ISSN (Online) 2321 – 2004
ISSN (Print) 2321 – 5526

INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH IN ELECTRICAL, ELECTRONICS, INSTRUMENTATION AND CONTROL ENGINEERING
Vol. 2, Issue 9, September 2014

Design of Optimal Degaussing Electronics for Ring Laser Gyroscope

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Abstract: Ring laser gyros are effective tools for large scale geodetic surveying at a high level of accuracy. They allow rotation of a sensor block with the system and analytical transformation of the output to the coordinate frame of interest such as frequency difference between two oppositely directed laser beams. This paper includes, elimination of the remnant magnetic field in a rectangular coil carrying current efficiently at some point of time by using optimal analysis. To eliminate the remnant magnetic field, one of the methods called degaussing is used. This can be achieved by PWM by changing the duty cycle in different ways. The design of optimal degaussing electronics by optimization principle comprises of selecting one of the three degaussing models described.

Keywords: Ring Laser Gyroscope, Space Vehicle, Laser Beam, Magnetic Field, Degaussing, Bias, Applied Voltage Time, PWM, Duty Cycle, Optimization.

I. INTRODUCTION

In the fast developing world the space vehicles are playing a vital role. Gyro is one of the major parts of the space vehicle. Gyro is used to measure the rotational rate of space vehicles. One of the laser technologies used in gyro is ring laser gyros. Ring laser gyros are effective tools for large scale geodetic surveying at a high level of accuracy. They allow rotation of a sensor block with the system and analytical transformation of the output to the coordinate frame of interest such as frequency difference between two oppositely directed laser beams.

This process is affected by internal and external factors so it is difficult to measure the frequency difference and to convert it to equivalent angle. The laser beam must be incident on the photo diode without any abstraction. If any magnetic field is present, the laser beam will bend, it must be avoided. But sometimes due to external influences gyro will effect by the magnetic field. So, we need to demagnetize the gyro. For demagnetizing the gyro, one method is used known as degaussing. Degaussing is the process of decreasing or eliminating an unwanted magnetic field. But it is generally not possible to reduce a magnetic field completely to zero, so degaussing typically induces a very small "known" field referred to as bias. The original method of degaussing was to install electromagnetic coils into system, known simply as coiling. As the current is proportional to the amount of flux, thus the flux can be controlled by varying the current. The current need to be applied to the degaussing card initially and this should be done within 3seconds or 2seconds or 1second. So within specified time, the current should reach the maximum value and the width of the pulse will be high i.e., 50% duty cycle. In the next 50 seconds the current should reach the minimum value which reduces the amount of flux and eliminates the magnetic effect and during this the width of the pulse should reduce gradually.

Microcontroller is operated at 5V. But the applied voltage is 28V. To convert this 28V to 5V we use the LM109 5V voltage regulator. The AT90S2313 is a 20 pin microcontroller manufactured by ATMEL. The major function of the microcontroller is to generate the PWM wave with changeable duty cycle.

Once PWM wave is generated it must be amplified by the power amplifier because the magnetic coil has a low resistance. Due to this it draws more power; if we connect the coils directly to the microcontroller it cannot supply such amount of power. For this purpose L6203 full bridge power amplifier is used. In this microcontroller, there is a power on reset button which resets the microcontroller before functioning. Generally every micro controller has a prescribed voltage level. If voltage fallen below the prescribed level it must be shut down. For this purpose ADM706 supervisory circuit is used.

To find out the absolute rotation of a system without getting in touch with the outer world and without using a mechanical gyro, Sagnac in the year 1911 devised an experiment called "Travelling time experiment" (sagnac interferometer) which is a laser based rotation sensor that enables the observer inside a rotating system to measure the travelling time of a signal which propagates around a closed loop.

Working Principle:

The basic principle of operation is that a single optical sensor can measure any rotation about its sensitive axis. Therefore three optical sensors one along the independent directions is required to sense exactly the orientation in inertial space at all times. One of the exceptional properties of RL (Ring Laser) is its *non-*

sensitivity to linear acceleration. RLG works on the principle of Sagnac Effect.

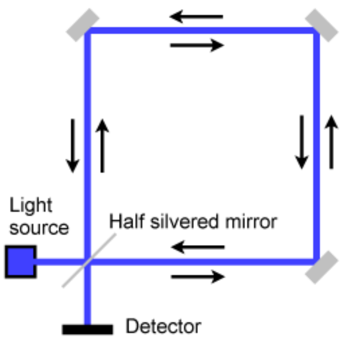

Fig.1 : Direction of laser beam in Ring laser gyro

The Sagnac effect is named after French physicist Georges Sagnac, is a phenomenon encountered in interferometer that is elicited by rotation. The Sagnac effect manifests itself in a setup called ring interferometer. A beam of light is split and the two beams are made to follow a trajectory in opposite directions. To act as a ring the trajectory must enclose an area. On return to the point of entry the light is allowed to exit the apparatus in such a way that an interference pattern is obtained. The position of the interference fringes is dependent on the angular velocity of the setup. This arrangement is also called a Sagnac interferometer. If two pulses of light are sent in opposite directions around a stationary circular loop of radius R, they will travel the same inertial distance at the same speed, so they will arrive at the end point simultaneously.

According to Sagnac, the difference in time that two beams, each travelling in opposite directions, take to travel around a closed path mounted on a rotating platform is directly proportional to the speed at which the platform is rotating.

$$F \propto \theta$$

Laser Interferometers:

The measuring capacity in interferometers of lamp of single wavelength as source of light is limited because of their low resolution and short measuring range. If the light source is replaced by a laser source, measurement can be done over a long distance because it facilitates to maintain the quality of interference fringes over long distance. Since laser is highly monochromatic coherent light source that follows all the principles of light, the fringes formed due to interference of laser are very sharp, accurate and precise.

It uses two-frequency laser system with opposite circular polarization. These beams get split up by beam splitter B_1, one part travel towards B_2 and the other towards external cube corner where the displacement has to be measured. Unlike Michelson Interferometer, mirror is not used as a reflector. Instead cube corner reflector is used. It reflects

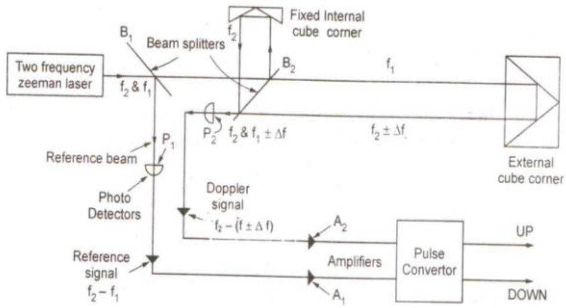

Fig.2 : Operation of Interferometer

light parallel to its angle of incidence regardless of cube corner reflector's alignment accuracy. Beam splitter B_2 optically separates the frequency f_1, which alone is sent to the movable cube corner reflector. The second frequency f_2 from B_2 is sent to a fixed reflector. When these two light sources again meets once the cube corners reflect them to produce alternate light and dark interference patterns. When the movable reflector moves, the returning beam frequency will be Doppler shifted slightly up or down by Δf. Thus, the light beams moving towards the photo-detector P_2 have frequencies f_2 and $f_1 \pm \Delta f$. P_2 changes these frequencies into electrical signal. Photo detector P_1 receives signal from the beam splitter B_1 and changes the reference beam frequencies f_1 and f_2 into electrical signal. An AC amplifier A_1 separates the frequency difference signal $f_2 - f_1$ and A_2 separates the frequency difference signal $f_2 – (f_1 \pm \Delta f)$. The pulse converter extracts Δf, one cycle per half wavelength of motion. The up and down pulses from the converter are counted electronically and displayed in analog or digital form on the indicator. From the value of Δf, the distance moved by the moving cube corner can be determined.

There is no chance of deterioration in performance due to ageing or wear and tear.

II. DEGAUSSING

Degaussing is the process of decreasing or eliminating an unwanted magnetic field. It is named after Carl Friedrich Gauss, an early researcher in the field of magnetism. Due to magnetic hysteresis it is generally not possible to reduce a magnetic field completely to zero, so degaussing typically induces a very small "known" field referred to as *bias*. So for the degaussing purpose here we generate a code and fuse that generated code into an IC. After dumping the code into the integrated circuit we fix it to the degaussing PCB and generate a kind of wave form that eliminates the unwanted magnetic field and could assist the sensor for proper functioning.

The most major issue striking the R.L.G takes place when the Periscope prism fails to focus the outgoing wave onto the photodiode. This has certain external factors to be responsible of which magnetic field is one Prominent one. Sometimes due to external influences gyro is effected by the magnetic field so to de-magnetize the GYRO, one method is used known as *deguassing*. Degaussing is the process of eliminating or decreasing an unwanted magnetic field.

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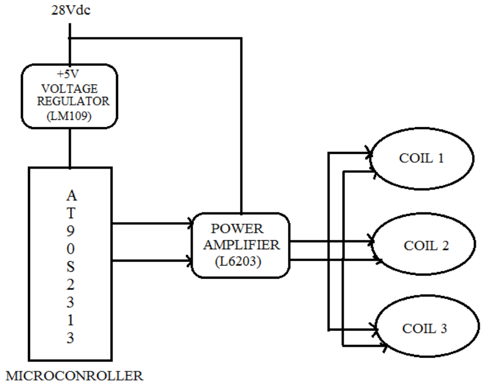

Fig.3 : Block diagram of Degaussing Electronic Circuit

The fig.3 shows the block diagram of degaussing electronic. The main blocks includes Voltage regulator, Power Amplifier, Coils and Microcontroller.

Pulse-width modulation (PWM) is a very efficient way of providing intermediate amounts of electrical power between fully on and fully off. A simple power switch with a typical power source provides full power only, when switched on. PWM is a comparatively recent technique, made practical by modern electronic power switches. PWM can be used to reduce the total amount of power delivered to a load without losses normally incurred when a power source is limited by resistive means. The main advantage of PWM is that power loss in the switching devices is very low.

The actual rotational rate is being converted to the equivalent pulses & the standard number of pulses obtained for the rotation of earth is given by the mathematical formula as follows:

No. of pulses = vertical component of earth's rotation per hour at a location

Scale factor:

If we consider the latitude of Hyderabad it is given as 17°.22'.31" and the longitude of Hyderabad is 78°.28'.27". We know that earth rotates 360° in 24 hours so in 1 hour it rotates an angle of 15°.

So the vertical component of the earth's rotation per hour is given as

$$x = z \sin \theta$$

$$x = 15° \sin (17°.22'.31")$$

$$x = 4.49 \text{ deg/ hour}$$

We know that 1 degree = 3600 arc – sec and 1 hour = 3600 seconds

$$x = 4.49 \text{ arc – sec /sec}$$

$$x = 44.9 \text{ arc-sec/10sec}$$

The scale factor is given as:

$$S.F = 4A/ \lambda L$$

Scale factor calculation for 28cm Gyro:

$$\lambda = 632.8 \text{ nm} = 0.632 \times 0.001\text{mm}$$

A = 3985.1 mm
L = 283.689 mm
S.F = 88905.523 mm
= 1552.318 count /deg
= 0.4311 count/sec
= 1/0.4311 arc-sec/pulse
=2.319arc-sec/pulse (for two pulses)
=2.319/2= 1.14 arc –sec/pulse(for one pulse)

No. of pulses = 44.9 / 1.14 = 37 pulses
= 37 ± 5 pulses / 10 sec.

PWM wave can be generated by comparing predetermined waveform with a reference voltage level or by making simple analog circuits. There is a different way of PWM generation by timer to choose operation mode and compare output mode for generating the desired PWM.

Phase correct PWM mode:

This mode is very similar to the Fast PWM mode except that whenever the value of the timer reaches its maximum value then instead of clearing the value of the timer it simply starts counting down. The value of the pin toggles only when the value of the OCR0 matches with the TIMER0 counter.

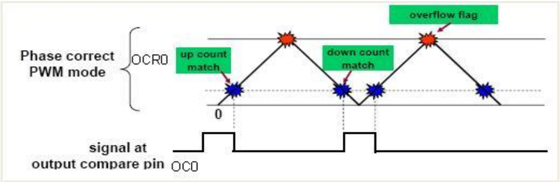

Fig.4: Operation of timer in phase Correct PWM mode

Here,
tout = ttimer = 2 x tclock x OCR;
Hence,
fout = fclock / (2 x OCR);

To program for degaussing circuit (i.e., to create a PWM wave with changeable duty cycle), we have to store the timer value into the register, this value is different for our three methods. So we have to calculate for the three timer register values of 1sec, 2sec as well as 3sec raise and 50sec fall by the above mentioned formulae at scale factor followed by selection of mode of operation.

For UpCount,

No. of steps = (time taken by current to reach max value) / (Time period of signal);

Value of each step is = (half the time period of the signal) / (No. of steps);

For DownCount,

No. of steps = (time taken by current to reach minimum value) / (Time period of the signal);

Value of each step is = (half the time period of signal) / (No. of steps);

Consider a reference value in order to have synchronization between the step values of up count and down count.

Timer:

We use timers every day - the simplest one can be found on your wrist. A simple clock will time the seconds, minutes and hours elapsed in a given day.AVR timers measure a given time interval. An AVR timer in simplest term is a register. Timers generally have a resolution of 8 or 16 bits. So an 8 bit timer is 8 bits wide, and is capable of holding value within 0-255. This register has a magical property - its value increases/decreases automatically at a predefined rate (supplied by user). This is the timer clock. And this operation does not need CPU's intervention.

III. MAGNETIC FIELD IN A RECTANGULAR COIL

The magnetic field at some particular point in a rectangular coil is the sum of the magnetic field due to all four sides (individual current elements) of the rectangle at that point. So, we can calculate the total magnetic field at a point in a rectangular coil by adding the magnetic fields (B) due to all four sides of that rectangle. The Biot-Savart law allows us to calculate magnetic field due to steady current through a small element of wire. Since direction of magnetic field due to different current elements of an extended wire carrying current is not unique, we need to add individual magnetic vectors to obtain resultant or net magnetic field at a point. This method of determining the net magnetic field follows superposition principle, which says that magnetic fields due to individual small current element are independent of each other and that the net magnetic field at a point is obtained by vector sum of individual magnetic field vectors. i.e., $\mathbf{B}=\sum \mathbf{B}i=\mathbf{B}1+\mathbf{B}2+\mathbf{B}3+\mathbf{B4}$.

Biot-Savart Law for a finite straight wire:

It relates the magnetic field to the magnitude, direction, length, and proximity of the electric current.

The mathamatical expression for the biot savart's law of electromagnetism is given by,

$B=\mu_0 I\ (\sin\varphi_1+\sin\varphi_2)\ /4\pi R$ *Tesla(or)Weber/m*^{2}.

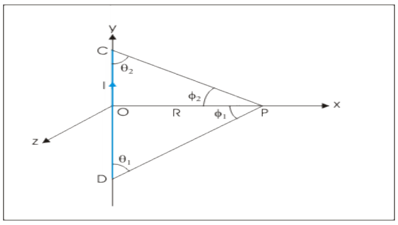

Fig.5: Distance of P from a straight line (side of rectangular coil)

By using before equation, calculating the magnetic field at point P with respect to all four sides of a rectangle having independent current carrying straight lines:

w.r.t. side CD:

$B_1= \mu_0 I\ (\sin\varphi_1+\sin\varphi_2)\ /4\pi R$ *Tesla(or)Weber/m*^{2}

where , $\mu_0=4\pi*10^{-7}$ H/m(or)Weber/A.m.

I is the current through the coil.

R is the perpendicular distance from point P to the line.

We can find the magnetic field w.r.t the sides DA, AB, BC as B_2, B_3, B_4 respectively also. Hence the Total magnetic field surrounded at the point P in a rectangular coil is $\mathbf{B= B_1+B_2+B_3+B_4}$ **Tesla**. For a coil having 'N' no. of turns, total magnetic field, $\mathbf{B_T=NB}$.

Consider a point in a rectangular coil having dimensions 15x10cm at a perpendicular distance of 0.86cm from a side CD and 5cm from side DA.

15x10 cm

The magnetic field, B is given by

$B=\mu_0 I\ (\sin\varphi_1+\sin\varphi_2)\ /4\pi R$ *Tesla (or) Weber/m*^{2}.

The maximum magnetic field observed for a point P in a rectangular coil i.e., w.r.t side CD. At this point, B_2, B_3, B_4 are very less compared to B_1.

For 1sec raise and 50sec fall of current, B_1=72.77 Gauss.

For 2sec raise and 50sec fall of current, B_1=67.66 Gauss.

For 3sec raise and 50sec fall of current, B_1=55.55 Gauss.

These are the peak magnetic fields when the pulse reaches to it's maximum duty cycle, measured by Gauss meter placed in a degaussing (rectangular) coil at point P which is at a distance of 0.86cm from side CD and 5cm from sides CB (or) DA.

IV. OPTIMIZATION PRINCIPLE

In statistics, we can consider maximum - likelihood estimation (MLE) as an efficient method of estimating the parameters for a statistical model for the model's parameters. For a fixed set of data and underlying statistical model, the method of maximum likelihood selects the set of values of the model parameters that maximizes the likelihood function. Intuitively, this maximizes the "agreement" of the selected model with the observed data. Maximum-likelihood estimation gives a unified approach to estimation. Suppose there is a sample $x_1, x_2,\ldots, x_n$ of n independent and identically distributed observations, coming from a distribution with an unknown probability density function $f_0(x)$. $f_0 = f(x|\ \theta_0)$.

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The value θ_0 is unknown and is referred to as the *true value* of the parameter. It is desirable to find an estimator $\hat{\theta}$ which would be as close to the true value θ_0 as possible. Both the observed variables x_i and the parameter θ can be vectors.

The log-likelihood function is:

$$\ln \mathcal{L}(\theta\,;\,x_1,\ldots,x_n) = \sum_{i=1}^{n} \ln f(x_i|\theta),$$

The method of maximum likelihood estimates θ_0 by finding a value of θ that maximizes, $\hat{\ell}(\theta;x)$. This method of estimation defines a maximum-likelihood estimator (MLE) of θ_0 …

$$\{\hat{\theta}_{\mathrm{mle}}\} \subseteq \{\underset{\theta\in\Theta}{\arg\max}\ \hat{\ell}(\theta\,;\,x_1,\ldots,x_n)\}.$$

In our problem, first we fixed a point in a rectangular coil and calculated the magnetic fields for our three models of design. Here we have a variable, ‘t’ i.e., raise time (1sec, 2sec, 3sec), and calculated their respective magnetic fields.

Our aim is to estimate time (t) by finding a value of current (I) that maximizes the magnetic field (B) at the point P in a rectangular coil by MLE estimation.

Now by applying the values into the equation of optimality principle, we get the result as the highest magnetic field at the point P in a rectangular coil carrying current controlled by a PWM wave with 1sec raise and 50sec fall than the other two aspects (2sec raise and 50sec fall, 3sec raise and 50sec fall).

Hence, the degaussing can be efficiently done by the PWM wave with the duty cycle 1sec raise and 50sec fall of time than any other control.

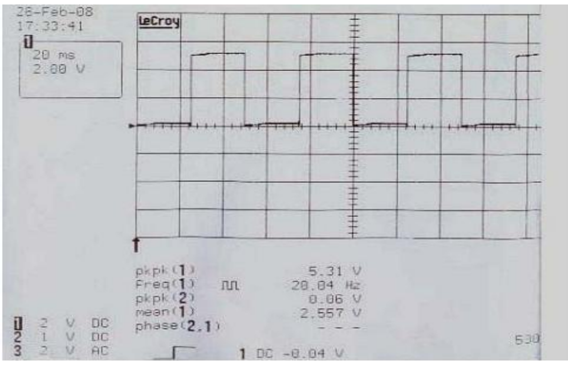
V. TEST RESULTS

After fusing the hex code into the microcontroller, it is inserted into the degaussing PCB which is designed according to the specifications that are described above. After building the degaussing PCB, switch on the power supply and the output can be viewed in the cathode ray oscilloscope, with pulse rising to maximum. This process should be done for the remaining models.

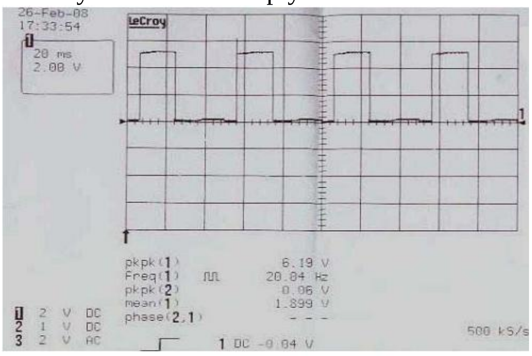
Position (I_{max}) from zero to one second. After one second the pulse slowly starts narrowing and finally reaches to the minimum position i.e. to zero (I_{min}=0) exactly at 51seconds. So, all this procedure should be completed precisely in 51 seconds. The output of the pulses is shown in the below figure.

$0 \rightarrow 0.5$ ==> one second

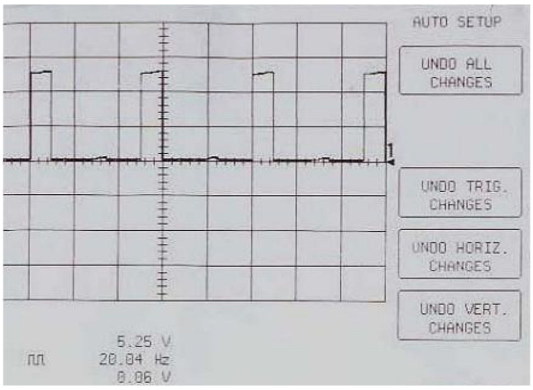
$0.5 \rightarrow 0$ ==> Fifty seconds



The above output wave form is the one we got while doing the experiment, in which it precisely starts rising from the initial stage zero to the final stage i.e the peak stage within one second. The below shown are the graphs that are the outputs taken after one second to fifty one seconds, where the pulse goes to minimum position after the fifty one second sharply.



As shown in the figure the above output graph has peak to peak voltage of 6.19 volts with frequency of 20.04Hz. Whereas the peak to peak voltage for the second instruction in about 0.06 volts. And the mean is nearly two volts. All these considerations are taken within 500 ks/s.



Hence from the above results the degaussing of the pulse width is achieved by using the AT90S2313 Microcontroller.

In this same fashion, one second raise and fifty seconds fall, two second raise and fifty seconds fall are also done and measured the current values, so that we can calculate the magnetic field at every point.

No. of turns of the rectangular coil, N=450

For 1sec raise and 50sec fall of current:

Magnetic field, B_1=72.77 Gauss.

For 2sec raise and 50sec fall of current:

Magnetic Field, B=67.66 Gauss.

For 3sec raise and 50sec fall of current:

Magnetic Field, B=55.55 Gauss.

Then, optimization principle performs a major task in selecting a right approach for our system. It optimizes the time by measuring current to maximize the magnetic field. So this operation gives the system approach for 1sec raise and 50 sec fall of a PWM wave for high magnetic field generation within one second. So it completely removes remnant magnetic field in RLG by placing a very small bias value.

Hence optimization principle gives the best system as: 1sec raise and 50sec fall of PWM wave for degaussing a current carrying rectangular coil in RLG.

VI. CONCLUSIONS

Thus we conclude that, by using theAT90S2313 AVR Microcontroller and AVR Studio we have designed a system for degaussing a current carrying rectangular coil efficiently in a ring laser gyroscope by optimal analysis. Here we dealt with the best optimizer to calculate the results so, this sets for the best system for degaussing a coil in RLG at all gravitational conditions.

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