July 31, 1945. J. L. SNOEK ET AL 2,380,616

MAGNETIC SYSTEM

Filed May 3, 1941

Fig. 1

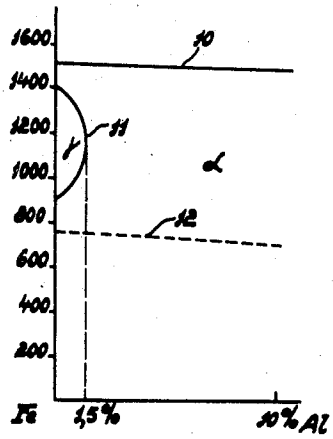



Fig. 2

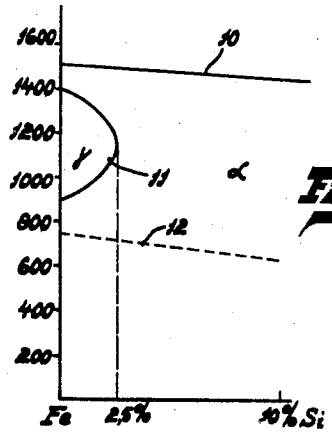



Fig. 3

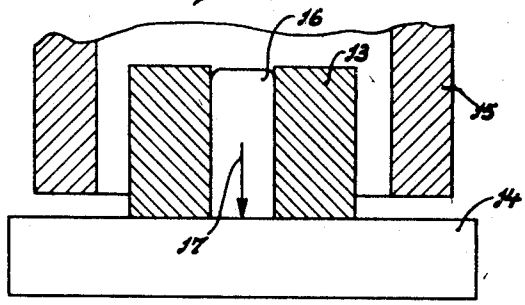



Fig. 4

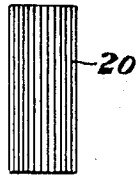



Fig. 6

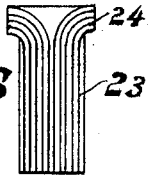
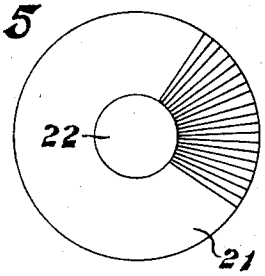



Fig. 5




INVENTORS
JACOB LOUIS SNOEK
LUITJE ALONS
BY H. S. Snover
ATTORNEY

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# UNITED STATES PATENT OFFICE

2,380,616

## MAGNETIC SYSTEM

Jacob Louis Snoek and Luitje Alons, Eindhoven, Netherlands; vested in the Alien Property Custodian

Application May 3, 1941, Serial No. 391,620
In the Netherlands June 20, 1940

1 Claim. (Cl. 22—200)

This invention relates to such magnet systems comprising one or more air gaps which either have an electric energization or are provided with one or more permanent magnets and which are built up from material of good magnetic conductivity at inductions higher than 10,000 gauss.

In such magnet systems the total weight of the system with a field intensity of from 6000 to 8000 gauss in the air-gap with the utilisation of a permanent magnet having a $(BH)_{max}$ lower than 2,000,000 will be substantially governed by the quality of the magnet steel used. In this case it is amply sufficient that the material of magnetic conductivity employed for the other parts of the circuit should be normally fired soft iron. The use of material having special magnetic properties does not give any particular advantage. If, however, in the construction of the system use is made of a magnet steel whose $(BH)_{max}$ is higher than 2,500,000, say 5,000,000, it is possible to ensure a considerable increase of the field intensity in the air gap or else a considerable saving in weight of the magnet system with identical field intensity in the air gap if the soft iron is replaced by material of higher conductivity at a high induction.

In the use of electrical energization of magnetic circuits also a considerable reduction of the quantity of magnetic material or else a reduction in energization can be obtained if at high inductions use is made of material having a particularly high permeability.

It is well-known that for the purpose of obtaining the maximum field intensity in the air gap or of reducing the dimensions of the circuit use may be made at given points of material exhibiting very high magnetic conductivity at inductions higher than 10,000 gauss. As an example of such material, it has been proposed to use an iron-cobalt alloy containing substantially equal parts of iron and cobalt. Because of the magnetic isotropy of the composing crystals this alloy has a high permeability in all directions independent of the crystal orientation.

According to the invention, the magnetic material used is an alloy containing a substantial proportion of iron, and thus having a positive crystal anisotropy, but having added to it one or more elements in such amounts that while cooling from the solidification temperature down to ordinary temperature the alloy only traverses the magnetic transition point (Curie point), the cooling of the fusion being directed in such manner that the solidification gives rise to directional crystals (columnar crystals) whose direction is selected with reference to that direction of the magnetic field which is to be expected in the magnet system.

It has been found that the orientation of these columnar crystals is such that a [1,0,0] direction or axis of the crystals extends parallel with the direction of the columns. Since with materials exhibiting positive crystal anisotropy the [1,0,0] direction has a very high magnetic conductivity at inductions which closely approach magnetic saturation, the direction of the columnar crystals with such material is always a direction of good magnetic conductivity. For other directions the magnetic conductivity is generally much lower due to the arbitrary orientation of the columnar crystals about their long axis.

The use of this material leads to a decrease of the magnetic leakage in the proximity of the air gap and thus to an increase of the field intensity in the air gap.

Besides, the iron alloy according to the invention is more easily machined than the well-known iron-cobalt alloys.

For parts of the magnetic circuit in which the lines of force are curvilinear, such as in pole pieces, the said alloy comprising directional columnar crystals cannot be used directly, since columnar crystals can only grow out along a straight line. By jumping-up or upsetting, the material may, however, be shaped into such form that the desired correlation of the crystal orientation to the direction of the lines of force is obtained. After the jumping-up operation the material must, however, be refired in order that the internal stresses produced may be removed.

In order that the invention may be clearly understood and readily carried into effect it will now be described more fully with reference to the accompanying drawing, in which:

Figs. 1 and 2 are diagrams of the variation of the solidification temperature and the transition points of iron-aluminium and iron-silicon alloys, respectively.

Fig. 3 shows a casting and cooling method with a view of obtaining directional columnar crystals.

Figs. 4, 5 and 6 show three forms of construction of elements thus cast of a magnet system.

Referring to Figs. 1 and 2, the line 10 indicates the variation of the solidification temperature of an iron-aluminium and an iron-silicon alloy respectively. The line 11 indicates, in either case, the variation of the transition points between gamma and alpha phases with temperature. On cooling from the solidification temperature to ordinary temperature an alloy of iron-aluminium contain-

ing more than 1½% of Al traverses no longer the gamma-phase but permanently remains in the alpha-phase. Thus, a crystal formation is set up which, with the correct manner of cooling, leads to columnar crystals. The line **12** indicates the variation of the magnetic transition point. This point is therefore always traversed during cooling so that the casting eventually cooled exhibits magnetically conductive properties, as is the case with an iron-silicon alloy comprising more than 2½% of silicon or an addition of silicon and aluminium in conjunction to the extent of more than 2%.

On the other hand, however, the addition of aluminium and silicon decreases the maximum induction obtainable of the alloy so that it is advisable that only this minimum quantity of aluminium or silicon should be used.

Fig. 3 illustrates the method of casting and directional cooling with a view of obtaining columnar crystals in the desired direction. A casting mould **13** having no bottom is placed on an artificially cooled copper plate **14**. The casting mould is surrounded by a furnace **15**.

The casting mould **13**, which in the present case is intended for the formation of a central pole of the magnet system of an electro-dynamic loudspeaker, has poured into it a quantity of a liquid iron-aluminium or iron-silicon alloy of the required composition. The furnace **15** is caused to assume a temperature of about 1200° C. so that the casting mould is itself also heated. The supply of heat to the furnace **15** is decreased so that the casting slowly cools entirely. The lowermost part of the casting **16** is in direct contact with the cooled plate **14**; hence all heat will be withdrawn from the casting in the direction of the arrow **17**.

There will be a formation of columnar crystals one of the axes of which extends parallel with the longitudinal axis of the cylindrical piece **16**. It has now been found that the [1, 0, 0] direction extends parallel with the long axis of the columnar crystals so that the maximum magnetic conductivity coincides with the direction of heat withdrawal, in the present case the longitudinal axis of the cylinder **16**. It is to be expected that the direction of the magnetic field in a central pole of an electro-dynamic magnetic system also extends along this axis.

Fig. 4 shows a form of construction of a cylindrical component member **20** of a magnet system. As described with reference to Fig. 3, this piece has cooled to such extent during solidification that the [1, 0, 0] direction of the columnar crystals extends parallel with the longitudinal axis of the piece. The piece should be placed in such manner in a magnetic circuit that the field also extends in the direction of the longitudinal direction. These conditions occur, for example, with the central pole of an electro-dynamic magnet system.

The form of construction shown in Fig. 5 comprises a disc-like plate **21** in which a central cylindrical aperture **22** is formed. Component members of this kind are used, for example, as the annular pole plate of an electro-dynamic magnet system. The magnetic field to be expected extends radially in such a pole so that the withdrawal of heat, during solidification of such a piece should occur at the outer circumference and in this case the [1, 0, 0] direction of the columnar crystals is also radial.

Since columnar crystals can only grow out along a straight line component members of magnet systems in which the direction of the magnetic field diverges from the straight line cannot be built up directly from material crystallised in columnar crystals, since the magnetic conductivity is substantially less outside the [1, 0, 0] direction of the crystal. As a matter of fact it is, however, possible for such component members to be adapted for the object sought if the material is given such a form by jumping-up that the direction of the columnar crystals is altered to accord with the direction to be expected of the magnetic field. It is necessary that after jumping-up the internal stresses set up by firing should be removed although this results in the particularly favourable crystal form being slightly lost.

Fig. 6 shows a form of construction of the central pole pin of an electro-dynamic magnet system. The uppermost part **24** which forms the pole piece proper is so deformed by jumping-up of the cylindrical pin **23** that the direction of the columnar crystals is bent-off radially to the sides so that it is altered to accord with the direction of the lines of force that laterally emerge towards air gap.

What we claim is:

A method of producing magnetically conductive material, according to which use is made of material of positive crystal anisotropy containing a major proportion of iron, which consists in adding to said material such component ingredients that while cooling from the solidification point down to ordinary temperature only the magnetic transition point is traversed and no phase-change occurs in the material as it solidifies, pouring said material in the fused state into a casting mould, and then cooling the cast material in a given direction in such a manner as to give rise to columnar crystals in the direction of maximum magnetic conductivity.

JACOB LOUIS SNOEK.
LUITJE ALONS.