Platinum Alloy Permanent Magnets

THE DESIGN OF MAGNETIC CIRCUITS FOR PLATINAX II

By L. A. Ford, B.Sc.

Research Laboratories, Johnson Matthey & Co Limited

Platinax II, a cobalt-platinum alloy, is one of the most powerful permanent magnet materials known. Because of its high performance, its principal applications are in miniaturised units where size and weight considerations are of the utmost importance, or where the geometry of the magnet excludes the use of other materials. It is readily fabricated and machined, enabling magnets of complex shape to be manufactured to close tolerances, and it will operate for long periods in highly corrosive environments. To obtain the maximum advantage from its use, it is necessary to design magnetic circuits carefully so as to exploit as fully as possible the magnetic characteristics of the alloy. Data are given in this article that will assist engineers to make the most effective use of Platinax II.

It is some years since investigations by a Johnson Matthey research team into alloys of the cobalt-platinum system led to the development of Platinax II, an extremely powerful permanent magnet material.

Since then the principal applications of this alloy have been for miniaturised units, such as hearing aids and electric watches, where advantage is taken of the exceptionally high magnetic performance of the material, and in instruments where powerful magnets must be subjected to highly corrosive conditions, such as meters that measure and control the flow of corrosive liquids.

In applications of this type, it is essential for magnetic circuits to be properly designed, so as to ensure that effective use is made of the properties of the magnetic material. This is particularly important when a high performance material such as Platinax II is to be used, and necessitates redesign of the magnetic circuit if a material of lower performance is to be replaced.

Operating Characteristics

The performance of a permanent magnet material is shown by its demagnetisation curve. A typical curve for Platinax II is given in Fig. 1 illustrating, together with the derived energy-product curve, the three properties of residual induction (B_r), coercive force (H_c) and maximum energy-product $(BH)_{max}$.

Although these figures are valuable in making comparisons between different materials, they give only an approximate guide to the way a magnet will function in service. Final performance depends very largely upon the point at which the magnet works on, or adjacent to, its demagnetisation curve. This is governed by factors that can often be controlled, such as magnet shape and the type of external circuit in which it operates.

For example, the working point of a magnet that operates free from stray magnetic fields lies on the demagnetisation curve provided that the magnet is magnetised in its circuit and is not subsequently disturbed. Its magnetic performance is determined by the amount of energy that it makes available, and this is proportional to the product $(B \times H)$ at the working point. The available energy

This hearing aid by Fortiphone Limited contains two Platinax II magnets in disc form, one .003 inch thick by $\frac{5}{16}$ inch and the other .005 inch thick by $\frac{5}{16}$ inch. By the use of Platinax II magnets the combined microphone, amplifier and earphone unit has been considerably reduced in size and weight without loss of sensitivity

therefore reaches a maximum value at the $(BH)_{max}$ position and in order to obtain maximum economy of magnetic material a magnet should, whenever possible, operate at this point, i.e. at B_dH_d in Fig. 1.

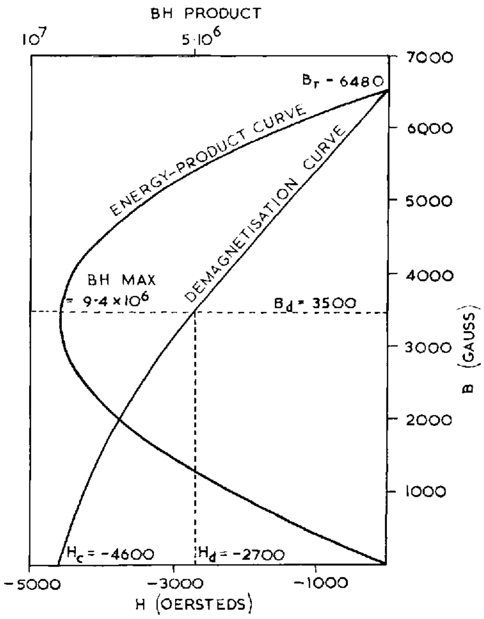


Fig. 1 The high values of coercive force (H_c) and energy-product (BH) for Platinax II are indicated by the demagnetisation and energy-product curves. For maximum economy of material a magnet should work at a point on the demagnetisation curve corresponding to $(BH)_{max}$, i.e. at B_dH_d

The working points of four cylindrical magnets are shown in Fig. 2 on the demagnetisation curve for Platinax II. Each magnet was measured in three separate circuits, covering a wide range of self-demagnetising conditions.

It can be seen that even under arduous 'open-circuit' conditions (Fig. 2a) relatively short Platinax II magnets operate satisfactorily. The addition of a cylindrical iron extension produces some improvement in economy (Fig. 2b), while still further improvement is obtained by placing the magnets in an iron yoke (Fig. 2c). The effect of the improvement is clearly shown by comparing the sizes of magnets operating at approximately $(BH)_{max}$. For an open-circuit magnet, a length/diameter ratio of one-half is required, whereas for a magnet operating in the yoke

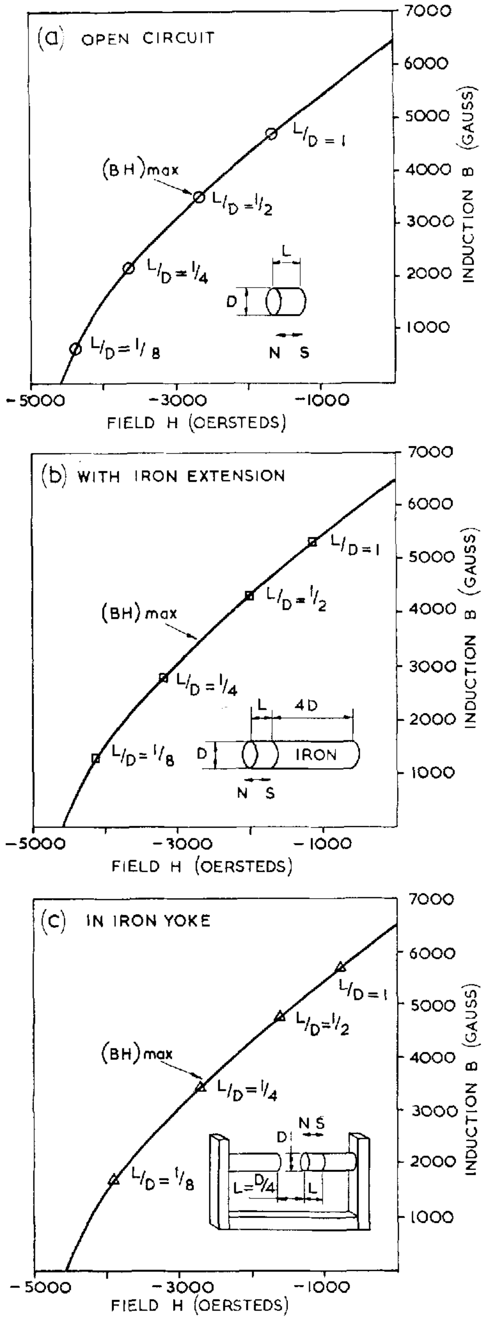


Fig. 2 A magnet's performance is governed by its shape and the type of circuit in which it works. Measurement of the working points of Platinax II magnet systems shows that (a) high performance is obtained from short, open-circuit magnets. Greater economy is achieved by (b) adding a short iron extension and by (c) placing the magnet in an iron yoke

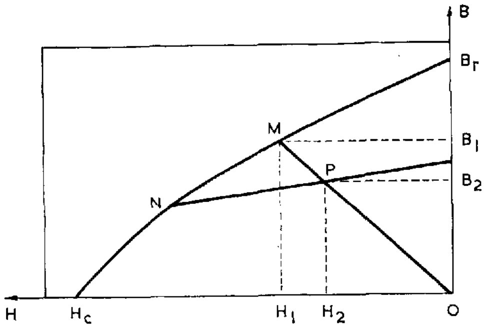


Fig. 3 The working point of a magnet subjected to a demagnetising field follows the curve from M to N. When the field is removed, a partial recovery is made and the working point moves along a recoil line to the position P. The performance of the magnet undergoes a corresponding change

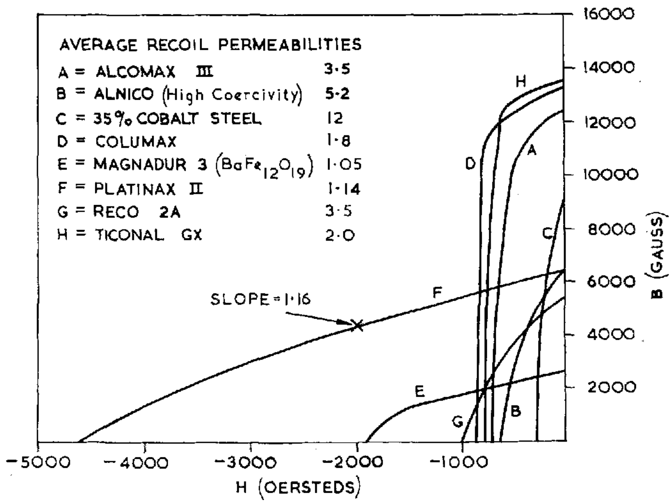
the ratio is reduced to one-quarter, representing a saving of 50 per cent in magnet material. The overall size of the magnetic circuit is naturally increased by such measures, but this may be justifiable if space and weight limitations are not severe.

Recoil Permeability

A magnet that operates in a demagnetising field suffers a loss in performance that is only partially regained when the field is removed. The extent of its recovery is determined by the recoil characteristics of the material from which it is made. This can be appreciated by considering a magnet that operates at a point M on the demagnetisation curve (Fig. 3) until, on being partially demagnetised by a field, its working point follows the curve to the point N. In the absence of further demagnetising forces it will remain there until the field is removed, whereupon, instead of retracing the curve to M, it will move along a recoil line to the point P, which becomes the new working point. The performance of the magnet undergoes a corresponding change in magnitude.

In order that the magnet shall have the minimum reduction of performance, it is necessary for the line NP, whose slope is a measure of recoil permeability, to lie as close as possible to the demagnetisation curve. In the ideal case when both lines have

Fig. 4 The demagnetisation curves of various permanent magnet materials are shown, together with values of average recoil permeability. Unlike high-energy materials having more "rectangular" curves, the recoil lines of Platinax II lie close to the main BH curve for a relatively large range, indicating high capacity to recover from the effects of demagnetising fields



the same slope, point P would coincide with point M, and the change in energy would be zero.

Platinax II is one of the few materials whose recoil lines lie very close to the main BH curve. Many other high-energy materials have demagnetisation curves of more rectangular shape, and although these exhibit good recoil properties over the upper sections of the curve, they are not maintained where the curves become steep. As a result, a demagnetising field that causes a temporary lowering of working point on to the steep section of the curve causes, on its removal, a substantial reduction of available energy.

Comparisons, made in the table, between the slopes of the recoil lines (μr) and the demagnetisation curve for Platinax II, show the remarkable similarity in values around the $(BH)_{max}$ point. It is evident that magnets operating in demagnetising fields at these points would recover almost completely on removal of the field.

The demagnetisation curves of some permanent magnet materials are shown in Fig. 4, together with published values of average recoil permeability. Curves for the more common high-energy materials, such as Ticonal GX and Alcomax III, are clearly of a more rectangular form.

The Magnetic Circuit

Energy produced by a permanent magnet is used in two ways. Its purpose normally is to provide a flux across a gap, but to do this energy is also used in losses around the remainder of the circuit. In practice, wasted energy generally far exceeds that which is usefully employed and in order to ensure adequate performance these losses must be taken fully into consideration.

The losses are of two types. Those requiring least compensation are the "series" or reluctance losses caused by inadvertent air gaps and by any associated iron path. These can be catered for by increasing the length of the magnet by a small factor, usually between 5 and 40 per cent.

Recoil Properties of Platinax II

Magnet Working Point H (oersted)	Magnet Working Point B (gauss)	Recoil Permeability (μr)	Slope of Demagnetisation Curve
—2000	4000	1.13	1.16
—3000	2800	1.14	1.34
—3600	1900	1.16	1.66

The second type of loss is caused by leakage flux, that is flux which passes outside the useful gap and therefore cannot be used. This produces a very considerable effect on magnet performance, since it generally wastes between 50 and 95 per cent of the total energy produced. Its magnitude depends mainly upon circuit geometry and this allows certain measures to be taken to avoid unnecessarily high losses, for example, by ensuring that circuit components are spaced sufficiently far apart. Unfortunately leakage losses cannot be eliminated, and so compensation must be made for them by increasing the cross-section of the magnet, generally by a factor of between 2 and 20 times.

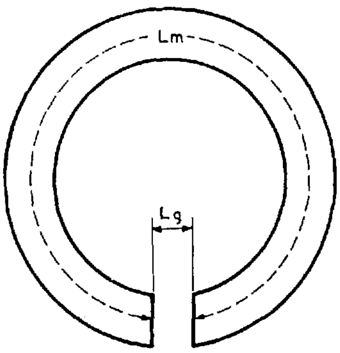


Fig. 5 A ring magnet with a short air gap

Whenever possible it is an advantage to make the largest increase at the point farthest from the gap (i.e. at the neutral point) as this section must be large enough to supply the total of both useful and leakage flux. As the gap is approached, the amount of "leakage" to be provided for diminishes, and the required increase in section can be progressively reduced.

The problem of finding suitable dimensions is approached by considering a hypothetical magnetic circuit in which all the energy produced by the magnet is usefully employed. This condition is nearly achieved by the simple magnet shown in Fig. 5, consisting of a ring having a very short air gap across which all the flux is assumed to flow uniformly. Summing the magneto-motive forces around this circuit:

$$L_m H_w - L_g H_g = 0$$

$$\text{or } L_m H_w = L_g H_g \qquad (1)$$

where L_m = magnet length
B_w, H_w = working point of magnet
L_g = length of air gap
H_g = field in air gap

Furthermore the flux in the magnet is the same as that in the air gap hence:

$$B_w A_m = B_g A_g \qquad (2)$$

where A_m = magnet area
A_g = gap area
B_g = gap flux density
(= H_g numerically)

From equations (1) and (2):

$$L_m = \frac{L_g H_g}{H_w}$$

$$A_m = \frac{B_g A_g}{B_w}$$

$$V_m = \frac{L_g H_g^2 A_g}{B_w H_w}$$

where V_m = magnet volume

Therefore, applying the factors to correct for circuit losses:

$$L_m = \frac{L_g H_g}{H_w} \times K_1$$

$$A_m = \frac{B_g A_g}{B_w} \times K_2$$

$$V_m = \frac{L_g H_g^2 A_g}{B_w H_w} \times K_1 K_2$$

where in general K_1 lies between 1.05 and 1.4 and K_2 lies between 2 and 20.

Evaluation of the constants can sometimes be made, but this involves long and often complex calculations. It is far more convenient to base a design upon past experience wherever possible, and to assist in this measurements have been made on specimen Platinax II magnet systems.

Magnetic Field Measurements

Figs. 6 and 7 show flux distributions close to the pole faces of cylindrical magnets operating with various degrees of self-

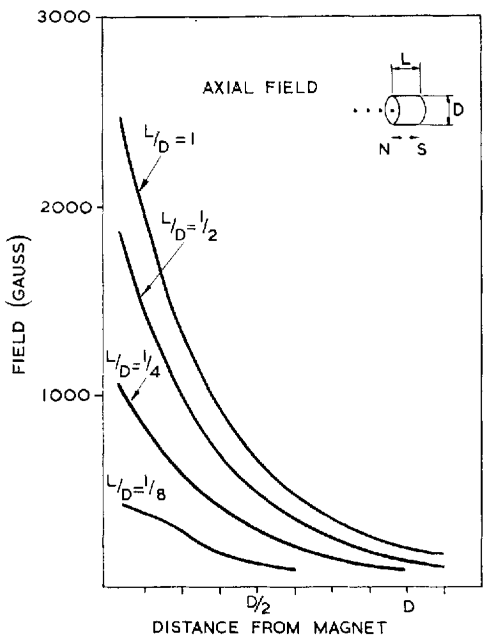


Fig. 6 The axial fields produced by "open-circuit" Platinax magnets vary with distance from the magnet. The effect of the increased self-demagnetisation of shorter magnets is illustrated by the lower fields they produce

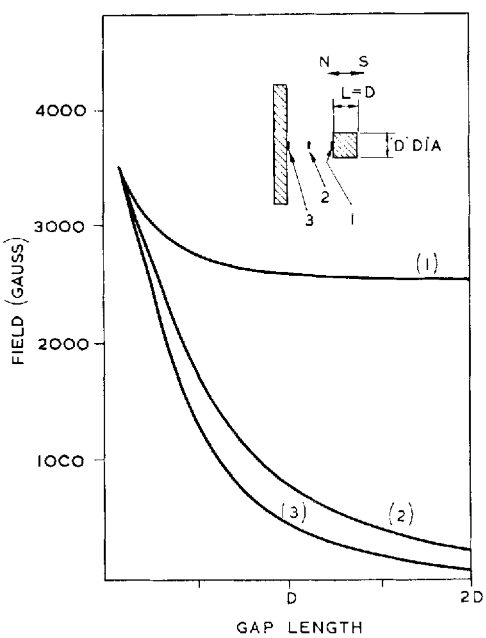


Fig. 8 An improvement on "open-circuit" working is obtained by placing the magnet near an iron plate. For a magnet with an L/D ratio of 1, this results in a 40 per cent increase in the maximum measured field

demagnetisation. The values obtained with open-circuit magnets indicate that fields diminish rapidly with distance.

Some improvement in maximum field was apparent when the open circuit conditions were moderated, although the tendency for fields to diminish rapidly with distance still remained. This is illustrated in Fig. 8, which shows the field intensities at three positions in a variable air gap separating a magnet from an iron plate. Whereas the maximum field measured on an open circuit magnet with an L/D ratio of 1 was 2500 gauss (Fig. 6), when the same magnet was placed near the iron plate the maximum field increased to 3500 gauss.

Further improvements in performance were obtained by placing the magnets between iron cylinders of similar diameter, each having an L/D ratio of 4. The field intensities shown in Fig. 9 were obtained with the magnet in contact with one cylinder and separated by a short air gap from the other. Using this

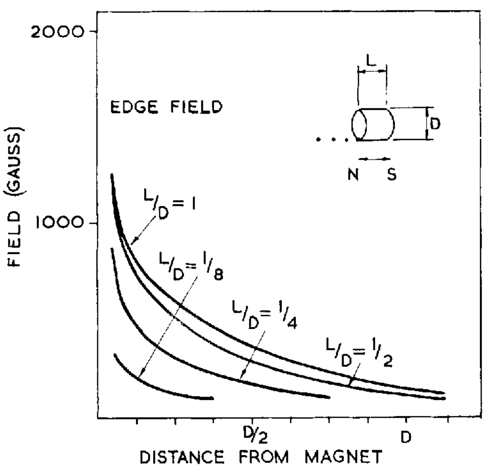


Fig. 7 Edge fields produced by "open circuit" Platinax II magnets vary in a similar way to those on the axis. However, because the magnetic field diverges to a much greater extent near the edge, the resultant field intensities are lower

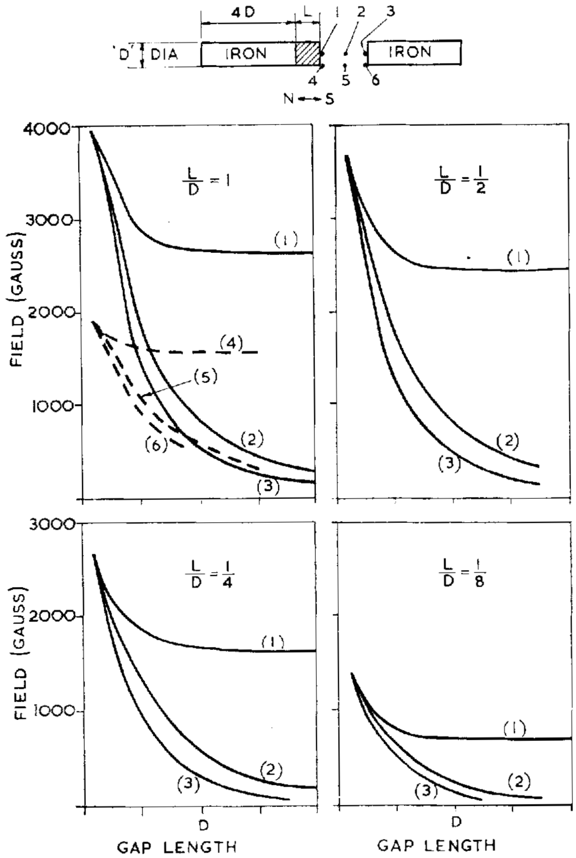


Fig. 9 Improved performance is obtained by extending the magnetic circuit with iron cylinders. The increase in field over "open-circuit" figures ranges from approximately 50 per cent for the longest magnet (L/D = 1) to nearly 250 per cent for the shortest (L/D = $\frac{1}{8}$). The axial fields were measured at positions 1, 2 and 3, and the edge fields at positions 4, 5 and 6

arrangement, the magnet having an L/D ratio of 1 gave a maximum measured field of approximately 4,000 gauss.

Magnetic Stability

In designing a magnet for a particular job it is important to know how it will react when subjected to demagnetising forces. If magnetisation is carried out before assembly into its circuit, for example, the magnet's own demagnetising field causes it to operate on a recoil line. Further reductions in flux can occur as a result of careless handling before or during assembly.

Although Platinax II is highly resistant to demagnetising forces, it is good practice to safeguard against possible loss of performance by magnetising after assembly whenever possible. This is particularly true for very short magnets in which self-demagnetising forces are high. Apart from safeguarding their performance, the likelihood of contamination from magnetic debris is reduced.

Apart from the demagnetisation forces encountered before assembly, magnets frequently operate in demagnetising fields that would, in normal circumstances, cause a reduction in their performance. To provide for greater stability in service a magnet can

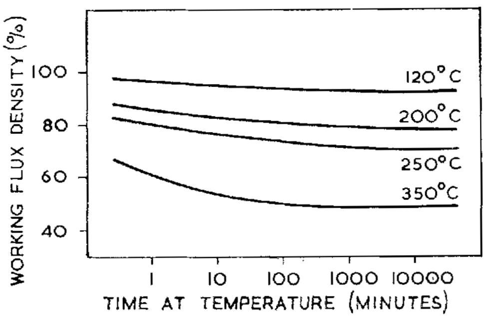


Fig. 10 Platinax II magnets, in common with other types, lose performance when heated. The rate of loss is high at first, but diminishes quickly until, after approximately three hours, a stage is reached where little further change occurs. A short preliminary heat treatment will enable a magnet to operate uniformly at temperatures up to at least 350°C

Design Recommendations for Platinax II

1 Use Platinax II for small but very powerful magnets

2 Use Platinax II for magnets that operate in corrosive liquids or in strong demagnetising fields

3 Use Platinax II when small fabricated parts are required

4 Design at the $(BH)_{max}$ point for maximum performance

5 Stabilise magnets where necessary against demagnetising fields and high working temperatures before putting them into service

6 Magnetise after assembly where possible

be stabilised beforehand by deliberately applying a demagnetising field slightly in excess of that to be encountered later.

Temperature Effects

In common with other magnetic alloys, the performance of Platinax II drops progressively with increase in temperature, as shown in Fig. 10. Following a moderate rise in temperature, performance may be restored by remagnetising after cooling, but at temperatures above 300 to 350°C the losses are caused by changes in alloy structure which can only be rectified by a special heat treatment. If a magnet is required to work at temperatures where these changes occur it will inevitably suffer a gradual deterioration in performance unless steps are taken to stabilise it. This can be done by a preliminary heat treatment which, while reducing performance, ensures that no further deterioration occurs when the magnet is used at high temperature.

Often the most convenient method of fixing a magnet is by soldering or welding, either of which can cause a local deterioration. If magnetisation can be carried out after assembly the loss may not be permanent, especially in low temperature operations such as soft soldering.

Magnetic Holding Power

Forces of attraction between magnet poles that are in contact can be approximately calculated by using the formula:

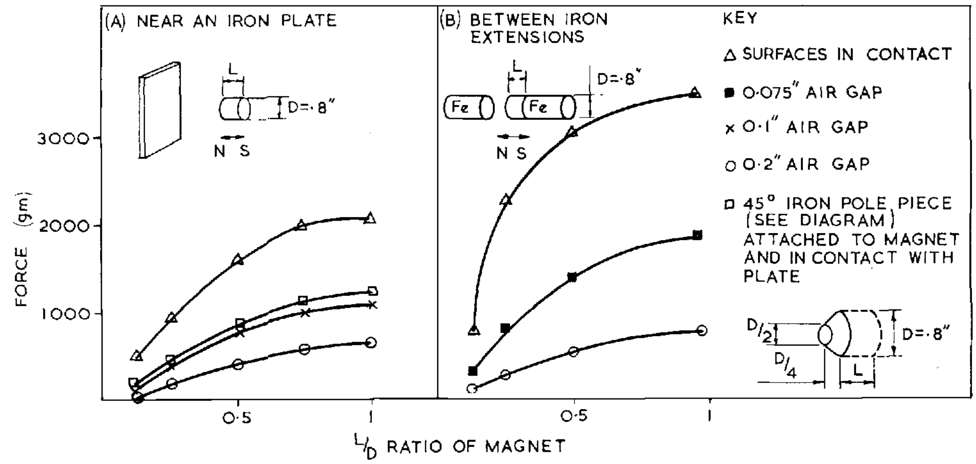


Fig. 11 Forces produced by Platinax II magnets vary with magnet geometry and the type of circuit in use. Examples of two basic circuits are given, showing the forces produced under a variety of conditions

$$\text{Force in dynes} = \frac{B^2A}{8\pi}$$

where A = area of magnet pole face in cm^2
B = flux density at contact in gauss

It is sometimes necessary to know the forces that exist between magnetic components separated by an air gap. Specimen figures are shown in Fig. 11 illustrating the changes in mechanical force that occur when the magnet length is altered. Throughout these tests, the diameters of magnets, and of extensions when used, remained at 0.8 inch.

In general, forces produced by magnets operating near an iron plate increase steadily with increasing magnet length up to a length/diameter ratio of approximately three-quarters. Beyond this point, further increases in length produce only small changes. A similar trend is shown by magnets operating between iron extensions, but in this case the curves begin to level off at a smaller length/diameter ratio. This agrees generally with the changes observed in working point in Fig. 9, and illustrates that the effective length of the magnet is increased by the additional iron.

Attempts to increase holding power by attaching tapered iron pole pieces to the magnet have been unsuccessful, evidently because leakage is introduced which cancels the effect of possible flux concentration.

Economics

Platinax II contains 76.7 weight per cent platinum and naturally is of high intrinsic value. The magnetic characteristics as outlined above are, however, quite exceptional and if due attention is paid to careful design, economic circuits are feasible. Platinax II obviously has its major applications for miniaturised circuits where it is necessary to have high flux in restricted spaces and where a small magnet can be fabricated from strip or wire.

Acknowledgment

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Alternating Current Polarisation of Noble Metal Surfaces

THE FORMATION OF PLATINUM AND PALLADIUM BLACKS

It has been observed that the reproducibility of a platinum electrode can be improved by a pre-anodisation treatment. The explanation of this effect has been in some doubt, and a recent paper by Dr J. P. Hoare of the General Motors Research Laboratories (*Electrochimica Acta*, 1964, **9**, (5), 599–605), throws new light on the matter.

The effect of AC currents on small beads of noble metals was studied and it was noted that whereas black films were formed on the surface of platinum and palladium when treated in this way, no such films were observed on gold, iridium or rhodium. Some oxidation did occur on the gold and iridium and, if a DC current was superimposed on the AC so that the AC swing was not centred about a point more oxidising than that originally used, then the 'black' formation did not occur on platinum or palladium and oxides were formed here also.

Dr Hoare deduces from his study that the mechanism of the formation of these blacks is via the dissolution of hydrogen, since it is well known that platinum and palladium will react readily with hydrogen, whereas gold, iridium and rhodium will not. The break-up of the surface is attributed by the author to the successive absorption and desorption of this hydrogen.

Further, measurements of double layer capacity, a technique that can detect changes of surface area, confirmed that the platinum and palladium surfaces increased in area after polarisation whereas the rhodium surface did not. The increases of area noted for the gold and iridium are explained by the formation and reduction of oxide films. J. H.