



Since the beginning of this century the horseshoe shape has represented, and been immediately recognised, as a permanent magnet: usually painted red with the poles marked black.

Particularly up to 1935 but even up to 1950, this was the most commonly made shape, as the materials used to make efficient permanent magnets required as much material as possible between the poles, whilst still having the poles close together where they were needed.

The devices using the magnet, whether it was a telephone receiver, electricity (kWh) meter, car & motorcycle dynamo or loudspeaker, all had to make room for the horseshoe shaped magnet if maximum energy with stability were to be achieved.

I'm sure that most of you will have seen pictures of the old "candle stick" telephone with the receiver at the end of a long handset. This shape was convenient to hold up to your ear, but also necessary to house the long horseshoe magnet. Today the magnet, which does the same job, measures only 9.5 x 4 x 5mm.

The earliest manufactured materials used for magnets were hardened steels. Magnets made from these materials were easily magnetised since the amount of energy they could hold was low, but that also meant that they were easy to demagnetise, that is they were very unstable. This instability could be caused by opposite or alternating magnetic fields, by vibration or by small temperature changes.

As an alternative to the horseshoe shape, magnets were made as long rods or bars – with poles at each end as far apart as possible to try to obtain a stable magnetic field. Naturally magnets of this shape were not easy to use. Due to the low performance of permanent magnets up to the 1930's, most loudspeakers and other devices requiring high fields were powered by electromagnets.

Various additions were made to the steels to improve their properties as magnets; the best results were obtained with 35% Cobalt Steel. This was an expensive material, but widely used for instruments in the 1930's. The brake magnets on kWh meters used 9% Cobalt Steel as more space was available.

All these materials were called isotropic; that is they could be magnetised in any direction and still give the same magnetic performance. The method of magnetising these hardened steels was by using an electromagnet to align the magnetic domains in the magnet. It was even possible to achieve a reasonable level of magnetisation by tapping bar or rod magnets with a hammer whilst they were aligned along the earth's magnetic field.

However in the mid 1930's, a new series of alloys were discovered. These were alloys specially developed for use as permanent magnets and were based on an unlikely combination of aluminium, nickel and iron. These materials, which later had other additions, particularly cobalt, are known as the Alnico range of alloys and for many years represented the most commonly available material, and indeed is still widely used today.

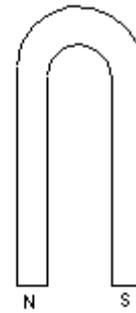


# PERMANENT MAGNET PROGRESS

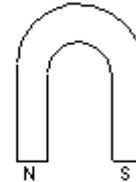
by Cedric Mundy, Magnetics Consultant

Probably one of the most significant advances in permanent magnet technology was the discovery that the domains in Alnico alloys could be aligned in any desired direction by heating the magnets and then cooling them in a magnetic field to give a preferred magnetic direction. This alignment gave something like five times greater performance in this preferred direction than in any other direction. Magnets so treated are called Anisotropic, and can only be magnetised in this predetermined direction.

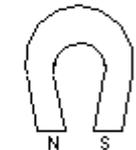
These materials offered very significant advantages over the hardened steels. They contained over six times more energy per unit volume, they could be heated up to over 500°C without any permanent loss of magnetism and were virtually impossible to demagnetise by vibration or mechanical shock.



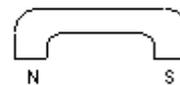
1910  
Tungsten Steel



1925  
Cobalt Steel



1935  
Alnico



1945  
Alnico



1950  
Alcomax



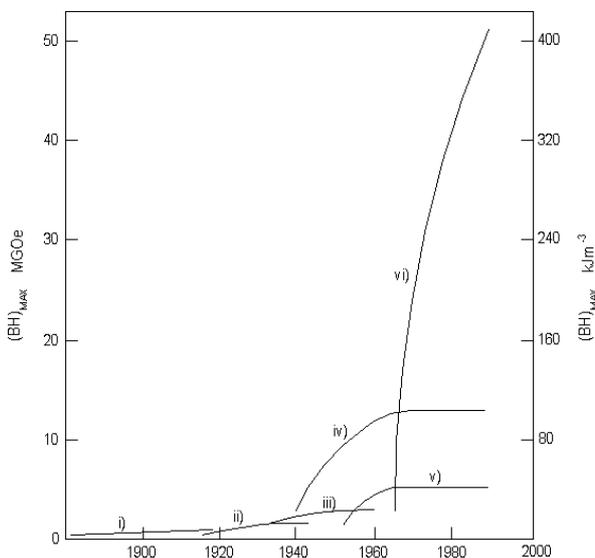
1955  
Ferrite



1965  
Samarium Cobalt



1985  
Neodymium Iron Boron



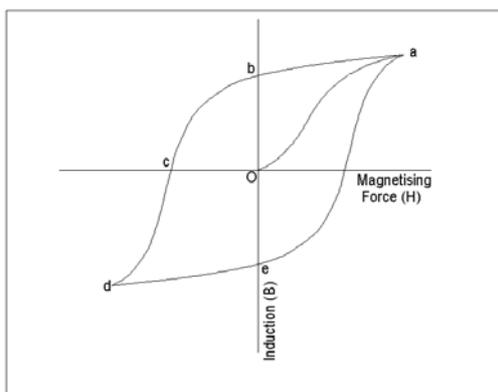
Improvements of  $(BH)_{max}$  of different classes of permanent magnets during the last 100 years: i) Pre-cobalt Steels. ii) Cobalt Steels. iii) Isotropic Alnico. iv) Anisotropic and columnar AlNiCo. v) Barium and Strontium Ferrite. vi) Rare-earth alloys.

Due to the greatly increased magnetic strength of these new materials it was necessary to have improved measuring equipment, and better ways of expressing the performance of different magnetic materials.

The most commonly used expression in relation to magnetic strength is  $BH_{max}$ . This represents the maximum energy available per unit volume and in SI units is measured in  $\text{kJ/m}^3$ . However to show the complete characteristics of a magnet, we have to look at its performance curve and to do this we must examine the second quadrant (boc) of its hysteresis curve. (Fig.1)

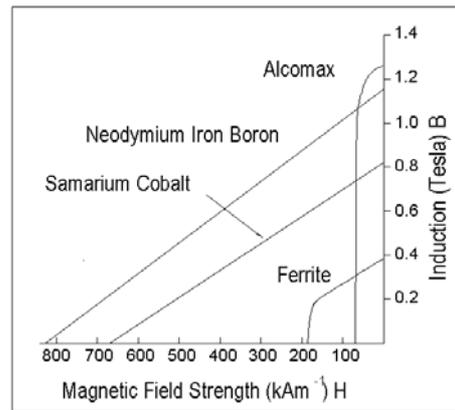
This curve is like a magnetic fingerprint: - no two magnets have exactly the same characteristics, but all magnets in each family group are similar and can be readily recognised. (Fig.2)

Due to the high raw material cost of the Alnico alloys, much work was being done to find a cheaper permanent magnet material. This development work resulted in the birth of the ceramic ferrite. These are produced in both isotropic and anisotropic grades. Mixed powders are pressed in a tool and fired (sintered) in a kiln at high temperature. Anisotropic grades are pressed whilst a magnetic field is applied and then fired. Rings made from anisotropic ferrite are used in almost all loudspeakers and arc shaped segments used in most lower-priced DC motors (e.g. car windscreen wiper & lawn mower motors).



Complete Hysteresis Curve

Fig (1)



Typical 2nd quadrant demagnetisation curves

Fig (2)

The ferrites have a very high coercive force and are thus very difficult to demagnetise. Two magnets placed together with 'like' poles facing would have little effect on their magnetic strength, whereas up to the development of the ferrites two like poles together would cause very high field strength losses.

This high resistance to demagnetisation makes any device using these high coercive force materials so much more stable that for applications where low cost is required and space is not restricted - ferrite magnets have ousted Alnico and today very large tonnages are produced and used every year throughout the world.

However in the 1960's a new magnetic material was developed, principally in the USA, using Samarium and Cobalt. These magnets, usually known as Rare Earth Cobalt, are produced in a very similar way to the ferrite magnets, but provide maximum energy figures of between 145 and 180  $\text{kJ/m}^3$  (i.e. some six times higher than the best ferrite). Two grades are available,  $\text{SmCo}_5$  (known as 1:5) and  $\text{Sm}_2\text{Co}_{17}$  (known as 2:17). This tremendous improvement in the



maximum energy available from a permanent magnet made possible by exceptionally high coercive forces has led to a completely new era of permanent magnet technology.

Only regular shapes are possible with Rare Earth Cobalt magnets, but due to the high magnetic fields generated, much simpler magnetic circuits are used and soft iron pole pieces are seldom needed.

Samarium Cobalt magnets are not as temperature stable as Alnico materials as they have lower maximum working temperatures. These are 250°C for 1:5 grades and up to 350°C for 2:17 grades. However, for most applications these levels are sufficient. One disadvantage is that these materials are very brittle, to such an extent that two magnets jumping together will almost certainly shatter, so great care has to be taken when handling any Rare Earth Cobalt magnets. Both the raw material and production costs for this material are high.

More recently a new material, Neodymium-Iron-Boron (NdFeB) has become available. Again produced by pressing powders in a magnetic field before sintering in an inert atmosphere - these materials provide energies up to 250 kJ/m<sup>3</sup>, and it has been reported that up to 400 kJ/m<sup>3</sup> has been achieved under laboratory conditions.

Although still brittle, these materials are much stronger than Samarium Cobalt, but they can suffer from corrosion, and so have to be protected when used in some arduous environments. They also have a lower maximum working temperature (150°C).

All these magnetic materials can be produced in resin or plastic bonded form. Although having much lower properties than the solid material, they can be made in more complex shapes and to closer mechanical tolerances.

The four major types of magnetic materials being used today are those shown in Fig.2, but naturally improvements are still being made, mostly to improve the stability of Neodymium - Iron - Boron magnets.

SI UNITS OF MAGNETISM & THEIR CGS EQUIVALENTS
Induction B (1Tesla = 10,000 Gauss)
Magnetising & Demagnetising Force H (1kA/m = 12.5 oersted)
Energy Product BH (1kJ/m <sup>3</sup> = 0.125 MGOe)