June 2, 1964 O. M. STUETZER 3,135,208

MAGNETOHYDRODYNAMIC PUMP

Filed April 30, 1962 2 Sheets-Sheet 1

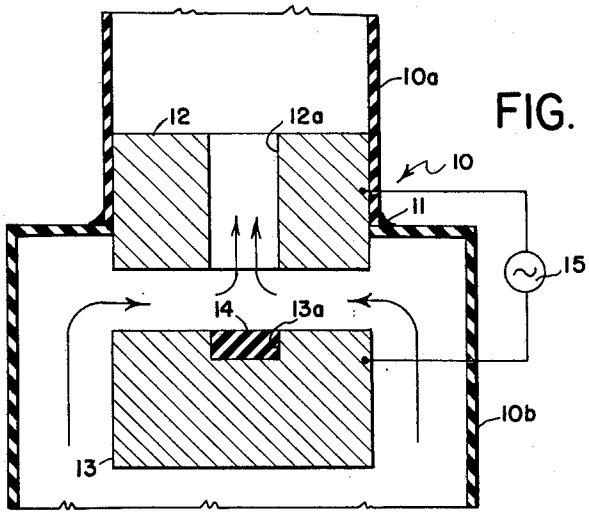


FIG. 1

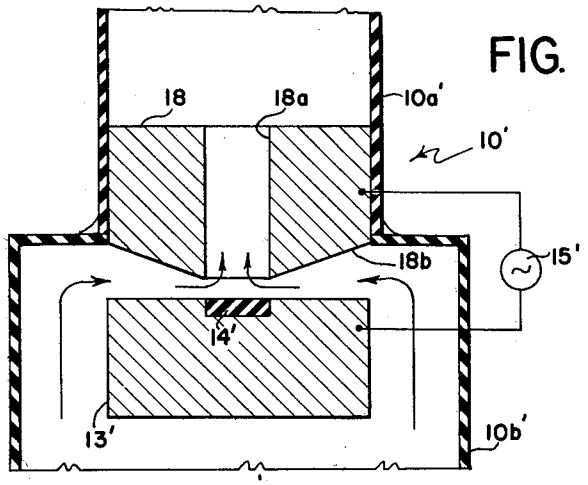


FIG. 2

INVENTOR.
OTMAR M. STUETZER
BY Allen M. Sutton
ATTORNEY

June 2, 1964 O. M. STUETZER 3,135,208

MAGNETOHYDRODYNAMIC PUMP

Filed April 30, 1962 2 Sheets-Sheet 2

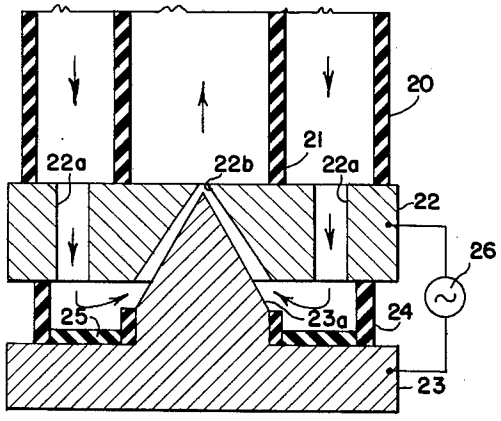


FIG. 3

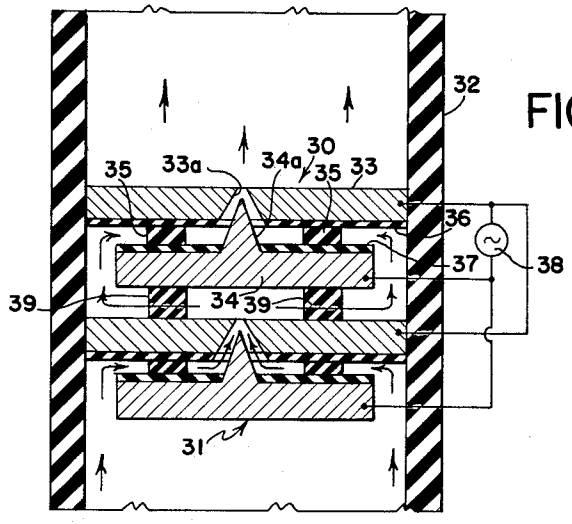


FIG. 4

INVENTOR.
OTMAR M. STUETZER
BY
Allen M. Sutton
ATTORNEY

United States Patent Office 3,135,208 Patented June 2, 1964

3,135,208

MAGNETOHYDRODYNAMIC PUMP

Otmar M. Stuetzer, Hopkins, Minn., assignor, by mesne assignments, to Litton Systems, Inc., Beverly Hills, Calif., a corporation of Maryland

Filed Apr. 30, 1962, Ser. No. 191,235
4 Claims. (Cl. 103—1)

This invention relates to pumps, and, more particularly, to an improved pump for pumping conductive fluids, which operates on the principles of magnetohydrodynamics.

Magnetohydrodynamics is that field of science which deals with the reactions induced in an electrically conductive fluid in the presence of a magnetic field. It is, in effect, a union of two branches of physical science, one dealing with fluid flow and the other with electromagnetic fields. For a theoretical treatment of the phenomena of magnetohydrodynamics, reference may be made to a book entitled Magnetohydrodynamics by R. K. M. Landshoff, Stanford University Press, 1957, and to a book entitled Magnetohydrodynamics by T. G. Cowling, Interscience Publishers, Inc., New York, New York, 1957. In addition, many scientific and technical papers have been published on the subject within the last several years.

It is known that if a highly conductive fluid is placed in a magnetic field and current is passed through the fluid at right angles to the magnetic field, the fluid is pumped in a direction normal to both the magnetic field and the direction of current flow. This phenomenon has been investigated for many years and various pumps operating on this magnetohydrodynamic principle have been proposed. Each of the pumps heretofore known has, by necessity, included means to provide a magnetic field extending across and normal to the flow path of the conductive fluid. In the case of a direct current pump, a permanent magnet could be used to provide the magnetic field, but, in the case of an alternating current pump, means were required to reverse the magnetic field in synchronism with the reversals of the pumping current. In either case, the magnetic field required was relatively high, which necessitated the use of correspondingly large magnets or induction coils. The magnetohydrodynamic pump of the present invention is believed to constitute a major improvement over such pumps heretofore known, in that no external means are required to provide a magnetic field across the flow path of the conductive fluid. In addition, the pump of the present invention is usable with pumping currents ranging in frequency all the way from direct current to microwave frequencies of alternating current.

In its broader aspects, the present invention provides a magnetohydrodynamic pump for pumping conductive fluids, which comprises means defining a flow path for the fluid with two electrodes located in the flow path. The first electrode has an aperture to permit fluid flow through the electrode, and it substantially completely obstructs the flow path except for the aperture. The second electrode is spaced upstream from the first electrode; it is solid and is so shaped as to permit fluid to flow between the two electrodes and through the aperture in the first electrode. Means are provided for energizing the electrodes to cause electrical current to flow through the conductive fluid between the two electrodes.

It is well known that, when current flows through a conductor, a magnetic field is created about the conductor by the current flow. In the present case, the current flowing between the two electrodes of the pump creates a magnetic field in that area between the two electrodes, which is at right angles to the direction of current flow between the electrodes. Thus, the fluid is pumped in a direction normal to both the magnetic field and the direction of current flow without the use of an external magnet or coil.

The invention, together with various objectives and advantages, will be better understood by reference to the following description of several embodiments, taken in conjunction with the accompanying drawings, in which

FIGS. 1, 2 and 3 are diagrammatic sectional views of three embodiments of single-stage pumps constructed according to the invention; and

FIG. 4 is a diagrammatic sectional view of another embodiment of the invention utilizing two pumping stages.

FIG. 1 illustrates diagrammatically a relatively simple embodiment of the invention that may be conveniently used to illustrate its principles of operation. The magnetohydrodynamic pump shown comprises a conduit **10** having an upper section **10***a* and a lower section **10***b*, which together define a flow path for the conductive fluid to be pumped. The conduit **10** is made of an insulating material, such as glass or ceramic, and the upper section **10***a* is of smaller cross-sectional area than the lower section **10***b*. The cross-sectional shape of the conduit **10** is of no particular importance and it may conveniently be either cylindrical or rectangular. The upper and lower sections may be made integrally with each other or they may be separate sections joined together by conventional means, such as the cement **11**.

An electrode **12** is positioned within the smaller upper section **10***a* of the conduit and is provided with an aperture **12***a*, which extends substantially through the center of the electrode on the axis of the conduit. The cross-sectional shape and size of the electrode **12** is the same as that of the upper conduit section **10***a* so that the electrode substantially completely obstructs the flow path except for the aperture **12***a* through the electrode.

A second electrode **13** is positioned in the larger section **10***b* of the conduit and spaced from the bottom surface of the first electrode **12**. The electrode **13** is of the same cross-sectional shape and size as the electrode **12**, and the facing surfaces of the two electrodes (that is, the lower surface of the electrode **12** and the upper surface of the electrode **13**) are substantially planar. The electrode **13** is provided with a recess **13***a* in its upper surface into which an insulating plug **14** is set. The shape of the recess **13***a* is substantially the same as that of the aperture **12***a* in the upper electrode **12** and its depth is of no particular significance.

The two electrodes **12** and **13** are connected across a potential source **15**. The potential source **15** is shown as being of the alternating current type but, as previously noted, the frequency of the voltage source may vary over an extremely wide range from direct current up to microwave frequencies of alternating current.

In operation, when the conduit **10** is filled with a conductive fluid and the voltage source **15** is connected as shown, current flows between the two electrodes **12** and **13**. This current, which is quite high because of the very low resistance of the conductive fluid, creates magnetic flux which follows concentric circles about the axis of symmetry of the duct and the electrodes. This, together with the current density in the slots, causes a pressure P to be built up normal to both the magnetic field and the direction of current flow, that is, from the outside to the inside of the electrodes. If the direction of current flow reverses alternating current), the magnetic field also reverses, so that the pressure does not reverse. The pressure P may be approximated by the expression

$$P=\frac{\mu . I^2}{(D\pi)^2}$$

where μ is the induction constant (1.6×10^{-6}) and D is the diameter of the two electrodes. Thus, it is seen that the current flowing between the electrodes has to

be high to obtain sizable pressure effects. The power needed is not great, however, because the voltage needed to create the current is low. In practical cases, the current may range from 10 to 100 amperes, and the voltage need be only a few millivolts.

The purpose of the insulating plug **14** in the center of the electrode **13** is to prevent current from flowing to or from that area of the electrode **13** and to provide a maximum current density between the opposing faces of the two electrodes.

Conductive fluids that may be pumped by the magneto-hydrodynamic pump of the invention may be of several types, and the invention is in no way limited to the use of any particular fluid. Examples of suitable fluids are the liquid forms of mercury, gallium and sodium, or a suitable highly conductive electrolyte. In addition the invention contemplates the use of a highly conductive hot gas plasma as a conductive fluid. The principal qualification is that the fluid to be pumped must be highly conductive.

The embodiment of the invention shown diagrammatically in FIG. 2 is very similar to that shown in FIG. 1 and those parts in FIG. 2 bearing a prime superscript may be identical to the corresponding parts shown in FIG. 1. The principal difference between the two pumps is that the electrode **12** in the embodiment shown in FIG. 1, which has a substantially planar lower surface, is replaced by an electrode **18** having a differently shaped lower surface. The electrode **18** is provided with an axial aperture **18***a* to permit the passage of fluid, and with a frusto-conical lower surface **18***b*. The lower surface **18***b* of the electrode is so shaped that it is farthest from the upper planar surface of the electrode **13'** at its outer edge. The reason for the frusto-conical shape of the lower surface of the electrode **18** is that it leads to a better distribution of the magnetic field existing across the space between the electrodes **18** and **13'**. Otherwise, the operation of the pump shown in FIG. 2 is identical with that shown in and described with reference to FIG. 1.

FIG. 3 illustrates diagrammatically an embodiment of the invention that, because of a somewhat modified electrode configuration, provides a higher current density and consequent higher magnetic field between the cooperating surfaces of the two electrodes. In that embodiment, the flow path for the conductive fluid is defined by an outer conduit **20** and by a concentrically arranged inner conduit **21**, both conduits **20** and **21** being made of an insulating material. Secure to the lower ends of the conduits **20** and **21** and coaxial with conduits is an electrode **22** having a plurality of slots **22***a* extending through it in the area between the inner and outer conduit. A second electrode **23** is coaxially mounted below the first electrode **22** and may be spaced apart from it by an insulating cylindrical spacer **24**.

Pumping action is provided in the embodiment shown in FIG. 3 in the volume between the surface of an aperture **22***b* formed through the electrode **22** and the surface of a conical portion **23***a* formed on the electrode **23**. The aperture **22***b* in the electrode **22** and the conical portion **23***a* on the electrode **23** are preferably coaxial with the axis of the inner conduit **21**. The aperture **22***b* is frusto-conical in shape, being widest at its lower end adjacent the electrode **23**, and the conical portion **23***a* of the electrode **23** extends into the aperture. It is particularly pointed out that the angle of the converging surface of the frusto-conical aperture **22***b* is less acute than is the angle of the converging surface of the conical portion **23***a* of the electrode **23**. Because of this configuration, the magnetic field is well distributed throughout the pumping space and the current density may be made quite high. In order to prevent current from flowing in other than the pumping space, a layer of insulating material **25** may cover those portions of the electrode **23**, other than the conical portion **23***a*, which are in contact with the conductive fluid.

When the electrodes **22** and **23** are connected across a voltage source **26**, pumping occurs in the same manner as previously described. A high density current flows between the electrode **22** and the conical portion **23***a* of the electrode **23**, which creates a high magnetic field at right angles to the direction of current flow. This results in pressure being created which forces the conductive fluid to flow in a direction normal to both the magnetic field and the direction of current flow between the electrodes, that is, upwardly through the space between the conical portion **23***a* and the surface of the aperture **22***b* and out through the aperture **23***b*. Thus, the liquid flows downwardly through the outer conduit **20**, through the apertures **22***a* in the electrode **22**, through the aperture **22***b*, and then upwardly through the conduit **21**.

FIG. 4 illustrates diagrammatically an embodiment of the invention utilizing two pumping stages **30** and **31** arranged in series. Because the two stages **30** and **31** are identical in construction, only the pumping stage **30** will be described in detail.

The flow path for the conductive fluid is defined by a conduit **32** made of an insulating material. The upper pump stage **30** comprises an electrode **33** having an axial frusto-conical aperture **33***a*. Arranged upstream from the electrode **33** is a second electrode **34** having a conical portion **34***a* which extends into the aperture **33***a*. The electrodes **33** and **34** may be conveniently separated by insulating spacers **35**. Again, as in the embodiment shown in FIG. 3, the converging surface of the frusto-conical aperture **33***a* is less acute than is the angle of the converging surface of the conical portion **34***a*, so that the two surfaces are spaced farther apart at the upstream end of the aperture **33***a* than at the downstream end. In order to prevent undesired current flow between non-pumping portions of the electrodes **33** and **34**, a layer of insulating material **36** may be provided on the lower surface of the electrode **33**, and a similar layer **37** may be provided on the upper surface of the electrode **34**. Thus, current flow, and hence pumping action, are restricted to the space between the surface of the aperture **33***a* and the conical portion **34***a*.

When the electrodes **33** and **34** are connected across a voltage source **38**, pumping action occurs which is very similar to that previously described with reference to the other embodiments of the invention. The high density current flowing between the surface of the aperture **33***a* and the surface of the conical portion **34***a* causes a magnetic field to be set up at right angles to the direction of current flow. As a consequence, the conductive fluid which fills the conduit is pumped in a direction normal to both the direction of current flow and the direction of the magnetic field, and the fluid is forced upwardly through the aperture **33***a*.

The lower pumping section **31**, which is separated from the uper section by insulating spacers **39**, operates in a fashion identical to that of the upper pumping section **30**. As many pumping sections may be arranged in series as are necessary to suit the pressure requirements of the particular application involved.

In some applications, it may be desirable to connect the pump sections **30** and **31** electrically in series rather than in parallel as shown. This may easily be done by replacing one or more of the insulating spacers **39** with a conductive spacer. In that case, the collector electrode of the upper section and the emitter electrode of the lower section would be connected to the two sides of the voltage source **38**, and the other two electrodes would be electrically connected only to each other.

Although the various embodiments of the invention have been illustrated diagrammatically with some constructional details omitted for the sake of clarity, it is believed that the invention has been fully described. The

various details not described are all felt to be conventional and their provision well within the capabilities of one skilled in the art. For example, the various glass-to-metal seals may be made by well known means, and the electrodes may be conventionally mounted in the conduits on brackets or spiders.

It is now apparent that the invention provides a magnetohydrodynamic pump which possesses a number of advantages over those previously known. Of course, its outstanding advantage is that it requires no magnetic field that must be externally provided. It may be used with a voltage source of virtually any frequency, because when the pumping current between the two electrodes of the pump reverses in accordance with the alternations of the voltage source, the magnetic field caused by the current also reverses. Therefore, pumping action always occurs in the same direction. Each of the various embodiments of the invention is symmetrical in construction and, therefore, it is extremely simple and easy to manufacture. In addition, very small voltages are involved, so that there is little danger of injury to personnel using the pump. Although several embodiments of the invention have been described, it is apparent that many modifications and variations may be made by one skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. A magnetohydrodynamic pump for pumping conductive fluids comprising means defining a flow path for said fluid, a first electrode in said flow path and having an aperture to permit fluid flow through said first electrode, said first electrode substantially completely obstructing said flow path except for said aperture, a second electrode in said flow path spaced upstream from said first electrode, said second electrode being solid and shaped to permit said fluid to flow between said first and second electrodes and through said aperture in said first electrode, said aperture being frusto-conical in shape and being widest adjacent said second electrode, and said second electrode including a conical portion extending into said aperture, and means for causing electrical current to flow through said conductive fluid between said first and second electrodes to provide a magnetic field in the space between said electrodes.

2. The magnetohydrodynamic pump defined by claim 1, wherein the angle of the converging surface of said frusto-conical aperture is less acute than the angle of the converging surfaces of said conical portion of said second electrodes.

3. A magnetohydrodynamic pump for pumping conductive fluids comprising means defining a flow path for said fluid, a first electrode in said flow path and having an aperture to permit fluid flow through said first electrode, said aperture being substantially in the center of said first electrode and being frusto-conical in shape and being widest adjacent said second electrode, said first electrode substantially completely obstructing said flow path except for said aperture, a second electrode in said flow path spaced upstream from said first electrode, said second electrode being solid and shaped to permit said fluid to flow between said first and second electrodes and through said aperture in said first electrode, said first and second electrodes being axially aligned in said flow path with said second electrode including a conical portion extending into said aperture, and means for causing electrical current to flow through said conductive fluid between said first and second electrodes to provide a magnetic field in the space between said electrodes.

4. The magnetohydrodynamic pump defined by claim 3, wherein the angle of the converging surface of said frusto-conical aperture is less acute than the angle of the converging surface of said conical portion of said second electrode.

References Cited in the file of this patent

UNITED STATES PATENTS

902,106	Northrup	Oct. 27, 1908
1,660,407	Bainbridge	Feb. 28, 1928
2,669,183	Godbold	Feb. 16, 1954

FOREIGN PATENTS

698,623	Great Britain	Oct. 21, 1953
718,429	Great Britain	Nov. 17, 1954

OTHER REFERENCES

Textbook of Physics, by Poynting and Thomson, pp. 138 and 139, 1920 edition.