

WHAT IS A FLUXGATE MAGNETOMETER?



Fig 1 A typical ring fluxgate magnetometer showing the two sense windings and the toroidal excitation winding.

1 The Fluxgate Magnetometer

A magnetometer is a device to measure the strength of a magnetic field. Magnetometers have been in use for a couple of thousand years, ever since it was discovered that the Earth's magnetic field could be used as an indicator of where North is. The simplicity of simply suspending a magnet in the Earth's field and allowing the torque resulting from misalignment to restore the magnet to the aligned position has much to recommend it: simplicity, robustness, easily gimbaled stable and easy to read. But as a magnetometer you would need to measure the torque to find the strength of the field and, these days, there are smaller cheaper devices which have the great advantage of giving an output in electrical form. Electrical magnetometers are needed when an electrical signal is needed – to measure the angle of a shaft or to find out where North is.

A steady field is not the easiest of things to measure. A steady field cannot of itself generate a voltage. What was needed was a simple, robust and stable component. Over many years the fluxgate magnetometer has evolved to meet all of these requirements.

The fluxgate magnetometer is a form of parametric amplifier. The thing to be measured is not itself directly detected, but indirectly via another effect. The effect used in this case is the property of **permeability**. It is this (strictly: *relative* permeability and denoted by the symbol μ) which is the parameter which is changed so as to cause the desired effect.

The outcome we want is to be able to measure a steady magnetic field. The magic of the parametric approach is that it turns the steady field into a changing field. It is done by altering the permeability of a core material. A core placed in a field has the effect of concentrating the field in the region of the core. See Fig 2.

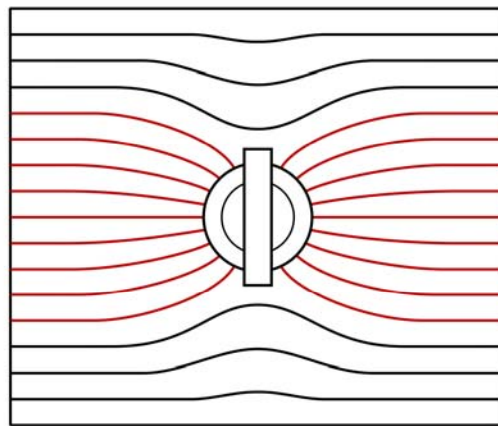


Fig 2

The ring object is the magnetic core and the rectangle is a sense winding

Fig 2 shows a representation of how the **Lines of Force** of the field are distorted by a piece of material with a high permeability – such as iron. Any piece of iron alters the shape of the earth's field which surrounds it in the same way.

But magnetic materials like iron (and the special Ni-Co alloy we use) all have a common feature: there comes a density of Lines of Force beyond which the property of permeability falls dramatically. This is called **saturation**. Fig 3 shows a typical relationship between the number of lines in a given area of metal (**B** denotes **Flux Density**) and the strength of the **magnetising force** or field, **H**.

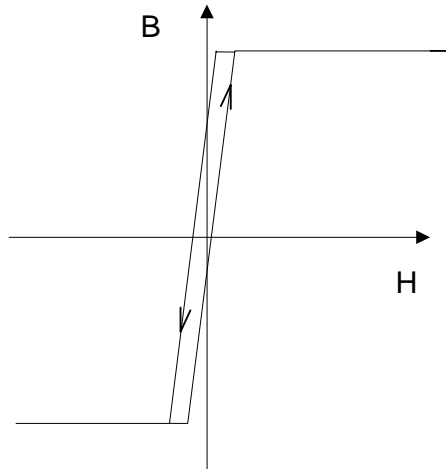


Fig 3 Flux Density vs Magnetising Force

So as H increases – in either direction – a value for B is reached which can no longer increase. The slope of the curve of Fig 3 is the permeability and changes suddenly from near vertical ($\mu=100000$) to near horizontal ($\mu=1$).

[Fig 3 also shows that the path from left to right is not the same as from right to left. This property of **hysteresis** can be a source of error if not handled correctly]

Fig 4 shows that, in a strong field, a metal's permeability can become the same as that of air ($\mu=1$). It magnetically disappears and Fig 4 shows those same lines of flux in Fig 2 but this time the ring of metal is no longer, magnetically, present.

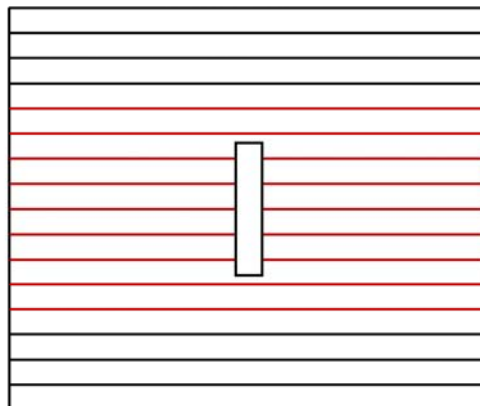


Fig 4

Note that four of the lines of flux now, no longer, 'thread' the rectangle. The two lines at both the top and the bottom pass outside. This is the phenomenon at the heart of the fluxgate magnetometer: flux is gated to be inside or outside a coil placed in the position shown by the rectangle. There is a change of flux in that coil when the metal changes to being saturated and again when it changes back. But that flux change in a coil directly generates a voltage (and current too if there is a load) during the transition. All electrical generators work that same way. But, to change the permeability of a metal we need to use another magnetic field; this is called the **excitation** field. The disadvantage of this, of course, is that a way has to be found to keep the excitation field from directly causing a voltage to be generated by itself. Fortunately a way was discovered many years ago in which a core in the form of a ring can have several fields in it which do not interfere with each other – except insofar as they share the same core and so are all affected by its permeability.

The fields are:

- one is in the circumferential direction of the ring
- a second is across the plane of the ring
- a third field is across the plane but at right angles to the second
- a fourth field can be at right angles to the plane of the ring.

Any one of these could be the excitation field and any of the others could be the one generating a voltage.

This description is of the fluxgate magnetometers made by Autonnic. These are all ring devices such as shown in Fig. 1 in which the excitation is the circumferential field which is generated by a toroidal **excitation winding**. This modulates the permeability of the core – take a look at one of our data sheets – the A3501, for example. This permeability change in turn modulates the amount of flux due to the steady field which is threaded through a **sense winding** wound around the outside of the ring.

To summarise: a steady flux is in the plane of a special ring core which is inside a sense winding which generates no voltage because there is no change in flux. However, it can change if another, toroidal winding around the ring has a changing current in it. When this current changes it causes a change in the circumferential field in the ring, and so the property called permeability changes. But there is no direct transformer action from one winding to another because although the circumferential flux is within the sense winding there is no *net* threading – what goes to the left in one part

of the ring goes equally to the right halfway round the ring. But if the permeability drops the flux threading the sense winding due to the steady field is reduced and a voltage is generated; if the permeability is increased the field is increased and a voltage is also generated – but in the opposite direction.

Most of the Autonnic magnetometers are made with two sense windings at 90° to each other so as to be able to resolve the direction of the steady field in the plane of the core.

Finally, for a very special application (the application for which Autonnic supply fluxgate magnetometers to many companies around the world), the measurement of the earth's magnetic field, Autonnic make the core float in a liquid, see Fig. 5. By doing this the plane of the core is always horizontal and so, by fitting two sense windings, that component of the earth' field which is horizontal is resolved, whatever the angle of the magnetometer itself.

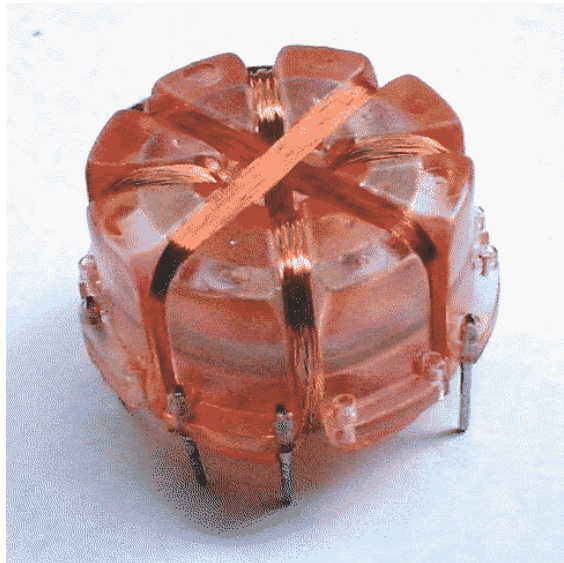


Fig 5

This floating core is also the basis of our patented '3rd-axis' inclinometer which can resolve tilt in 2 axes to 0.01°.

2 Some Definitions

The Magnetising Force (H) inside a long solenoid is defined as a vector along the axis of the coil of magnitude equal to the ampere turns per metre of the solenoid

The Magnetic Flux (ϕ) through a circuit is such that a rate of change of flux of one Weber per second induces an e.m.f. of 1 volt per turn of the circuit

The Magnetic Flux Density (B) at a point is the magnetic flux per unit normal area. It is a vector having the same direction as the magnetising force.

Unit: Weber per square metre. Thus in a uniform field $\phi = BA$

Where A is the area normal to B

Lines of flux

A magnetic field exists round a conductor carrying an electric current and also round a magnet since the elementary magnetic dipoles of a magnetic material are due to molecular currents. These lines of force may be demonstrated by, for example, the use of iron filings.

A magnetic field line or line of force is defined as the path along which a free north pole would travel in the magnetic field.

The lines of force of a magnet run outwards from a north pole and inwards to a south pole. The north seeking pole of a compass needle in the earth's field points towards magnetic north, therefore the lines of force of the horizontal component of the earth's field are parallel lines running from south to north.

The permeability of a medium is the quotient B/H where H is the magnetising force and B the flux density. It is the slope of the graph of B against H.

Unit: Henry per Metre

In a medium $B = \mu H$

In free space $B = \mu_0 H$

Where μ_0 (the permeability of free space) $= 4\pi \times 10^{-7}$ Henry metre⁻¹

Relative Permeability μ_r of a medium is the (dimensionless) ratio of the permeability of the medium to that of free space.

Saturation

Is the term given to phenomenon when the relative permeability of a material falls with increasing H. It represents in the inability of the material to increase its flux density no matter how strong the magnetising force gets. The B at which this occurs is known as the ***maximum flux density***.

Terrestrial Magnetism

The earth's field at a point is completely defined if three quantities, called the magnetic elements, are known:

These magnetic elements are the horizontal component; the magnetic variation; and the angle of dip.

The magnetic variation at a point is the angle between the magnetic and geographical meridians.

The magnetic meridian at a point is the vertical plane containing the direction of the earth's magnetic field.

The angle of dip is the angle between the horizontal and the direction of the earth's total magnetic field.

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