Magnetometer

What does it do?

We are surrounded by magnetic fields. They are generated by electrical current in our electrical installation, TVs, computers, speakers and many other sources. Earth also has it's own magnetic field. Magnetometer is a device that can measure magnetic field. Earth's magnetic field is relatively small, so measuring it is pretty delicate process.

How does it work?

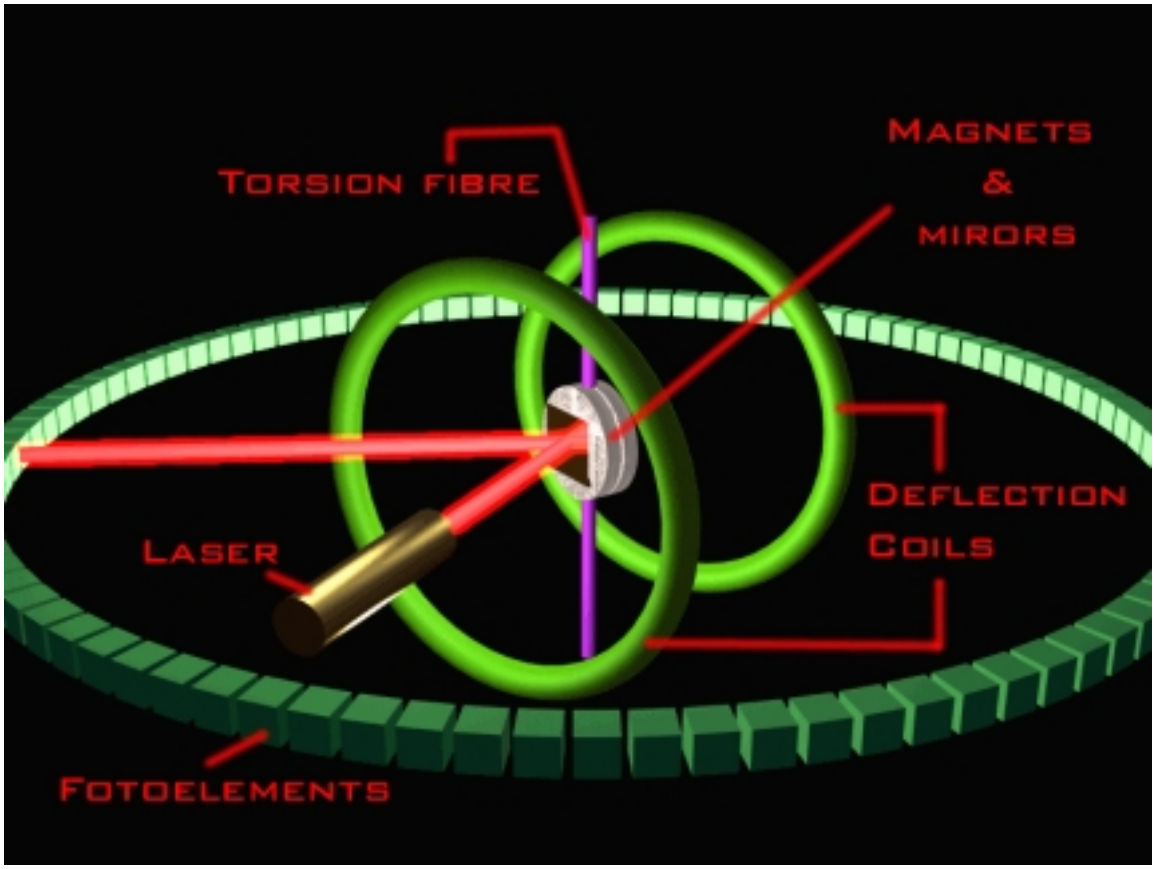
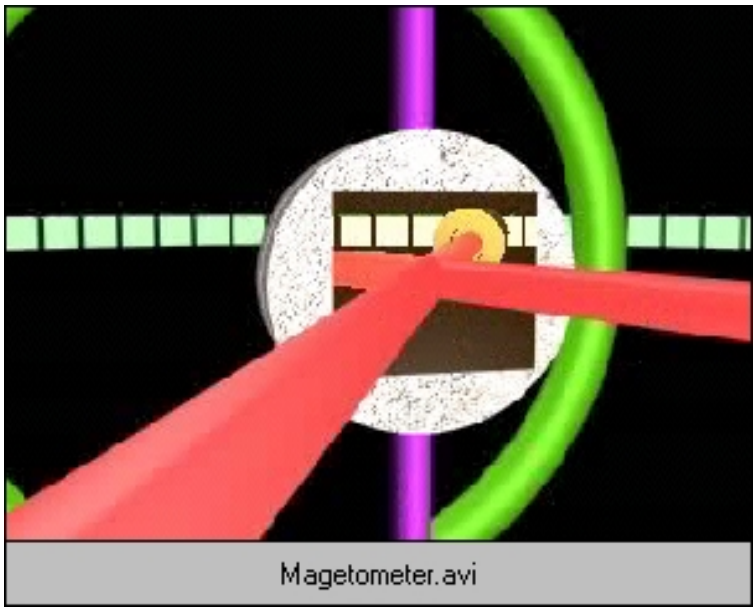


Figure 1 Basic components of our torsion balance type magnetometer

There are many designs of devices which measure magnetic field. The one described here is a torsion balance type of magnetometer. It is made of a permanent magnet suspended on an elastic fiber in such way that it can freely rotate around fiber axes. A magnet is firmly connected with fiber, which is our torsion spring. When we put this system into magnetic field magnet will turn and try to turn so to be aligned with magnetic field. The tension of the spring will try to move it back into its original position, and magnet will end somewhere between original position and magnetic field direction. We have thus just made a compass. If we glue mirror to the magnet and shine a laser beam on it we will see the reflected beam somewhere on the wall few meters away.

In such arrangement reflected beam will move quite a bit on the wall for very small changes in angle of magnet. This means that when a small change in magnetic field causes magnet to rotate well see reflected beam moving a few mm to left or right. This is shown in the animation below (double-click to see it) That mechanism is used to measure the strength of the field.



Double click on the picture above to see animation of magnetometer at work.

Will we really make magnetometer as described in previous section?

No. We will make a bit different magnetometer, which has the same basic idea. We want to automate the magnetometer. This requires that we get somehow electrical output from our magnetometer. So for example when the filed is of strength x we would like to get y=f(x) volts out of our electronic system. We could make a array of photo-elements which would measure how much has the reflected beam moved from original position, but that would require a lot of photo-elements and a lot of space. It would be expensive and impractical. What we'll do is we'll put only two photo-elements. Then, well use coils to generate magnetic field and position reflected beam between the two elements. Next, we'll monitor the elements. If magnetic field changes we will detect that and change the current through coils in such way to return the beam between the photo-elements.
So, this sounds nice, but how do we know the magnetic field? Well, the field generated by coil is function of current that goes through coils. By measuring this current we can calculate magnetic field. If the magnetic field changes by ΔB then we will see this as change in current by ΔI.

How do we control the coils and how do we measure current through them?

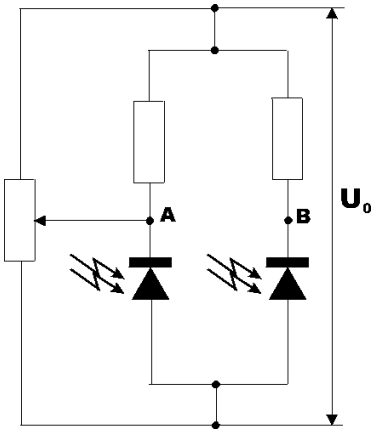


Figure 2 Photo elements setup - if both diodes conduct same current points A and B are on the same potential, if not The potential difference V_{AB} measures how much has the beam moved and in what

Control electronics is responsible for keeping the laser beam in between two photo-elements (photo-diodes or photo-cells).Unless they are uniformly lit by laser beam there will be a potential difference V_{AB} between points A and B of the circuit shown in Figure 2. This voltage is then amplified by differential amplifier and then to the integrator. Integrated signal is used as input for coil's driver circuit. What this means is that as long as $V_{AB} = 0$ the current remains the same. If $V_{AB} \neq 0$ current is adjusted so that V_{AB} returns to zero. Thus the laser beam is held between the photo diodes.
In series with coil there is a resistor of a precise value. Current that passes through coils must be the same as the current that passes through resistor since they are in series. Thus with Ohm's law:

$$U_{mesured} = R_{sense} \cdot I_{resistor} = R_{sense} \cdot I_{coils}$$

So we see that voltage across resistor is directly proportional to current we want to measure.

This is supposed to be automated instrument. How is measured data recorded?

So we see that we can measure magnetic field if we measure voltage across R_{sense}. Voltage can be easily digitized. In fact, any soundcard can do the job so that is just what we'll use. The problem of recording data is then just to make software, which will get data form soundcard, process it if necessary and save it to hard disk.

Final notes

This is just small introduction in the whole project. You can see the diagram of the magnetometer in Figure 3. Please note that this project has not yet been built, so some changes to the original design may be expected.