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the exchange of information and ideas on Radio Science."

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ANNUAL GENERAL MEETING OF THE INSTITUTION

The TWENTY-FIRST ANNUAL GENERAL MEETING of the Institution (the thirteenth since incorporation) was held at the London School of Hygiene and Tropical Medicine, London, W.C.1, on September 25th, 1946, commencing at 6 p.m.

Mr. Leslie McMichael (President) took the Chair and was supported by other officers of the Institution and members of the Council. Over eighty other members were present at the start.

The Secretary read the notice convening the meeting, which had also been published in the July/August 1946 Journal.

1. Minutes of the Annual General Meeting held on October 5th, 1945.

A report of the Twentieth Annual General Meeting was given in the October/December 1945 Journal (pp. 185 to 187) and the President (Mr. Leslie McMichael) moved that this record should be adopted as the official minutes. The proposal was unanimously approved and the minutes signed as correct.

2. Minutes of the Extraordinary General Meeting held on December 21st, 1945.

The Secretary stated that the Extraordinary General Meeting, held at the offices of the Institution on December 21st, 1945, was convened for the same reason as the meeting held on March 23rd, 1945.

Unfortunately, at the March meeting, only one resolution was taken to cover both the proposed alterations to the Memorandum as well as to the Articles of Association. The alterations to the Memorandum required the approval of the Court but not the alterations to the Articles of Association. Mr. Justice Uthwatt (now Lord Uthwatt) in the Chancery Division of the High Court on November 12th, 1945, directed that a further Extraordinary General Meeting should be held, and this meeting was duly held on December 21st, 1945. A notice of the two separate resolutions required was circulated to all corporate members in November, 1945, and, in addition to the members present at the meeting, 123 proxies were also received voting in favour of the alterations. The Resolution altering the Memorandum was subsequently confirmed by Mr. Justice Vaisey in the Chancery Division of the High Court on January 14th, 1946.

The minutes of the Extraordinary General Meeting, held on December 21st, 1945, were then unanimously approved on the proposal of Mr. L. Grinstead, seconded by Mr. E. A. Spreadbury.

3. To receive the Annual Report of the General Council.

Mr. Leslie McMichael referred to the July/August 1946 Journal, pp. 130 to 138, which gave the Annual Report in full and stated that separate copies of the Annual Report had also been sent to corporate members with the notice convening the meeting. Mr. McMichael continued by stating that one of the disadvantages of annual reports being discussed at an Annual General Meeting was that, for various technical reasons, such a Report was not considered by the membership until the Institution was well launched into the next year; members would be far more interested to learn whether the progress made in the 1945/6 year was being maintained in the current year.

If membership was any criterion, then the answer was in the affirmative, for, as seen in recent issues of the Journal, the number of proposals received—and what was more important, accepted—was very broadly equivalent to the same number of proposals accepted during the relevant period of the year under review.

The examination continued to draw entries from an increasing number of candidates, all of which should eventually result in a further increase in membership, for, by and large, the standard of candidates entering for the examination was considerably better than it was a few years ago.

As shown in the circulated report, all sections of the Institution's work showed a considerable expansion during this first peace time year. Mr. McMichael concluded by moving the adoption of the Annual Report subject to any comment thereon.

In supporting the President's motion for the adoption of the report, Mr. S. R. Chapman stated that there would be a more appropriate opportunity for ex-

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pressing appreciation of Mr. McMichael's services at the dinner which was to be held on October 31st, 1946. The progress shown in the Annual Report being discussed had been very largely due to the guidance and encouragement received from Mr. McMichael. Throughout his two years of office, the retiring President had missed only one meeting of the General Council, and had also attended many meetings of Standing Committees.

A notable feature of the Report was the recommendation that the Chairmen of the Local Sections should become *ex officio* members of the General Council, and that was a step in the right direction. It would emphasise the national character of the Institution besides giving wider counsel in the direction of the Institution's affairs. If the recommendation was adopted it was proposed that the matter should be passed on to the Local Sections for confirmation and that an Extraordinary General Meeting should be held in due course to amend the appropriate clauses in the Articles of Association.

Mr. Chapman concluded by stating that if the Report was unanimously approved, members would also give an expression of their thanks to Mr. McMichael at the same time.

The adoption of the Report and the vote of thanks to the retiring President was carried with hearty acclamation.

4. To elect the President of the Institution for the year 1946/7.

Mr. McMichael stated that members would already have seen from the Journal and the Annual Report that the General Council had unanimously recommended that Admiral the Viscount Mountbatten of Burma should be elected as President for the year 1946/47. The fact that he had been a Vice-President of the Institution since 1935, and was therefore at this moment senior Vice-President of the Institution, was in itself sufficient expression of the membership's, as well as the Council's, views on this important matter. Mr. McMichael, therefore, had much pleasure in formally moving the election of Admiral the Viscount Mountbatten of Burma as President of the Institution.

Mr. E. A. Spreadbury said that, as a member of some years standing, it gave him great pleasure to second the proposal made by the President that Admiral the Viscount Mountbatten of Burma be elected President of the Institution for 1946/47. He recalled with pleasure the election of Viscount Mountbatten as Vice-President of the Institution, an office which he had now held for some 10 years. His advancement in the Royal Navy, and the position he held today, rather dwarfed the fact that it was as a radio officer in the senior service that Viscount Mountbatten had merited election as an officer of the Institution. Older members of the Institution had followed with pride Viscount Mountbatten's career, especially during the past five years, and in unanimously electing him President of the Institution they were conferring upon him the highest honour the Institution could bestow and, at the same time, the Institution was receiving in return an honour and a distinction in having such a distinguished personality to guide its destinies for the next twelve months.

The resolution was carried with hearty enthusiasm.

Mr. McMichael stated that he had that afternoon received a letter from Admiral Mountbatten regretting his inability to be present, although he had endeavoured to make arrangements to attend the Annual General Meeting. Mr. McMichael stated, however, that he would advise Admiral Mountbatten of the warmth with which the members present had signified their approval to his election to the office of President.

5. To elect Vice-Presidents of the Institution.

Referring to Council's nominations, Mr. McMichael stated that it was not necessary for him to comment on the services given to the Institution by Dr. James Robinson, who now became the senior Vice-President. Air Vice-Marshal R. S. Aitken had recently taken up a senior appointment in the industry, whilst the attendance tonight was a tribute to Mr. L. H. Bedford, who would shortly be reading his latest paper. The Council recommended that the fourth and new Vice-President should be Mr. Paul Adorian.

During his long association with the Institution, Mr. Adorian had served not only as a member of Council, but as a member of various Standing Committees. Whilst it was rare for the Council to mention an individual in the Annual Report, it was felt necessary in the last Annual Report to thank Mr. Adorian for the way in which he had served the Institution as Chairman of the Technical Committee during the very difficult years of war.

Dr. James Robinson, Air Vice-Marshal Robert S. Aitken, Mr. Leslie H. Bedford and Mr. Paul Adorian were then unanimously elected Vice-Presidents of the Institution for the year 1946/47.

6. Election of the General Council.

Members were advised by Mr. McMichael that the nominations made by the General Council were unopposed, which was regarded as a compliment to the members nominated, and a welcome was extended to the following new members of the General Council :—

Mr. C. E. Bottle, M.B.E. (Member) ; Air-Commodore W. C. Cooper, M.A., C.B.E. (Member) ; Mr. W. E. Miller, M.A. (Cantab.) (Member) ; Commander L. A. Brown (Associate Member) ; Mr. H. E. Drew (Associate Member).

Mr. J. W. Ridgeway (Member) was re-elected a member of Council and Mr. McMichael referred to the services of Messrs. H. Brennan, T. D. Humphreys and M. M. Levy, who had completed their term of two years of the General Council and who had now retired.

7. To receive the Auditor's Report, Accounts and Balance Sheets for the year ended March 31st, 1946

Mr. J. W. Ridgeway stated that the Institution's accounts for the year ended March 31st, 1946, were circulated to the corporate membership, with the Annual Report, on August 14th, and the report and the accounts were reproduced in the July/August, 1946, Journal. It would be seen from the accounts that the present position of the Institution was sound, but that special action was called for to maintain that position in the future.

During the 12 months in question, the Finance Committee had presented two estimates to the Council, and it was interesting to note that the final figures, both in income and expenditure, showed that those estimates had been very conservative. By comparing the last accounts with those published in the September, 1945, Journal, it would be seen that the present position was very satisfactory. In the last year, all the liabilities carried forward from the previous balance sheet had been cleared, in spite of the financial handicap suffered by the Institution during the first years of the war, and the Committee was able to report to the membership an excess of income over expenditure of some £800.

It was already apparent that this year would exceed the last year's figures, but it was necessary to take into account the need for increasing the membership if the Institution was to carry out the work which it considered necessary on behalf of its members. To do so would cause an increase in expenditure. The accommodation at present occupied was now full and an increase in Institution staff was essential in order to carry out the work required of the secretariat. The Institution was not purely a London organisation, and, apart from the principal expenditure for headquarters staff and publications, it was also necessary to consider the expenditure involved in maintaining the very active Sections of the Institution, not only in this country, but throughout the Empire. Development in the past had been stifled by lack of finance, and in order to fulfil present plans it was essential to have a strong membership.

The present subscription rates were very reasonable compared with other professional Institutions of a like character, but the Finance Committee did not think it necessary to increase subscriptions, provided that the increase in the Institution's membership was at least maintained. The greater the increase in membership, the better would the Institution be able to provide for the facilities and services to the membership.

Mr. Ridgeway stated that the Committee and Council had kept a most careful watch on the financial affairs of the Institution and formally moved the adoption of the accounts relating to the special and general funds. So far as the special funds were concerned, the Benevolent Fund has been very well supported by the membership during the past year; in view of the increasing calls made upon the Fund, it was hoped that such support would be increased in the years to come and so enable the Institution to assist members at a time when a friend in need was a friend indeed.

In accordance with the resolution taken at the last Annual General meeting, the remainder of the special Prisoners of War Fund had been paid into the Benevolent Fund.

In seconding the proposal for the adoption of all the accounts, Dr. G. A. V. Sowter expressed the thanks of the membership to Mr. J. Ridgeway for his successful work as Chairman of the Finance Committee; such a position was no sinecure and involved much careful thought and work.

The accounts and auditor's reports were then unanimously approved.

8. Appointment of Auditors

Mr. S. R. Chapman moved a unanimous resolution that Messrs. Gladstone, Titley and Company, of 74 Victoria Street, London, E.C.4, be appointed auditors to the Institution for 1946/7.

9. Appointment of Solicitors

The meeting approved the recommendation of the Council that Messrs. Braund and Hill, 6 Gray's Inn Square, London, W.C.1, be reappointed as Solicitors to the Institution for a further year.

10. Awards to Examination Prize Winners

Mr. C. Ridgers (now an Associate) was not only the most outstanding candidate of the year, and therefore received the President's Prize, but he also wrote the best examination paper in Radio Measurements and was also awarded the Measurements Prize.

Mr. McMichael also stated that Mr. W. Hares, who was a flying officer at the time he wrote the examination, was the most outstanding candidate from the Army, the Navy and the Air Force and presented him with the Mountbatten Medal.

11. Other Business.

Mr. McMichael said that before vacating the Presidential Chair he wished to express, in public, his grateful thanks to Mr. Clifford and his staff for their help during the past two years. A vote of thanks to the Secretariat was given most cordially.

Mr. Leslie H. Bedford then gave his paper on " The Strobe Principle in Radio and Radar" which will be published in the January 1947 Journal.

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CHOICE OF MATERIALS FOR TROPICAL RADIO EQUIPMENT

by

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and

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Abstract. This paper is a brief guide which should assist in the examination of radio and similar equipment to decide whether or not it is suitable for tropical use.

Introduction

With the present industrial accent on export it is felt that a paper dealing with the suitability, or otherwise, of components and materials intended for use in radio apparatus in the tropics would now be opportune.

To be suitable for tropical use, equipment must be proof against failures due to :—

(1) Moisture and heat.
(2) Growth of fungi.
(3) Attack by insects.

Moisture and Heat

It is convenient to regard these two agents together, since they are co-operative ; tropical climates are at once very humid and very hot. Moisture may be introduced into equipment in any or all of four principal ways :—

(*a*) Absorption by materials.
(*b*) "Breathing" of equipment, due to rise in temperature and expulsion of air, followed by fall in temperature and influx of moist air.
(*c*) Condensation of moisture on non-absorbent surfaces ; or condensation due to fall in temperature, e.g. at night, or when aircraft become airborne.
(*d*) Direct influx by exposure of equipment to rain, etc.

In addition, high temperature by itself may cause failures. Typical failures due to these agents are deterioration of materials and components, loss of insulation properties, corrosion of metals and general misalignment of circuits with decrease in output and sensitivity.

Growth of Fungi

The presence of moisture in turn gives rise to the growth of fungi ; fungi cannot live at a relative humidity (R.H.) of less than 70 per cent., and the ideal conditions for growth are temperatures of 25° C. to 35 ° C. with R.H. 90 per cent. to 100 per cent. The growth of fungi encourages the formation of a water film over the affected surface, which in turn increases the growth. Fungi will grow on wax, textiles, rubber, leather, wood and some plastics. The presence of organic dust will stimulate growth, and enable fungi to grow even on metals and glass.

Typical failures due to growth of fungi are deterioration of materials and components, loss of insulation properties, corrosion of metals, formation of water films over affected surfaces, etching of glass, and chemical breakdown of affected materials : naturally, performance of equipment will also suffer.

Attack by Insects

Although of less general importance than deterioration due to moisture, heat and fungi, insect attacks can cause much damage, mainly to external ancillary equipment such as packing-cases, satchels, etc. Insects responsible are principally :—

(*a*) **Termites** (*Isoptera*).—Termites (erroneously termed "white ants") feed principally on wood or materials containing cellulose (e.g. canvas). They will also attack rubber and soft metals, more especially when seeking cellulose foods. They do not like working in sunlight.
(*b*) **Beetles** (*Coleoptera*).—Ghoons attack wood, while carpet beetles and "woolly bears" attack materials containing animal protein (e.g. leather, wool and bristles).
(*c*) **Miscellaneous.**—The miscellaneous pests include moths, carpenter bees, mud wasps, crickets, etc., but the damage done by them is never as considerable as that caused by the insects mentioned in (*a*) and (*b*).

The Preliminary Examination

The following points should be looked for when making a preliminary examination of equipment :—

Unsuitable Components and Materials

These are dealt with in the section dealing with the detailed examination.

Moisture Traps

Any point where moisture may collect is a potential source of failures. Examples are closely adjacent contacts, double tag-boards, laminated bakelite components, valve-holders, cathode-ray tube holders, and cable forms. Moisture traps may be divided into four classes :—

(*a*) Traps due to large cavities (e.g. junction boxes).

(*b*) Traps depending on capillary action (e.g. cable forms).

(*c*) Traps due to laminated constructions (e.g. tag-boards).

(*d*) Traps due to incomplete sealing (e.g. I.F. transformer cans).

Drainage

Closely allied to the question of moisture traps is the question of drainage. If there is no way of preventing moisture from entering equipment, drainage holes must be provided so that condensed moisture may drain away freely. This is most important where high voltages are concerned, as in cathode-ray equipment. There must be complete sealing or complete drainage.

Ventilation

If hermetic sealing is impossible, ventilation holes must be provided so that the temperature within the equipment does not rise to an excessive value, say above 70° C. These holes must never be drilled in the top covers of equipment. This, of course, permits the influx of moist air, so that ventilation must be accompanied by complete protection against moisture and fungi. The fitting of air blowers is always recommended.

Dust Traps

Any place where dust may be trapped is a potential growing area for fungi. Examples are crevices in metal construction, raw surfaces of materials, and tacky surfaces of materials.

Contact Potentials

When two dissimilar metals are separated by a thin film of moisture, electrolytic action and subsequent corrosion takes place. Examples are valve pins to valveholder contacts, and valve top caps to top cap contacts. Contact potentials between dissimilar metals should be less than 0·25 volt, and joints between them should be sealed (not filled) with varnish.

Heat-dissipating Components

As far as possible these should be kept at the bottom of equipment to dry out upper components, and kept away from components and materials which are liable to suffer as a result of excessive heating.

High Voltages

Potential differences greater than 300 volts must not exist between adjacent tags on tag-boards, etc., unless the spacing exceeds ⅜ in. Voltages greater than 500 volts should not be switched on until equipment is warm (i.e. until heaters have been run for some time). Arcing contacts of any kind must never be enclosed.

DETAILED EXAMINATION OF COMPONENTS

Accumulators	In general, suitable.
Aluminium	When anodised, suitable.
Bitumen	Suitable. Dust may accumulate on the surface and support fungus growth, but the higher temperature at which bitumen becomes "tacky" renders it much more suitable than wax.
Cables	See **Wiring.**
Cadmium (Plating)	Suitable. Thickness should be at least 0·0003 in. Surface corrosion may take place, but this is not likely to be serious.
Cements	In general, not completely suitable, due to tendency to absorb moisture, and, in the case of rubber-based cements, to premature gelling at high temperatures.
Chokes	See **Transformers** and **Chokes.**
Chromium (Plating)	Suitable.
Coils (H.F.)	Unsuitable. All wax-protected coils; coils wound with cotton-covered or silk-covered wire; coils wound with wire smaller than 44 S.W.G.
	Suitable. Coils protected by polystyrene or bakelite varnish; coils wound with plain enamelled, enamelled cotton, or enamelled silk covered wire; bitumen-protected coils; coils enclosed in hermetically sealed cans.
Coils (V.H.F.)	Unsuitable. Coils wound with unplated wire.
	Suitable. Coils wound with silver-plated wire, with iron dust cores or slugs coated and loaded with polystyrene varnish.
Coil Formers	Unsuitable. Plain distrene; unloaded ebonite; cellulose based plastics.
	Suitable. Ceramic; loaded polystyrene; loaded distrene; loaded ebonite.
Condensers	Unsuitable. All wax-protected condensers; paper or cardboard-cased tubular condensers; transmitting type rectangular moulded mica condensers; protected silvered mica condensers; bead, cup and disc, or non-insulated ceramic condensers; moulded rectangular cased paper or electrolytic condensers with base insert; rectangular metal-cased condensers

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DETAILED EXAMINATION OF COMPONENTS

Condensers *(continued)*	without rolled seams and glazed ceramic terminals ; air dielectric condensers with mycalex base. Suitable. Metal cased tubular condensers with neoprene end seals ; moulded cased tubular condensers ; moulded silvered mica or stacked foil condensers ; insulated tubular ceramic condensers (Erie Ceramicons) ; pot type silvered ceramic or stacked mica condensers ; rectangular metal-cased condensers with rolled seams and glazed ceramic terminals ; air dielectric condensers with glazed ceramic base ; hermetically sealed condensers.
Condensers (Variable)	Unsuitable. Mica dielectric compression trimmers with mycalex base or insulators and rotor bearings not locked. Suitable. Air dielectric trimmers with ceramic base or insulators and rotor bearings locked ; Mullard concentric trimmers ; all air dielectric condensers.
Contacts	Unsuitable. Unplated light contacts ; "flat" to "flat" heavy current relay contacts ; cadmium to silver, zinc to silver, nickel to zinc, or aluminium to silver contacts. Suitable. Silver-plated light contacts; "dome" to "dome" or "dome" to "flat" heavy current relay contacts.
Copper (Plating)	Suitable. Thickness should be at least 0·0003 in.
Cork	Unsuitable.
Cotton	Unsuitable unless treated with fungicide.
Crystals	Suitable. These are normally hermetically sealed.
Desiccators	Suitable. Silica gel, calcium chloride ; phosphorus pentoxide. Should only be used in containers in which it is not possible for air to circulate or replace itself ; failing this, regular replacement of desiccator is necessary.
Dry Batteries	Unsuitable. Unsealed types with cardboard cases. Suitable. Bitumen sealed types with impregnated moisture- and fungus-resistant cases.
Empire Cloth	Unsuitable.
Felt	Unsuitable unless treated with fungicide.
Finishes	Unsuitable. Plain zinc, plain aluminium, plain ferrous metals. Suitable. Chromate passivated zinc, anodised aluminium, cadmium, chromium, copper, nickel, rhodium, silver, tin.
Fungicides	Suitable for use on materials to prevent fungus growth. Volatile fungicides may cause corrosion of metals or swelling of rubber. Fungicides must be carefully selected to guard against corrosion of metals with which they may come in contact.
Gearing	Ferrous metals unsuitable for small gear wheels.
Jacks	Suitable if plastic constituents are protected.
Keys	Suitable if plastic constituents are protected and contacts (q.v.) are of suitable type.
Knobs	Unsuitable. Metal knobs with single grub screw. Suitable. Plastic knobs screwed to shaft.
Labels	Unsuitable. Plain paper labels, even if varnished and treated with fungicide. Suitable. Resin treated, high wet strength paper labels, varnished and treated with fungicide ; traffolite labels.
Lacquers (Protective)	Suitable for temporary protection against moisture, but have usually a lower water resistance than recommended types of varnishes ; the drying time of lacquers is shorter than that of recommended types of varnishes ; the addition of a fungicide is recommended.
Lamps	Unsuitable. Post Office type. Suitable. Coiled-coil type.
Lanolin	Unsuitable. Lanolin grease. Suitable. Hardened lanolin grease (neutralised wool grease), lanolin/resin grease, lanolin/resin solution.
Leather	Unsuitable unless chrome-tanned and treated with fungicide.
Lubricants	Unsuitable. Fatty lubricants, low viscosity lubricants. Suitable. Mineral or hydrocarbon lubricants ; high viscosity lubricants.
Metal Rectifiers	Unsuitable. Copper oxide rectifiers. Suitable. Selenium rectifiers.
Meters	Unsuitable unless hermetically sealed.

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DETAILED EXAMINATION OF COMPONENTS

Nickel (Plating)	Suitable. Thickness should be at least 0·0003 in.
Nylon	Suitable.
Optical Instruments	Unsuitable unless hermetically sealed. Partial protection may be obtained by the use of fungicides, lutings and suitable moisture- and fungus-resisting materials.
Paints	Usually only moderately suitable. It must be borne in mind that the question of selecting paints sometimes depends on considerations other than tropicalisation measures, e.g. camouflage, anti-gas measures, etc. Stoved paints are better than air-dried paints.
Paper	Unsuitable unless of resin-treated high wet strength type, treated with fungicide.
Plastics	Suitable. Thermosetting plastics should be preferred to thermoplastics; however, polythene (polyethylene) and polyvinylchloride (thermoplastics) are better than any thermosetting plastics. Thermosetting plastics are liable to fungus growth, particularly on cut edges, which may be prevented by treating with varnish and fungicide, and by avoiding cellulose fillers. Cellulose acetate plastics are under investigation. Recommended plastics are: (*a*) thermosetting or asbestos fillers; (*b*) thermoplastics—polythene, polyvinylchloride, loaded polystyrene and polymethyl methylacrylate.
Plugs and Sockets	Unsuitable. All plugs and sockets the contacts of which are closely spaced, or are separated by materials which will support fungi or water films. Suitable. Plugs and sockets with well spaced contacts, mounted on fungus and moisture-resisting material, and preferably capable of being sealed with protective grease.
Porcelain	Suitable, especially if glazed. Unglazed porcelain surrenders absorbed moisture readily on warming.
Rayon	Unsuitable. Regenerated cellulose rayon, unless treated fungicide. Suitable. Acetate rayon.
Regulators (Carbon pile)	Suitable.
Relays	Unsuitable. Post Office relays. Suitable. Ericsson Type K relays; hermetically sealed relays.
Resins	In general suitable, except resins used in solder, which will support fungus growth if contaminated by dust.
Resistors (Fixed)	Unsuitable. Uninsulated carbon resistors, Mullard carbon resistors, Dubilier B.T. resistors, vitreous enamelled wirewound resistors with side termination, Dubilier wirewound resistors. Suitable. Insulated carbon resistors, vitreous enamelled wirewound resistors with ferrule termination, hermetically sealed resistors.
Resistors (Variable)	Unsuitable unless hermetically sealed.
Rhodium (Plating)	Suitable.
Rivets	Suitable only for non-replaceable components.
Ropes	Unsuitable unless treated with copper naphthenate, with or without creosote.
Rubber (Natural)	Suitable, especially if vulcanised and kept free from contact with lubricants or silver.
Rubber (Synthetic)	Unsuitable. Vulcanisates, thioplasts. Suitable. Butyl, neoprene (must not be used in contact with substances liable to acid corrosion), perbunan, hycar.
Screws	Suitable, especially when cadmium plated. The shearing strength must be considerable.
Silk	Suitable, but treatment with fungicide is recommended.
Silver (Plating)	Suitable.
Sleeving	Unsuitable. All textile sleeving with the exception of pure silk. Suitable. Rubber sleeving, unreinforced plastic sleeving (e.g. P.V.C.)
Springs	Unsuitable. Sprung steel springs. Suitable. Nickel steel springs, phosphor bronze springs.
Switches (Rotary)	Unsuitable. Switches with synthetic resin bonded (S.R.B.) paper wafers. Suitable. Switches with glazed ceramic wafers and silver-plated contacts.
Switches (Toggle)	Unsuitable. Switches with S.R.B. paper laminations. Suitable. Switches with moulded cases; slow "make and break" switches.

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DETAILED EXAMINATION OF COMPONENTS

Tag Boards	Unsuitable. Fabric-based plastics (e.g. S.R.B. fabric). Suitable. Paper-based plastics (e.g. S.R.B. paper), varnished and treated with fungicide.
Tape (Insulating)	Unsuitable. Standard black adhesive tape. Suitable. P.V.C. adhesive tape.
Tin (Plating)	Suitable if applied by hot tin dipping; failing this, electroplating to at least 0·0004 in. thickness.
Transformers and Chokes (Audio frequency)	Unsuitable. All unprotected transformers and chokes; wax or varnish impregnated transformers and chokes; transformers and chokes without bobbin flanges and with unsuitable bobbin material. Suitable. Transformers and chokes dip-sealed with bitumen; hermetically sealed transformers and chokes.
Transformers and Chokes (Radio frequency)	The same requirements apply for these as for r.f. coils and coil formers.
Valves	Unsuitable. All glass valves, unless top caps and bases are secured with non-moisture-absorbent cement; all zinc metallised valves unless treated with nitro-cellulose lacquer. Suitable. Metal valves, American type; glass valves, American type with metal base shell; tin metallised valves; glass valves with glazed ceramic bases.
Valveholders	Unsuitable. Laminated plastic valveholders, especially S.R.B. paper. Suitable. Moulded plastic valveholders; ceramic valveholders.
Valve retainers	Unsuitable. Retainers where S.R.B. paper or fabric makes contact with the top cap; plain zinc plated spring clips. Suitable. Spun glass retainers; passivated zinc plated spring clips (check contact potentials).
Varnishes (Protective)	Suitable for temporary protection against moisture, but unless regular warming (e.g. running of equipment) takes place, moisture films may form under the surface of the varnish. The addition of a fungicide is recommended.
Washers	Shakeproof washers are unsuitable, since they bite into metal, thus destroying finishes and stimulating corrosion.
Wax	Unsuitable.
Wiring	Unsuitable. All wiring with textile sleeving (except pure silk); cable forms tied with string; electrical cables "Met" series, i.e. with metal-braided outer covering. Suitable. Bare wire; wiring with unreinforced plastic sleeving (e.g. P.V.C.); cable forms (if unavoidable) tied with P.V.C. filament, electrical cables "Vin" series; i.e. with outer sheath of P.V.C. plastic or suitable synthetic rubber; enamelled wire.
Wood	Suitable woods which resist fungus growth and termite growth are teak, danta and southern cypress. Other woods are unsuitable unless treated with a fungicide which will also protect against insects.
Wool	Unsuitable unless treated with fungicide.
Zinc (Plating)	Unsuitable. Plain zinc plating. Suitable. Zinc plating followed by passivation; zinc spraying followed by stoving; zinc dipping to at least 0·0003 in. thickness.

Conclusion

This examination is not intended to be a guide to the tropicalisation of radio and similar equipment, and accordingly no details of tropicalisation methods or specific tropical components have been given; but it should serve as a guide to deciding whether or not equipment is suitable for tropical use.

The efficiency and effectiveness of radio equipment used in tropical climates depend on two factors :—

(i) Complete and reliable hermetic sealing, or use of components, materials and designs suitable for tropical conditions, or both.

(ii) Adequate care and maintenance.

Without both these factors no equipment can be considered as tropicalised.

Acknowledgment

This paper represents the correlation of information acquired from research groups of the various Ministries, together with the results of a certain amount of work performed by the authors themselves, while serving with the Royal Air Force. Thanks are due to the Air Ministry for permission to publish the paper.

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THE RADIO TRADES EXAMINATION BOARD

formed by

The British Institution of Radio Engineers.
The Radio Industry Council.
The Radio and Television Retailers' Association.
The Scottish Radio Retailers' Association.

RADIO SERVICING CERTIFICATE EXAMINATION

The third examination under the Board's auspices was held in London, Manchester and Glasgow, on May 4th, 1946. Seventy-two (72) candidates were admitted to the entire examination of whom forty-four (44) satisfied the Board in both parts. Six (6) candidates satisfied the Board in the written examination and will be permitted to re-attempt the practical test, and nine (9) candidates were successful in the practical only, and will be permitted to take the written examination.

PASS LIST—MAY, 1946

The following have satisfied the Examiners in the May, 1946, Examination :—

Passed entire Examination

ARROWSMITH, Jack	Glossop, Derby
ASHTON, Harry	Liverpool, 13.
BESTER, Arthur	London, E.8
BIRCH, Kenneth	Halifax, Yorks.
BRIERLEY, Ronald	Mickleover, Derby
BURKILL, Arthur H.	Willesden, N.W.
BURNS, John F. Paxton	Berwick-on-Tweed
BUTLER, Norman F.	Walsall, Staffs.
CAUSLEY, Kenneth F.	Pembury, Kent
COKER, Herbert M.	Kings Lynn
COLEMAN, Arthur E.	Alton, Hants.
DUNN, John H.	Glasgow, E.1
DUNN, Leonard S.	London, S.W.8
EDMUNDS, Thomas A. J.	London, W.6
FARR, Joseph H.	Northampton
GASKILL, H.	New Mills, Stockport
GRABOW, David	Hampstead, N.W.2
GRIFFITHS, Albert W.	Birmingham, 22.
HOARE, Richard	Littlehampton
HUXTABLE, Cyril	Newhaven, Edinburgh
KERR, Robert	Edinburgh
KNOWLES, Frank S.	Warlingham, Surrey
LAWRIE, Andrew	Ross-shire
McDONALD, Robert	Leith
NEWTON, Eric C.	Huntingdon
NUGENT, Ronald F.	West Ealing
OSBOURNE, Arthur	W. Plymouth
PERRY, John	Blandford, Dorset
PLANT, Richard L. Cheadle	Stoke-on-Trent
POULTER, George J.	Parkstone
REEDER, David J.	Middlesbrough
RIDLEY, Ronald R.	Ipswich
RIMMER, John B.	Glasgow, S.4
RONDEAU, Howard S.	Romford
ROSE, Frank E.	Raynes Park, S.W.
ROSE, Frederick	Sunderland
STANDLEY, Robert W.	Sleaford
TUFFIN, Norman L.	Minehead, Som.
TULLY, Leonard J. F.	Tunbridge
VINCENT, Robert E.	Edgware
VIVIS, Victor	Sleaford, Lincs.
WILLIAMS, Kenneth F.	London, S.E.
WORDEN, John A.	Preston
YOXALL, Edmund G.	Tolworth, Surrey

Passed Written Examination

BASS, William J.	Walsall
FAIRBAIRN, Harry A.	Eastbourne
GLEDHILL, Ronald	Blackpool
HALLIDAY, Robert E. J.	Stanmore
LEWIS, Reginald W.	Wolverhampton
OXBOROUGH, Frank W.	Southampton

Passed Practical Examination

ANDERSON, James David	Glasgow
BRADFORD, John	Edinburgh
BROWN, Rowland G.	Surrey
COCHRANE, William	Edinburgh, 7.
FORSTER, Ernest J.	Newport, Mon.
JOHNSON, William F.	Rochdale
NEVILLE, John F. W.	London, N.W.9
PARSONS, Ronald E.	London, S.W.16
THOMAS, Kenneth G.	Southampton

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THE DESIGN AND APPLICATION OF MODERN PERMANENT MAGNETS

by

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SUMMARY

The development of the modern anisotropic permanent magnet alloy has greatly facilitated the application of permanent magnets to electrical apparatus which previously would operate efficiently only with energised magnets.

Modern permanent magnets frequently permit the design of smaller, lighter and cooler apparatus, with reduced power consumption. Accordingly a relatively neglected branch of science has now acquired considerable importance from the engineering as well as the economic aspect.

The paper surveys the engineering application of permanent magnets with particular reference to the use of "Ticonal G" alloy.

CONTENTS

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* Mullard Wireless Service Co. Ltd.

Section 1. GLOSSARY OF TERMS USED

Aging.—The change in magnetic performance of a permanent magnetic alloy over a period of time. It may be natural or accelerated.

Anisotropic.—A material having directional properties. In this paper it will be considered as a material with very pronounced magnetic properties in one direction.

B.—See Flux Density.

B_r.—See Remanence.

$(BH)_{max}$.—The maximum product of B and $-$H of any point on the demagnetisation curve (2nd quadrant of the hysteresis loop). Usually designated $(B_d H_d)_{max.}$ in U.S.A.

B_{sat}.—The value of B corresponding to saturation.

Ballistic Galvanometer.—An instrument used to measure a quantity of electricity. It has a moving system with a large moment of inertia and a natural period of at least 1 second and usually about 10 seconds. It does not give a steady deflection but a throw proportional to the quantity of electricity passed through it.

Coercive force.—(H_c). The magnetomotive force which must be applied to a magnetic material to reduce to zero the residual flux in a closed or short-circuited specimen after complete saturation.

Consequent poles.—Magnetic poles occurring at other than the ends of a magnet.

Curie point.—Temperature at which ferro magnetic properties cease to exist.

Demagnetisation.—The reduction of residual flux. It may be partial or complete.

Demagnetisation curve.—That portion of the normal hysteresis loop in the second quadrant showing the flux in the magnetic material as related to the magnetising force applied in a direction opposite to the residual flux.

Diamagnetic.—A term applied to a substance which has a magnetic permeability less than unity.

Dimension ratio.—The ratio of the length of a magnet in the direction of magnetisation to its diameter, or the ratio of the length of the magnet to the diameter of a circle which has an equal area to the cross sectional area of the magnet.

Energy product curve or loop.—Is a graphical representation of the external energy produced by a magnet. It is the product of the flux density and demagnetising force as shown on the normal demagnetisation curve. The maximum of this product as shown on such a curve is known as $(BH)_{max}$. This value divided by 8π gives the theoretical optimum magnetic energy in ergs per c.c. of material which can be set up in an external magnetic circuit associated with it.

Ferro-magnetic.—A term applied to a substance which has a permeability much greater than unity and which varies with flux density, e.g. iron, nickel, and cobalt.

Flux density.—(B). The number of lines of flux, or maxwells, per unit area (sq. cm.) in a section normal to the direction of the flux.

Fluxmeter.—This is essentially a ballistic galvanometer with little or no restoring force to the moving system; generally it is calibrated in maxwells.

Fullness factor.—$(BH)_{max}/B_r \, . \, H_c$.

Gauss.—Unit of flux density. One gauss equals one maxwell per sq. cm. The symbol B is used for flux density in magnetic materials, and symbol H for flux density in air.
Gauss = total flux in maxwells/area (cm^2).

Gilbert.—A unit of magnetomotive force, the M.M.F. required to produce one maxwell magnetic flux in a magnetic circuit of unit reluctance. Also defined by the equation M.M.F. in gilberts = $4\pi/10$ ampere turns.

H.—See Magnetising force.

H_c.—See Coercive force.

H_{sat}.—The value of H corresponding to saturation.

Hard magnetic materials.—Magnetic materials, having a large hysteresis loop, which are not easily demagnetised, i.e. permanent magnet materials.

Hysteresis.—The tendency of a magnetic material to persist in any magnetic state that already exists.

Hysteresis loss.—The work expended in magnetising and demagnetising a ferro-magnetic material through one complete cycle; usually defined in ergs per cycle per cubic centimetre at a given peak flux density.

Hysteresis curve.—The graphical representation of the relationship between the magnetising force and the resultant induced magnetisation of a ferro-magnetic material, when the magnetising force is carried through a complete cycle.

Incremental permeability.—The ratio of change in flux to the change in magnetising force for any position on the magnetisation curve or hysteresis loop. The change in magnetising force must be applied in the reverse direction from the immediately preceding change.

Induction intrinsic (or ferric induction).—It is that portion of the induction in excess of the induction in a vacuum for the same magnetising force, $= B - H$ and frequently denoted by $4\pi I$ or $4\pi J$.

Induction magnetic.—The magnetic flux resulting when a substance is subjected to a magnetising influence.

Isotropic.—A material which has no directional properties. A cube of isotropic magnet material may be magnetised equally well between any two opposite faces.

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Keeper.—A piece of magnetically permeable material placed between the poles of a permanent magnet to reduce external field and demagnetising effects.

Leakage.—That portion of a magnetic field which is not useful.

Leakage coefficient or factor.—The ratio of total flux produced to the useful flux.

Line.—A term commonly used interchangeably for a maxwell.

Magnetic flux.—(Φ). The term applied to the physical manifestation of a condition existing in a medium or material subjected to a magnetising influence. The quantity is characterised by the fact that an E.M.F. is induced in a conductor surrounding the flux during any time that the flux changes in magnitude. The C.G.S. unit is the maxwell.

Magnetic poles.—The areas of a magnet where the lines of flux converge or diverge.

Magnetising characteristic.—The B.H. curve from zero B and H to saturation.

Magnetising force.—(H). The magnetomotive force per unit length at any given point in a magnetic circuit. It may be defined in terms of ampere turns, but in this paper the C.G.S. unit is used. The C.G.S. unit is the *oersted* and may be defined by the equation :—

Magnetising force in oersteds

$$= \frac{\text{M.M.F. (in gilberts)}}{\text{length in cms.}}$$

Magnetomotive force.—(M.M.F.). That which produces or tends to produce a magnetic flux. The C.G.S. unit is the gilbert. In a magnetic circuit it is the work required to carry a unit magnetic pole around the circuit against the magnetic field.

$$\text{M.M.F. in gilberts} = 4\pi/10 \text{ ampere turns.}$$

Maxwell.—The C.G.S. unit of magnetic flux. It is the flux produced by an M.M.F. of one gilbert in a magnetic circuit of unit reluctance. Also defined in terms of induced E.M.F.—when a conductor cuts magnetic flux at the rate of 10^8 maxwells per second, one volt is induced.

Minor hysteresis loop.—Any hysteresis loop smaller than the major loop.

Oersted.—(H). The C.G.S. unit of field strength ; an M.M.F. of one gilbert per cm.

Paramagnetic.—A substance of permeability slightly greater than unity.

Permeability.—(μ). The ratio of the magnetic flux induced in a given medium to that which would be produced in a vacuum by the action of the same magnetic force.

$$\mu = \frac{\text{B (magnetic induction in gauss)}}{\text{H (magnetising force in oersteds)}}$$

Permeameter.—An instrument for determining the magnetic properties of a sample or testbar.

Permeance.—The reciprocal of reluctance.

Recoil.—The condition of a magnet when its M.M.F. is reduced by reducing the reluctance of its circuit or when an external demagnetising force is removed.

Recoil curve, recoil line, or recoil loop.—The minor hysteresis loop where the magnet is working when under conditions of recoil. As a minor hysteresis or recoil loop in the 2nd quadrant deviates so slightly from a straight line it is usually drawn as a straight line joining the demagnetisation curve to the B axis and referred to as the recoil line or recoil loop.

Recoil percentage.—In this paper the recoil percentage will be considered as :—

$$100 - \left(\frac{\text{working M.M.F.}}{\text{maximum M.M.F.}} \times 100\right)$$

Recoil permeability.—As a recoil line indicates a change of B with respect to H the slope of the line may be conveniently specified as having a permeability referred to as the recoil permeability or incremental permeability of the material.

Reluctance.—It is the property of the magnetic circuit to resist magnetisation. Thus the amount of magnetic flux resulting from a given M.M.F. acting on a magnetic circuit is determined by the magnetic reluctance of the circuit.

$$\text{Reluctance} = \frac{\text{M.M.F. in gilberts}}{\text{flux in maxwells}} \text{ or } \frac{l}{\mu A}$$

1 cm. cube of vacuum has unit reluctance.

Remanence or residual induction.—(B_r). The maximum induction which remains in the steel (a closed or short-circuited specimen) after being magnetised to complete saturation.

Saturation or saturation intensity.—Theoretically it is the condition which occurs in a ferro magnetic body when magnetised to such a flux density that no increase in intrinsic induction occurs when the magnetising force is further increased, i.e. when the increase in B equals the increase in H. In this paper it will be considered as the minimum degree of magnetisation which will produce the maximum area of hysteresis loop, i.e. the major hysteresis loop.

Soft magnetic materials.—Ferro magnetic materials having a small hysteresis loop and which are easily demagnetised.

Stability.—The ability of a permanent magnet to produce a magnetic field which is constant with respect to time.

Stabilisation.—The process of subjecting a magnet to a demagnetising influence greater than that which it is normally expected to receive under operating conditions so that it will remain stable during use.

Weber.—10^8 maxwells.

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Section 2. MAGNETIC THEORY

2.1. Development of Permanent Magnet Alloys

Apart from magnetic ore found to exist naturally in various parts of the world, hardened carbon steel was probably the first material used for the manufacture of permanent magnets.

Ordinary carbon steel, when quenched from about 800°C., acquires a glass-hard surface which has pronounced permanent magnetic properties. The characteristics which are obtained with this type of magnet vary considerably with the composition of the steel. The permanent magnetic properties reside mainly in the glass-hard surface and this gave rise to the theory that magnetism occurs only in the outer layers of substances, so that a more powerful permanent magnet results when it is built up of several plates or laminations in preference to one solid piece. This and similar theories were undoubtedly true when applied to the early types of permanent magnets, but no longer apply to modern permanent magnet alloys.

The earliest permanent magnets, used generally for a variety of purposes in practical engineering, e.g., meters, dynamos, compasses, etc., were probably made of tungsten and chrome steel. These magnets were different from the earlier hardened steel type in that their properties did not reside mainly at the surface, but were distributed throughout the cross section.

About 1920, the cobalt series of permanent magnets was developed. These had the great advantage of being very versatile as well as being of higher efficiency, and represented a marked advance in permanent magnet manufacture. The proportion of cobalt in the steel controls the performance of the finished magnet, so that in a given space a choice of performance may be made, or for a specified performance a choice of size may be made.

It was generally found where weight was of little importance that magnets containing about 9 per cent. cobalt were economical. The cobalt steels, in common with earlier steels, have the very useful property of being machinable. They can be cast, rolled, turned, drilled and tapped, and lend themselves to the manufacture of intricate shapes to close tolerances. They are relatively strong and tough, hence they are still widely used.

The next great step in the development of permanent magnets was due to the work of Mishima in Japan, which resulted in the nickel-aluminium series being introduced in this country about 1933. These alloys were subsequently improved by the addition of cobalt. The newer alloys are generally characterised by extreme hardness and brittleness resulting from pronounced crystal structure. They are not generally machinable other than by grinding, unless given a prolonged and careful heat treatment. This treatment usually consists of heating to about 900° C. and cooling slowly and continuously for a period of one or more days. While this renders the alloy sufficiently soft to be drilled and tapped by ordinary methods, the process is necessarily expensive.

The nickel-aluminium range of alloys has a high coercive force which makes it possible, and desirable, to use small rectangular blocks in place of the conventional " U " shapes previously employed. This has also led to a more scientific approach to design problems, and has forcibly brought home to designers the fact that magnets of this type, with their relatively small leakage surface, cannot be satisfactorily magnetised before assembly.

Experiments were made with the nickel-aluminium alloys to increase their magnetic performance by heat treatment in a magnetic field.[1] The resulting increase in magnetic performance of approximately 10 per cent. was probably not considered a commercial proposition, as the special heat treatment would appear more costly than an increase in the size of the magnets to achieve a similar performance.

The latest advance in magnetic alloys is due to the Philips Research Laboratories at Eindhoven.[2] Here, the anisotropic or directional alloy was developed, which, when correctly manufactured and heat treated in a magnetic field under carefully controlled conditions, gives a magnetic performance in the region of $(BH)_{max} = 6{\cdot}0 \times 10^6$, which is three to four times greater than the performance of any previous commercially obtainable alloy.

It is important to note that with this anisotropic alloy the high performance can only be obtained when the operating flux is in the same direction as that of the field used during heat treatment, but it need not necessarily be of the same polarity.

Because modern directional materials have been magnetically treated during their manufacturing processes, it is frequently and incorrectly assumed that the magnetic field is permanently fixed in the magnet and that the fundamental characteristics of permanent magnets no longer apply to these materials. It should be clearly understood that this is not the case.

The special manufacturing processes produce an increased efficiency along a predetermined dimension of the magnet, and the polarity or direction of subsequent magnetisation is of no consequence provided it follows the direction of the field used during manufacture.

These alloys follow the fundamental laws of permanent magnets and may be magnetised either in one direction or the other along the magnetic axis with identical results and they may be magnetised and demagnetised any number of times without in any way reducing or changing their magnetic characteristics.

The paper deals mainly with "Ticonal G" and its industrial applications, since this material evidences the latest and most scientific advance in permanent magnet technique and is in abundant supply to the electrical and radio industry.

Fig. 1 shows graphically the performance of "Ticonal G" and the reduction in magnetic characteristics of

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" Ticonal G " as the operating flux deviates from the magnetic axis.

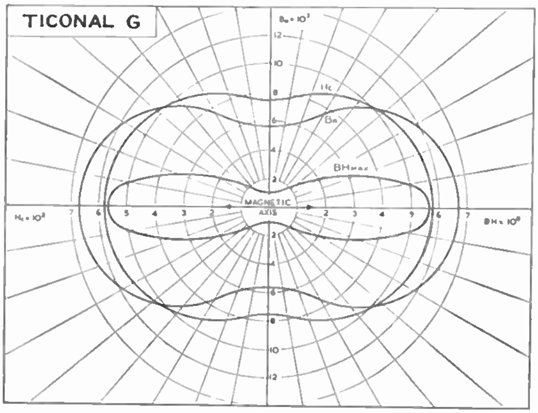

Fig. 1.—The change in magnetic characteristics of "Ticonal G" as the operating flux deviates from the predetermined magnetic axis.

2.2. Commercially Obtainable Magnet Alloys

The early type of tungsten, chrome and low content cobalt steel magnets are relatively strong and tough ; before hardening they may be rolled, forged, drilled and tapped as is ordinary steel ; it is only after heat-treatment that they become relatively hard and, to some extent, brittle.

As the cobalt content in cobalt steel increases, the steel becomes increasingly hard and brittle, showing a tendency to crack or crumble during machining operations.

Aluminium-nickel alloys are extremely hard and crystalline with a marked tendency to crack. They cannot be rolled or forged and only with great difficulty can they be machined or drilled. They are manufactured by sintering or casting to shape followed by final grinding.

The anisotropic materials are even harder, more crystalline, and difficult to machine other than by grinding.

The average physical characteristics of cast " Ticonal G " are :—

Specific gravity. 7·3.

Hardness. 600 Vickers.

Mean Coefficient of expansion. + 11·3 × 10^6 per °C

Resistivity. 47 $\mu\Omega/\text{cm}^3$ at 25° C.

Recoil permeability. 3·0 (approx.)

An important point, not always obvious, is that although the anisotropic magnet alloy is considerably more expensive per pound weight, compared with other materials, its efficiency is so high that for a given performance its cost is frequently less than that of the other materials ; this fact added to the advantages of a lighter

COMPARATIVE DEMAGNETISATION CURVES

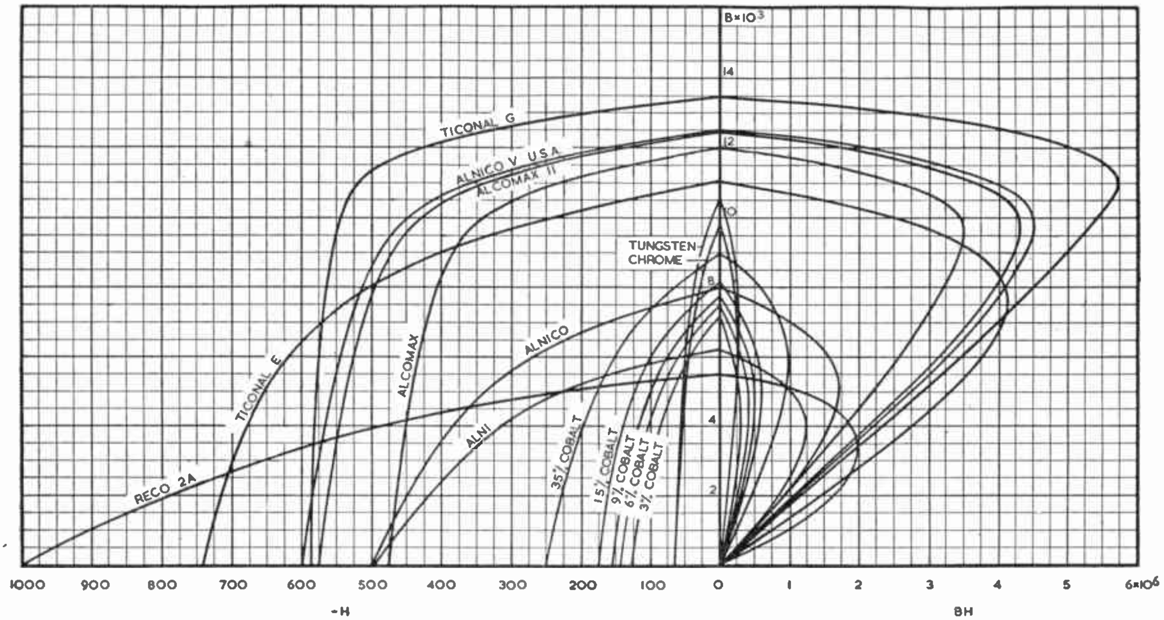

Fig. 2.—Published characteristics of commercially available permanent magnet alloys.

PERFORMANCE OF VARIOUS COMMERCIAL PERMANENT MAGNET ALLOYS.

AMERICAN

Material	Nominal Composition (balance Fe)	$(BH)_{max} \times 10^6$	B_r gauss	H_c oersted	B working gauss	H working oersted	Recommended Saturation values	
							B_{sat} gauss	H_{sat} oersted
Alnico V (Orange)	8 Al, 14 Ni, 24 Co, 3 Cu	4·5	12,500	600	9,680	465	17,000	3,000
Modified Alnico V	8 Al, 14 Ni, 24 Co, 3 Cu	4·25	11,200	660	8,500	500	16,000	3,000
New K.S.	3·7 Al, 17·7 Ni, 27·2 Co, 6·7 Ti	2·03	7,150	785	4,150	490	13,000	3,000
Honda Metal	3·3 Al, 18 Ni, 27 Co, 6·7 Ti	2·0	7,100	780	4,250	470	13,000	3,000
Cunife	60 Cu, 20 Ni	1·8	5,700	600	4,500	390	8,400	2,400
Alnico XII	6 Al, 18 Ni, 35 Co, 8 Ti	1·75	5,800	950	3,100	565	13,200	4,000
Alnico II (Red)	10 Al, 17 Ni, 12·5 Co, 6 Cu	1·55	7,300	530	4,620	335	12,900	2,000
Modified Alnico II	10 Al, 17 Ni, 12·5 Co, 6 Cu	1·55	7,000	600	4,200	370	12,900	2,000
Alnico I (Blue)	12 Al, 20 Ni, 5 Co	1·4	7,100	450	4,600	305	12,500	2,000
Alnico III (Green)	12 Al, 25 Ni	1·4	7,000	470	4,300	325	12,000	2,000
Modified Alnico III	12 Al, 25 Ni	1·4	6,700	555	3,800	370	12,000	3,000
Mishima Metal	13 Al, 29 Ni	1·4	6,000	550	3,900	360	12,000	3,000
Modified Alnico IV	12 Al, 28 Ni, 5 Co	1·35	6,000	620	3,800	360	11,600	3,000
Alnico IV	12 Al, 28 Ni, 5 Co	1·25	5,200	750	3,000	415	11,600	3,000
Vicalloy	52 Co, 10 V	1·02	9,000	300	5,530	185	15,000	1,000
Remalloy Comol	12 Co, 15 Mo	1·0	9,330	243	5,900	170	17,000	1,000
Cunico	45 Cu, 25 Ni, 30 Co	0·85	3,400	710	2,020	420	8,000	3,200
Simanal	86·5 Ag, 8·8 Mn, 4·7 Al	0·08	595	575	—	—	20,830	20,000
Cunife II	50 Cu, 20 Ni, 2·5 Co	0·78	7,300	260	4,680	167	9,500	2,400
Kato's Oxide Vectalite Sintered Oxide	30 Fe_2O_3, 44 Fe_3O_4, 26 Co_2O_3	0·5	1,600	900	944	530	4,800	3,000
36% Cobalt Steel	—	0·95	9,600	240	6,150	155	15,500	1,000
17% Cobalt Steel	—	0·62	9,000	165	5,900	105	15,000	1,000
5% Tungsten Steel	—	0·32	10,300	70	6,900	46	14,500	300
3½% Chrome Steel	—	0·29	9,200	65	6,400	45	13,500	300
Manganese Steel	—	0·18	10,000	43	6,250	29	15,000	300
Carbon Steel	—	0·18	8,600	48	5,625	32	14,800	300

BRITISH

Material	$(BH)_{max} \times 10^6$	B_r gauss	H_c oersted	B working gauss	H working oersted	Recommended Saturation values	
						B_{sat} gauss	H_{sat} oersted
Ticonal G.	5·7	13,480	583	11,000	520	17,000	3,000
Ticonal F (44/44)	4·8	12,400	600	10,000	480	17,000	3,000
Alcomax II	4·3	12,400	575	9,570	450	17,000	3,000
Ticonal E (42/50)	4·1	11,070	740	7,500	550	16,000	3,000
Ticonal D (3·8)	3·8	12,000	600	9,000	420	16,000	3,000
Alcomax	3·5	12,000	475	9,500	370	16,000	2,000
Reco 2A	1·92	5,500	1,000	3,300	600	13,000	4,000
Alnico	1·7	8,000	500	5,200	327	13,500	3,000
Alnico (high coercive)	1·7	6,500	620	4,250	400	13,500	3,000
Hynico	1·63	7,250	628	4,660	350	12,500	3,000
Alni	1·25	6,200	490	4,000	312	12,000	2,000
Alni (high coercive)	1·25	4,700	700	2,840	440	11,500	3,000
Hynical	1·15	5,250	674	3,290	350	11,500	3,000
35% Cobalt Steel	·95	9,000	250	5,930	160	15,500	1,000
15% Cobalt Steel	·62	8,200	180	5,250	118	15,000	600
9% Cobalt Steel	·5	7,800	160	5,000	100	15,000	600
6% Cobalt Steel	·44	7,500	145	4,680	94	15,000	500
3% Cobalt Steel	·35	7,200	130	4,220	83	15,000	500
6% Tungsten Steel	·30	10,500	65	6,980	43	14,500	300
3% Chrome Steel	·285	9,800	70	6,200	46	13,500	300

TABLE 1.—This table is based on manufacturers' published data.

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and more compact construction usually renders the re-design of apparatus well worth while.

The performance of various commercially obtainable permanent magnet alloys is shown in Table I, and graphically in Fig. 2.

These figures are based on manufacturers' published data, but discrepancy exists between figures quoted by different manufacturers for similar materials. It should be noted that data referring to permanent magnets usually applies to test pieces of a size and shape correct for optimum heat treatment, and where the scale and outer layers of the material are removed. Magnets made of the same materials, but left as cast, and of a size or shape not conducive to optimum heat treatment, will have a performance lower than may be expected from examination of published data.

The magnetic characteristics of various soft magnetic materials are shown in Table 2, and graphically in Fig. 3. These characteristics vary considerably with different specimens of similar material and these figures are given only as a guide. Actual characteristics should be measured or obtained from the manufacturers.

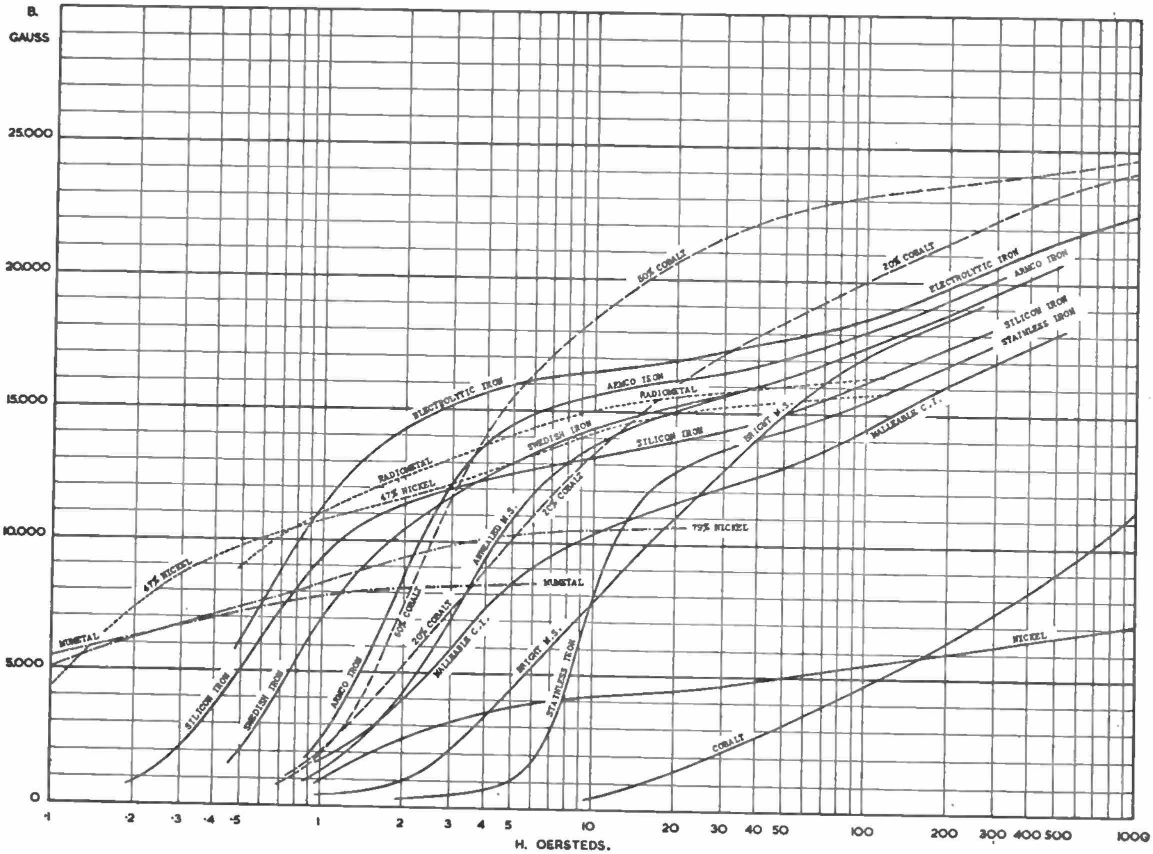

Fig. 3.—The approximate characteristics of soft magnetic materials.

2.3. The Hysteresis Loop, Recoil Loop, Recoil Slope and Recoil Permeability

In order that a clear conception of the properties of a ferro magnetic material may be obtained, reference should be made to its hysteresis loop which is a convenient graphical method of showing the relation between flux density and magnetising force. (See Fig. 4.) The area of the loop is a measure of the energy expended in taking the substance through a complete magnetic cycle to saturation in both directions.

When considering soft magnetic materials, the whole of the hysteresis loop is of great importance, but in the case of hard or permanent magnet materials it is mainly the 2nd or 4th quadrant which is of interest to designers. Manufacturers need to be aware of the values of H_{sat} and B_{sat} so that the alloy may be correctly magnetised to give its optimum performance.

VALUES OF FLUX DENSITY B IN KILOGAUSS

H. (Oersteds) →	·02	·05	·1	·2	·5	1	2	5	10	20	50	100	200	500	1000
Cobalt Iron 50% Co. 50% Fe.	—	—	—	—	0·5	1·8	7·5	15·7	18·5	20·8	22·5	23·1	23·6	24·2	—
Cobalt Iron 20% Co. 80% Fe.	—	—	—	—	—	2·0	5·3	10·1	13·4	16·1	18·4	20·1	21·6	23·2	24·1
Electrolytic Iron	—	—	—	—	6·3	11·2	14·2	16·0	16·5	17·0	17·8	18·7	19·9	21·7	22·5
Armco Iron	—	—	—	—	—	2·5	8·5	14·5	15·6	16·2	17·0	18·1	19·3	21·5	22·5
Swedish Iron	—	—	—	—	2·0	7·0	10·5	13·0	14·3	15·2	16·3	17·3	18·8	—	—
Silicon Iron	—	—	—	0·8	5·0	9·5	11·5	12·5	13·2	13·9	15·0	16·1	17·5	19·2	—
Mumetal	1·4	4·0	5·5	6·3	7·0	7·9	8·2	8·3	—	—	—	—	—	—	—
Nickel Iron 79 Ni. ..	1·0	3·0	5·0	6·2	7·3	8·3	9·2	10·2	10·5	10·7	—	—	—	—	—
Nickel Iron 47% Ni. ..	—	1·6	4·3	7·5	9·8	10·8	11·7	13·0	14·2	15·0	15·4	15·7	—	—	—
Radiometal..	—	—	—	—	9·0	11·0	12·5	14·0	15·0	15·6	16·0	—	—	—	—
Bright Mild Steel	—	—	—	—	—	0·5	1·0	4·5	7·8	11·0	15·0	17·2	18·0	—	—
Black Mild Steel	—	—	—	—	—	2·5	6·0	11·0	13·5	14·8	16·0	17·3	18·5	20·7	—
Bright Mild Steel, Annealed	—	—	—	—	—	1·2	5·1	11·0	13·7	15·0	16·3	17·4	18·5	20·7	—
Malleable Cast Iron ..	—	—	—	—	—	1·8	4·0	8·4	10·4	11·6	13·0	14·5	16·1	18·0	—
Stainless Iron	—	—	—	—	—	—	0·3	1·0	7·9	12·8	14·3	15·4	16·8	—	—
Cobalt	—	—	—	—	—	—	—	—	0·5	1·5	3·2	4·8	6·4	9·0	11·3
Nickel	—	—	—	—	—	1·0	2·6	3·7	4·1	4·4	5·0	5·6	6·2	6·6	7·1

TABLE 2.

Table showing the approximate characteristics of soft magnetic materials.

The behaviour of a permanent magnet material in the 2nd quadrant of its hysteresis loop is not usually fully explained. It is generally shown as a smooth curve indicating values of B corresponding to values of $-H$ while H steadily becomes more negative from $H = O$ to H_c. Fig. 5 shows the 2nd quadrant, or demagnetisation curve, and energy product loop of " Ticonal G. " The energy loop is drawn by plotting the product of B and $-H$ against B.

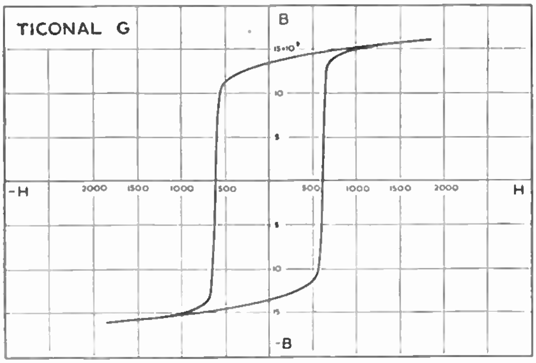

Fig. 4.—The hysteresis loop of "Ticonal G."

Under practical conditions, most magnets will be subjected to a variable demagnetising influence, i.e., the value of $-H$ does not remain constant. The variation may be small or negligible, when it is due only to local external fields of small magnitude; on the other hand, the variation may be large for motors and generators which are subject to varying armature reactions and occasionally have their armatures removed for maintenance purposes.

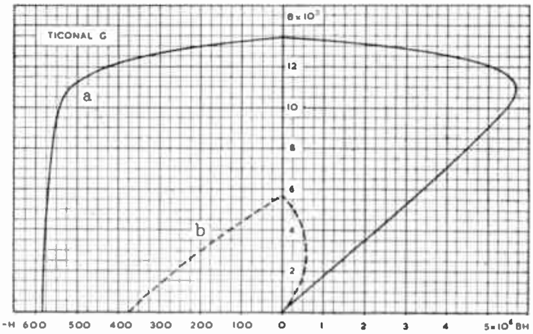

Fig. 5.—The normal demagnetisation curve and energy loop for "Ticonal G" :-

(a) When the flux is parallel to the magnetic axis.

(b) When the flux is at 90° to the magnetic axis.

Under these conditions, when $-H$ is changed to a value nearer zero the magnitude of B no longer corresponds to that indicated by the major hysteresis loop or demagnetisation curve, but abruptly leaves it as illustrated in Fig. 6 which shows the normal demagnetisation curve of "Ticonal G," and the behaviour of the material when H reaches a value of -520 oersteds, is

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then reduced to zero, and returns again to −520 oersteds.

This somewhat elliptical shape (X.Y.) is known as a minor hysteresis loop, as is any loop which is smaller than the major loop. Minor hysteresis loops in the 2nd or 4th quadrant of the major loop are sufficiently small, and so nearly parallel to each other that for practical purposes they may be considered and drawn as parallel straight lines joining the demagnetisation curve to the B axis. As the flux under these conditions is in a state of recoil, the average slope of a minor hysteresis loop may be designated the recoil or incremental permeability of the permanent magnet material.

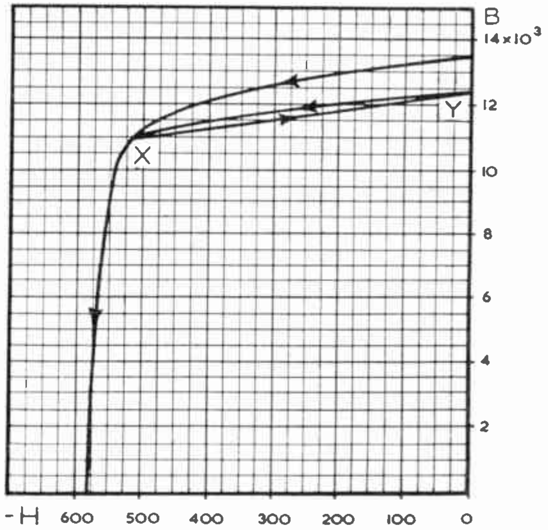

Fig. 6.—The demagnetisation curve of "Ticonal G" showing its behaviour when H alternates between 0 and — 520.

Fig. 7 shows the demagnetisation curve of "Ticonal G" with three minor loops, illustrating how closely they approximate to parallel straight lines.

It should be noted that when a permanent magnet is working under conditions of recoil it cannot give a BH product equal to its $(BH)_{max}$ and that design data, taken from the major loop, may prove misleading if used for motors, generators and other apparatus working under conditions of severe recoil.

2.4. Magnetic Specification, Methods of Comparing Magnetic Performance and the Terms in which Magnetic Alloys are usually Specified

The magnetic properties of permanent magnet materials are usually specified by the values of H_c, B_r and $(BH)_{max}$. The terms H_c and B_r are of little use to an engineer, since the value of H_c refers to the magnetomotive force between the opposite faces of a centimetre cube of magnet material when its flux is reduced to zero after saturation and is therefore giving no magnetic energy. Similarly, B_r is the value of the flux given by a cm. cube under conditions of complete short circuit after saturation, when again no magnetic energy is available.

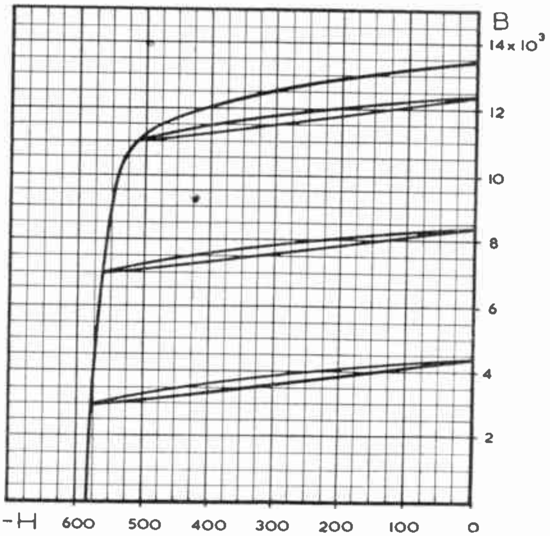

Fig. 7a.—The demagnetisation curve of "Ticonal G" showing three minor loops.

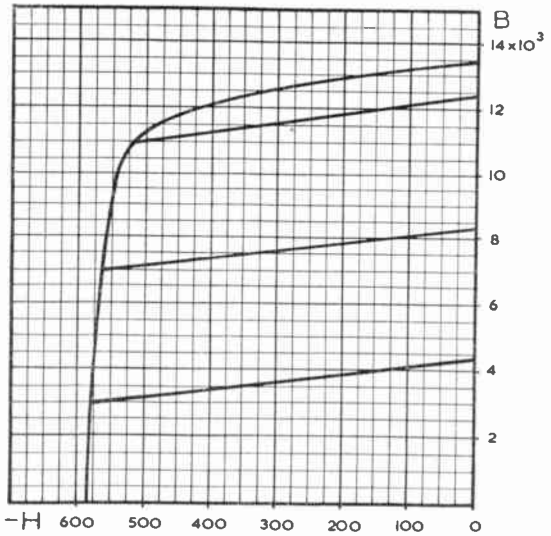

Fig. 7b.—The demagnetisation curve of "Ticonal G" showing how the three minor loops are usually depicted.

While $(BH)_{max}$ is the criterion of magnetic performance and represents the highest obtainable product of the values of B and $-H$ corresponding to any point on the major hysteresis loop in the 2nd quadrant, the $(BH)_{max}$ figure does not indicate the actual values of B and H concerned.

Engineers require a magnetic specification giving the values of B and H corresponding to $(BH)_{max}$. These most important figures are generally the basis of designs, and it is at these values, for apparatus where the magnetic field may be regarded as static, that the designer endeavours to arrange that the permanent magnet material shall work. In this paper, the values corresponding to $(BH)_{max}$ are designated the working B and working H of a magnetic alloy.

The value of recoil, or incremental permeability, is useful for design work when the magnet is working under conditions of recoil. In the event of the recoil permeability being required but not specified, a useful approximation is to assume that the recoil line is parallel to the major hysteresis loop where it crosses the B axis. (See Figs. 6 and 7.)

Curves illustrating the performance of a magnetic alloy should be considered part of a magnetic specification and should be drawn to axes of B and H. Curves drawn to axes of $4\pi I$ or $4\pi J$ and H show optimistic properties and may prove particularly misleading to designers when they relate to materials with high values of H_c.

In illustration of this point, Fig. 8 shows the demagnetisation curve of a specimen of relatively high coercive force permanent magnet material (Reco 2A), (*a*) drawn to axes of $4\pi I$ and H and (*b*) drawn to axes of B and H.

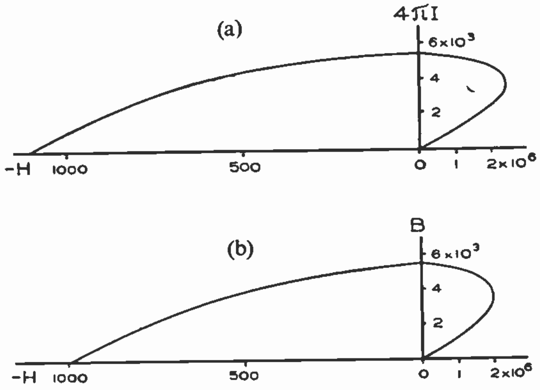

Fig. 8.—The demagnetisation of a relatively high coercive force permanent magnet material (a) drawn to axes of $4\pi I$ *and H and (b) drawn to axes of B and H.*

2.5. The Difference between Magnetic Specifications using the Terms $4\pi I$, and B

Textbooks frequently show hysteresis loops drawn to axes of $4\pi I$, or $4\pi J$ and H in place of B and H. At first sight, the difference may appear small, or even negligible. The difference is that $4\pi I = B - H$, meaning that $4\pi I$ is the value of flux produced by a permeable body in excess of that which would be produced by the same magnetising force if the permeable body were removed.

In the 2nd quadrant of the hysteresis loop, which is of the greatest importance in permanent magnet design, the value of H is negative; $4\pi I$ is therefore a larger quantity than B, except at the point where the curve passes through the vertical axis ($H = O$) and the greatest difference occurs at the H_c point.[3]

In early types of permanent magnets where the value of B is large in proportion to H, the difference between $4\pi I$ and B may be negligible, but with modern alloys of high coercive force the difference becomes quite important, as is illustrated in Fig. 8. The value given for H_c on curve (a) is greater than that for curve (b). Similarly values given for the performance of an alloy are sometimes misquoted as $(BH)_{max}$ when in reality they are $(4\pi I\ H)_{max}$—an appreciably higher value for modern alloys with high values of working H.

B is the practical unit which is of most value to engineers and designers and care has been taken in the paper not to confuse it with other units and to present all engineering data in terms of B.

2.6. Measurement of Magnetic Properties and Performance

Flux Density

Measurements of magnetic flux are based on the definition that when magnetic flux cuts a conductor at the rate of 10^8 lines per second, an E.M.F. of 1 volt is produced. Also from the definition of the henry, that when the current in an inductor of 1 henry is changing at the rate of 1 ampere per second, an E.M.F. of 1 volt is induced across its terminals, it follows that the rate of change of linkages is 10^8 per second, and taken over a period of 1 second the current may increase from zero to 1 ampere, resulting in 10^8 linkages. Therefore, with a mutual inductance of 1·0 henry and a current of 1·0 ampere switched on in the primary, a fluxmeter connected to the secondary should show a deflection corresponding to 10^8 maxwell turns; by suitably choosing the value of mutual inductance and adjusting the primary current, the fluxmeter may be calibrated. This is, in fact, a method frequently adopted for the calibration of a fluxmeter.

Probably the most widely used method of measuring magnetic flux is to employ a calibrated search coil in conjunction with a fluxmeter. Here the coil would consist of a number of turns of wire wound on a non-magnetic former and calibrated in terms of effective area together with its D.C. resistance. A search coil where the area enclosed by one turn is 1 sq. cm. and which has 60 turns, is referred to as having an effective area of 60 sq. cms. The D.C. resistance of a search coil should normally be kept as low as possible, as it is liable to impair both the damping and accuracy of the fluxmeter with which it is used. The D.C. resistance of a search coil intended for use with the familiar Grassot fluxmeter should not exceed 10 ohms.

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The effective area of simple single layer search coils may usually be satisfactorily calculated, but in the case of multi-layer coils it may become necessary to calibrate them in a known magnetic field conveniently produced by a solenoid.

Providing the solenoid is uniformly wound and is long compared with its diameter the field generated in its centre will be :—

$H = \frac{4\pi NI \cos \alpha}{10l}$ where α = half the angle subtended at the centre of the coil by a diameter at one end.

Measurements of flux density are usually the mean value of the flux over the space enclosed or swept by the search coil. The difference between the mean and peak flux is usually considered negligible in a parallel gap where the area is large compared with the length of the flux path,[4] e.g., the gap of a loud speaker magnet.

As an illustration of the variation of flux density which normally occurs Fig. 9 shows the actual flux density measured in the gap of a moving coil loudspeaker where the radial width of the gap is 0·038 in. and its depth $\frac{5}{32}$ in. The usual method of specifying and measuring the flux density in this and similar apparatus consists in measuring the total flux in the gap, assuming the gap to be the space between the pole faces (or under the smaller pole face if the poles are dissimilar) and dividing the total flux by the cross sectional area of the gap. An exaggerated figure for flux density may be obtained by restricting the measured area of flux to the centre of the gap.

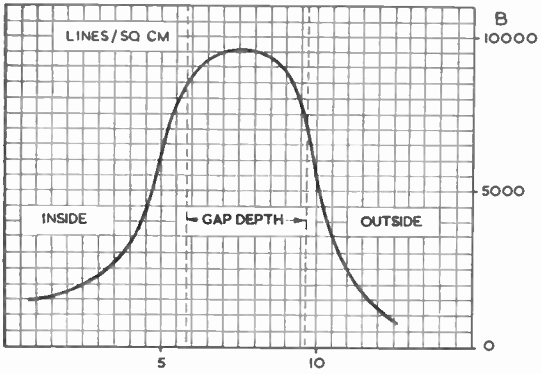

Fig. 9.—The variation in measured flux density through the gap of a moving-coil loudspeaker.

It is possible to measure the total flux or flux density in the gap of a moving coil speaker assembly by moving a search coil from the inner to the outer edges of the gap, but this method is not easy unless a mechanical device is used to move the coil through a precisely measured distance.

Another method is to measure the mechanical reaction between the flux and a coil carrying D.C. located in the gap. With this method either a constant current is used and the pull on the coil increased till it pulls free of the gap, or a constant pull is used and the current decreased till the coil leaves the gap. The mean value of flux density in the space occupied by the coil may then be calculated from the formula :—

Force in dynes $= \frac{HlI}{10}$ Where H = lines per sq. cm. (H = B in air)

l = length of conductor in cms. I = current in amperes in the coil.

One of the easiest methods of measuring the flux density in the working gap of a moving coil loudspeaker assembly is to use a differential search coil.[4] This is a coil so designed that when it is in position in the gap of the moving coil speaker assembly, one winding is at the inner edge of the gap and the other at the outer edge of the gap. (See Fig. 10.) The two windings are of an equal number of turns and are wound in opposition. Consequently, when the coil is removed from the gap the inner coil cuts the flux in the gap plus the leakage flux radiated from the face of the centre pole, while the outer winding cuts only the leakage flux radiated from the face of the centre pole ; as the coils are connected in opposition, the deflections caused by the leakage flux will cancel.

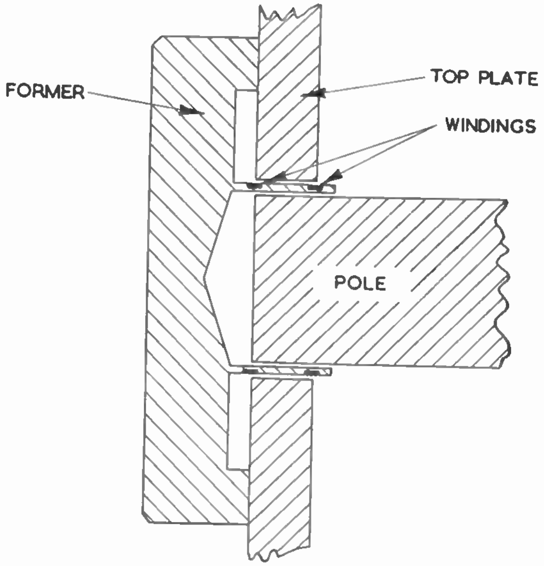

Fig. 10.—A differential search coil in position in the magnetic circuit of a loudspeaker.

The effective area of a differential search coil is the area between the two coils, which is π times the diameter of the coils times the distance between them, multiplied by the number of turns in one coil.

A useful method of measuring the effective flux density in a moving coil instrument, providing the moving coil is of low resistance and shunts are disconnected, is to connect the terminals of the instrument under test directly to a fluxmeter. If then the pointer is moved through a measured angle of rotation the area swept by one turn, and consequently the effective area swept by the whole coil, can easily be calculated.

$$\text{Effective area swept by coil} = \frac{\text{degrees rotation}}{360} \times 2\pi D\, l / N \text{ sq. cms.}$$

Where :—D = mean distance between opposite sides of the moving coil in cms.

l = effective average length of conductor, i.e., length of iron core in cms.

N = number of turns on coil.

The reading of the fluxmeter divided by this area will give the effective flux density in the instrument.

Fluxmeters

Fluxmeters[5] are essentially galvanometers which will measure small quantities or charges of electricity and there are two main groups in common use, the ballistic type and the Grassot type.

The ballistic galvanometer is one which gives a throw proportional to the charge which is induced in a search coil connected to it. The duration of the charge must therefore be less than half the natural period of the galvanometer. Its sensitivity need not be high, but its scale deflection should preferably be uniform. High accuracy of measurement is possible if the instrument is calibrated against a standard mutual inductance using a sub-standard ammeter at the point corresponding to the deflection given by the flux being measured.

The Grassot fluxmeter is a moving coil instrument with negligible restoring torque to the moving system so that a given charge will cause a proportional deflection regardless of whether the time of duration of the charge is negligible or appreciable. Actually, this ideal state of affairs is not reached and the measurement should be made as quickly as possible as steady losses introduced by pivot friction will cause a reduced deflection if the search coil is moved slowly.

The accuracy of measurement using a Grassot fluxmeter is of the order of 1·5 per cent., except for small deflections. This is adequate for most purposes.

BH Curves

During the manufacture of permanent magnet alloys, measurements of the demagnetisation curve of the material have to be made. Probably the most useful general test apparatus for this purpose is the M.L. test gear[6] made by Messrs. Lucas.

This apparatus consists essentially of a universally adjustable magnetic circuit of negligible reluctance in which an accurately measured block of magnet alloy may be inserted.

The magnetising coil is positioned around the magnet which may be saturated by passing a heavy current through the coil. The demagnetising force ($-H$) is applied by adjusting and reversing the direction of the current in the coil and an ammeter calibrated directly in terms of $-H$ is included in the coil circuit. The flux maintained in the magnetic circuit passes through a disc driven at constant speed. The disc is of sufficiently generous proportions and such a close fit in the magnetic circuit that the error caused by its reluctance may normally be disregarded. The E.M.F. generated in the disc, measured between the spindle and periphery, is proportional to the total flux in the magnetic circuit.

Adjustable shunts across the ammeter compensate for the length of the magnet under test, while adjustable series resistance in the voltmeter circuit compensates for cross sectional area. This apparatus, essential for a magnet manufacturer, is, in addition, extremely useful for magnet users. The complete specification of this apparatus is contained in British Standard Specification No. 406, 1931.

Magnet acceptance tests

Routine acceptance tests on a magnet designed for a special purpose may usually be made by testing the magnet at a single point on its demagnetisation curve at or near to the $(BH)_{max}$ point, where the magnet should be working under operating conditions in the apparatus for which it is designed.

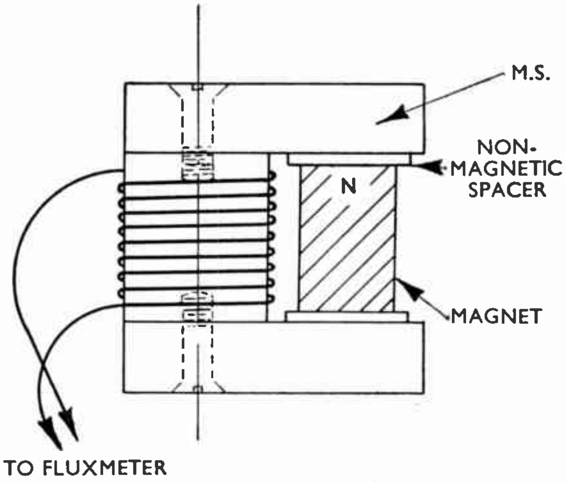

Fig. 11.—A jig for testing a magnet at a point on its BH curve. The reluctance of the magnetic circuit of the jig should be similar to that circuit in which the magnet is intended to work, and under these conditions test in this jig will indicate the final performance of the magnet.

In order to simulate the magnetic circuit for this purpose a jig may easily be constructed from mild steel or equivalent material and arranged so that the magnet under test is in a circuit whose reluctance is similar to the reluctance in which the magnet will be working when in its associated piece of apparatus. The flux in any part of the circuit may be measured and comparative figures obtained. Fig. 11 illustrates a simple test jig of this type.

Care should be exercised in designing these jigs as the reluctance into which the magnet works is by no means the reluctance of the gap where the useful flux passes. It is the reluctance of the gap in parallel with all the leakage paths and can conveniently be defined as the reluctance of the useful part of the circuit divided by the leakage factor of the circuit.

The method of using a test jig of this type is to insert the magnet, magnetise to saturation either in an electromagnet or by a winding on the jig itself, remove the jig complete with magnet from the electromagnet, connect the search coil to the fluxmeter and pluck out the magnet.

The fluxmeter will read the value of the flux maintained in the circuit by the magnet multiplied by the number of turns of the coil. Therefore, if the magnet is working into a reluctance in the test jig which is similar to that in which it will finally work, the reading of the fluxmeter will be proportional to the magnet's performance under working conditions.

Test jigs of this sort are easy to construct and are quite robust for factory use. They give reliable results quickly but should always be checked carefully before use as it is not easy to arrange that the magnet is working at the same point on its demagnetisation curve as it will work under operating conditions.

A convenient test apparatus, suitable for checking small magnets, is illustrated in Fig. 12. It consists of a moving coil meter with the magnet removed and replaced by carefully annealed soft iron pole pieces brought out to make contact with the magnet under test. On these pole pieces are wound magnetising coils which should be situated as close as possible to the magnet. The coils must be capable of saturating the magnet when the control switch is moved to the " magnetise " position and the control switch should be spring loaded to return to " off." When the control switch is moved to the test position, a value of current pre-set by an adjustable resistor is passed through the moving coil. As the current in the coil is a fixed value, the deflection of the pointer will be proportional to the residual flux in the iron circuit plus that given by the magnet.

Since the electromagnetic damping of the instrument under these conditions will be very low the pointer tends to have a considerable period of oscillation. If, however, a stop is fixed at the low pass limit, a reject magnet will not cause the pointer to move while a pass magnet will cause it to leave the stop and oscillate.

This apparatus may test a magnet at a point nearer B_r than is required owing to the leakage radiated from the pole pieces and the low reluctance of the moving coil meter. Adjustment may be made to the test point by using a brass or non-magnetic shim between the magnet under test and the pole pieces, but care must be exercised when doing this as the sensitivity of the apparatus will rapidly fall as the thickness of the non-magnetic shim increases. Another method of adjusting the test point is to use a separate winding carrying a pre-set current acting in opposition to the residual flux in the magnet.

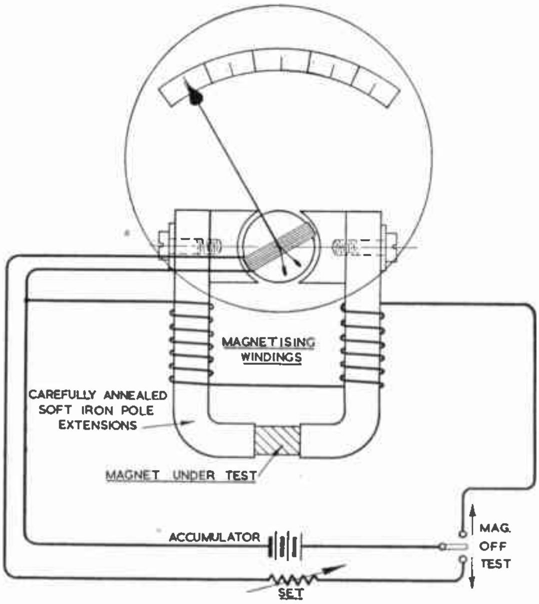

Fig. 12.—An apparatus for checking the performance of a small magnet at a point on its demagnetisation curve.

Section 3. UTILISATION OF MODERN PERMANENT MAGNETS

3.1. Self Demagnetising Effect and the Influence Different Shapes and Alloys have on this Characteristic

In the case of a magnet designed for use in an instrument where it normally works in an iron circuit, the magnet is of a length and cross section such that when it is in position in its circuit and fully magnetised, it should be working at or near its $(BH)_{max}$. If the magnet is magnetised before being put into its magnetic circuit, it will be in a condition of open circuit during the brief interval between removing it from the magnetising jig and assembling it into its associated circuit unless special precautions are taken to prevent this.

Under open circuit conditions, the magnet will be working into a higher reluctance than that for which it was designed and therefore its flux density will fall from the value corresponding to $(BH)_{max}$ to a value where a balance is obtained between its magnetomotive force and flux. Consequently, when it is finally in position in its circuit, the magnet will be working with a reduced

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M.M.F. on its pole faces, i.e. on a recoil loop, one end of which will be on the demagnetisation curve at the lowest point at which the magnet stabilised itself during its brief open circuit condition. Under these circumstances, the performance of the magnet will be lower than is expected. (See Section 2.3.)

The difference between magnetising separately and magnetising *in situ* will depend upon the type of alloy and the physical dimensions of the magnet ; the performance after separate magnetising may easily be only 20 per cent. of that which would be obtained by magnetising *in situ.*

If special arrangements are made to prevent open circuiting the magnet by carefully sliding it from the magnetising jig into an iron short circuiting yoke, and from this yoke into the instrument, the loss of performance may be considerably reduced and perhaps eliminated, but this procedure is seldom necessary as it is usually quite convenient to magnetise the magnet in its working position.

This self demagnetising effect when the magnet is open-circuited is most marked on modern high performance permanent magnet alloys, and as the efficiency of a magnet increases, and its size and area of leakage surface correspondingly reduced for a given purpose, the effect becomes more serious.

Conversely, older types of magnets with their lower efficiency necessitating greater size and leakage surfaces do not exhibit this tendency to self demagnetisation to such a marked degree ; in the case of " U " shaped magnets where the leakage surfaces of opposite polarity are brought close together, the self demagnetisation effect may, in some instances, be negligible.

3.2. Demagnetising Effect of Contact by Permeable Objects and Methods of Protecting against this Effect

A modern magnet correctly designed for a given purpose and properly handled should prove as stable as can be measured providing its field is undisturbed.

It is not generally known that if a magnetic or permeable object, such as a screwdriver or spanner, is allowed to make contact with the magnet other than at its pole faces, such a disturbance of the magnetic field results that the magnet's performance is permanently impaired and re-magnetising becomes necessary.

The reason for this is that when a permeable object is allowed to contact the sides of the magnet considerable flux is diverted from its normal path to the pole faces to the point of contact. This results in the flux direction in the area adjacent the point of contact becoming out of alignment with the remaining flux of the magnet.

When the object is removed from the magnet, the point where it made contact and the surrounding area will remain with its direction of magnetisation out of alignment forming a magnetically weak spot in the magnet which can only be removed by complete saturation or remagnetisation of the whole magnet.

In the case of powerful magnets used for magnetrons, a fall of 100 lines per sq. cm. in the flux density of its gap is not unusual if a screwdriver is allowed accidentally to touch the magnet. This effect is most pronounced in magnets where the magnetic potential is high or when working with little reduction of performance for purposes of stabilisation or adjustment. It is correspondingly less on magnets working with low field intensities and with a considerable degree of stabilisation.

The only methods of guarding against this effect are by the use of non-magnetic tools and parts near the magnet or by surrounding the magnet with a non-magnetic material which physically prevents contact or even close proximity of permeable objects. The protecting material may be moulded around or cast on the magnet, or it may take the form of a shield or cover. The thickness of the protection should bear a close relation to the magnetic potential and the alloy of which the magnet is manufactured, and the degree of reduction or stabilisation of its field. Greater spacing is required in the vicinity of the poles and the spacing may be graded down to practically zero at the centre or neutral point of a magnet. This system of graded protection is seldom used except in the case of large magnetron magnets where a considerable thickness of material is required near the poles which, if applied to the whole magnet, would make it unnecessarily bulky and heavy.

3.3. Manufacturing Problems

It is sometimes suggested that permanent magnet manufacturers place unreasonable obstacles in the way of designers, but it should be realised that magnet manufacture is a highly skilled and specialised industry and there are very real difficulties in the manufacture of certain shapes and designs of magnets. The method of manufacturing anisotropic magnets is by casting or sintering ; they cannot be rolled or forged.

Cast Magnets

Cast magnets are manufactured by melting the correct quantities of the various metals together in a high frequency induction furnace. Raw materials of the highest quality are invariably employed and the use of a high frequency furnace is essential to maintain this high degree of purity and attain the precise degree of control necessary for successful manufacture. The magnets are cast by specialised modern foundry methods, and the castings are afterwards roughly ground, examined and prepared for heat-treatment.

The exact heat treatment will depend on the composition of the alloy, the shape and size of the casting, and the purpose for which it is to be used.

The heat treatment consists generally in raising the temperature to approximately 1,300 deg. C., soaking at this temperature for a time and then cooling the magnet at a controlled rate in a magnetic field of the required intensity and direction, with a final soaking at 600 deg. C.-650 deg. C. for a considerable period.

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After heat treatment, the magnets are ground, inspected, tested, demagnetised, and finally despatched.

This may seem quite a straightforward manufacturing process, but the following are some of the manufacturers' difficulties. The composition of the alloy must be held within very precise limits ; for instance, a tolerance of ± 0·2 per cent. is the maximum that can be allowed on the aluminium content if the high performance of the alloy is to be maintained. The aluminium, however, volatilises at the temperature at which the alloy melts and is continuously being lost, therefore the closest control of melting temperature and time is essential as any deviation results in considerable variation of the aluminium content. Re-melting the alloy to correct a deviation in chemical analysis usually results in solid or gaseous contamination and consequently an unusable material.

The inclusion of minute traces of many substances normally existing as impurities in the required elements seriously reduces the final performance of the alloy, and may involve scrapping the entire melt.

The next problem is the production of a magnetic field of the required intensity and direction for the magnetic heat treatment. The intensity of the field required is in the region of H = 3,000 oersteds, which means that unless the field is relatively short and straight difficulty arises in producing it. Consequently, "U" shaped magnets almost invariably show relatively low performance because the field used during their magnetic treatment is not of the correct direction or intensity.

The generation of correct magnetic fields for the production of small circular magnets where the magnetic flux is normally following an approximately circular path is only possible by means of a conductor carrying an electric current. The current required to produce a field of the necessary intensity is more than sufficient to melt, if not volatilise, the conductor carrying it unless such a conductor is specially designed.

In the case of large magnetron magnets for aircraft use, where the highest performance for the lowest weight is essential, ring type magnets which are treated in a circular magnetic field are unchallenged and the production of the enormous magnetic fields required for the manufacture of these magnets raises many interesting problems in electrical engineering.

Sintered magnets

Sintered magnets are manufactured by highly compressing into dies the correctly proportioned and mixed finely divided individual metallic powders. The resultant pellet is subsequently raised to and held at a high temperature to allow the metals to diffuse into one another.

The specific gravity of sintered magnets depends to some extent on the pressure used in the dies, and is normally a few per cent. less than that of a cast magnet.

The magnetic properties of correctly processed sintered magnets should be approximately the same as those of cast magnets. Sintered magnets can be made in smaller sizes than can be economically obtained by casting, and can also be held to closer tolerances. Magnets produced by the sintering process are uniform in magnetic properties and in mechanical dimensions. The sintering process becomes economical where long runs of magnets under 1 oz. in weight or where complicated shapes or greater toughness than can be obtained from cast magnets is essential.

Where space is limited designers will find that sintered anisotrophic magnets open up a new field for efficient miniature apparatus which previously could not be explored due to limitations of earlier magnet alloys.

3.4. Method of Finding the Magnetic Axis of Anisotropic Magnets

In the case of circular magnets with a diametric magnetic axis the direction of the axis may become lost, and under the these circumstances physical or microscopic examination or even chemical etching gives no useful information.

The direction of the magnetic axis may be found if the magnet is placed in a powerful magnetic field where the value of H is preferably not less than 2,000 oersteds. The magnet will then rotate with considerable force until its magnetic axis is in the same direction as the applied magnetic field.

Searching for poles with a compass or magnetometer will prove misleading as the magnets are roughly demagnetised in an A.C. field before leaving the factory so that the small residual flux bears no relation to the magnetic axis.

In the case of square or rectangular blocks, a magnetic test is the best method of finding the magnetic axis since the performance of a magnet in any direction other than along its magnetic axis is only some 10 per cent. of normal and consequently confusion is unlikely to arise. (Refer Fig. 5, page 185.)

3.5. Magnetic Stability under Conditions of Heat, Vibration, External Fields and Time

Early types of quench hardened permanent magnet steel show appreciable change of characteristics during the period immediately following hardening. This is due to a slow metallurgical change in the steel which normally takes place over a period of several years, and can show itself as a change in field strength of a magnetised magnet.

It is possible to accelerate this effect by heating the steel, and it is found that the artificial aging effect of one hour at 100 deg. C. is approximately equal to one year at normal room temperature.

In the case of modern anisotropic magnets ("Ticonal G") the most careful tests have failed to detect any metallurgical instability. This is to be expected, since the last process in the heat treatment of magnets (holding at approximately 600 deg. C, for a period of

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several hours) results in structural and metallurgical stability of a very high order.

Such magnets are unaffected by normal instrument temperatures and will, if necessary, operate satisfactorily up to a temperature of 500 deg. C. With their high coercive force they are particularly resistant to the effects of stray demagnetising fields, and will remain unaffected under severe conditions of vibration, when correctly stabilised.

The stability of modern magnet materials with time is such that although it is known that immediately after magnetisation there is a small drop in performance, exponential in form, the change is so small that the drift on freshly magnetised but undisturbed magnets is hardly measurable.

Careful tests on "Ticonal G" magnets, begun less than two seconds after magnetising, showed a drop in performance of 0·3 per cent. in the first 2½ minutes increasing to nearly 0·5 per cent. by the next day; during the following year no further change could be detected.

Under all conditions where a magnet is required to give constant performance it should be correctly stabilised.

3.6. Stabilisation

Under the special conditions obtaining, for example, in sub-standard instruments, a magnet is required to have a very high stability of performance. It has just been stated that immediately following magnetisation the performance of a magnet drops quickly during the first few moments, following an exponential curve. The drop in performance over a long period appears to depend on the material used for the manufacture of the magnet. For most magnet alloys of high coercive force the total drop is believed to be in the region of 2 per cent., most of which takes place in the first few minutes.

The drop in performance of "Ticonal G" is considerably less than this, and many instruments using "Ticonal G" magnets and calibrated a short time after magnetisation remain well within their rated accuracy, provided they are not subjected to unusually high external stray fields.

In the case of intruments where the highest degree of stability is required, the magnetic circuit must be finally assembled before being magnetised, and after saturation the magnet should be working in its associated circuit at, or slightly above, the $(BH)_{max}$ point on the demagnetisation curve. A suitable demagnetising influence should then be superimposed in the magnetic circuit, forcing the operating point of the magnet down lower than it would normally come to rest, so that when the demagnetising field is removed, the operating point of the magnet takes up its position on a minor hysteresis loop.

The intensity of the demagnetising or stabilising field should be such that the operating point of the magnet is forced to a lower value than it would ever reach during the most severe operating conditions, after which the magnet and its associated circuit must not be disturbed either mechanically or magnetically.

In practice, when modern anisotropic magnet alloys are used, instruments expected to withstand conditions of vibration, temperature and stray fields are stabilised by a reduction of approximately 3 per cent. of the field strength measured immediately after magnetisation.

Stabilisation may be effected with either A.C. or D.C. provided it is done correctly. The demagnetisation influence for stabilisation should be applied evenly to the whole magnet by raising the effective reluctance of the magnetic circuit either by restricting the external leakage field, or by a reverse M.M.F. generated in its circuit.

Usually the most convenient method of stabilising a magnet is to use a large open coil carrying A.C. and to pass the freshly magnetised instrument through the coil. The coil should be constructed to possess as uniform a field as possible with the value of A.C. set so that a reduction of flux of approximately 3 per cent. is obtained in the magnet.

Further, demagnetisation may be employed as a means of adjustment to the instrument, in place of the more usual method of adjusting magnetic or electrical shunts. For workshop and test room use, a method of demagnetisation which is under precise control is required and this is conveniently arranged by using A.C. in series with a choke having a movable core to give continuously variable control.

A reduction of magnetic performance which may incorrectly be regarded as stabilisation may be caused by partial demagnetisation of part of the magnet. This is generally found to be unsatisfactory and the magnet is liable to partial recovery after this treatment. This effect may be accidentally produced by allowing a magnetic object such as a steel screwdriver or screw to make contact with the magnet. If it is subjected to this sort of treatment some 50 per cent. of the performance may be lost and the importance of protecting a magnet against such treatment cannot be over-emphasised.

Many magnet alloys tend to recover a small proportion of their last change particularly when there is more than 10 per cent. reduction of flux. Careful measurements have detected this effect in some permanent magnet alloys, but so far this effect has not been detected in "Ticonal G" magnets even when demagnetised down to 40 per cent. of their initial flux density.

It is important to note that stabilisation dates from the last disturbance or re-distribution of the magnetic field, and that the practice of storing magnets for long periods before use may be advantageous in the case of quench hardened types but serves no useful purpose in the case of modern anisotropic magnets.

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3.7. Limitations Imposed on Design by Present Available Materials

In spite of the outstanding advances made during recent years in most branches of science, the characteristics of materials available for use in magnetic circuits are very limited. The flux carrying capacity of the better materials has not been greatly improved during recent years and is only approximately twice that of ordinary commercial grades of mild steel.

When it is considered that the available materials will at best only attain a flux density in the region of 25,000 lines per sq. cm. and that no known substance has any appreciable magnetic insulating properties, the difficulties of producing a very high flux in a given space or piece of apparatus become apparent.

In apparatus such as meters, microphones, loudspeakers, etc., this figure of 25,000 lines per sq. cm. is seldom approached owing to unavoidable leakage in magnetic circuits ; in any design, the material carrying the flux to the working gap can only carry approximately 25,000 lines per sq. cm., but this material must not only carry the useful and fringing flux but also the leakage flux which is radiated profusely from the sides of the poles. This leakage field may be greater than the useful field, so while ingenious shaping of the pole pieces has a great influence on the final value of flux density in the working gap, a figure of 20,000 lines per sq. cm. is seldom exceeded in commercial apparatus. Fields of intensity considerably higher than 25,000 lines per sq. cm. are in the nature of laboratory experiments and can only be produced by the use of heavy currents.

Regarding the limitations of permanent magnet alloys themselves, the modern anisotropic alloys with their $(BH)_{max}$ in the region of $6{\cdot}0 \times 10^6$ are considered by many people to represent the practical limit in performance of permanent magnets, but the author knows of no reason why alloys giving a considerably superior performance should not be developed. There are indications that the values of B may not greatly be increased, and it would appear, therefore, that if new alloys are developed with much greater values of $(BH)_{max}$, the increase will be obtained by the use of higher working values of H.

3.8. Necessity for Magnetisation as a Final Operation in Manufacture in order to obtain Maximum Efficiency

It has been shown in paragraph 3.1 on self demagnetisation effects that a magnet designed for use in an associated iron circuit cannot be magnetised, removed from the magnetising jig and placed in its magnetic circuit without a drop in performance, and that the type of magnet and its physical dimensions control the drop in performance under these conditions. Also, the loss of performance due to this cause is greater with modern, highly efficient, magnet alloys, due to their smaller dimensions. Accordingly the necessity for magnetisation as a final operation becomes more than a theoretical method of obtaining slightly increased efficiency ; it becomes, in most cases, a necessity.

This final magnetisation is advantageous in other respects. It permits the magnets to be used in a thoroughly demagnetised condition, rendering their assembly and checking ordinary mechanical operations not requiring the use of special non-magnetic tools or measuring instruments. It also prevents the magnet and its associated circuit collecting magnetic dust and it allows any dust or filings which may have accidentally been collected to be easily dislodged by a light air blast or other suitable means. The finally assembled instrument, after thorough cleaning and inspection, and a check on freely moving parts, which may otherwise be masked by eddy current damping, may then be magnetised and, if necessary, stabilised.

3.9. Magnetic Efficiency

Magnetic efficiency is a term which should be carefully specified before it is used. It may conveniently be regarded as the magnetic energy in the space where it is required compared with the weight of alloy producing this energy. This method of assessing efficiency takes into consideration both the magnetic alloy used and the design, but should only be used for comparison purposes where identical gaps are concerned.

An alternative method is to compare the flux in the space where it is required with the total flux generated by the magnet. This method of assessing magnetic efficiency takes into consideration primarily the design, but the properties of the magnetic alloy used may influence the leakage factor of the magnetic circuit to a considerable extent.

In the case of loudspeaker magnets, the dimensions of the working air gap influence the apparent efficiency of the magnetic circuit to such an extent as frequently to confuse engineers. Consider, for instance, an assembly where all the dimensions remain constant except the depth of the gap (the thickness of top or front plate). For a given flux density in the gap the magnetic potential across the gap and the external leakage fields will remain practically constant, so in the event of the depth of the gap being doubled the flux in the gap will also become doubled while the losses remain practically constant ; thus the apparent efficiency increases with increase of top plate thickness.

In the case of moving coil indicating instruments, the magnetic efficiency may conveniently be expressed as the relation between the total flux passing through the space swept by the moving coil and that generated by the magnet.

In order to promote magnetic efficiency, it is essential that the permanent magnet, which is the source of magnetic flux, be placed as near as possible to the place where the flux is used. The employment of long conducting bars or rods results in very high leakage.

The magnetic efficiency of magnetron magnets is not easy to define since the operative volume of the

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magnetron is usually small compared with the gap of the magnet. The author's method is to measure the mean flux in the gap over a volume of the magnetron, and compare it with the weight of the magnet producing the flux.

This method is not quite as straightforward as it would appear, since the field required for the magnetron should be uniform and parallel, but as the magnet producing the field becomes smaller and more efficient, the field it produces may become more distorted. Therefore, while the field may be measured by a search coil and a fluxmeter and show the value required, its usefulness may be impaired by non-uniformity.

It should be noted that the magnetic energy in a gap is proportional to the square of the flux density, and this must be taken into account when comparing the relative efficiencies of magnets giving dissimilar performances.

3.10. Methods of Magnetisation

The correct magnetising of a modern magnet is, on account of its high coercive force, by no means as simple as magnetising earlier types of magnets, and the use of a powerful electromagnet is usually found to be the most convenient method.

The M.M.F. necessary to magnetise a modern magnet is so great that a large proportion of the flux produced by the electromagnet is lost. This may lead to saturation of the electromagnet before the magnet itself becomes saturated.

Magnetisation is quite straightforward in the case of instruments where a short block type magnet is used and where the magnetic direction is between opposite sides of the block.

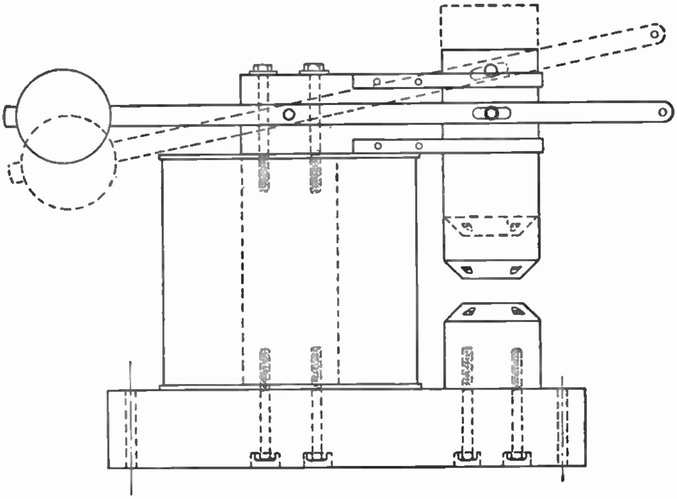

Fig. 13.—*A typical adjustable electro-magnet for magnetising permanent magnets.*

The completed instrument, after inspection, should be placed between the poles of an electromagnet which may conveniently be adjustable to fit various instruments, and the power switched on for sufficient time to allow the magnetising current to reach a maximum. Fig. 13 shows a typical electromagnet for this purpose.

The M.M.F. of the electromagnet must be sufficient to reach the value of H_{sat} of the magnet. In practice, the production of this value of H may incur considerable losses due to reluctance of air spaces and joints and due, to a small extent, to the reluctance of the magnetising electromagnet itself. For practical purposes, it is usual to apply a value of H considerably in excess of that required in order to provide a safety factor to cover carelessness on the part of the operator, variations in supply current and various other factors which are are difficult to measure or calculate.

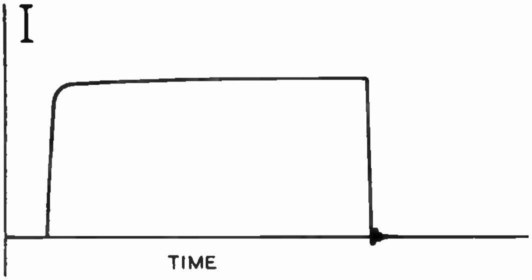

Fig. 14.—*Typical magnetising impulse where the D.C. or magnetising circuit is switched.*

The flux produced by the electromagnet must be sufficient to saturate the magnet with its associated iron circuit which will be in parallel with the magnet, and to supply the external leakage flux inherent in the magnet assembly and electromagnet during the magnetising operation. In practice it is safe to assume that only 10 per cent. of the flux produced by an electromagnet is usefully employed.

Theoretically the time taken to magnetise a magnet is negligible, but in practice a short period of time is necessary for two reasons; one is, that the inductance of the magnetising circuit causes the current to take a certain time to build up to the required value, and the other reason is that, as the magnetising field builds up, eddy currents are generated in the outer layers of a large magnet, delaying slightly the building up of the magnetising field in the magnet itself.

The delay due to the first cause may be several seconds if a very large electromagnet is used, while the delay due to the second cause is known to be less than 1/25th of a second in magnet sections of Ticonal up to 3 in. diameter.

Care should be taken that the magnetising current is not allowed to become oscillatory on switching off, since a reverse current will tend to demagnetise the magnet.

There are several methods of reducing this reverse surge, which invariably tends to take place when an inductive circuit is broken. One method is to use only sufficient current to magnetise thoroughly the magnet under consideration so that any back surge will be small compared with the main magnetising impulse, but this method involves considerable risk of not fully magnetising the magnet. Another method is to use rectified A.C. where the switches are in the A.C. circuit. Fig. 14 shows a magnetising impulse on an electromagnet using switches in the D.C. or magnetising circuit, and Fig. 15 shows an equal magnetising impulse generated by rectified A.C. and switched in the A.C. circuit.

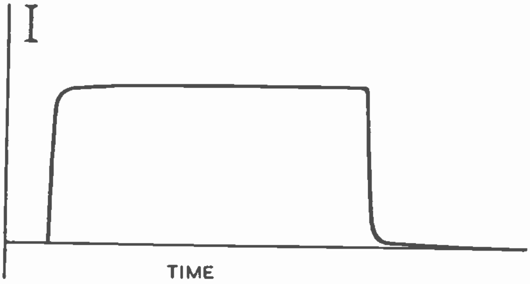

Fig. 15.—Typical magnetising impulse of rectified AC switched in the AC circuit.

The latter method is much to be preferred as there is no tendency to produce back surges and no high voltages are generated across the magnetising windings ; thus the need for heavy insulation to avoid the risk of breakdown is eliminated.

If it is necessary to use switches in the D.C. or magnetising circuit a useful method of reducing inductive surges is to shunt a non-inductive load directly across the magnetising coil. Carbon filament electric lamps are particularly useful for this purpose as their resistance decreases when the voltage across them rises and they also serve to indicate that the apparatus is functioning correctly.

As practical examples of magnetising with an electromagnet consider the loudspeaker magnet assembly shown in Fig. 23, where a "Ticonal G" magnet is used of length 2·31 cms. and cross sectional area 8·55 sq. cms., and the moving coil meter magnet shown in Fig. 24 (C) or any similar piece of apparatus provided it is using a magnet of the same dimensions.

Table 1, shows the manufacturers' recommended value of $H_{sat} = 3{,}000$ and $B_{sat} = 17{,}000$ for "Ticonal G." Therefore this particular magnet will require for saturation a minimum magnetising M.M.F. of

$$\text{Length in cms.} \times H_{sat} = 2{\cdot}31 \times 3{,}000 = 6{,}930 \text{ gilberts}$$

As the losses in the magnetising circuit will be high and difficult to calculate, a safety factor of 3 is not over generous ; therefore an electromagnet will be specified capable of giving an M.M.F. of 6,930 × 3 = 20,790 gilberts.

Since M.M.F. in gilberts $\times \frac{10}{4\pi}$ = ampere-turns, the requirement will be

$$\frac{20{,}790 \times 10}{4\pi} = 16{,}500 \text{ ampere-turns.}$$

The minimum flux required for magnetising the magnet itself will be

Cross sectional area of magnet in sq. cms. × B_{sat} = 8·55 × 17,000 = 145,300 lines.

The magnet is, however, shunted by its own iron circuit which must, of necessity, be saturated while saturating the magnet ; this means that the complete magnet assembly will require approximately twice the flux for the magnet itself, i.e. 290,600 lines.

As during magnetisation a relatively high value of M.M.F. is used, the leakage flux radiated from both the magnet assembly and the electromagnet will be so high that it is unwise to expect more than about one fifth of the total flux to pass through the magnet assembly unless the electromagnet is carefully designed or its leakage is actually checked.

Therefore, the electromagnet will be specified to have an iron circuit equal to

$$\frac{\text{Flux required in magnet assembly} \times 5}{\text{Maximum B of its iron}}$$

$$= \frac{290{,}600 \times 5}{15{,}000} = 97 \text{ sq. cms. or approximately 4 in.}$$

square section.

In the magnet assembly chosen for this example the saturation flux of the magnet will be approximately the same as that required for its associated iron circuit, and while this ratio generally holds for apparatus where the iron circuit is designed only to carry the working flux of the magnet, occasionally the iron circuit has other functions necessitating a larger section which must be taken into account when assessing the flux required from the electromagnet.

Very much higher magnetising efficiency may be obtained when the magnetising coil surrounds the magnet itself, but this is not always convenient and usually complicates the magnetising operation. Under these conditions the flux in the magnetising iron circuit will be only that generated in the magnet assembly during saturation and the total M.M.F. required can easily be calculated.

If sufficient power is available the external iron circuit may be entirely omitted and the magnet magnetised by the intensity of field induced in it by the coil.

Impulse Transformer

A convenient method of magnetising is by using the field produced by a very heavy surge of current in the form of a pulse. The apparatus required comprises a source of D.C., usually a motor-generator set supplying about 30 amps. at 250 v., and an impulse transformer. The D.C. source is connected to the primary, the inductance of which is so high that the primary current reaches a maximum of approximately 25 amps. about three or four seconds after being switched on ; during this period magnetic energy is being built up in the iron circuit of the transformer.

The secondary is a single turn, usually of composite construction, brought out to a heavy copper short circuiting bar. The current in the secondary is a long low intensity half-cycle while primary current is rising, but when the primary current is switched off an enormous surge of current (peak of approximately 75,000 amperes) is generated in the secondary as shown in Fig. 16. This current, passing through the short circuiting bar, generates a very powerful circular field which is suitable for magnetising "U" shaped, curved, or circular magnets.

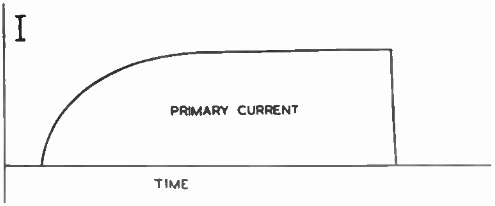

Fig. 16a.—Diagram illustrating the primary current in an impulse transformer.

The duration of the magnetising impulse with this apparatus is quite short, being in the region of 1/100th to 1/500th of a second. Consequently very heavy sections of magnet material may not be fully saturated because of the shielding effects of eddy currents generated by the rapid building up of the field in the outer layers of the section ; this prevents the full intensity of the magnetising field penetrating to the inner parts of the magnet before the magnetising impulse ceases.

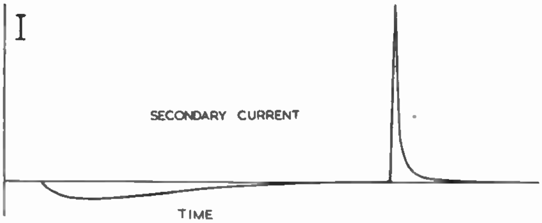

Fig. 16b.—Diagram illustrating the secondary current in an impulse transformer.

Oscillographic examination of magnetising impulses obtained from this apparatus shows an extremely peaky wave form believed to be the result of unavoidable arcing at the primary circuit breaker.

Heavy D.C. Magnetising

Probably the neatest method of magnetisation consists in using a heavy direct current obtained from a transformer rectifier unit. The apparatus required for this method is one where the 3-phase supply voltage may be continuously varied from zero to maximum by means of a regulator-transformer and the magnetising current is obtained from a transformer and rectifier unit capable of giving up to 10,000 amperes at 10 volts.

This apparatus, illustrated diagrammatically in Fig. 17, can be used to generate magnetising fields of almost any shape or intensity by the use of a single conductor or a simple helix of heavy cable. It is extremely versatile, does not create surges or induce high voltages and is not dangerous to operators.

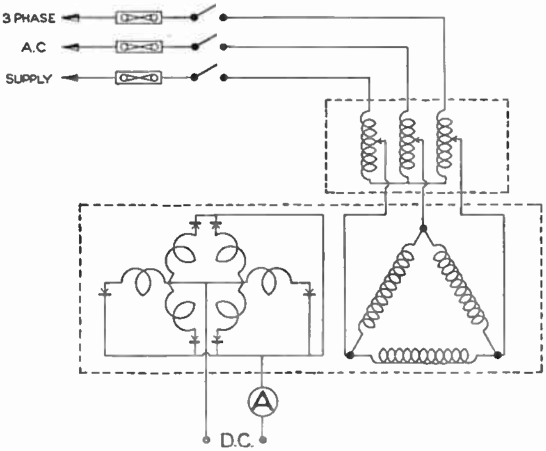

Fig. 17.—Diagram of direct current apparatus operating from 3-phase AC supply and capable of giving up to 10,000 amperes DC for magnetising large magnets.

Thyratron-controlled Half-cycle Magnetiser[7]

A type of magnetiser used in the U.S.A. consists essentially of a thyratron-controlled ignitron, giving in existing equipments a controlled half-wave pulse of current of 40,000 amperes maximum.

The apparatus has the advantage of being compact, inexpensive, rapid in operation and of low power consumption, operating directly from A.C. mains.

3.11. The Difficulty of Magnetising a Small Modern Magnet by a Larger One.

In order that a modern anisotropic permanent magnet alloy shall be magnetised correctly, it is essential that it is taken to the extremity of its major hysteresis loop. This means that it requires approximately a flux

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density of 17,000 lines per sq. cm. and an M.M.F. of 3,000 gilberts per linear cm.

When an endeavour is made to magnetise small magnets on the pole faces of a larger magnet without permeable pole pieces, the flux density produced in the small magnet will not reach saturation because the area of pole adjacent to the point of contact on the large magnet approaches saturation.

If a small magnet is placed between the poles of a larger magnet a flux density in the region of 10,000 lines per sq. cm. may be produced in it under favourable conditions. A higher value than this is unlikely with a working value of flux of the magnet in the region of 10,000 lines per sq. cm., unless the poles are faced with a soft magnetic material capable of collecting the flux from a large area of the pole and conducting it to the small magnet which requires to be magnetised. Also if the required density of flux is obtained and conducted to the small magnet it must have a magnetic potential sufficient to equal H_{sat} of the magnet.

In order to magnetise thoroughly a small magnet by a larger one the larger magnet must be capable of giving the saturation density required by the small magnet, at the magnetic potential required, while still maintaining its usual external leakage field. This means that under practical conditions the large magnet must at least have some twenty times the cross section of the small one and five or ten times its length ; it must also be carefully arranged with soft magnetic pole tips.

3.12. Demagnetisation

Owing to the difficulty of using or assembling fully or partially magnetised magnets, it is frequently necessary to demagnetise permanent magnets completely and manufacturers require a quick and efficient method of doing this.

The demagnetisation of modern magnets with their high coercive force requires considerable power and the only practical method is to use a powerful alternating field of approximately H= 1,000. Lower values of H tend to leave a small amount of residual flux in the magnets and this effect is more apparent in larger magnets where the inner sections are screened to a certain extent. The generation of this strong field necessitates the use of a high value of ampere-turns, but as the demagnetising coil is only likely to be used intermittently the conductors may be loaded considerably above their normal continuous rating.

Fig. 18 is a scale drawing of a demagnetising coil consisting of approximately 260 turns of 12 s.w.g. D.C.C. wire arranged in four separate series coils. When connected to 400 volts 50 cycles/sec. A.C. mains the current is approximately 25 amperes.

The method of using such a coil is to switch on, preferably by a foot-operated switch which cannot be left on, and to pass the magnets to be demagnetised through the coil. The magnets will be subjected to the maximum A.C. field in the centre of the coil, but as they are moved past the centre the field diminishes in intensity until at a point only a short distance from the coil the field is too weak to disturb the magnets.

While theoretically the magnet should take a negligible time to demagnetise, it is found in practice that large magnets need to remain a few seconds in the centre of the coil to become fully demagnetised. This effect is believed to be caused by the eddy current shielding effect of the outer layers of the magnet.

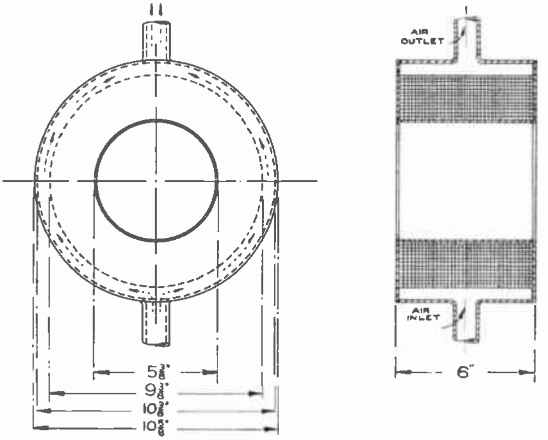

Fig. 18.—A practical demagnetising solenoid for operation on 50 ~ AC mains.

During demagnetisation a slight rise in temperature of the magnets may be noted, but this does not impair the magnets in any way.

Attempts at demagnetising by using D.C. are seldom successful, usually resulting in failure to reduce the flux to zero, or overshooting and magnetising in the reverse direction ; as can be seen from the hysteresis loop, the slope of the BH curve is a maximum at zero B.

Section 4. MAGNET DESIGN

4.1. General Principles

For most purposes it is convenient from a design point of view to consider that the flux density is uniform in a magnet of uniform cross section. The leakage flux from the surface of the magnet may be included in the overall leakage factor of the entire assembly. This assumption does not generally introduce appreciable errors unless the magnet has a length-to-section ratio exceeding approximately 2.

The method of designing a permanent magnet for a given application is in many cases quite straightforward and applications can be divided generally into two classes, namely operation under static conditions, and operation under conditions of recoil.

Magnets Working under Static Conditions

Magnets used for loudspeakers, meters, eddy current

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brakes, and for apparatus where a constant field is required, fall into the first class mentioned and should be relatively simple to design. The problem may be looked upon as a question of matching the magnet to its load, the load being considered as the reluctance of the working air gap, or the air gap in which useful flux is required, in parallel with the leakage reluctance.

As the dimensions of the gap are usually definitely settled by other considerations a certain M.M.F. is needed to maintain a given flux density in the specified gap and the value of this M.M.F. equals the product of flux density in lines per sq. cm. and the linear distance in cms. across the gap. In practice there will be losses in the iron circuit and joints which must be taken into account and these will result in an increased value of M.M.F. being required from the magnet.

The M.M.F. produced by the magnet is proportional to its length in cms. multiplied by its working H.

Hence the length of the magnet is :—

$$\frac{\text{Total M.M.F. required in the magnetic circuit}}{\text{working H of the magnet alloy}}\ \text{cms.}$$

This quickly determines one main dimension of the permanent magnet.

The other dimension required is the cross-sectional area of the magnet ; this should be such that the magnet will supply at its working flux density the flux required in the working gap, plus the leakage flux. It is the estimation of the leakage flux which causes difficulty, and some guidance in estimating the leakage flux in various types of apparatus is given in the appropriate later sections of the paper.

If the magnet is to be stabilised, increased dimensions will be required to compensate for the reduction in performance resulting from stabilisation.

Magnets Working Under Conditions of Recoil

In the second class of applications, the design of the magnet has been the subject of mathematical work usually resulting in formulæ requiring precise data which are only available from measurements on an actual working model. The following method may therefore be of considerable practical use to designers.

The performance of a magnet alloy under various percentages of recoil on minor hysteresis loops originating at different points on the demagnetisation curve may be plotted in various ways. Fig. 19 shows the performance of "Ticonal G" in terms of BH product for various percentages of recoil plotted against the values of — H corresponding to the origin of the minor loops.

It will be clear from an examination of Fig. 19 that for any given percentage of recoil the maximum energy is always obtained when the maximum value of $-H$ corresponds to the value of $-H$ at $(BH)_{max}$. That is, when the magnet is working on a minor loop originating at the $(BH)_{max}$ point on the demagnetising curve. For this reason it is convenient for reference purposes to plot the performance of the magnet and its operating flux against the percentage recoil on this loop. Fig. 20 shows the energy obtainable in terms of BH product and the corresponding values of B, against various percentages of recoil obtained in this way for "Ticonal G."

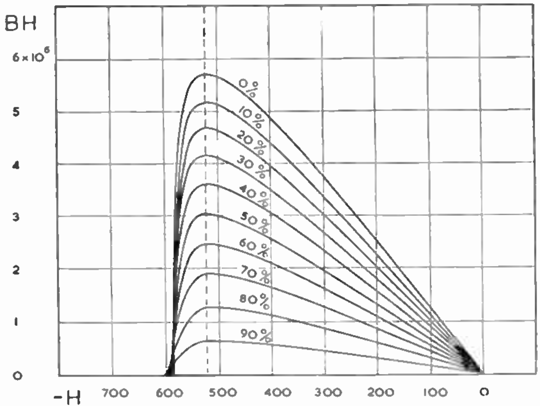

Fig. 19.—The performance of "Ticonal G" under various percentages of recoil plotted against the value of — H corresponding to the origin of the minor loop.

Take first the case of a permanent magnet D.C. motor ; when running at full load the motor will require a definite flux in the armature tunnel and a definite M.M.F. will be required to maintain this flux.

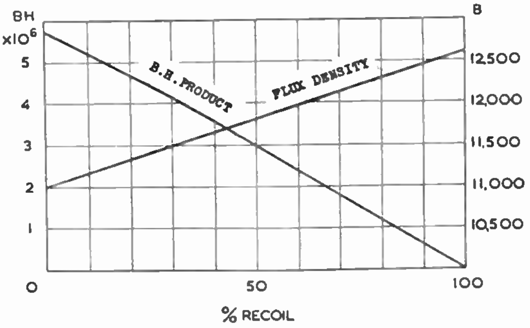

Fig. 20.—Showing the energy obtainable in terms of BH product and the value of H against percentage recoil on "Ticonal G" on a minor loop originating at $(BH)_{max}$.

The peak demagnetising influence which the permanent magnets will be called upon to withstand will be due either to the armature reaction when the motor is stationary and the current is switched on* or to the withdrawal of the armature from the stator for maintenance purposes with consequent considerable increase of magnetic circuit reluctance. The greater of these effects, usually the removal of the armature, should be taken into account for calculations.

**Under these conditions the current is limited only by D.C. resistance of the armature and brush gear and consequently armature reaction is at a maximum.*

The ratio between the full load and peak M.M.F. is therefore a constant, settled by the reluctance (as viewed by the magnets) of the machine running at full load compared with the reluctance of the machine with the armature removed. As this ratio is dependent on the geometry and leakage paths of the machine and is independent of the length of the magnets, the working M.M.F. may be expressed as a percentage of the maximum M.M.F.

The optimum length of the motor magnet may therefore be defined as :—

$$\frac{\text{peak M.M.F. on pole pieces} + \text{M.M.F. drop in iron circuit}}{\text{working H of the magnet alloy}}\ \text{cms.}$$

(Note working H is value of H corresponding to that of $(BH)_{max}$).

The cross-sectional area of the motor magnet will be that section which will supply the flux required by the armature plus leakage flux, and as the magnet will then be in a state of recoil on a minor hysteresis loop originating at $(BH)_{max}$ it will produce a value of flux higher than that at $(BH)_{max}$.

Therefore the cross-sectional area of magnet may be defined as :—

Cross-sectional area of magnet =

$$\frac{(\Phi\ \text{armature} + \Phi\ \text{leakage})}{\text{B of magnet at appropriate percentage recoil}\dagger}$$

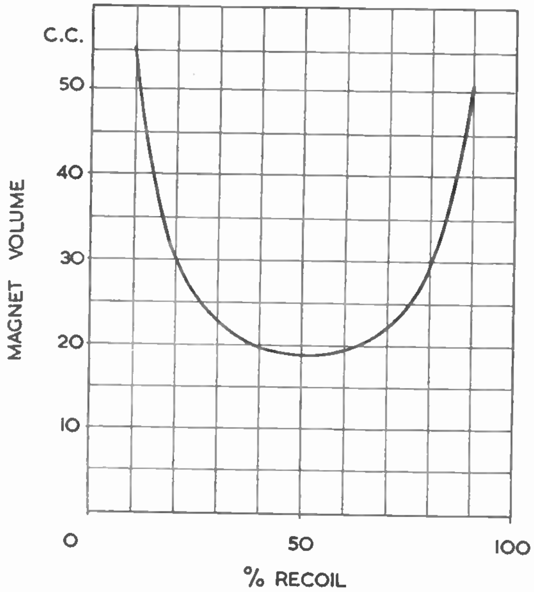

Fig. 21.—The volume of the field magnets of a motor plotted against percentage recoil where the value of recoil is controlled by shunting the field magnets.

The percentage recoil depends upon the ratio of the reluctance of the flux path when the armature is removed to the reluctance when the armature is in position and running at full load. The smaller the external or leakage flux, the greater will be the percentage of recoil with correspondingly lower performance of the magnet as shown in Fig. 20.

If, however, it is assumed that the various leakages are concentrated into one reluctance which may be varied at will, thus varying the percentage recoil under which the magnets operate, then the relation between the volume of the magnets and the percentage recoil is expressed by Fig. 21.

The graph is drawn for "Ticonal G" and shows that a minimum volume of magnet alloy is required when the percentage recoil is limited to approximately 51½ per cent.

When the graph is re-drawn with an assumed recoil permeability of zero, it will be found that the minimum quantity of magnet is required when the percentage recoil is limited to exactly 50 per cent.

It follows, therefore, that the volume of magnet material necessary for the motor will decrease as the leakage flux increases till a limiting value is reached where the leakage flux is approximately equal to the useful flux.

In a practical motor, an appreciable part of the leakage passes through the space normally occupied by the armature and hence the total flux is not quite twice the useful flux when the armature is in position.

The optimum leakage reluctance may more easily be specified for practical purposes as that value of reluctance which limits the rise in M.M.F. when the armature is removed from the stator to twice its value when the motor is at full load, and under these conditions a minimum volume of magnet is required.

The design of the magnets for a motor therefore becomes for practical purposes :—

Length of magnet in cms. =

$$\frac{\text{Twice full load M.M.F.} + \text{M.M.F. drop in iron circuit}}{\text{working H of magnet alloy}}$$

Cross sectional area of magnet in cms.^{2} =

$$\frac{\text{Flux required by armature at full load} \times 2}{\text{B of alloy when wrkg. at 50\% recoil from } (BH)_{max}}$$

If the reluctance of the leakage paths cannot be calculated with sufficient accuracy, the values of M.M.F. can easily be found by measuring the flux in any external leakage path, the value of flux being of course proportional to the M.M.F. producing it; if necessary, the reluctance of the leakage paths can be adjusted by machining operations.

The foregoing method is applicable to the calculation of dimensions of magnets required for any type of apparatus where they are working under conditions of recoil.

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†*See Fig.* 20.

General Notes on Design

When using anisotropic magnet alloys, care should be taken that the design does not require the flux to follow any path in the magnet other than that of the field used during manufacture.

Collecting the flux from the sides of a bar magnet treated in a straight field will result in increased losses in the magnetic circuit itself owing to the high reluctance of the magnet when the flux does not follow the magnetic axis, and increased leakage as the magnet tends to radiate flux from ends of the magnetic axis.

It should be remembered that published data referring to permanent magnet materials usually applies to test pieces where the size and shape is correct for optimum heat treatment and where the scale and outer layers of the magnet are removed. Magnets made of the same materials but left as cast, and not of a shape conducive to optimum heat treatment, will have a performance lower than may be expected from examination of published data.

The author recommends, for anisotropic magnets, not ground on all faces, that values of B and H slightly lower than those published should be used for design work. In the case of curved or " U " shaped magnets, which cannot work at $(BH)_{max}$ designers will be well advised to consult the magnet manufacturer regarding performance data.

4.2. Permanent Magnet Loudspeakers

In the design and manufacture of commercial loudspeakers where the cost of the magnet is of major importance, the magnetic energy requires to be used in the most efficient and economical manner.

For any given flux density the M.M.F. required, and consequently the length of the magnet, may be considered for practical purposes as proportional to the radial width of air gap. The leakage field, known usually to consist of the larger part of the total flux given by the magnet, is maintained by the M.M.F. across the gap and so the cross-sectional area of the magnet is influenced considerably by the radial width of the air gap. Therefore it is most desirable to restrict the radial width of the air gap to the lowest practical value.

The limits of the gap are set by the physical dimensions of the moving coil and the amount of clearance necessary for the coil during its maximum excursion, the distortion of the moving coil due to the heat generated by the power dissipated in it, humidity, age or general conditions of service, and the known manufacturing tolerances. In general, the optimum radial width of air gap will be found to follow closely the empirical relation that the radial width of the air gap should be 2 per cent. of the diameter of the coil plus 0·020 in.

The thickness of the top plate at its pole face (or depth of air gap) is also found to bear a close relation to the radial width of the gap and the optimum value from a manufacturing standpoint appears to be about five times the radial width of the air gap. A gap depth less than this is uneconomical as it results in a low proportion of the flux being usefully employed while a deeper gap, with a correspondingly longer moving coil, requires more careful manufacture.

The mechanical dimensions and the flux in the gap of a permanent magnet loudspeaker are usually fixed by acoustic requirements and manufacturing considerations, leaving the magnet designer considerable choice between different types of construction and magnetic available materials.

The design is seldom based entirely on technical excellence as the designer must take cost into consideration (usually a most important factor) and deal with materials, machines and operators.

While this paper deals mainly with the use of modern anisotropic permanent magnet alloys, the following comparisons with other materials may be enlightening.

At present, the cost of anisotropic alloy is approximately the same as for earlier materials on a purely energy basis but due to larger physical dimensions of the latter a considerable part of the available flux is lost by leakage ; the smaller size of a high efficiency magnet considerably reduces the value of leakage flux and hence with correct design, the cost of an anisotropic magnet for a given purpose should be appreciably less than that of other types of magnet. Since a small magnet requires a correspondingly small iron circuit, further savings in materials, weight, and cost should be obtained.

Against these advantages is the loudspeaker manufacturer's reluctance to scrap an old and well-proven design and re-tool for a new one, together with the problems of interchangeability of parts and increased stocks of parts to cover all designs. This sometimes results in a magnet being designed merely to fit existing parts and the inefficiency which may result is unfairly attributed to the magnet.

It should be emphasised that the higher the performance and efficiency of a magnetic alloy, the greater is the necessity for correct design of the magnet to secure the high efficiency.

The performance required from the magnet in a loudspeaker is easily specified. The product of the flux density in the gap in lines per sq. cm. and the linear distance across the gap in cms., i.e., radial width of the gap, gives the M.M.F. required. The magnet must supply this M.M.F. together with the M.M.F. required for the remainder of the iron circuit. The length of the magnet may therefore be defined as that length which when working at the value of H corresponding to $(BH)_{max}$ will give the total M.M.F. required across the air gap and in the iron circuit.

It is usually found that in normal commercial loudspeakers, where the gap flux density does not exceed 12,000 lines per sq. cm. and where the iron circuit is not

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worked at unduly high flux density, the M.M.F. loss in the iron circuit is approximately 20 per cent of that across the gap; this order of increase for the length of the magnet may be taken as average and be used in the absence of other data.

The cross-section of the magnet must be such that it will supply the useful flux required in the gap, plus the leakage flux.

For an ordinary commercial permanent magnet loudspeaker assembly using a ring type magnet, as shown in Fig. 22, the leakage flux may be divided into three parts:

(*a*) External leakage between the centre pole face and the top plate.

(*b*) Internal leakage from the centre pole to the top plate and magnet.

(*c*) External peripheral leakage between top and bottom plates; this is increased by the use of a steel cone chassis.

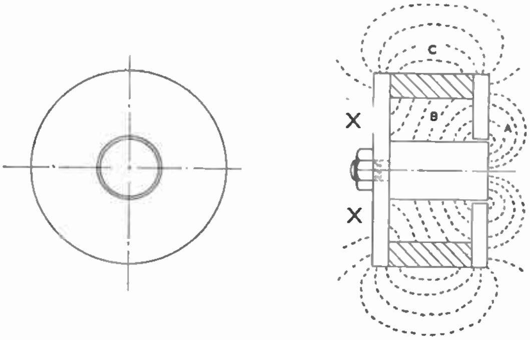

Fig. 22.—*A typical loudspeaker permanent magnet assembly using a ring type magnet.*

In ring type assemblies, the external leakage (*c*) may be reduced by making the magnet longer than necessary, which is obviously uneconomical, or by reducing its diameter until the internal leakage (*b*) increases at a faster rate than the external leakage decreases. The highest efficiency results when the magnet is reduced in diameter until the clearance between the magnet itself and the centre pole is about ten times the radial width of the gap.

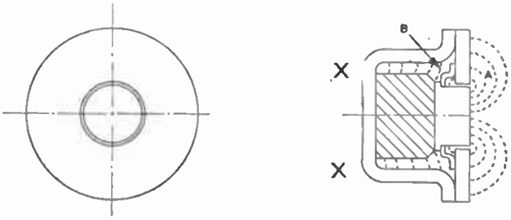

Fig. 23.—*A typical permanent magnet loudspeaker assembly using a central pillar type magnet.*

If the flux density is not too high, the required cross section of a high efficiency magnet may conveniently be accommodated under the centre pole as illustrated in Fig. 23. With this design, leakages (*a*) and (*b*) are still sensibly the same as in Fig. 22, but leakage (*c*) is entirely absent. This results in considerably higher efficiency occasionally exceeding 50% unless the centre pole has to be excessively tapered and the resulting large leakage surface causes high internal losses.

The iron circuit of the loudspeaker should be of such cross section that the material of which it is constructed will not be loaded to a flux density near saturation. The sections marked X in Figs. 22 and 23, which are usually the most highly loaded sections in the magnetic circuit, should be given special attention.

The flux density generally used by the author for ordinary commercially available grades of mild steel is 12,000 lines per sq. cm. maximum, although in practice, it is found that well annealed mild steel can sometimes work at 17,000 lines per sq. cm. without undue losses.

A point to be remembered when designing the iron circuit of a loudspeaker is that the leakage flux from the centre pole may, in some cases, be comparable with the useful flux; this means that the cross section of the centre pole at its base and the metal surrounding it must be capable of carrying twice the useful flux.

It is easily shown that if the flux density in the gap remains constant and the top plate thickness is doubled, the useful flux may be doubled, while the losses remain sensibly constant. Consequently, it may be assumed that a magnet assembly with a thicker top plate (or deeper air gap) is more efficient. This may be so, but not necessarily from the point of view of the loudspeaker manufacturer.

Similarly, if all dimensions are held constant except that the radial width of the gap is reduced, for example by half, the M.M.F. required to maintain the same flux density across the gap is also halved; this results in the leakage field being energised by half the original M.M.F. and the value of leakage flux is correspondingly reduced.

It can be seen, therefore, that taking into consideration the many variables which arise in loudspeaker design, including finally the shape and the volume of the magnet, the ratio of leakage to useful flux is not easily defined.

The following empirical formula may be found satisfactory for use with modern anisotropic ring type magnets of normal manufacture and of considerable help to an engineer who is suddenly called upon to design a magnetic circuit of this type without data or previous experience:

Leakage =

$$\Phi_g \times \frac{5 \times \text{radial width of gap}}{\text{depth of gap}} \times \frac{\text{outside dia. of magnet*}}{\text{length of magnet}}$$

* *Note.*—Where the magnet is not circular, this dimension should be considered as the diameter of the smallest circle which will contain the shape of the magnet.

In the case of loudspeakers using a central cylindrical

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magnet (of the construction illustrated in Fig. 23), the following empirical formula may be found useful :—
Leakage =

$$\Phi_g \times \frac{5 \times \text{radial width of gap}}{\text{depth of gap}} \times \frac{\text{Diameter of magnet}}{\text{Dia. of centre pole}}$$

As an illustration of the method used in the design of a moving coil loudspeaker magnet system, assume that a 1 in. diameter moving coil is to operate in a field of 10,000 lines per sq. cm. which is to be provided by a well designed permanent magnet system using "Ticonal G."

From the approximation that the radial width of the air gap = 2 per cent. diameter of coil + 0·020 in., a figure of 0·040 in. for the air gap is obtained. If this is exceeded an unnecessarily large magnet will be required; a smaller gap may result in manufacturing difficulty. The radial width of the air gap multiplied by five gives the best practical thickness of the top plate (or depth of air gap).

Converting to centimetres :—
Diameter of centre pole = 2·54 cms.
Radial width of air gap = 0·10 cms.
Depth of air gap = 0·51 cms.

The mean cross section of the air gap = π (Diameter of centre pole + one radial gap width) × Depth of gap = 4·23 sq. cms.

The flux in the gap = 4·23 × 10,000 = 42,300 lines.

If a central pillar type magnet design is to be used as illustrated in Fig. 23, appreciable tapering of the pole tip will be necessary to enable it to cover a magnet which will provide a flux density of 10,000 lines per sq. cm. in the gap ; therefore the efficiency will be lower than 50 per cent. and as a first estimate would be placed at 45 per cent.

The gap flux required = 42,300 lines, therefore if this represents 45 per cent. of the total flux given by the magnet, the magnet will be required to produce 94,000 lines which divided by 11,000 (working B of "Ticonal G"), gives a cross section of 8·55 sq. cms. which corresponds to a cylinder of diameter 3·3 cms. Checking the estimated leakage by means of the empirical formula :

$$\text{Leakage} = \Phi_g \times \frac{5{\cdot}0 \times 0{\cdot}10 \times 3{\cdot}3}{0{\cdot}51 \times 2{\cdot}54} = 1{\cdot}273$$

This leads to a leakage factor of 2·273 which corresponds to an efficiency of 44 per cent. This is well within the accuracy of the empirical formula and further correction is unnecessary.

This type of magnet can, with advantage, be slightly tapered with the smaller end towards the air gap. The taper, if used, should be proportioned so that as the leakage flux leaves the sides of the magnet the cross sectional area is reduced to maintain a constant flux density throughout the magnet corresponding to the optimum value (B working).

The M.M.F. required to maintain the flux in the air gap is the product of the flux density and the radial width of the air gap in cms. which value divided by the working value of H for the magnet gives the length of the magnet. To cover losses in the iron circuit and joints, 20 per cent. addition to the length is required and hence :—

$$\text{Length of magnet} = \frac{\text{Gap flux density} \times \text{Radial width} \times 1{\cdot}20}{\text{Working H of alloy}}$$

$$= \frac{10{,}000 \times 0{\cdot}10 \times 1{\cdot}20}{520} = 2{\cdot}31 \text{ cms.}$$

When, however, manufacturing considerations require that the magnet takes the more conventional form of a ring, say, of 3 in. diameter, the efficiency immediately drops.

From the approximation already given, the value of leakage flux will be :—

$$\Phi_g \times \frac{5 \times l_g}{\text{gap depth}} \times \frac{\text{outside diameter of magnet}}{\text{length of magnet}}$$

(l_g = radial width of air gap)

$$= \Phi_g \times \frac{5 \times 0{\cdot}10 \times 7{\cdot}6}{0{\cdot}5 \times 2{\cdot}31} = 3{\cdot}29 \times \Phi_g$$

Therefore the magnet will be required to produce a total flux of $\Phi_g \times 4{\cdot}29 = 42{,}300 \times 4{\cdot}29 = 182{,}000$ lines resulting in a ring whose cross-sectional area $= \frac{182{,}000}{11{,}000} = 16{\cdot}53$ sq. cms. Suitable dimensions are O.D. = 7·6 cms., I.D. 6·06 cms., and length of 2·31 cms. as before.

In loudspeakers where the flux density in the gap is more than 12,000 lines per sq. cm. the iron circuit will be required to carry a correspondingly higher value of flux and as ordinary mild steel begins to saturate above this figure, the iron circuit will tend to radiate the increased flux as leakage instead of conducting it to the gap. This necessitates the use of a larger magnet and iron circuit with resultant increased leakage surfaces and lower efficiency. For this reason there is great difficulty in producing high flux densities in loudspeaker gaps.

For moving coil microphones, where the excursion of the coil is extremely small and there is negligible power dissipation in the coil, the clearances can usually be made much smaller. In all other respects, however, the magnetic circuit of the moving coil microphone may be considered in the same way as that for a moving coil loudspeaker.

4.3. Galvanometers and Moving Coil Meters

The design of the movement of moving coil meters and galvanometers is governed by the instrument maker's technique and manufacturing considerations, and the magnet designer usually has the problem of designing a magnet to fit into the available space and produce a maximum stabilised flux in the finished instrument.

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There are many designs of moving coil instruments with a variety of magnetic circuits ; in some designs the magnet takes the place of the soft iron core inside the moving coil and is surrounded by a mild steel yoke in the form of a ring (see Fig. 24A), but the limited dimensions of the magnet lead to poor performance. Although the design makes good use of the flux from the magnet, it is not efficient magnetically because the magnet cannot work throughout at $(BH)_{max}$, and there is the added difficulty of obtaining a uniform field in the space swept by the moving coil. This type of instrument, however, has a very low external field and can undoubtedly be made smaller and neater than other types of instrument.

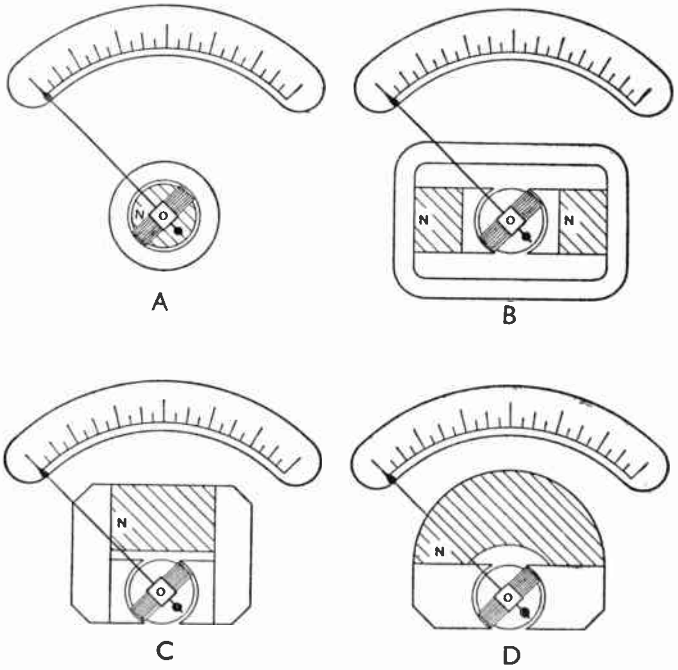

Fig. 24.—Illustrating various designs of permanent magnet indicating meters :—

A. Using a central magnet.

B. Using two sections of magnet to promote efficiency.

C. Conventional block magnet.

D. Conventional "U"-shaped magnet.

Probably the most efficient construction from a magnetic point of view is that of Fig. 24B where the magnet is in two sections and small pole shoes form the sides of the tunnel. An iron ring or yoke is used to carry the flux from the outer ends of the magnets and this serves as a magnetic screen against its own external field and against extraneous fields which would reduce the accuracy of the instrument.

Most moving coil instruments follow one of two main designs ; one construction uses a short straight block of magnet alloy (see Fig. 24C) and the other employs a " U "-shaped magnet as in Fig. 24D.

The block type requires a short straight block or bar, designed to work at $(BH)_{max}$, the bar being fitted between mild steel bars which conduct the flux to the sides of the moving coil tunnel. The mild steel bars, being at maximum magnetic potential, will cause considerable leakage of flux, but the design has the great advantage of allowing easy magnetisation as a final operation in the manufacture of the instrument.

The design of the magnet for this type of meter is quite straightforward. The product of the flux density in the air gap and the radial width in cms. of the two air gaps in series gives the M.M.F. required at the sides of the tunnel.

This value of M.M.F. divided by the working H of the magnet alloy it is proposed to use, gives the length of magnet necessary to produce the required M.M.F. Owing to losses in the iron circuit, an increase should be made to the length and 20 per cent. is usually found to be adequate for this purpose.

The product of the useful flux and leakage factor* will give the total flux required from the magnet. This total flux divided by the working B of the magnet alloy will give the cross-sectional area of the magnet.

" U "-shaped magnets, with their high length-to-section ratio, were necessary when early types of magnet alloys were used.

The length and section necessary for use in an average moving coil instrument is such that the modern anisotropic alloy of high coercive force does not lend itself to manufacture in this shape except under special conditions.

It should be noted that the efficiency of a curved or " U "-shaped magnet will not be as high as that of block type magnet, since the former will not be working throughout at $(BH)_{max}$. Therefore, in the design of a " U "-shaped magnet the difference in length between the longest and shortest magnetic paths must be kept as small as possible, and the effective magnetic length for calculation purposes should be considered as being midway between the mean and minimum lengths.

The working flux density of a "U"-shaped magnet in influenced by the severity of the "U" bend, but is unlikely to be less than 80 per cent. of that for a straight block.

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* *If the leakage factor cannot easily be estimated, a factor of 3 may be adopted as average for a normal instrument.*

With "U"-shaped magnets a higher percentage of the flux is usefully employed, and consequently the external field is lower, but a serious disadvantage of modern anisotropic "U"-shaped magnets is that magnetisation is exceedingly difficult other than by the use of very heavy currents.

Instruments for special purposes requiring a high order of sensitivity may employ a circular magnet. This type of magnet is not easy to manufacture in anisotropic alloy due to the difficulty of obtaining a circular field of sufficient intensity during heat treatment and although it is the most powerful form of magnet for its size and weight, manufacturing costs are necessarily high.

During manufacture of moving coil instruments the magnet should, if possible, be magnetised as the final operation before calibration ; the necessity of careful handling after magnetisation cannot be overemphasised.

If permeable objects are allowed accidentally to make contact with the magnet, the disturbance of its field at the point of contact will result in altered performance of the magnet and remagnetisation becomes necessary.

The stability of modern anisotropic magnets is so high that many instruments using these magnets in an un-aged or unstabilised condition will remain well within their rated accuracy. An effective method of stablising consists in passing the magnetised instrument, before it is calibrated, through a large solenoid carrying an alternating current of sufficient magnitude to reduce the meter deflectional sensitivity by approximately 3 per cent. This treatment will ensure that the meter is not subsequently affected by extraneous fields of lower intensity. (See Section 3.6.)

4.4. D.C. Motors, Generators and Alternators

The design of magnet systems for these machines is usually treated in a highly mathematical manner requiring precise information not usually available except from measurements on a completed machine.

The following methods of designing field magnets for motors and generators undoubtedly meet a much needed requirement for clear and practical information on this subject.

Take first the case of the motor ; the designer will choose an armature capable of giving the required power output and this armature will require a certain field strength at a given M.M.F. between the poles for efficient operation at full load.

The field magnet system will be called upon to withstand two major demagnetising forces, one when the motor is starting and the armature current is limited only by the ohmic resistance of the armature and brush gear, and the other when the armature is removed for cleaning or maintenance. As these two demagnetising forces can only act separately the greater one must be used for calculation.

The magnet, therefore, will be subjected to an occasional peak demagnetising influence, i.e. high value of M.M.F. and will normally be working at a considerably lower value in a state of recoil on a minor hysteresis loop.

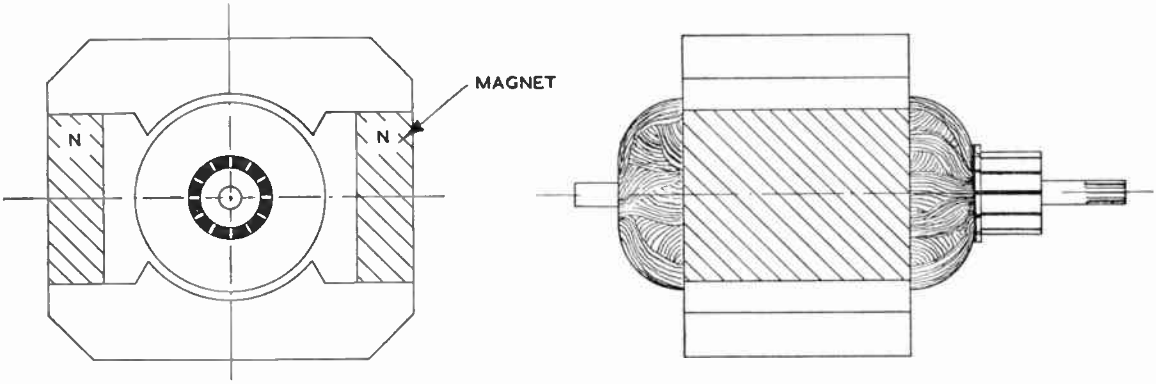

Fig. 25.—Diagram of a typical permanent magnet DC motor.

It was shown in Section 4.1 that the maximum energy is obtained from a magnet under conditions of recoil when the peak demagnetising force equals the value of $-$ H corresponding to $(BH)_{max}$.

It was also shown that when the recoil exceeded 50 per cent. magnetic efficiency (reduction of weight of magnet required for a given purpose) could be improved by shunting the magnet system in order to limit the recoil value to approximately 50 per cent.[8]

This means that if the leakage reluctance of the motor is such that when the armature is removed the M.M.F. between the pole faces rises to a value higher than twice the normal full load working M.M.F., the design of the stator must be altered. The leakage must be increased, if necessary, by deliberately shunting flux, so that the rise in M.M.F. is limited to twice the full load ; this occurs when the leakage flux approximately equals the useful flux.

A motor constructed as in Fig. 27 which is assumed to use "Ticonal G" magnets, requires, at full load, 50,000 lines in the armature tunnel and an M.M.F. of 500 gilberts between the pole faces. The measured reluctance of all leakage paths is approximately four times as great as that of the armature at full load, and, therefore, in the absence of a magnetic shunt, the M.M.F. across the poles will rise to five times that at full load, i.e. 2,500 gilberts and the magnets will be normally working at 80 per cent. recoil from this peak. Under these conditions, and allowing 20 per cent. for M.M.F. drop in the iron circuit, the optimum length of the magnets becomes :—

$$\frac{1{\cdot}20 \times \text{peak M.M.F. on pole faces}}{\text{working H of magnet}} = \frac{3000}{520} = 5{\cdot}76 \text{ cms.}$$

Since the reluctance of the leakage paths is four times that of the working armature, the leakage flux will be $\frac{50{,}000}{4}$ lines. This added to the armature requirement gives a total of 62,500 lines.

For this value of flux, the magnet will be at 80 per cent. recoil, and, from the graph in Fig. 20, it will be producing flux at the rate of 12,270 lines per sq. cm. Therefore the cross section of magnets will be $\frac{62{,}500}{12{,}270} = 5{\cdot}1$ sq. cms. and this completes the design of the magnets for this motor.

If, however, a magnetic shunt is used on this motor and the shunt is so adjusted that in parallel with all other leakage paths the total leakage reluctance equals that of the working armature, the rise in M.M.F. across the pole faces will be limited to twice normal, i.e., from 500 to 1,000 and the length of the magnets becomes :—

$$\frac{\text{Peak M.M.F.} \times 1{\cdot}20}{\text{Working H of magnet}} = \frac{1{,}200}{520} = 2{\cdot}31 \text{ cms.}$$

As the reluctance of the total leakage paths is now equal to that of the working armature the total flux required will be 100,000 lines and this must be obtained when the magnets are at 50 per cent. recoil and the flux density is 11,800 lines per sq. cms.

Therefore, the cross section of magnets will be :—

$$\frac{100{,}000}{11{,}800} = 8{\cdot}47 \text{ sq. cms.}$$

In the former case the volume of magnet alloy required was $5{\cdot}76 \times 5{\cdot}1 = 29{\cdot}35$ cu cms., while in the magnetic shunt case the volume of alloy is only $2{\cdot}31 \times 8{\cdot}47 = 19{\cdot}55$ cu. cms. This example illustrates the economy in volume and weight of magnet alloy which can be effected by careful design.

The foregoing method of design is based on measurements of reluctance which, it may be argued, are not at all easy to make. This is to some extent true, but in the case of a motor designed to work at 50 per cent. recoil all that is necessary is to check that when the armature is removed from its tunnel the M.M.F. rises to twice the normal working value; this can easily be done by measuring any external leakage with a fluxmeter and search coil as the leakage will be proportional to the M.M.F.

The design has also been based on the removal of the armature from its tunnel creating a greater demagnetising effect than that due to the starting reaction of the armature. While this is usually true, it is by no means always the case, and under conditions when the starting reaction has the greater effect, either the maximum armature current must be limited or the demagnetising effect of the starting reaction used for calculation.

In special applications small permanent magnet motors may be subjected to reverse rotation while current is still flowing. This treatment considerably increases the armature reaction and the peak M.M.F. in the motor, and due allowance must be made in the design of the motor and its field magnet for this effect if present.

As a further example of this method of design consider a permanent magnet motor required for a specific purpose. Assume that the armature has already been designed and that the field requirements are known so that only the field magnets remain to be designed.

Assume that the tunnel clearance and pole area is fixed, that 100,000 lines are required in the armature at an M.M.F. of 1,000 at full load and that the magnets are to be of "Ticonal G" operating economically (i.e. at 50 per cent. maximum recoil).

Therefore peak M.M.F. $= 1{,}000 \times 2$

$$\text{Length of magnets} = \frac{\text{peak M.M.F.} \times 1{\cdot}2}{\text{Working H of magnets}} = \frac{2{,}400}{520} = 4{\cdot}62 \text{ cms.}$$

Total flux from magnets is twice armature flux.

$$\text{Area of magnet} = \frac{\text{Total flux required}}{\text{B of magnet at 50\% recoil}} = \frac{200{,}000}{11{,}800} = 16{\cdot}95 \text{ sq. cms.}$$

The dimensions of the field magnets having been determined, all that remains is to arrange that the open circuit reluctance of the field assembly is equal to that of the working armature.

$$\text{Since reluctance} = \frac{\text{M.M.F.}}{\text{flux}}$$

The effective reluctance of the armature at full load $= \frac{1{,}000}{100{,}000} = 0{\cdot}01$

If the field can be designed by calculation to have a leakage reluctance of this value within 10 per cent., the result will usually be satisfactory; however, by arranging the reluctance to be lower than the calculated value, adjustment is possible by machining, after measurement.

For the cases D.C. generators or alternators with stationary fields, the design of the field magnets may be

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carried out in the same way except that with D.C. generators the short circuit armature reaction takes the place of the starting reaction of motors, while with alternators, short circuit through a low impedance (inductive)may produce the highest armature reaction.

4.5. Miniature D.C. Motors

Modern high efficiency permanent magnets have made possible the construction of miniature D.C. motors with efficiencies and power outputs hitherto unobtainable. An example is shown in Fig. 26.

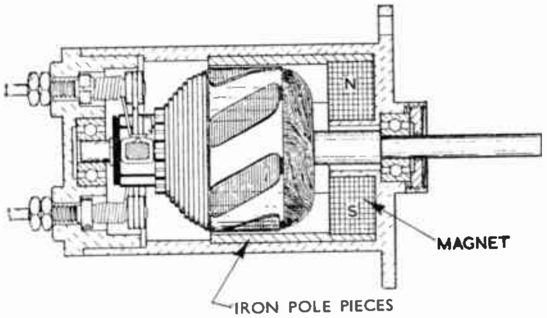

Fig. 26.—Sectional drawing of miniature DC motor.

Provided that the performance of the permanent magnet alloy is above a certain minimum the design of the magnets for these motors is mainly determined by mechanical considerations. For example, the magnet diameter is not usually smaller than that of the armature, while the thickness of the magnet is determined by the minimum thickness which can be reasonably manufactured and handled. The performance of "Ticonal G" is so high under these conditions of design that the magnet is usually appreciably larger than necessary, and parts of the iron circuit become saturated.

Since field windings are not used, the efficiency of the motor is improved, and the dimensions of the motor need not greatly exceed those of its armature.

Fig. 26 clearly illustrates the general design and construction of a typical motor of this type. The armature, running on small ball races, is of conventional design, using 0·014 in. Stalloy laminations with a seven slot lap winding suitable for continuous operation on 24 volts D.C. The commutator and brush gear are of conventional fixed position design using low resistance copper graphite brushes and the pole pieces are curved mild steel plates 0·080 in. thick, which make contact with the magnet disc located at one end of the motor.

A feature of this particular motor is the ease of assembly and manufacture by reason of its moulded bakelite construction. This motor gives the mechanical equivalent of 5 watts output at 6,000 r.p.m. with an efficiency of 35 per cent., and its maximum speed is approximately 9,000 r.p.m.

The limiting factor in the reduction in size of a motor is the construction of the armature, and motors, designed on lines similar to the one shown in Fig. 26, are now being manufactured in sizes down to approximately ½ in. diameter and 1 in. in length.

4.6. Generators with Rotating Magnets and Multipolar Rotors

The usual construction of small permanent magnet alternators employs a rotating two-pole magnet cored out and bushed to take the shaft, as in Fig. 27A.

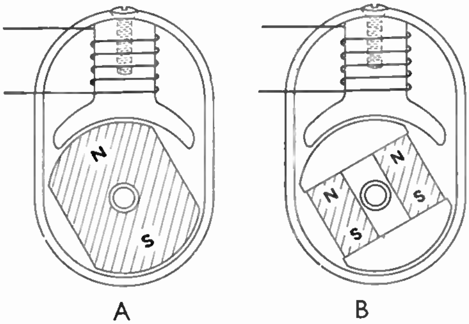

Fig. 27.

A. *A Conventional small alternator using a two-pole rotating magnet.*

B. *A small two-pole alternator employing magnet material more economically.*

This type of construction, while being inexpensive from ease of manufacture, is magnetically inefficient for three main reasons :—

(*a*) The magnetic length of the magnet is not a constant due to the curvature of its end surfaces.

(*b*) The magnetic section of the magnet is not constant.

(*c*) The flux at the surface of the magnet is subjected to such severe disturbance that partial demagnetisation of the surface results to a depth depending on the magnet alloy and the intensity of the magnetic disturbance at its surface.

A construction magnetically more efficient is indicated in Fig. 27B, where the magnets are of a constant magnetic length and section and the flux is passed into soft magnetic pole pieces, which serve to isolate the magnets from the severe magnetic disturbances occurring at the external surface of the rotor. A rotor of this type is, of course, suitable only for two poles or one cycle per revolution.

When more than two poles are necessary a magnet of the design shown in Fig. 28 may be used, but the difficulty of manufacturing such magnets in anisotropic alloy and the resulting inefficiency of the rotor is such that it is usually more economical to use a lower performance magnet material with a high coercive force. Multipolar rotors of this type require specially constructed magnetising jigs and their efficiency is, to a considerable extent, dependent upon the design and efficiency of the magnetising equipment used.

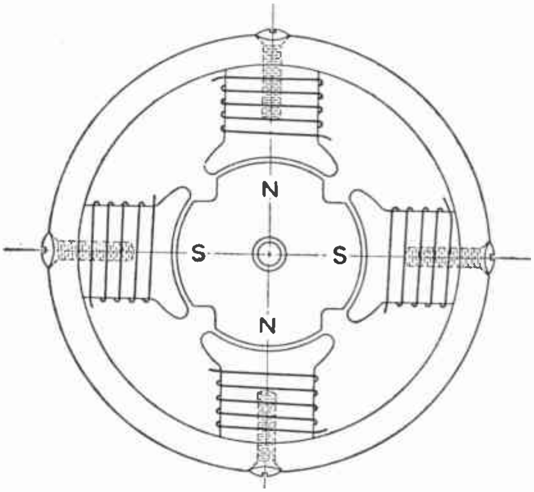

Fig. 28.—An alternator using a rotating four-pole magnet.

The high efficiency of anisotropic alloys may properly be utilised with a multipolar rotor designed in accordance with Fig. 29. Here a ring type magnet is used with its magnetic direction parallel to the shaft and the magnet is clamped between two iron pole plates with toothed edges so arranged that the teeth interleave. A rotor of this type is magnetised by passing a straight and parallel flux through it, parallel to the shaft, and this may easily be done by means of an ordinary electromagnet, each pole face of which is bored to accommodate the shaft. This construction will result in alternate teeth round the periphery of the drum assuming similar polarity, resulting in a multipolar rotor of any reasonable number of poles. The limit to the number of poles is set by magnetic fringing which is controlled by the ratio of space between alternate poles to clearance between the rotor and the stator.

This type of rotor is capable of giving a higher performance than one where the poles are magnetised on the face of a cylindrical magnet, but approximately 20 per cent. only of the flux given by the magnet can be usefully employed due to unavoidable flux leakage.

4.7. Special Wave-Shape Generators

Small alternators designed to produce voltage waves of special shape are frequently constructed with rotating magnets which have been carefully cut away to produce the require wave shape.

The shaping of a magnet for this purpose is difficult. The wave form cannot easily be predicted, hence design is largely empirical, and the frequency of this type of generator is usually one cycle per revolution to limit the number of specially shaped poles to two in view of magnetisation difficulties.

A rotor may be constructed as shown in Fig. 29, where a high efficiency ring type of magnet is clamped

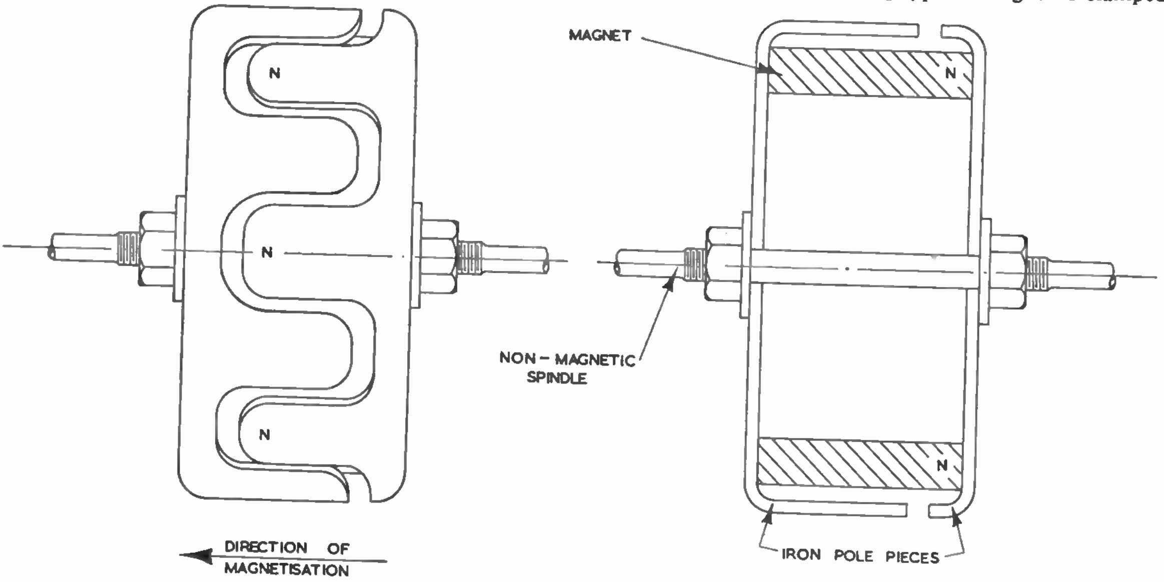

Fig. 29.—A multipolar rotor using a ring type anisotropic magnet.

between two circular iron plates with their edges turned towards one another, and separated by an air gap of approximately $\frac{1}{16}$ in. Used in conjunction with suitable stator poles, the relative movement of the air gap when the rotor is rotating may be used to produce a change of flux in the stator windings hence producing a alternating current of almost any desired wave form. For instance, when the air gap is moving sinusoidally a sine wave output is obtained while a zig-zag track would tend to produce a square topped wave, and a straight track with a single "V"-shaped deflection would produce a single square topped wave once every revolution of the rotor.

Thus with this type of rotor a definite wave form may be predetermined with some accuracy, but it will be found that fringing and partial saturation of the iron tend to modify the output wave shape. If a sharply rectangular type of wave is required, the minimum number of cycles per revolution should be used.

It should be noted that the magnetic efficiency of this type of rotor will be low and to some extent dependent on the wave form which is produced.

4.8. Microphones

The ribbon microphone is considered by many engineers to give a very good all-round performance, and consequently it is widely used in spite of the serious disadvantage of very low output. Improved sensitivity may be obtained by increasing the intensity of the magnetic field in the instrument, but considerable difficulties are involved. Fig. 30A shows a typical design of ribbon microphone using a "U"-shaped magnet with pole pieces collecting the flux from the ends of the magnet and carrying it to the edges of the ribbon.

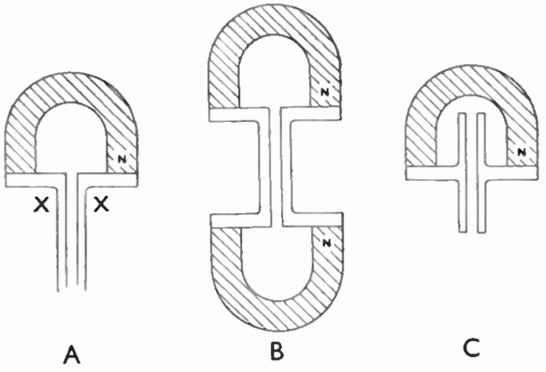

Fig. 30.—Diagrams of the magnetic circuit of ribbon microphones.

A. Using one magnet where the limit of flux is set by saturation of points "X."

B. Using two magnets carrying flux at both ends of the pole pieces.

C. A method of carrying the flux to the centre of the pole pieces.

In this construction the reluctance of the useful flux path is high, and consequently considerable leakage occurs and sections marked X have a high flux density. The direct substitution of a modern anisotropic magnet for one of the older type usually results in saturation of these sections; the small increase in flux density in the space occupied by the ribbon brings little improvement in sensitivity.

Designers are generally reluctant to increase the section of the pole pieces for acoustic reasons, but an increase in sensitivity can be obtained by reducing the distance between the poles and the width of the ribbon.

The sensitivity of the instrument may be appreciably improved if it is redesigned to use modern anisotropic magnets. Fig. 30B shows a design using two magnets supplying flux at both ends of the pole pieces resulting in a possible increase of approximately 100 per cent. of the effective field in this instrument while using pole pieces of the original section.

Another design where a higher operating flux density is obtained without increase in section of the pole pieces consists in feeding the flux to the centre of the pole pieces as shown in Fig. 30C.

The magnetic design of moving coil microphones may be carried out in the same way as for moving coil loudspeakers with the exception that the gap may be appreciably reduced on account of the limited excursion of the coil.

4.9. Telephone Receivers

Early designs of telephone receivers using low performance permanent magnets have a relatively high sensitivity, and the indiscriminate substitution of the magnet by one of higher efficiency and smaller dimensions may result in reduced sensitivity.

The path of the alternating flux which actuates the diaphragm of the telephone should be carefully considered. Part of the alternating flux path is the permanent magnet itself in parallel with its own leakage reluctance, and an early type permanent magnet with its necessarily large dimensions and high leakage provides a relatively low reluctance path for this flux. With a small high efficiency magnet with its much reduced leakage, the combined reluctance of the magnetic circuit including leakage may be very much higher than when using a low performance magnet. The effective permeability of modern anisotropic magnets under normal operating conditions is approximately 3, which means that unless special precautions are taken a high reluctance may well be offered to the alternating flux of the telephone receiver resulting in reduced sensitivity.

The method of overcoming this difficulty is to adopt a design where the magnetic leakage is high and to use a magnet of increased cross section. If necessary, the magnet may be deliberately shunted by a low reluctance

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path so that the combined reluctance of the magnet and its shunt will be low.

The diaphragm is also part of the magnetic circuit. A thin diaphragm is easily saturated while a thicker one may be too stiff, so that for small telephone receivers a composite diaphragm consisting of a flexible material with a central section of highly permeable material may be found to give the best results.

Any design where windings are used on the magnet itself or where a " U "-shaped magnet is used with windings on its poles will lead to reduced sensitivity and should be avoided.

One of the simplest designs of telephone receivers taking advantage of the high efficiency obtainable from anisotropic alloy is illustrated in Fig. 31. The construction shown is efficient and may be scaled down, if necessary, to very small dimensions.

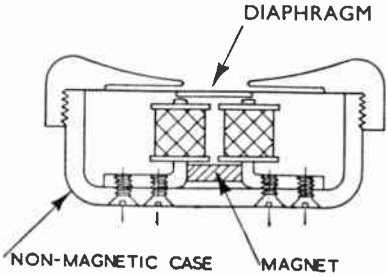

Fig. 31.—*Sectional diagram of a small telephone receiver using high efficiency anisotropic magnet.*

4.10. Pickups and Recorder Heads

Due mainly to the dimensions of the magnet usually employed in moving iron pickups only a small percentage of the total flux maintained by the magnet is usefully employed.

A modern magnet to give the magnetic performance required in such an instrument would be quite small and the use of so small a magnet frequently involves mechanical difficulties which render it more economical to use a larger magnet.

The following designs serve to illustrate the reduction possible in size and weight by the use of anisotropic magnet alloy. Fig. 32A shows a compact magnetic design using a rectangular block magnet. An alternative design, shown in Fig. 32B, uses less iron and a curved magnet resulting in a slightly lighter assembly.

The highest magnetic efficiency is obtained by the use of two small sections of magnet alloy located as closely as possible to the gaps, as shown in Fig. 32C, but this construction may not be the lightest in weight due to the necessity of an iron yoke to join the extremities of the magnets.

Recorder or cutter heads may be designed on similar lines to the moving iron pickup but need more powerful magnets. Excessive weight has to be avoided in these instruments and here the modern anisotropic magnets is of great assistance.

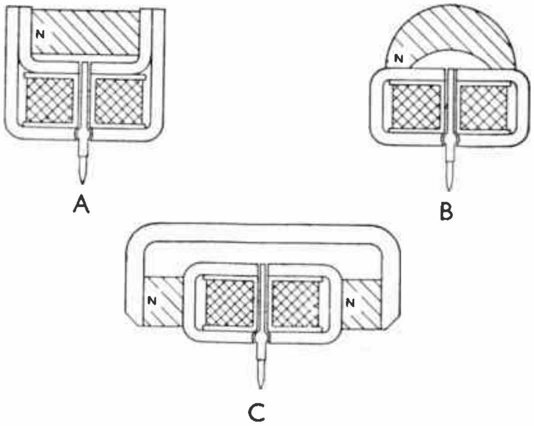

Fig. 32.—*Illustrating alternative magnetic designs of moving iron pick-ups.*

In the manufacture of pickups and cutter heads final magnetisation is a necessity if the size of the magnet and the weight of the finished instrument is to be kept low.

4.11. Magnetron Magnets

Magnets for use with magnetrons afford a good example of the potentialities of modern anisotropic magnet alloy since magnetic specifications, which were previously impossible with earlier magnet alloys, are now easily met.

Because of the large air gaps involved, the design of an efficient magnetron magnet is one of the most difficult problems a magnet designer will meet. How critical the design of such magnets can be, will be clear when it is understood that with a carelessly designed magnet the useful flux may represent only 2 to 3 per cent. of the total flux maintained by the magnet, whereas a carefully designed magnet of the same material may have an efficiency of 20 to 25 per cent.

The problem is too large to be dealt with adequately in the present paper.

4.12 Eddy Current Brake Magnets

Magnets designed for damping and braking have, up till now, generally been manufactured from rather low performance magnet alloy. The earlier alloys are particularly suited for the manufacture of this type of magnet due to their long length-to-section ratio.

Optimum braking efficiency is obtained with rectangular pole faces when the length is approximately four times the width, and the length dimension of the pole face being at right angles to the direction of motion. The rotating disc should project a short distance past a pole face (usually a width of the pole face approximately) to offer a short and low resistance path to the eddy currents generated during braking.

In the design of brake magnets manufactured entirely of high efficiency alloy, the length and section of alloy necessary for a given effect is so small that difficulty is experienced in carrying the magnet around the moving parts of the mechanism.

It is not necessary, however, to design and construct eddy current brake magnets entirely of anisotropic alloy. It is more convenient and economical to use a small block of alloy of correct length and section to produce the required flux and to use mild steel pole pieces bolted to the magnet block as shown in Fig. 33. The mild steel pole pieces may be easily machined to the required shape, and may be drilled and tapped to facilitate fixing. A magnet assembly of this type will withstand treatment which would completely upset the performance and stability of the usual type of brake magnet ; the mild steel poles may be short-circuited and magnetic objects may be allowed to touch them without impairing the subsequent performance or stability of the magnet, whereas in the case of the usual brake magnet manufactured entirely of magnet alloy the contact of a magnetic object will cause redistribution of flux and a loss of performance.

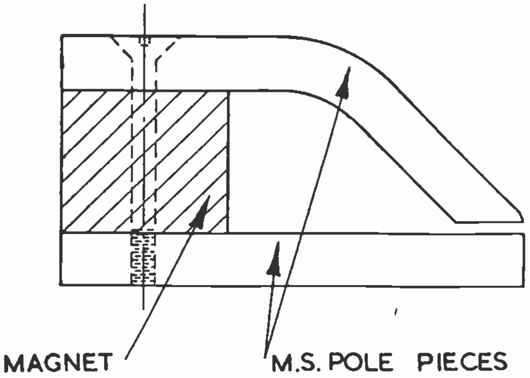

Fig. 33.—An eddy-current brake magnet using high efficiency anisotropic magnet alloy and mild steel pole pieces.

Further, a composite magnet can very easily be magnetised with a small and easily constructed electromagnet, whereas the normal type of magnet can only be effectively magnetised by the use of heavy current.

Users of damping or braking magnets are usually reluctant to employ a composite magnet owing to the risk of mechanical instability, but they are well advised to consider the advantages which can be obtained from the use of the composite type of magnet.

Eddy current brake magnets for use in watt-hour meters or other apparatus where a constant performance is required should be metallurgically stable and correctly magnetised, stabilised and handled. They should be stabilised by a demagnetising field whose intensity will exceed that of any effect which the magnet is likely to meet under operating conditions, and if subsequently any redistribution of flux is made, as, for instance, by the accidental contact of a magnet or permeable object the magnet should be resaturated and restabilised.

4.13 Magnet Filters

Modern permanent magnets, with their high efficiency, are finding many new uses. A use which is steadily growing in industry is for magnetic filtering of coolants and lubricants, in addition to normal filtration. The use of magnetic filters with machinery results in increased life of the moving parts resulting from cleaner oil ; the quantity of material escaping the normal filter which a magnetic filter will remove from the oil in a machine is surprisingly large. Magnetic filters are also finding their way into many industrial processes where the accidental inclusion of magnetic objects or particles must be avoided.

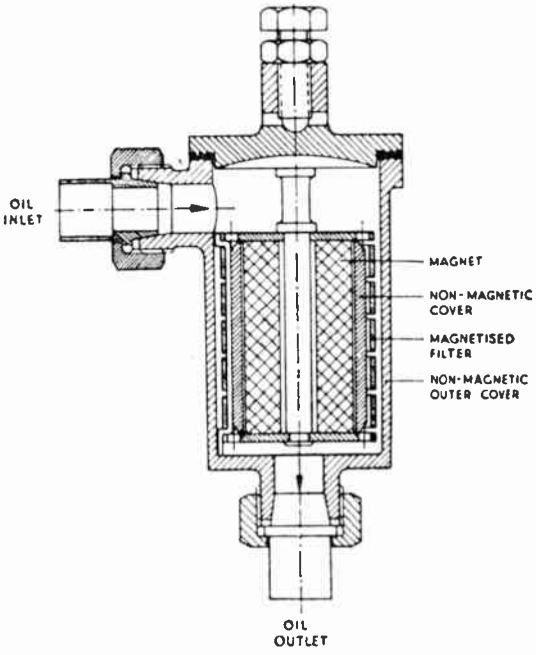

Fig. 34.—Sectional diagram of a magnetic oil filter.

The magnets used for filters should be designed to operate at or near to their BH_{max} when clean and all detachable cages, etc., are removed. Under all other conditions, the reluctance of the flux path of the magnet

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will be reduced by the cages and collection of ferrous particles.

The flux from the magnets should be collected and distributed by mild steel collector plates; failure to observe this requirement, i.e. allowing the flux to be distributed from the magnet itself, will result in gradual demagnetisation of the magnet with a corresponding fall in efficiency of the filter.

For the same reason, the sides of the magnet should be protected by non-magnetic material to prevent magnetic objects making contact with the magnet itself and disturbing its flux distribution.

A properly designed magnetic filter should retain its efficiency indefinitely.

(5) Acknowledgments

The author wishes to thank the Directors of The Mullard Wireless Service Co., Ltd., for permission to publish this paper based on work carried out in the laboratories of this company during the past few years.

Thanks are also expressed to various colleagues who assisted by helpful criticism and advice during the preparation of the paper and particularly to Mr. L. Grinstead, Chairman of the Papers Committee of the Institution.

(6) Bibliography

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[8] *Pat : App :* 32153/45 (*Holland*, 10-8-40.)

SUMMARY OF DISCUSSIONS ON THE PAPER

Mr. C. J. Scoles : Certain magnetron magnets have inserts which are obviously of a material different from that of the magnets proper. I should like to know the purpose of these inserts and whether they have any shunting effect on the magnet. Are the magnet poles cast round these inserts or are they fitted at a later stage in the manufacture?

Mr. W. S. Earle : In the case of an instrument such as a suspended system galvanometer, if the movement is removed from the magnet, say, for repair, is it advisable to put a keeper across the gap, or should the gap be left open? If a keeper is put across the gap, are the properties of the magnet upset?

Mr. Pollock : Why do loud speaker manufacturers prefer to use an external ring of Alnico, rather than a very much smaller and cheaper piece in the centre? It seems that the latter would have advantages, and would give much less external field for such application as television sets.

Mr. J. A. Sargrove : In the incremental type of application, such as in a moving iron loud speaker, there is usually a direct current flowing as well as an alternating current, and it is a custom to pass the D.C. in such a way that it aids the permanent magnetic effect. With modern materials, would it be advisable to pass the current in such a manner or is it immaterial?

Mr. A. C. Brittain : For purposes of demagnetising permanent magnets is there an upper limit on the high frequency side to which the magnetic material cannot respond? If, for example, 1 Mc/s is used instead of 50 c/s, would it demagnetise the magnet?

Mr. F. Lister : Are there any methods available for testing the unmagnetised magnetic material, as for instance by putting it into a coil and measuring, say, the inductance and the A.C. resistance, and can the results be correlated with the characteristics of the magnet as magnetised?

AUTHOR'S REPLY TO THE DISCUSSION

Mr. Scoles will note that Section 2.2 of the paper states that the high performance permanent magnet alloys tend to crack during manufacture. This effect is more noticeable in the large sections used in magnetron magnets.

The inserts observed would appear to be pieces of metal to reinforce the magnet castings, and are usually of mild steel or stainless steel. In the former case, shunting effect is produced which may appreciably reduce the performance of the finished magnet while in the later case, where a non-magnetic grade of stainless steel is used, a small loss is introduced due to the volume of magnet alloy displaced by there inforcing bars.

This tendency to flaw and crack can be considerably reduced by correct design and manufacturing technique. I have designed a wide range of magnetron magnets in anisotropic alloys but so far have not found it necessary to reinforce the castings.

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With regard to Mr. Earle's question on galvanometers, a keeper cannot serve any useful purpose under these conditions, and by using a keeper where the magnet alloy extends to the surface of the air gap, there is considerable risk of upsetting the flux distribution which may result in temporary instability coupled with a change of calibration or reduction of sensitivity.

The behaviour of a magnet under these conditions is discussed in sections 2.3 and 3.6.

* * *

Mr. Pollock raised the question of speaker design. The trend of design is towards the central type of magnet, but the chief difficulty and cause of delay appears to be due to the necessity of re-tooling.

The relative merits of the alternative speaker designs are dealt with at some length in section 4.2.

* * *

Regarding Mr. Sargrove's question on speakers. Theoretically it may be better to use the smallest possible magnet and to arrange that the D.C. component aids the magnet, but under practical conditions the D.C. component will amount to perhaps 10 ampere turns while the performance of the permanent magnet may be the equivalent of 1,000 or more ampere turns. Therefore this effect of the D.C. component is usually disregarded.

* * *

Mr. Brittain raised an interesting question on the upper limit of frequency for demagnetising purposes. The alternating demagnetising field produces eddy currents in the magnet which oppose the demagnetising field and reduce its effectiveness and penetration; 50 cycle fields are found to be too high a frequency for efficient demagnetisation of heavy sections and cause a certain amount of heating, while demagnetising fields in the region of one megacycle would cause considerable heating and the denagnetising effect would have very limited penetration.

(Owing to space limitations the contribution of Mr. G. L. Hamburger and the author's reply have had to be held over to the next issue of the Journal.)

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TRANSFERS AND ELECTIONS TO MEMBERSHIP

The following elections and transfers were recommended by the Membership Committee at their meetings of September 5th, 1946, and October 22nd, 1946, at which a total of 143 applications were considered, and have now been confirmed by the General Council.

Transferred from Associate Member to Full Member

MOSS, Hilary, Ph.D.(Eng.), B.Sc.	London

Transferred from Companion to Full Member

BURNHAM, Walter Witt	Blisland

Transferred from Associate to Associate Member

EDWARDS, Alan John	Birmingham

Transferred from Graduate to Associate

RAE, Donald, B.Sc.	Carlisle

Transferred from Student to Associate

BURKE, Norman William	Bromley
HODGES, Hugh Walter Charles	Bridgwater
JONES, Thomas Reginald Harold	London
MORLEY, Gilbert	Manchester
READ, Geoffrey Leonard	Hayes, Mddx.
SEHPOSSIAN, Haig	Egypt

Transferred from Student to Graduate

COOPER, Wallace George	London
HUPPER, Desmond	Henley
OKE, Domingo, Michael T.	London
SHEARS, Philip Antony	Cheltenham
STAUNTON, Eric Douglas	Kingston
STEIN, Gabriel	Jerusalem.

Elected to Associate Member

BATTLES, Robert Munroe, B.A.(Hons)	Ontario
CRAVEN, Arthur Swift	London
DEAN, Arthur William	Jerusalem
DIBDEN, Edgar Henry Kenneth, B.Sc.	Beckenham
ESLER, John Davis	Manchester
FOUWEATHER, Kenneth Walter Booth	London
GREEN, Charles William, M.B.E.	Manchester

Elected to Associate Member (Contd.)

KELLAWAY, Walter George, B.Sc.(Hons)	Exeter
LANCHESTER, Ronald Ainslie	London
MITCHELL, Robert John	Croydon
NAISH, Arthur John Brabant, M.A.	Hants.

Elected to Associate

ABRAM, Leo, B.Sc.	Manchester
ARTHUR, Herbert, M.Sc.	Bolton
AU YEUNG Wing Yip	High Wycombe
BARNES, Dennis Arthur Eustace	Sanderstead
BOND, William Harold, B.Sc.	Bexhill
BYARD, Arthur George	Bath
CUDLIP, Dennis Norman John	London
CUNNINGHAM-SANDS, James	Brighton
DUNSCOMBE, Mervyn John Morgan	Bristol
GREEN, Joseph Stephenson	London
HELLINGS, George Kenneth	W. Lothian
ISON, Harold Douglas Stuart	W. Lothian
JAGOE, Charles Malcolm, B.Sc.	Johannesburg
JOLLY, William Percy	Plymouth
LACOME, Bernard	Ottawa
LEIGHTON, John Donald	Penrith
LOWE, Edward, B.Sc.(Eng.)	Manchester
MALCOLM, Thomas	Renfrewshire
MARTIN, Albert Victor Jean	Paris
MUNRO, Martin	Glasgow
PRIESTLEY, Eric Holden, B.Sc.	Leigh-on-Sea
RICE, John	London
SCHEFERMANN, Albert Vernon, B.Sc.(Eng.)	Natal
SMITH, Kenneth David	London
THOMPSON, John de Morgan Campbell, B.A.	Oxford
TYLER, Eric	West Wickham
WATSON, James Douglas	Aberdeen

Elected to Graduate

WOODS, Alfred Walter Roy	Cape Town

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STUDENTSHIP REGISTRATIONS

The following were registered as Student members of the Institution at meetings of the Membership Committee held on September 5th and October 22nd, 1946, at which 61 proposals for Studentship were considered. The following registrations have now been confirmed by the General Council.

BARSKI, Stanislaw	Glasgow
BENN, David Donald	London
BENNETT, Anthony Robert	London
BRIGHTMAN, Barrie	Liverpool
BROWN, Patrick Hugh	London
BULL, Maurice Philip Goodwin	Burnham-on-Crouch
CAREY, Ronald Langer	Dublin
CHAGLA, Hassanate Rahimali	Karachi
CHYLAK, Bronislaw	Glasgow
CLARKE, Gerald Patrick	Dublin
COULTAS, Francis William	Swindon
COUPAR, Walter Knight	Cardiff
DAVIES, Richard	Brighton
DOWDALL, Cedric James	Bromley
FAHY, John Joseph	Co. Galway
FIGGEST, Harry John	London
FLAUM, Ronald Raphel	Ilford
GRAY, John	Folkestone
GREENE, Ernest Ruben	London
HERCUN, Zbigniew	Glasgow
HODGES, Norman Francis	Worcester
HOE, Gunn Chit	Penang
IMRIE, Thomas Colin	Gorleston
JOSHUA, Joshua Kattumbhagam	Travancore
KERR, David	Liverpool
KING, Kenneth Maurice	Exmouth
KIRKPATRICK, Mervyn Stewart, B.Sc.	N.S.W. Australia
LAWTON, Samuel Derek	Manchester
LEE, Alexander	Blythe Bridge, Staffs
LLOYD, Joy (Miss)	N.S.W. Australia
LOGIE, Frank McLean	Glasgow
LOH, Kwong Khoon	Penang
LUCZKA, Boleslaw	Glasgow
MACFARLANE, Neil	Ormskirk
MERZBACHER, Abraham Albert	Palestine
MURTY, Inspurapu Venkata, B.Sc.	Bombay
NORMAN, Geoffrey Percy	Epsom
O'CONNOR, John	Somerset
OGILVY, Alexander	Edinburgh
PARK, Alexander	Lanarkshire
PEARSON, Arthur William	Bournemouth
PHILPOTT, Stanley William David	Barkingside
PICKWELL, Leslie Harrison	Kenya Colony
PINTOFF, Edward	London
POWELL, Philip James	Bolton
RAJA RAO, T.K.	Bangalore
RAO, P. Laxminarayan	Bombay
READE, Norman Ivor	Reading
RILEY, Henry Phillips	N.S.W. Australia
RINDNER, Wilhelm	Palestine
ROMERO, Leroy Edon	London
ROW, Edward Francis	Topsham, Devon
SACHS, Maurice	Johannesburg
SLEPOWRONSKI, Romuald	Glasgow
STANKIEWICZ, Zygmunt	Glasgow
SURI, Narindra Kumar, B.A.	Rohtak, India
WAGENKNECHT, Mervyn Clarence	Queensland
WALE, Edward Frederick	Ilford
WILLIAMS, Peter Brundall	London
WILSON, Samuel Bernard Alexandria	Accra, Gold Coast
ZAMREJ, Andrzej	Glasgow

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NOTICES

Honours

The Council has tendered congratulations to **Group Captain George Norman Hancock** (Associate Member) on his appointment as a Commander of the Most Excellent Order of the British Empire (Military Division).

Previously, **Group Captain Hancock** had been Mentioned in Despatches.

Council has also congratulated the President, **Admiral the Viscount Mountbatten,** on his receiving the Grand Cross (Military) of the Order of George I from King George of the Hellenes for services during the war.

Royal Commission on Awards to Inventors

A Royal Commission has been appointed to determine the awards to be paid to inventors in respect of the user of their inventions, designs, drawings, or processes by Government Departments and Allied Governments during the war. The following have been appointed members of the Commission :—

The Rt. Hon. Lord Justice Cohen (Chairman).
K. R. Swan, O.B.E. (Deputy Chairman).
G. M. Bennett, Sc.D.
Lieut.-Col. Sir John Grenly, K.C.M.G., C.B.E.
Lieut.-Col. Sir George Lee, O.B.E., M.C.
Sir James Rae, K.C.B., K.B.E., J.P.
Sir William Stanier, F.R.S.
R. G. Lloyd, M.A., B.Sc., Barrister-at-Law (Secretary).

This Commission follows the general lines of that set up in 1919 and will normally sit in public.

The Royal Commission on Awards to Inventors has issued a pamphlet containing the relevant parts of its Terms of Reference, the Rules regulating the Procedure before the Commission, and General Instructions for the guidance of intending claimants before the Commission. Copies can be obtained from H.M. Stationery Office, or through any bookseller price 2d., by post 3d.

Graduateship Examination—May, 1947

The next examination will be held at Home and Overseas Centres on the 15th and 16th May, 1947.

Candidates residing in Great Britain, Northern Ireland and Eire should submit their entry forms not later than the 31st March, 1947. Those wishing to take the examination at Overseas Centres must submit their entry forms by the 1st January, 1946.

Radio Servicing Certificate Examination—May, 1947

The next examination will be held in principal centres throughout Great Britain and the first examination for the new Certificate will be held in May, 1947. Separate entry forms will be required from individual candidates and these can be obtained from the Secretary of the Board at 9 Bedford Square, London, W.C.1., or from the City and Guilds of London Institute, Department of Technology, 31 Brechin Place, South Kensington, London, S.W.7.

The dates of the written part of the examination are Tuesday the 6th May and Thursday the 8th May, 1947, and the practical test will take place on Saturday the 10th May, 1947.

The 1947 Convention of the Institution

A very large number of members have advised the Institution of their intention to be present at the Convention which will be held in Bournemouth, commencing on Monday, 19th May, 1947, and extending until the following Friday, 23rd May.

Council has now completed arrangements for the use of the Tollard Royal Hotel, Bournemouth, for the period of the Convention ; in view of the number of advices received, stating the intention of members to be present, it is likely that arrangements will be made with an additional hotel and so as to complete these arrangements, members are now receiving requests to give definite reservations.

Completion and return of these reservations will greatly help the responsible Committee in making arrangements ; reservations may be made for one, two, three or four nights.

The Committee also requests that members who are reading papers at the Convention should submit their manuscripts by the end of December next.

Obituaries

Council records, with deep regret, the sudden death of **Dudley William Watson** (Associate Member). Mr. Watson was killed in a motor accident a few days before the 21st Anniversary dinner, at which he intended to be present.

Elected an Associate in February, 1932, when he was serving with the Royal Navy in the Mediterranean Fleet, Mr. Watson was transferred to Associate Membership in July, 1944.

He had served in the Royal Navy for 30 years, and at the time of his death was 47 years of age.

The Council also very much regrets to record the death of **Clifford Warner** (Associate Member). Mr. Warner was successful in the Institution's Graduateship Examination in May, 1944, and in that year was elected an Associate, transferring to Associate Membership in February, 1946.

Mr. Warner died at the age of 31 years after a short illness.

Correction to Journal Advertisement

In an advertisement of Measuring Instruments (Pullin) Ltd., which appeared in a recent issue of the Journal, an incorrect price of £8 was given for the M.I.P. Series 100 Multi Range Test Set. Members should note that the correct price is £8 10s. 0d.

World Radio History

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HIS MAJESTY KING GEORGE VI

(Patron of the Institution.)

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