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(71) Applicant: TRW INC.
1900 Richmond Road
Lyndhurst Ohio 44124(US)

(72) Inventor: Shtarkman, Emil Meyer
27500 Franklin Road No.618
Southfield, Michigan 48034(US)

(74) Representative: Leiser, Gottfried, Dipl.-Ing. et al
Patentanwälte Prinz, Leiser, Bunke & Partner
Manzingerweg 7g 7
D-8000 München 60(DE)

(54) Fluid responsive to a magnetic field.

(57) A rheological fluid composition which is responsive to a magnetic field. The composition comprises magnetizable insulated, reduced carbonyl iron particles, a vehicle and a dispersant. The dispersant comprises fibrous carbon particles.

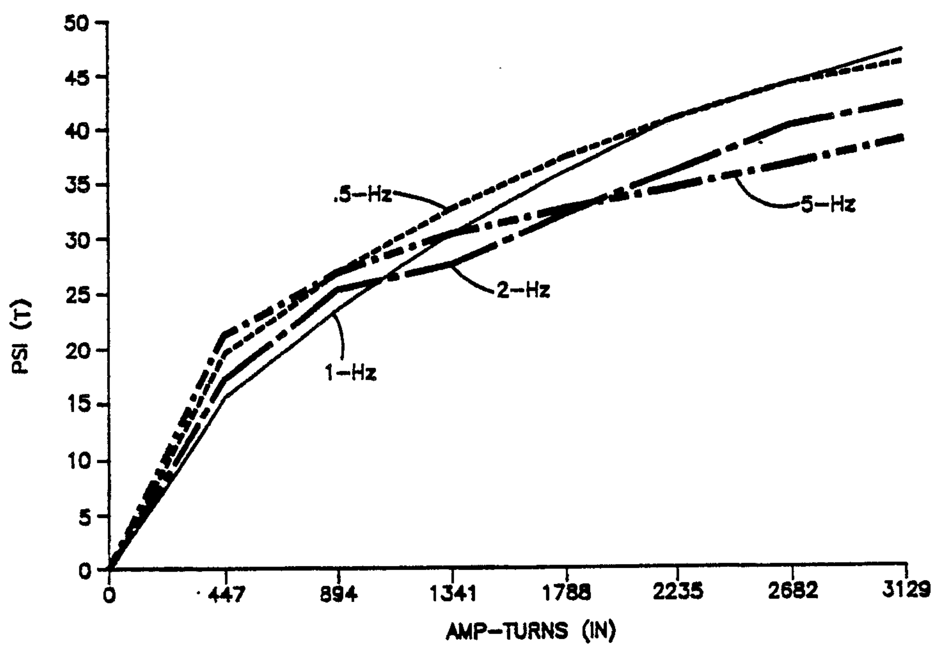

Fig.7

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FLUID RESPONSIVE TO A MAGNETIC FIELD

Background of the Invention

Technical Field

The present invention relates to a rheological fluid which is responsive to a magnetic field.

Background Art

Rheological fluids responsive to magnetic fields are known. Rheological fluids responsive to electric fields are also known. Such fluids are used in clutches, shock absorbers, and other devices. A characteristic of these rheological fluids is that, when they are exposed to the appropriate energy field, solid particles in the fluid move into alignment and the ability of the fluid to flow is substantially decreased.

Electric field responsive fluids and magnetic field responsive fluids include a vehicle, for instance a dielectric medium, such as mineral oil or silicone oil, and solid particles. In the case of a magnetic field responsive fluid, the solid particles are magnetizable. Examples, of solid particles which have been heretofore proposed for use in a magnetic field responsive fluid are magnetite and carbonyl iron. The fluid also may contain a surfactant to keep the solid particles in suspension in the vehicle.

A brochure published by GAF Corporation of Wayne, New Jersey, containing the code IM-785, captioned "Carbonyl Iron Powders", contains a discussion of carbonyl iron powders marketed by GAF Corporation. The iron particles are classified as "straight powders", "alloys", "reduced powders", and "insulated reduced powders". An example of a "straight powder" which is listed is a powder known as carbonyl "E".

A brief discussion is contained in the brochure concerning magnetic field responsive fluids. It is stated: "The spherically shaped particles of carbonyl iron presumably act like ball bearings in magnetic fluid coupling applications. The smallness of the iron particles gives larger surface area and more contacts than other powders and, hence, better transmission when locked. A lubricant and dispersant are generally required for best results." The discussion contains no disclosure concerning the type of carbonyl iron or dispersant to be employed in a magnetic field responsive fluid.

A publication entitled "Some Properties of Magnetic Fluids", J. D. Coolidge, Jr. and R. W. Halberg, AIEE Trans actions, Paper 55-170 (Feb. 1955), pages 149-152, discloses the use of different carbonyl irons in a fluid responsive to a magnetic field. The carbonyl irons disclosed include carbonyl "E" and carbonyl "SF", so-called straight powders, and carbonyl "L", carbonyl "HP", and carbonyl "C", all reduced powders. The article contains no conclusions concerning the preference of one carbonyl iron over another in a magnetic field responsive fluid.

A publication entitled "The Magnetic Fluid Clutch" by Jacob Rabinow, NBS Tech. Rep. No. 1213 (1948) [also, Trans. Amer. Inst. Elec. Eng. Preprint 48-238 (1948)] discloses the use of hydrogen reduced iron and carbonyl iron "SF", a "straight" powder as indicated above.

A publication entitled "The Magnetic Fluid Clutch" by S. F. Blunden, The Engineer, 191, 244 (1951) discloses the use of two grades of carbonyl iron, grade "ME" and grade "MC". Grade "ME" is said to be mechanically "hard" and grade "MC" is said to be mechanically "soft". Here also, no preference is given for one carbonyl iron over another.

A publication entitled "Further Development of the NBS Magnetic Fluid Clutch", NBS Tech. News Bull., 34, 168 (1950) discloses the use of carbonyl "E" powder in a magnetic fluid. Other compositional information concerning the fluid is also given.

Prior United States Patent No. 4,604,229 discloses the combination of a hydrocarbon carrier with 4%-10% magnetite, 8%-12% electrically conductive carbon black, and a dispersing agent. Powder magnetite (Fe_3O_4) is the fully oxidized magnetic oxide of iron, carbonyl iron, or iron-nickel. A similar disclosure is contained in United States Patent No. 4,673,997.

United States Patent No. 3,006,656 discloses a magnetic particle shock absorber using a composition which can contain carbonyl iron, a vehicle such as oil, and graphite. Carbonyl iron and magnetite are described as equivalant materials in the composition. It is not indicated in the patent which carbonyl iron was used.

United States Patent No. 2,519,449 discloses the combination of carbonyl E and solid, powdered graphite in a 50/50 blend. The continuous phase or dielectric medium in the composition is air. The graphite functions as a lubricant.

United States Patent No. 2,661,596 discloses a magnetically-responsive fluid which comprises 100 parts of iron carbonyl powder, 10 parts dielectric oil, and 2 parts dispersant, such as ferrous oleate. The form of carbonyl iron used is not disclosed. United States Patents Nos. 2,663,809 and 2,886,151 disclose the use of carbonyl iron in a fluid coupling. The form of carbonyl iron used is not disclosed.

United States Patent No. 2,772,761 discloses an electromagnetic clutch using a magnetically-responsive fluid comprising an iron powder which is an 80/20 blend of plast-iron and carbonyl "E", and a dispersant comprising 39% graphite, 46% naptha, and 15% alkyl resin, by way of example.

In United States Patent No. 4,737,886, an electroviscous fluid is disclosed. The fluid is responsive to an electric field. Fluids responsive to magnetic fields are also discussed. It is stated in the patent that such magnetic fields require "relatively large electric currents and substantial electrical circuits (for example, large coil windings) to cause the proper response in the fluid".

A publication entitled "Quest, Summer, 1986, pages 53-63, by Jack L. Blumenthal, published by TRW Corporation, discloses the composition and properties of a carbonaceous material comprising fibrous carbon particles manufactured in a carbon disproportion reaction. The carbon fibers of the individual particles are intertwined forming a porous structure. The particles are capable of incorporating and suspending other finely divided powders in fluids.

Summary of the Invention

It is an object of the present invention to provide an improved rheological magnetic field responsive fluid which has a high speed of responsiveness to a magnetic field and which magnetic field may be created by a relatively low current flow through a small number of coil windings.

The fluid composition of the present invention comprises a vehicle and solid magnetizable particles suspended in the vehicle. Preferably, the fluid composition also contains a dispersant. In accordance with the present invention, the magnetizable particles are insulated, reduced carbonyl iron particles.

The present invention also resides in the discovery of a novel dispersant for a magnetic field responsive fluid, which dispersant is fibrous carbon particles, each particle of which comprises intertwined carbon fibers having a length-to-diameter ratio in the range of about 10:1 to about 1,000:1. Preferably, the fibers have a surface area of about 300 square meters per gram.

Brief Description of the Drawings

Further features of the present invention will become apparent to those skilled in the art to which the present invention relates from reading the following specification with reference to the accompanying drawings, in which:

Fig. 1 is a view of an apparatus which uses a rheological fluid in accordance with the present invention;

Fig. 2 is a sectional view taken along line 2-2 of Fig. 1;

Fig. 3 is a plan view of a blade used in the apparatus of Fig. 1;

Fig. 4 is a perspective view of an electromagnet used in the apparatus of Fig. 1;

Fig. 5 is an enlarged sectional view taken along line 5-5 of Fig. 4;

Fig. 6 is a plan view of the electromagnet of Fig. 4; and

Fig. 7 is a graph illustrating operational characteristics of the apparatus of Fig. 1.

Description of a Preferred Embodiment

The fluid composition of the present invention comprises a vehicle, such as mineral oil, silicone oil, or CONOCO LVT oil; an insulated reduced carbonyl iron; and preferably a dispersant of intertwined carbon fiber particles.

Carbonyl iron is manufactured by the decomposition of iron pentacarbonyl $Fe(CO)_5$. This process produces a spherical unreduced particle which has what is referred to as an onion-skin structure due to minute carbon deposits in alternating layers. The carbon content is about 1%. Reduction or de-carburization of the unreduced powder is carried out by exposing the powder to a hydrogen atmosphere, followed by compaction. This destroys the onion-skin structure and produces a composite of randomly arranged minute iron particles. The carbon content of the powder is about 0.075%.

In accordance with the present invention, the reduced powders have an insulation coating to prevent particle-to-particle contact. The particles are physically soft and compressible. Their shape is spherical. Reduced particles which are also insulated are marketed by GAF Corporation under the designations "GQ-4" and "GS-6". The following Table 1 gives physical and chemical properties for the insulated, reduced powders:

TABLE 1

GAF Carbonyl Iron Powder Type	Avg. Particle Diameter Microns (Fisher Sub-Sieve Sizer)	Apparent Density g/cm^3	Tap Density g/cm^3	%Fe (Min)	%C (Max)	%O (Max)	%N (Max)
GQ-4	4-6	2.0-3.0	3.0-4.0	99.0	0.1	0.3	0.1
GS-6	3-5	1.2-2.2	2.2-3.2	99.0	0.1	0.3	0.1

The data of Table 1 can be found on page 4 of the GAF brochure mentioned above, bearing the identifying code IM-785. The disclosure of the GAF brochure is incorporated herein by reference.

The insulation coating can be any particle-coating agent capable of insulating the carbonyl iron particles and preventing interparticle eddy currents or dielectric leakage. The insulation coating on the "GQ-4" and "GS-6" powders is a discontinuous layer of silicon oxide, primarily silicon dioxide. Silicon comprises about 6.9 atomic percent of the surface composition of the carbonyl iron particles. Silicon dioxide is very dielectric, and provides electrical resistivity.

It is believed that the reduced powders have a more random arrangement of minute iron particles than the so-called "straight" powders, and that this results in a lower hysteresis effect than with the "straight" powders. The insulation on the powders enhances the efficiency of the magnetic fluid in reducing parasitic eddy currents around the particles, which eddy currents could adversely affect the magnetic field strength in the fluid.

When the magnetic fluid composition of the present invention is used in certain coupling applications, such as in a clutch, the moving parts of the clutch stir the composition effectively and no dispersant is required. This is particularly the case where permanent magnets are used, and thus the clutch is never demagnetized. In such an instance, settling of the iron particles presents no problems.

In those applications where a dispersant is required, the composition of the present invention can employ any dispersant or surfactant conventionally employed with a fluid responsive to a magnetic field. Examples of surfactants employed in the prior art are: dispersants, such as ferrous oleate or ferrous naphthenate; aluminum soaps such as aluminum tristearate or aluminum distearate; alkaline soaps, such as lithium stearate or sodium stearate, employed to impart thixotropic properties; surfactants such as fatty acids, e.g., oleic acids; sulfonates, e.g., petroleum sulfonate; phosphate esters, e.g., alcohol esters of ethoxylated phosphate esters; and combinations of the above.

A preferred dispersant material is fibrous carbon. Fibrous carbon is a carbon particulate in which each carbon particle is composed of a large number of intertwined small carbon fibers. One such fibrous carbon is "TRW Carbon", trademark, TRW corporation. The "TRW Carbon" is disclosed in the publication "Quest", mentioned above. The disclosure of this publication is incorporated herein by reference.

The "TRW Carbon" is made in a catalytic carbon disproportion reaction in which a low heating value fuel gas or other source of carbon is used as the reaction feed. The individual fibers in the fibrous carbon are from 0.05 to 0.5 microns in diameter and up to several thousand times as long as they are thick. A preferred average length to diameter ratio is in the range of about 10:1 to about 1,000:1. Most of the fibers contain a single crystallite of a ferrous metal (such as iron, nickel, cobalt, or their alloys) or ferrous metal carbide. The carbon fibers grow during the disproportion reaction from opposite faces of the single crystallites. The crystallite usually represents 1 to 10 percent by weight of the material, but can be reduced to as low as 0.1 percent by acid leaching. Except for the crystallite, the fibers are almost pure carbon plus a small amount of hydrogen such as 0.5 to 1 percent. The fibers may be either hollow or porous.

Intertwining of the fibers into aggregated particles occurs during the disproportion reaction. The intertwining and formation of small interstices in the carbon particles allows the fibrous carbon to incorporate the micron-sized carbonyl iron paticles and mechanically suspend the carbonyl iron particles dispersed in a fluid carrier. The fibrous carbon particles have a large surface area of about 300 square meters per gram and a low bulk density of about 0.02 to about 0.7 grams per milliliter. Pore volume of the fibrous carbon particles typically is about 0.5 to about 0.9 milliliters per gram.

The fibrous carbon particles have fluid-like characteristics and flow like a liquid similar to graphite. When placed in a liquid vehicle, in a dispersing amount, they thicken or gell the vehicle preventing settling of the carbonyl iron particles. They form a thixotropic mixture with the vehicle which has good flow properties when exposed to shear. The viscosity of the thixotropic mixture is relatively independent of temperature.

The vehicle of the composition of the present invention can be any vehicle conventionally employed in a fluid responsive to a magnetic field. Examples of suitable vehicles are set forth in the prior art referenced above. Preferably, the vehicle employed is an oil having a viscosity at about 100° F between one and 1,000 centipoises. Specific examples of suitable vehicles and their viscosities are set forth in the following Table 2:

TABLE 2

Vehicle	Viscosity
Conoco LVT oil	1.5 centipoises at 100° F
Kerosene	1.9 centipoises at 81° F
Light paraffin oil	20 centipoises at 100° F
Mineral oil (Kodak)	40 centipoises at 100° F
Silicone oil	700 centipoises at 100° F

The proportions of ingredients employed in the composition of the present invention can vary over wide ranges. In those compositions requiring the use of a dispersant, the dispersant is employed in an amount effective to disperse the carbonyl iron particles and to maintain such particles in suspension in the vehicle. The amount of vehicle used is that amount necessary for the vehicle to function as the continuous phase of the composition. Air pockets in the composition should be avoided. The remainder of the composition is essentially the carbonyl iron powder. Preferably, the carbonyl iron to dispersant weight ratio is about 90:10 to about 99.5:0.5. The weight of the vehicle is about 15% to about 50% of the combined weight of the carbonyl iron and dispersant.

Particular ratios selected depend upon the application for the composition of the present invention. Preferably, the proportions are such that the composition of the present invention has thixotropic properties and is mechanically stable in the sense that the compositions remain homogeneous for prolonged periods of time.

In those compositions consisting essentially of insulated, reduced carbonyl iron and vehicle, the vehicle is employed in an amount effective so that it is the continuous phase in the composition. The specific amount used is dependent upon the properties of the vehicle, such as viscosity. A preferred weight ratio of vehicle to carbonyl iron is in the range of about 15%-55% vehicle to about 85%-45% carbonyl iron.

Example

In this Example, 99% by weight carbonyl iron and 1% by weight TRW carbon were mixed together. A mixture of 20% by weight of Conoco LVT oil and 80% by weight of the carbonyl iron and TRW carbon mixture was then homogenized in a homogenizer for 12-24 hours under vacuum. Intensive mixing in the homogenizer functioned to thoroughly mix the TRW carbon and carbonyl iron with entrapment of the carbonyl iron in the fibrous structure of the TRW carbon. It also effected thorough wetting of all surfaces of the TRW carbon and carbonyl iron with LVT oil. The particular carbonyl iron employed was carbonyl "GS-6", trademark GAF Corporation.

A test apparatus was constructed to determine the coupling load characteristics of the composition under various conditions. The test apparatus is similar in construction to the shock absorber disclosed in co-pending Application Serial No. 339,126, filed April 14, 1989, assigned to the assignee of the present application. The test apparatus is illustrated in the drawings of this application.

Referring specifically to Figs. 1 and 2, the test apparatus 12 comprises a non-magnetic aluminum housing 14. The housing 14 comprises first and second housing sections 16 and 18 (Fig. 2) which are fastened together by bolts 20. The housing sections 16, 18 define a fluid chamber 22 (Fig. 2) in the right end portion 24, as viewed in the drawings, of the housing. A shaft 26 extends through the left end portion 28, as viewed in the drawings, of the housing 14. The shaft 26 has shaft end sections 30 and 32 (Fig. 2) and a shaft center section 34. The shaft 26 rotates in bearing assemblies 36 and 38. Seals 40, 42 prevent fluid leakage along the shaft 26.

The center section 34 of the shaft 26 has a square configuration. A rotor blade 44 is fixed to the center section 34 so as to rotate with the shaft. The rotor blade 44 has a configuration as shown in Fig. 3. It extends radially from the shaft center section 34 into the fluid chamber 22.

The right-end portion 24 of the housing 14 has an opening 45 in which holder 46 for an electromagnet 54 is located and an opening 47 in which a holder 48 is located for an electromagnet 56. The holders 46, 48 have chambers 50, 52, respectively, in which the electromagnets 54, 56 are located.

The holders 46, 48 are secured to the housing sections 16 and 18 by means of brackets 58, 60, respectively. Screws 62, 64 hold the coil holders 46, 48 to the brackets 58, 60, respectively. Screws 66 (Fig. 1) hold the brackets 58, 60 to the housing sections 16, 18. The electromagnets 54, 56 can be chemically bonded to the holders 46, 48 or alternatively fastened to the holders by screws not shown. The non-magnetic material of the housing 12 and holders 46, 48 minimizes leakage of magnetic flux from the electromagnets 54, 56.

Figs. 4, 5 and 6 show details of the electromagnets 54, 56. Each electromagnet 54, 56 comprises a soft iron core 70 around which an electrical coil 72 is wound. The electrical coil 72 is covered with an encapsulating material such as an epoxy. Each of the electromagnets 54, 56 has a pair of wire ends 74. An outer soft iron pole 76 extends around the coil 72.

The electromagnets 54, 56 are mounted so that the poles of the electromagnets 54 face the poles of the electromagnet 56. The rotor blade 44, and the fluid chamber 22, are positioned between the electromagnets 54, 56. The spacing between one electromagnet and the blade is about 0.25 millimeters. The blade thickness is about two millimeters. In the present Example, the center core 70 of each electromagnet has a diameter of 1.50 inches. The outside diameter of each electromagnet is three inches. The outer pole 76 has a radial thickness of 0.1875 inches. Each electromagnet coil 72 has 894 wire turns.

When the coils 54, 56 are energized, each electromagnet generates its own magnetic field. Lines of magnetic flux are established between the two electromagnets. The lines of magnetic flux pass through the fluid in the fluid chamber 22 and through the rotor blade 44. These lines of magnetic flux act on the fluid in the fluid chamber 22 to vary the resistance to movement of the rotor blade 44 in the fluid.

To test the coupling strength of the magnetic fluid of the present invention, when exposed to a magnetic field, the shaft 26 was connected by means of arms 78 (Fig. 2) to a torque motor (not shown). The torque motor was associated with a means for measuring torque. Different currents were applied to the electromagnets 54, 56. The torque required to turn the blade in the magnetic fluid in chamber 22, under the influence of the magnetic field, was measured. The results of the test are shown in Fig. 7.

Referring to Fig. 7, the current flow in amp-turns is plotted along the X axis. The current employed varied from zero to about three and one-half amps (3129 amp turns). The resistance to turning of the blade 44 in terms of pounds per square inch is given along the Y axis and varied from about zero to about 50 psi. This measurement was obtained by dividing the pounds of torque required to turn the blade by the blade surface area exposed to the magnetic responsive fluid in chamber 22. Also measurements were taken at different frequencies of oscillation varying from 0.5 Hertz to 5 Hertz.

As shown, the resistance to turning at zero current was nearly zero indicating excellent lubricating properties of the composition of the present invention. The resistance to turning increased rapidly with increase in current flow up to about 38-48 pounds per square inch at 3129 amp-turns (about 3 1/2 amps). The measurements were taken at different frequencies and all measurements followed quite similar curves indicating that the composition of the present invention is relatively frequency insensitive.

In contrast, a conventional magnetic field responsive fluid would require currents of substantially greater magnitude to achieve equivalent coupling strength. That is, a conventional magnetic field responsive rheological fluid might provide a coupling strength of less than one pound per square inch with a magnetic field generated with a current flow of about 3129 amp-turns. Thus, the rheological fluid of the present invention permits the construction of very compact, magnetic field responsive fluid devices having a relatively high coupling strength.

From the above description of a preferred embodiment of the invention, those skilled in the art will perceive improvements, changes and modifications. Such improvements, changes and modifications within the skill of the art are intended to be covered by the appended claims.

Claims

1. In a rheological fluid composition which is responsive to a magnetic field, which fluid composition comprises a vehicle, and a solid magnetizable particulate suspended in said vehicle, the improvement wherein said magnetizable particulate is an insulated, reduced carbonyl iron.
2. The fluid composition of claim 1 wherein said composition comprises a dispersant for dispersing the magnetizable particulate throughout the vehicle, the vehicle being the composition continuous phase.
3. The fluid composition of claim 2 wherein said dispersant comprises fibrous carbon particles, the fibers of which have a length-to-diameter ratio in the range of about 10:1 to about 1,000:1.
4. The fluid composition of claim 3 wherein said vehicle has a viscosity in the range of about one-1,000 centipoises at 100 °F.
5. The fluid composition of claim 4 wherein said composition comprises:
a mixture of carbonyl iron and a dispersant comprising about 0.5%-10% by weight of said dispersant and about 90% to 99.5% by weight of said carbonyl iron; and
a vehicle in the amount of about 15%-50% of the weight of said mixture.
6. In a rheological fluid composition which is responsive to a magnetic field, which fluid composition comprises a vehicle, a solid magnetizable particulate suspended in said vehicle, and a dispersant, the improvement wherein said dispersant comprises fibrous carbon particles the fibers of which have a length-to-diameter ratio in the range of about 10:1 to about 1,000:1.
7. The fluid composition of claim 6 wherein said carbon fibers have a surface area of about 300 square meters per gram.
8. The fluid composition of claim 7 wherein said magnetizable particulate is an insulated, reduced carbonyl iron.
9. The fluid composition of claim 8 comprising a mixture of carbonyl iron and a dispersant comprising about 0.5%-10% by weight of said dispersant and about 90% to 99.5% by weight of said carbonyl iron, and a vehicle in the amount of about 15%-50% of the weight of said mixture.

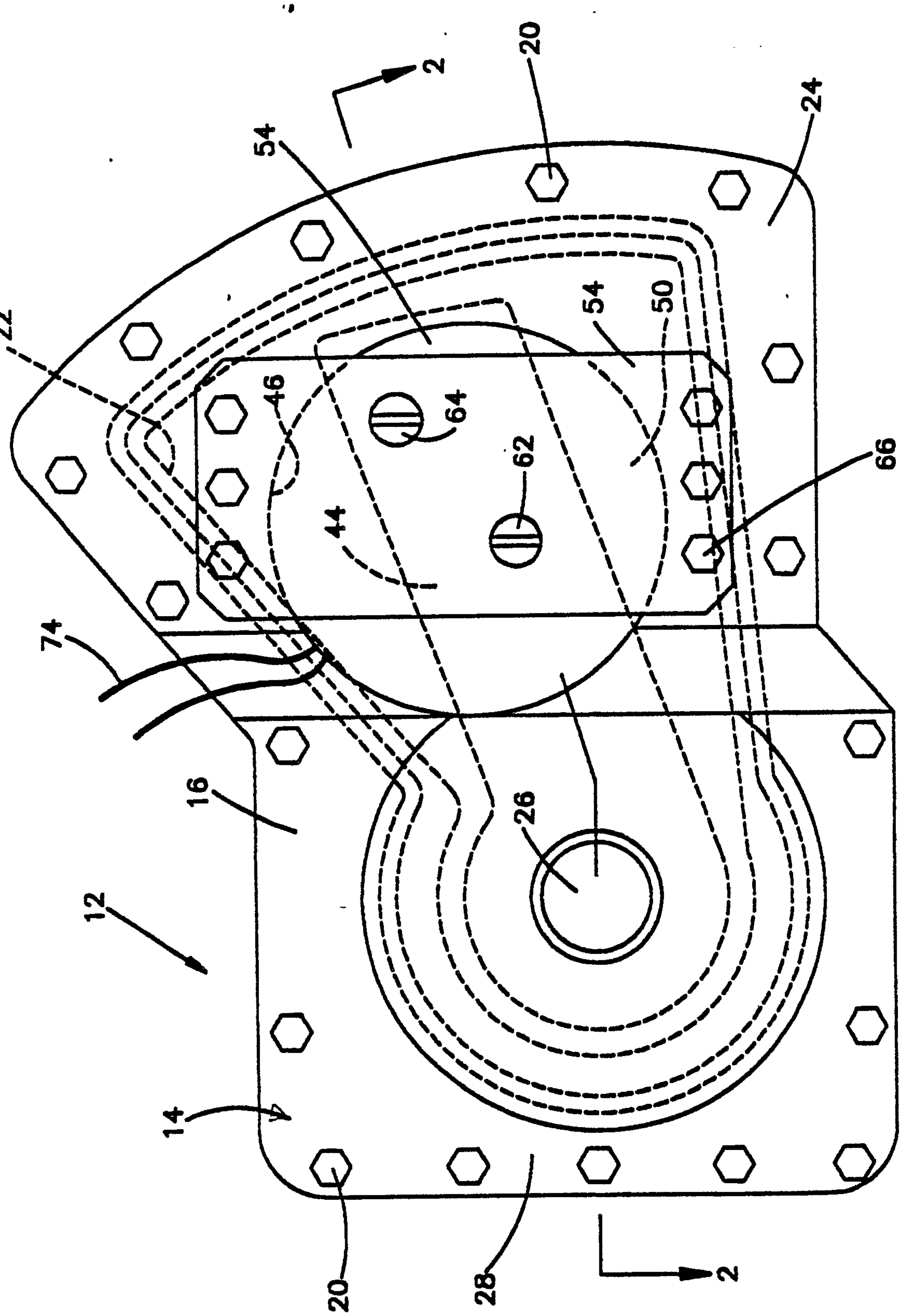

Fig.1

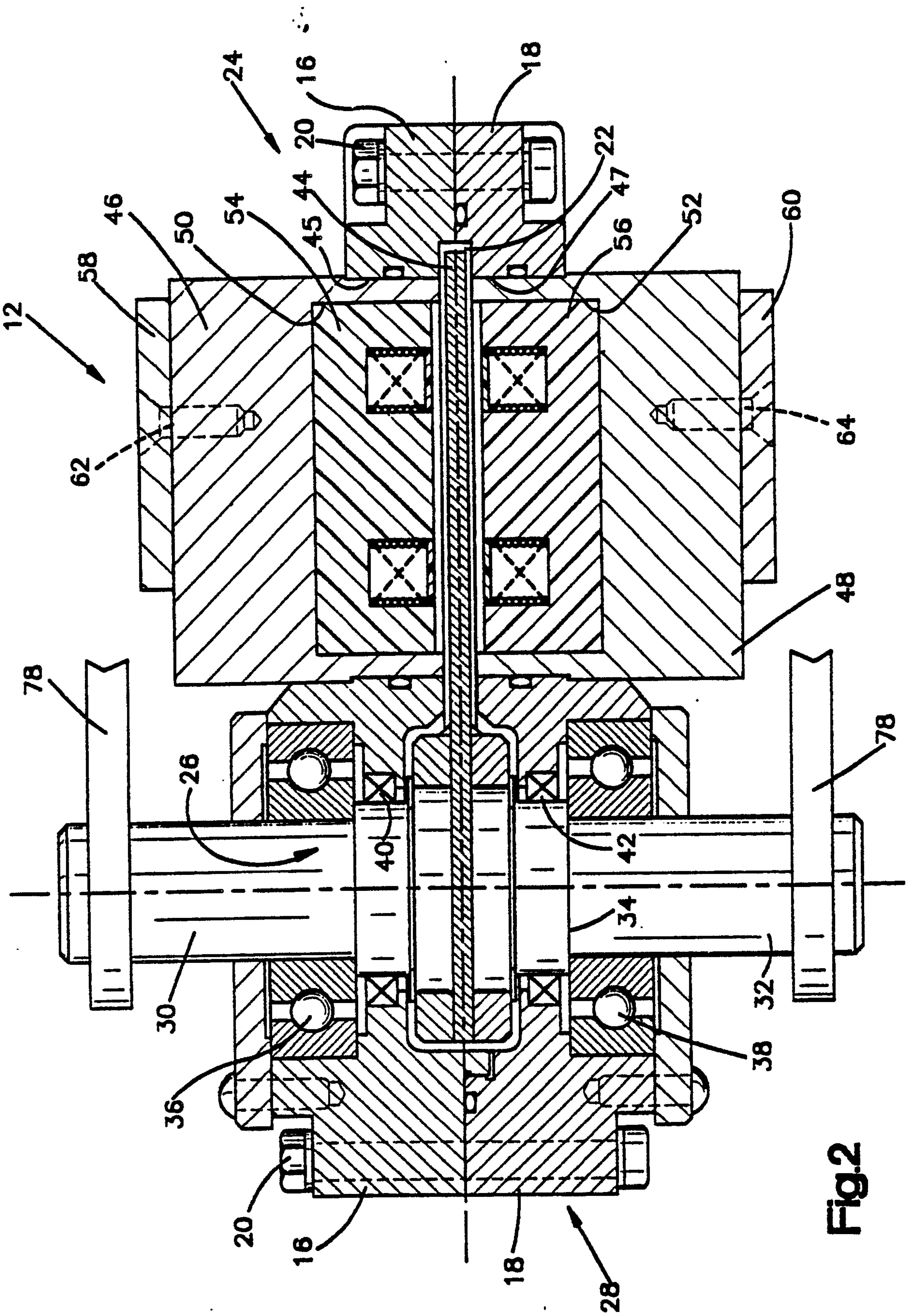
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Fig.2

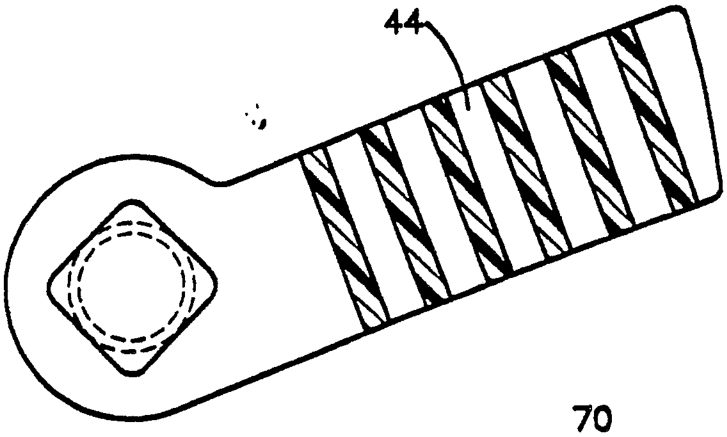

Fig.3

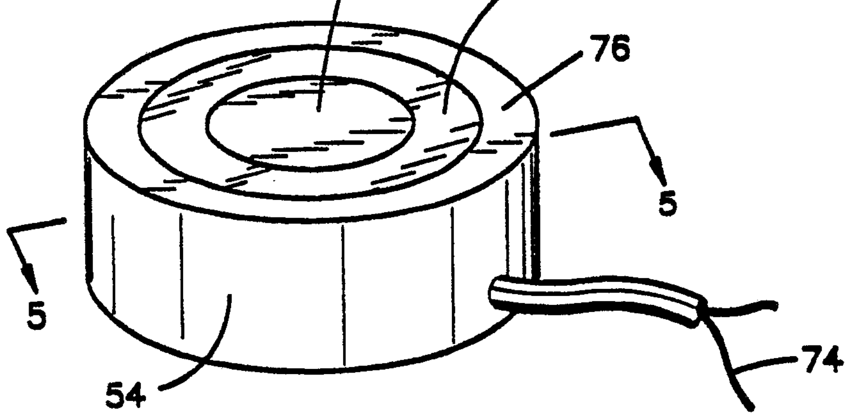

Fig.4

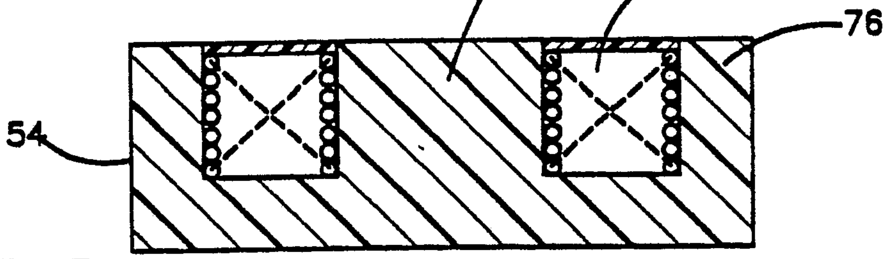

Fig.5

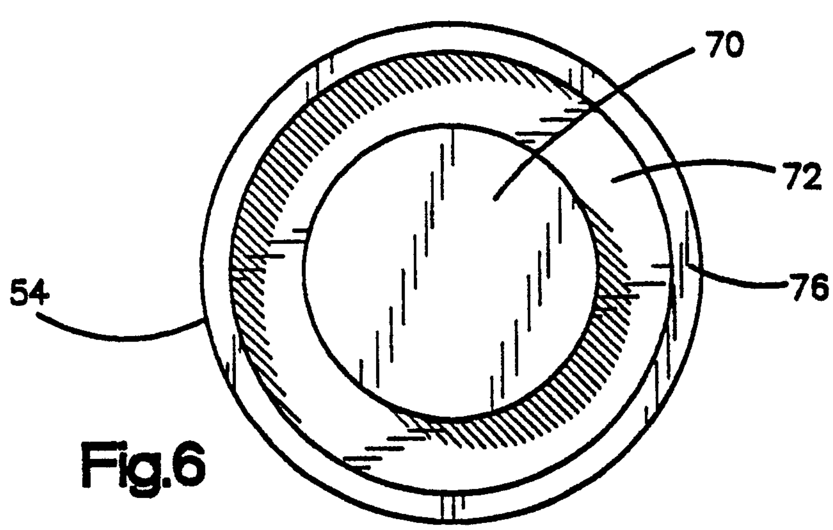

Fig.6

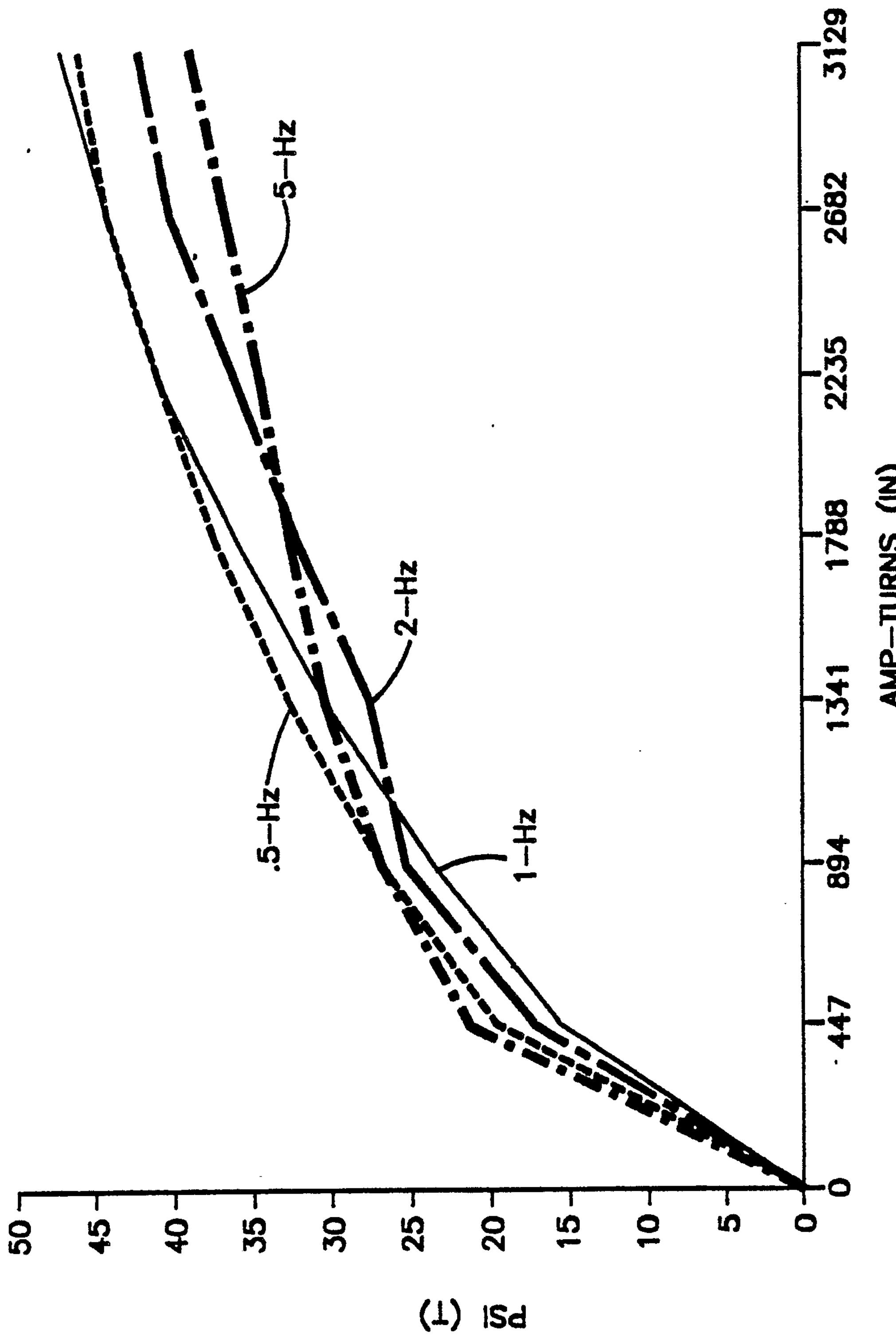
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Fig.7