PCT WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 5 : **H01F 7/02, G01R 33/38**	**A1**	(11) International Publication Number: **WO 94/18682** (43) International Publication Date: 18 August 1994 (18.08.94)

(21) International Application Number: PCT/GB94/00227

(22) International Filing Date: 7 February 1994 (07.02.94)

(30) Priority Data:
9302843.9 12 February 1993 (12.02.93) GB

(71) Applicant *(for all designated States except US)*: OXFORD INSTRUMENTS (UK) LIMITED [GB/GB]; Old Station Way, Eynsham, Witney, Oxon OX8 1TL (GB).

(72) Inventors; and
(75) Inventors/Applicants *(for US only)*: BEASLEY, Paul [GB/GB]; 3 Villeboys Close, Abingdon, Oxon OX14 3XP (GB). HANLEY, Peter [GB/GB]; Western Lodge, Forest of Dean, Gloucestershire GL15 5JQ (GB).

(74) Agent: GILL JENNINGS & EVERY; Broadgate House, 7 Eldon Street, London EC2M 7LH (GB).

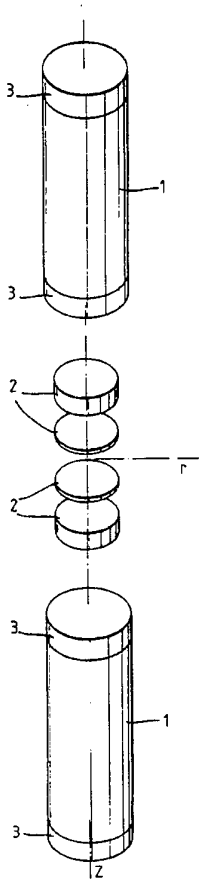
(81) Designated States: JP, US, European patent (AT, BE, CH, DE, DK, ES, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).

Published
With international search report.

(54) Title: PERMANENT MAGNET

(57) Abstract

A permanent magnet comprises a main body (1) of a first, magnetically hard ferromagnetic material, at least one pole of the main body carrying an auxiliary body (3) of a second magnetically hard ferromagnetic material. The first material is magnetically softer than the second material.



FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AT	Austria	**GB**	United Kingdom	**MR**	Mauritania
AU	Australia	**GE**	Georgia	**MW**	Malawi
BB	Barbados	**GN**	Guinea	**NE**	Niger
BE	Belgium	**GR**	Greece	**NL**	Netherlands
BF	Burkina Faso	**HU**	Hungary	**NO**	Norway
BG	Bulgaria	**IE**	Ireland	**NZ**	New Zealand
BJ	Benin	**IT**	Italy	**PL**	Poland
BR	Brazil	**JP**	Japan	**PT**	Portugal
BY	Belarus	**KE**	Kenya	**RO**	Romania
CA	Canada	**KG**	Kyrgystan	**RU**	Russian Federation
CF	Central African Republic	**KP**	Democratic People's Republic of Korea	**SD**	Sudan
CG	Congo			**SE**	Sweden
CH	Switzerland	**KR**	Republic of Korea	**SI**	Slovenia
CI	Côte d'Ivoire	**KZ**	Kazakhstan	**SK**	Slovakia
CM	Cameroon	**LI**	Liechtenstein	**SN**	Senegal
CN	China	**LK**	Sri Lanka	**TD**	Chad
CS	Czechoslovakia	**LU**	Luxembourg	**TG**	Togo
CZ	Czech Republic	**LV**	Latvia	**TJ**	Tajikistan
DE	Germany	**MC**	Monaco	**TT**	Trinidad and Tobago
DK	Denmark	**MD**	Republic of Moldova	**UA**	Ukraine
ES	Spain	**MG**	Madagascar	**US**	United States of America
FI	Finland	**ML**	Mali	**UZ**	Uzbekistan
FR	France	**MN**	Mongolia	**VN**	Viet Nam
GA	Gabon				

PERMANENT MAGNET

The invention relates to permanent magnets.

In the field of well logging, it has been found useful to employ permanent magnets in NMR well logging equipment such as that described in US-A-4350955 and WO-A-93/14413.

In view of the need in these applications to obtain closely controlled fields in the working region of sufficient homogeneity, it is usually necessary to use expensive magnetic materials such as Sm-Co. There is a desire therefore to use cheaper magnetic materials, in particular relatively softer (i.e. magnetically softer) magnetic materials. Unfortunately, with softer materials the lines of the magnetic flux leaving the magnet do not follow a desired and accurately controllable path leading to inhomogeneities in the working region.

In accordance with the present invention, a permanent magnet comprises a main body of a first magnetically hard ferromagnetic material, at least one pole of the main body carrying an auxiliary body of a second magnetically hard ferromagnetic material, the first material being magnetically softer than the second material.

With this invention, a cheaper permanent magnet is obtained by using the relatively softer material for the main body but an accurate and controlled flux path is achieved by providing the auxiliary body of a harder magnetic material.

The terms "soft" and "hard" for ferromagnetic materials are well known and are defined for example in "Electricity and Magnetism" by W J Duffin, published by McGraw Hill, 2nd Edition 1973, pages 336-337. A "soft" ferromagnetic material can be considered as one with a zero remanence and coercivity. In practice, soft ferromagnetics have a small coercivity, a low loss because of a narrow loop, and a high permeability. Pure iron and 3% S:Fe are typical soft ferromagnetic materials. The invention, however, is concerned with the use of hard ferromagnetic

materials which should have a relatively large remanence and coercivity. Examples include alloys of Fe, Al, Co and Cu, known generically as Alnico alloys (which comprise a group of "softer", hard ferromagnetic materials) and cobalt-rare earth materials such as cobalt-samarium and NdFeB which constitute "harder" hard ferromagnetic materials.

In a typical example, the first material may comprise Alnico and the second material Ne-Fe-B or SmCo.

An important application of the invention is in well logging equipment in which two permanent magnets according to the invention are positioned substantially coaxially with like poles facing each other. For example, the invention could be used in the arrangement of US-A-4350955 or in the invention of WO-A-93/14413.

An example of a well logging magnet assembly according to the invention will now be described and contrasted with a previous proposal with reference to the accompanying drawings, in which:-

Figure 1 is a perspective view of a known magnet assembly;

Figure 2 is a view similar to Figure 1 but showing an example of a magnet assembly according to the invention;

Figure 3 illustrates the variation of radial field with radius for the Figure 1 and Figure 2 examples respectively; and,

Figure 4 illustrates the variation of magnetic potential for different types of magnet.

The magnet or probe assembly shown in Figure 1 comprises a pair of main, permanent magnets 1 which are aligned and spaced apart along a Z axis. The poles of these magnets 1 facing each other are of the same sense. Arranged between the main magnets 1 is a set of permanent shim magnets 2.

A line 4 in Figure 3 illustrates the variation in the magnetic field due to the assembly shown in Figure 1 and it will be seen that a substantially homogeneous region 5 is

generated radially spaced from the magnet assembly itself. In practice, this region would be arranged to fall within an area to be examined using a NMR process and have sufficient homogeneity or uniformity for such a process, e.g. better than 100 ppm.

The ferromagnetic material used to make up the main magnets 1 will typically be a "hard" material which is not easily magnetised but at the same time is difficult to demagnetise. This material should be contrasted with a "soft" magnetic material which usually has a very narrow hysteresis loop, that is, low values of coercive force and high permeabilities. Within the group of hard magnetic materials, there are relatively soft materials, for example alnico, which would generate a field profile of the type shown by the line 4 in Figure 3. The advantage of this material is that it is cheap and readily available but it has a relatively low magnetic energy and is relatively easily demagnetisable.

The magnets 1 could also be made of a magnetic material at the harder end of the group of hard ferromagnetic materials, for example Ne-Fe-B or SmCo which have high magnetic energy and are difficult to demagnetise but which are very expensive.

Figure 2 illustrates an example of a magnet assembly according to the invention which it can be seen is generally similar to the Figure 1 example. However each of the magnets 1 is made of a relatively softer, hard magnetic material and is tipped with a magnetic material 3 which is relatively harder than the magnetic material making up the main body of the magnet 1. For example, the main body could be made of alnico while the tips 3 are made of Ne-Fe-B or SmCo.

The Table below illustrates the typical properties of suitable relatively softer, hard magnetic materials and relatively harder, magnetic materials.

	$(BH)_{max}(J/m^3)$	$H_c(A/m)$	$B_r(T)$
Relatively soft			
5% Chromium steel	2.4×10^3	5×10^3	0.94
Standard Alnico	1.4×10^4	4.2×10^4	0.8
Alnico (high remanence)	1.8×10^4	8×10^4	0.62
Relatively hard			
Cobalt-samarium CO_3Sm	1.5×10^5	1×10^6	1.50
NdFeB	2.8×10^5	1×10^6	1.20

Source: "Electricity and Magnetism", Duffin, W.J. (See above).

The invention provides a much more cost effective magnet with the relatively harder, hard magnetic material of the tips 3 only being used where it is actually required, i.e. at the ends of the main body of the permanent magnet 1 where the material is demagnetising. This can be explained by reference to Figure 4. Figure 4a illustrates one end of a permanent magnet 1 of the type shown in Figure 1 and made of a soft ferromagnetic material where it can be seen that the magnetic potential is not confined to the pole face of the magnet.

Figure 4b illustrates the same magnet made throughout of a much harder magnetic material and in this case the magnetic potential is confined to the pole face.

Figure 4c illustrates the end of a magnet 1 of the type shown in Figure 2 and it can be seen here that the diverging magnetic potential shown in Figure 4a has been redirected so that the majority of the magnetic potential is confined to the pole face thus achieving substantially the effect of the Figure 4b example but without the need to make the entire permanent magnet from the expensive, harder hard magnetic material.

The presence of the tipped material 3 has a secondary advantage which can be seen in Figure 3. A line 6 indicates the magnetic field profile and it can be seen

that the radial extent of the homogeneous region has significantly increased over the untipped version.

CLAIMS

1. A permanent magnet comprising a main body (1) of a first magnetically hard ferromagnetic material, at least one pole of the main body carrying an auxiliary body (3) of a second magnetically hard ferromagnetic material, the first material being magnetically softer than the second material.

2. A magnet according to claim 1, wherein the first material is chosen from the group comprising chromium steel, standard Alnico and Alnico (high remanence).

3. A magnet according to claim 1 or claim 2, wherein the second ferromagnetic material is chosen from the group comprising cobalt-samarium and NdFeB.

4. A magnet assembly comprising a plurality of magnets (1,2) whose magnetic axes are substantially aligned, at least two of the magnets (1) comprising permanent magnets according to any of the preceding claims arranged with like poles facing each other.

5. An assembly according to claim 4, wherein the magnets (1,2) generate magnetic fields which produce a resultant field in a working region radially spaced from the assembly which has sufficient homogeneity to carry out a nuclear magnetic resonance experiment.

Fig.1.

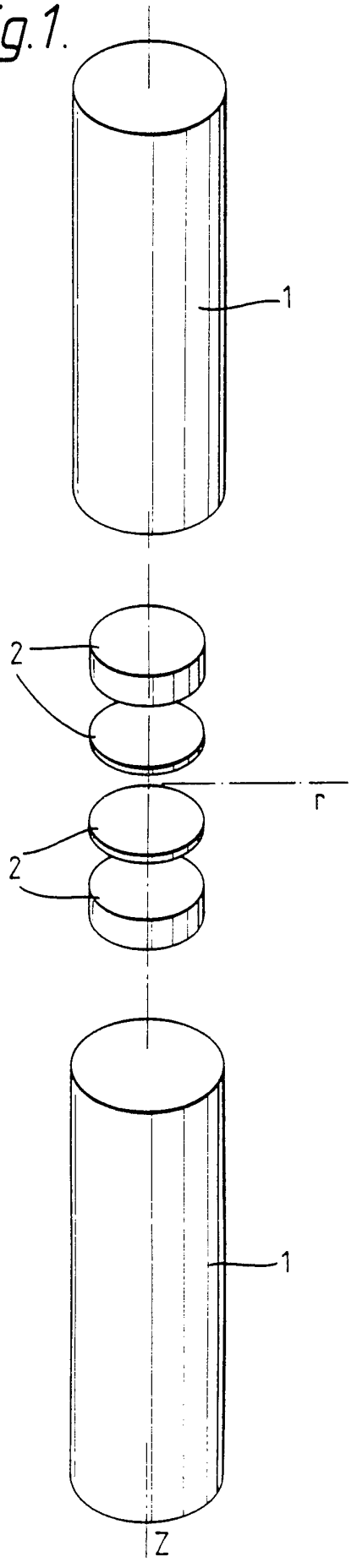
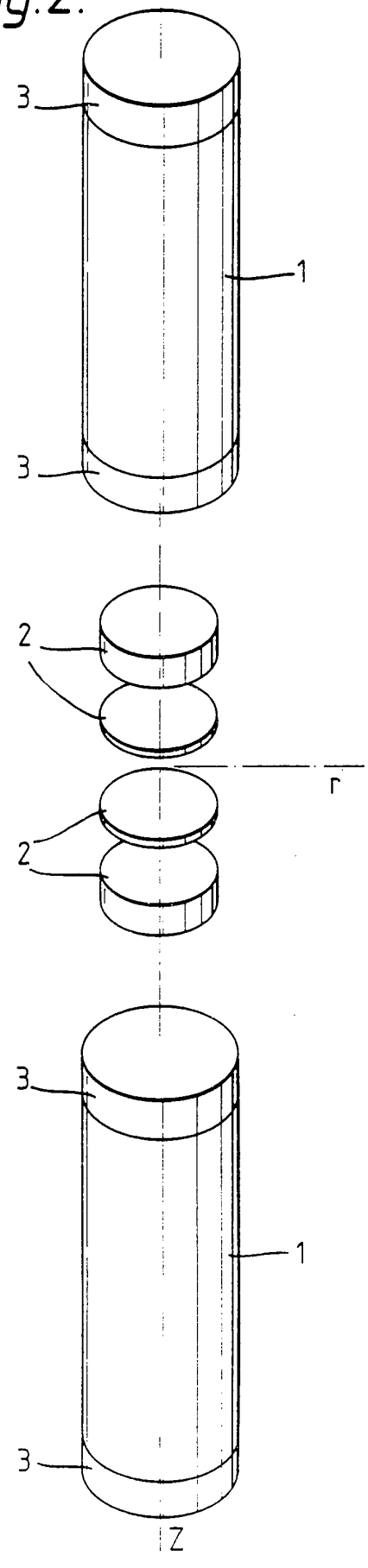


Fig.2.



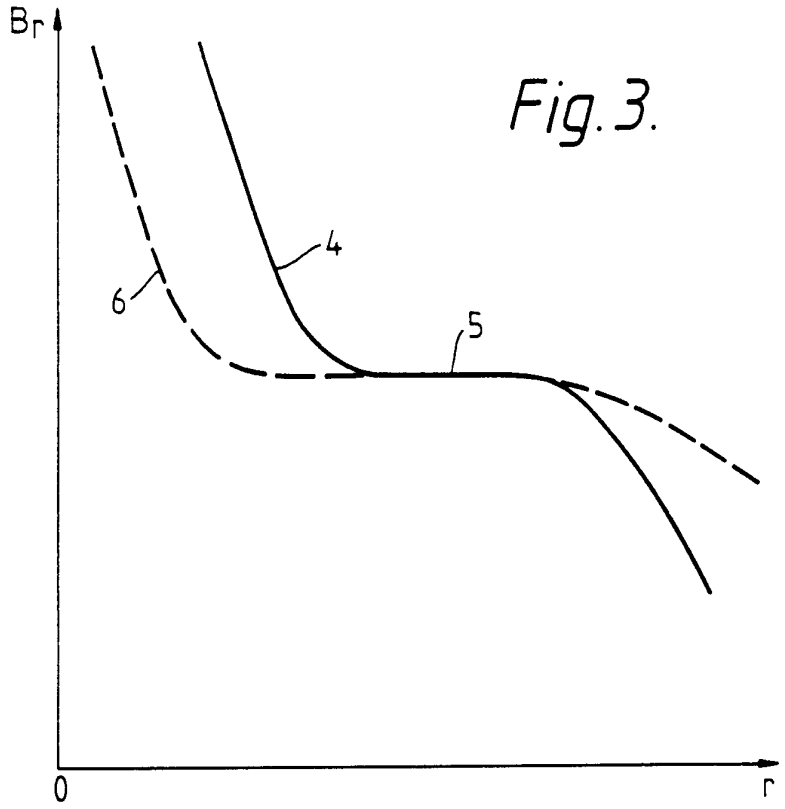
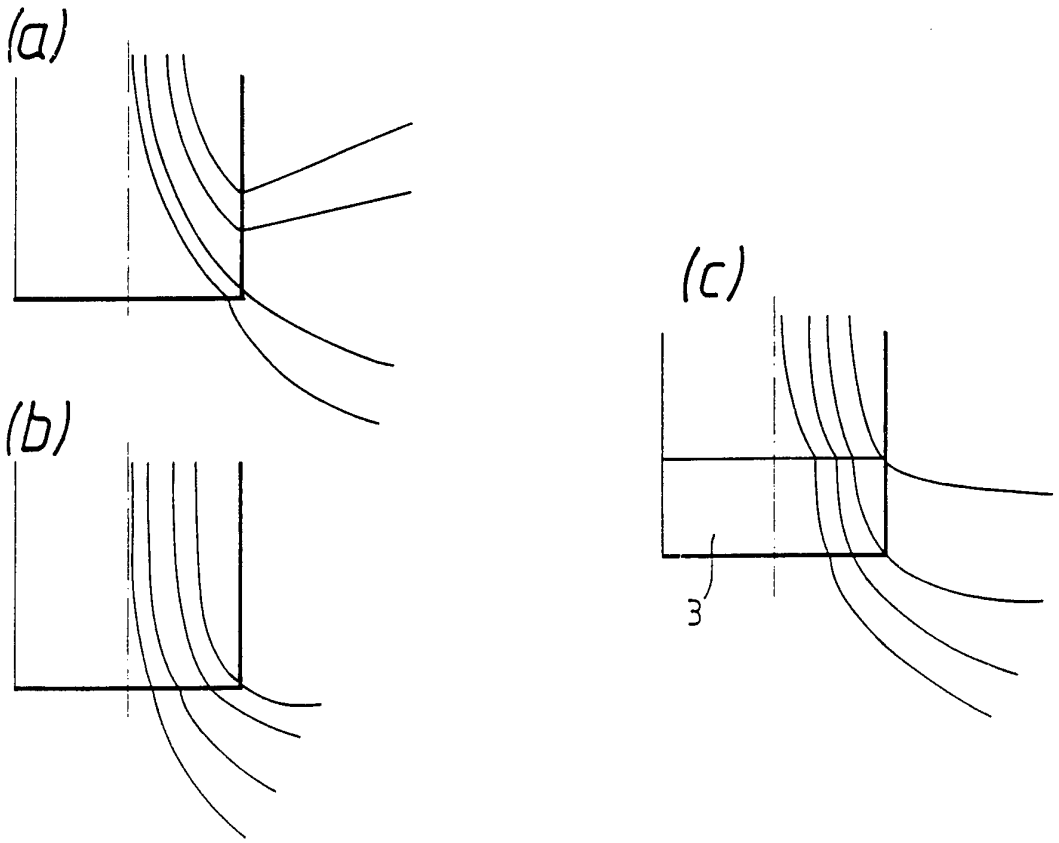


Fig.3.

Fig.4.



INTERNATIONAL SEARCH REPORT

Interr al Application No
PCT/GB 94/00227

A. CLASSIFICATION OF SUBJECT MATTER
IPC 5 H01F7/02 G01R33/38

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 5 H01F G01R

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X A	US,A,3 768 054 (W.NEUGEBAUER) 23 October 1973 see column 5, line 51 - column 6, line 21; figure 4	1-3 4,5
X	EP,A,0 479 278 (SHIN-ETSU CHEMICAL CO) 8 April 1992 see column 3, line 10 - column 4, line 15; claims 1,2.8; figures 1,2	1,3
X	PATENT ABSTRACTS OF JAPAN vol. 10, no. 376 (E-464) 13 December 1986 & JP,A,61 170 004 (NAMIKI PRECISION JEWEL CO LTD) 31 July 1986 see abstract	1,3

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search
15 April 1994

Date of mailing of the international search report
22. 04. 94

Name and mailing address of the ISA
European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+ 31-70) 340-2040, Tx. 31 651 epo nl,
Fax: (+ 31-70) 340-3016

Authorized officer
Decanniere, L

Form PCT/ISA/210 (second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

...formation on patent family members

Intern al Application No
PCT/GB 94/00227

Patent document cited in search report	Publication date	Patent family member(s)		Publication date
US-A-3768054	23-10-73	NONE		
EP-A-0479278	08-04-92	JP-A-	4144540	19-05-92
		JP-A-	4144541	19-05-92
		JP-A-	4144542	19-05-92
		US-A-	5148138	15-09-92