertheless the system exhibits high sensitivity.

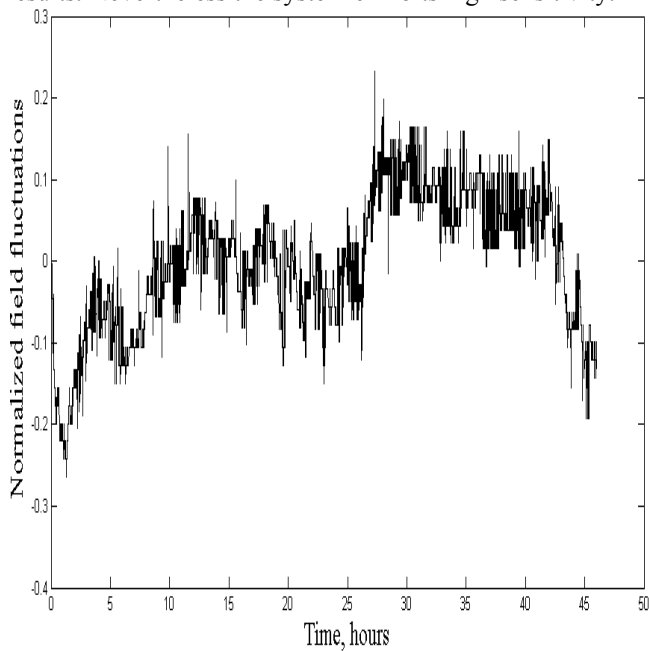


Fig. 6

IV. CONCLUSION

ZMY20M is strongly dependent on temperature thus it needs compensation when used for weak field monitoring. The electromagnetic compensation method provides a suitable solution for the sensitivity temperature reliance but introduces difficulties for hardware compensation of the offset thus a software correction using temperature measurement was applied. The system possesses high sensitivity but due to lack of sensitive calibration tools scaling and determining the real values of the field is not present at the moment. Future development of the system includes calibrating and scaling the output and further investigation of the temperature reliance of the sensor.

V. ACKNOWLEDGEMENT

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