THE PATENT OFFICE

(12) UK Patent (19) GB (11) 2 273 133 (13) B

(54) Title of Invention

Displacement pump

(51) INT CL^6; **F04B 17/04 43/04 45/04, H02K 7/14 // H02K 13/00 41/03 41/035**

(21) Application No
9304961.7

(22) Date of filing
11.03.1993

(30) Priority Data

(31) **9225404**

(32) **04.12.1992**

(33) **GB**

(43) Application published
08.06.1994

(45) Patent published
18.10.1995

(52) Domestic classification
(Edition N)
F1W WCK WGR W100 W102
W104 W220
B7V VBA
H2A AKA2 AKQQ AK101
AK102 AK104 AK108 AK110
AK117 AK121 AK214S
AK216S AK217R AK508
AK807
U1S S1966 S2004

(56) Documents cited
GB2263140 A
GB1444614 A
EP0499367 A2

(58) Field of search

As for published application
2273133 A *viz:*
UK CL(Edition L) **F1W WCK**
INT CL^5 **F04B 17/04 43/04**
45/04
updated as appropriate

Additional Fields
UK CL(Edition N) **H2A**
Online: WPI

(72) Inventor(s)
William Alexander Courtney

(73) Proprietor(s)
William Alexander Courtney
17 Vale Road
Timperley
Altrincham
Cheshire
WA15 7TQ
United Kingdom

(74) Agent and/or
Address for Service
William Alexander Courtney
17 Vale Road
Timperley
Altrincham
Cheshire
WA15 7TQ
United Kingdom

2275155

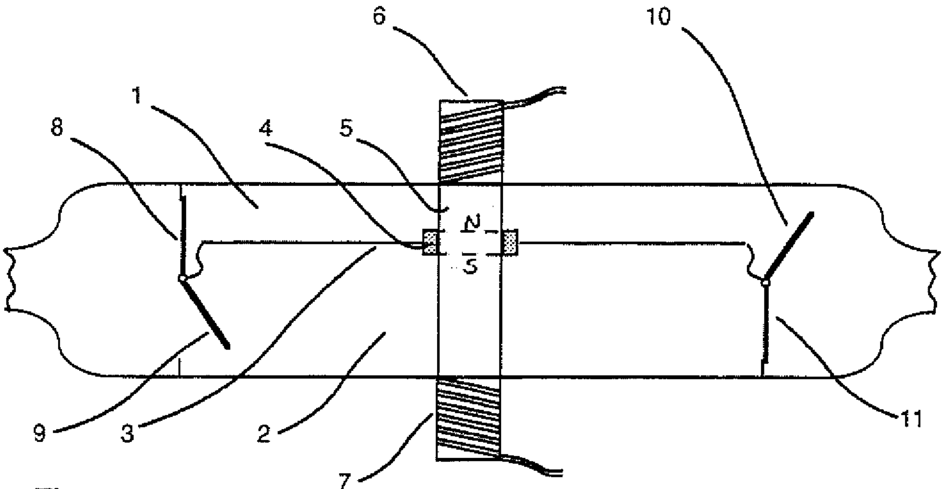

Fig 1

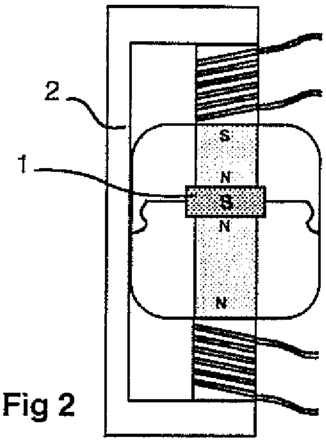

Fig 2

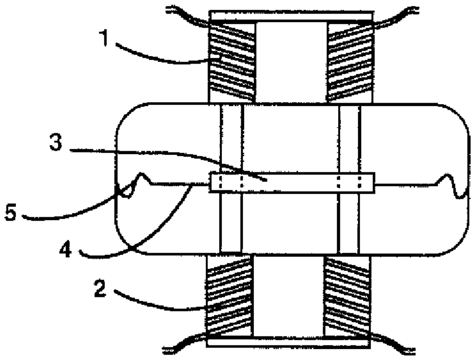

Fig 3

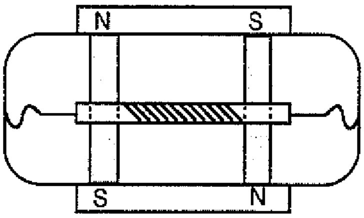

Fig 4

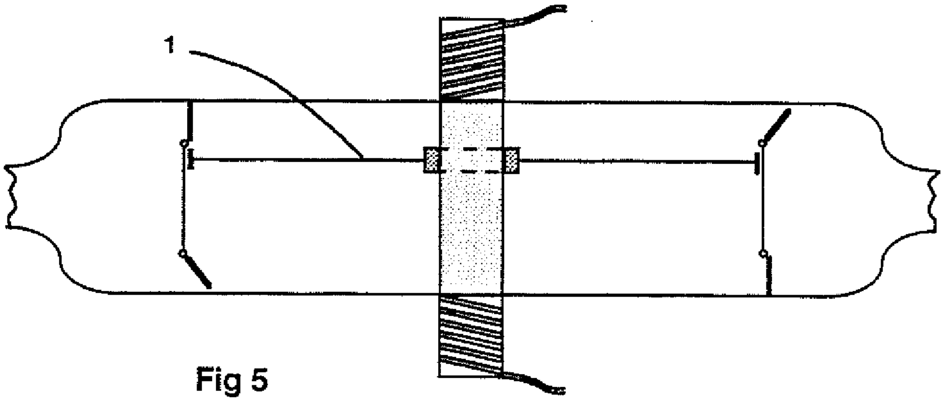

Fig 5

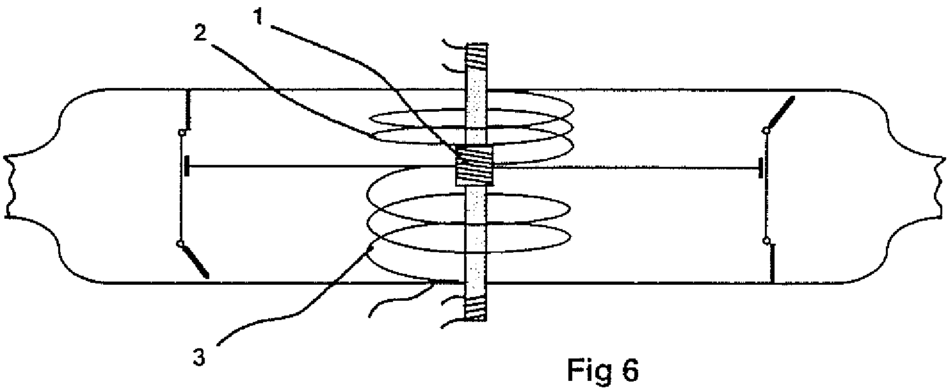

Fig 6

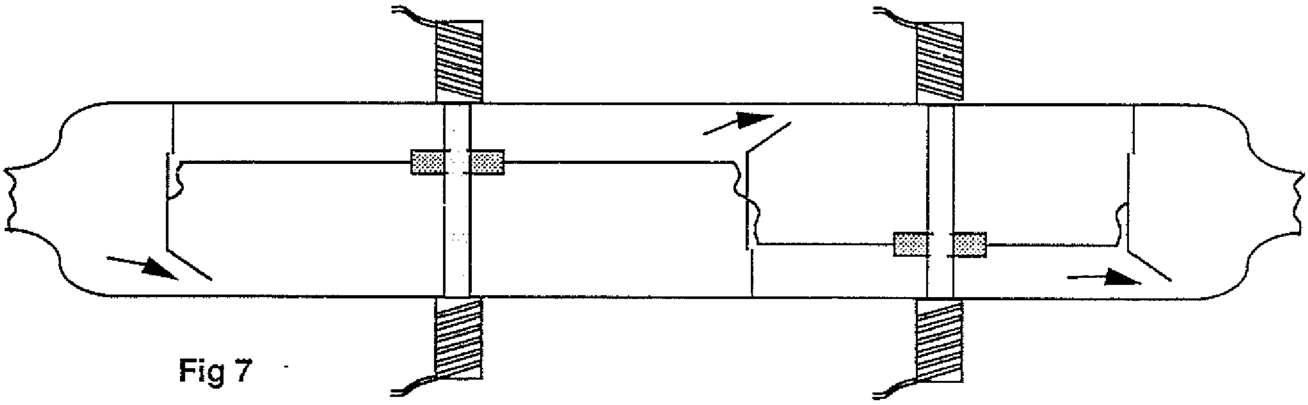

Fig 7

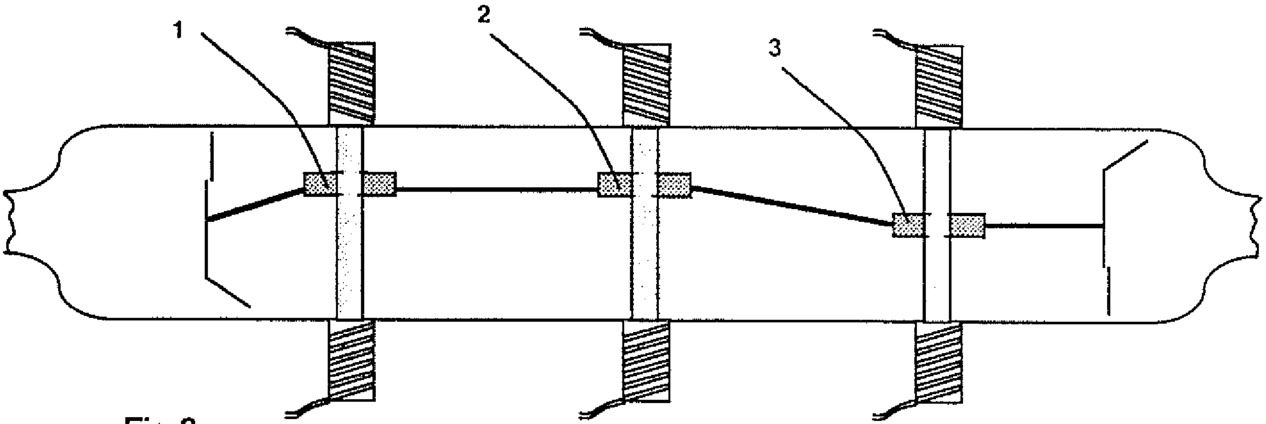

Fig 8

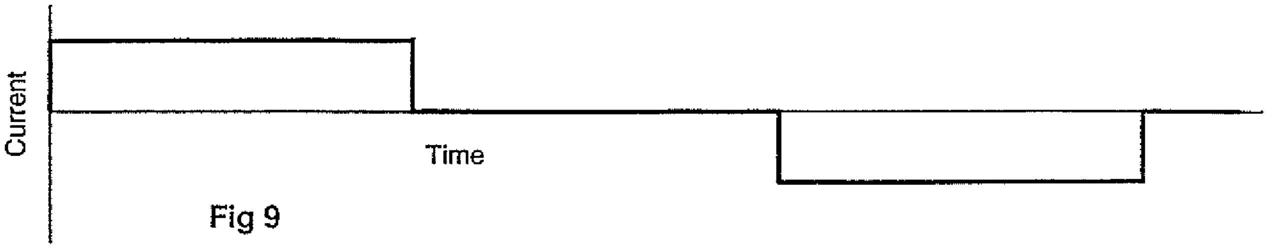

Fig 9

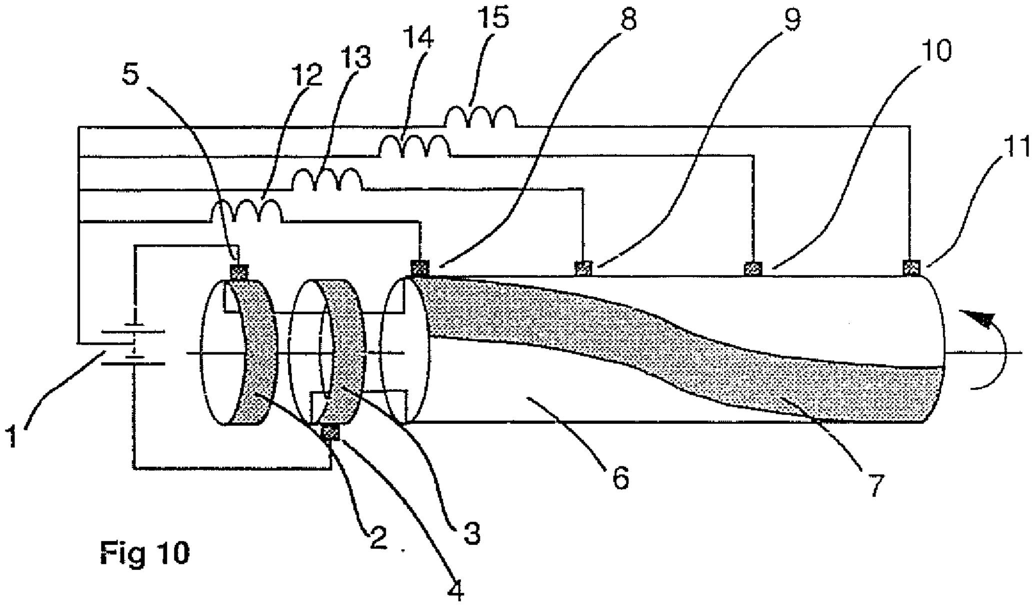

Fig 10

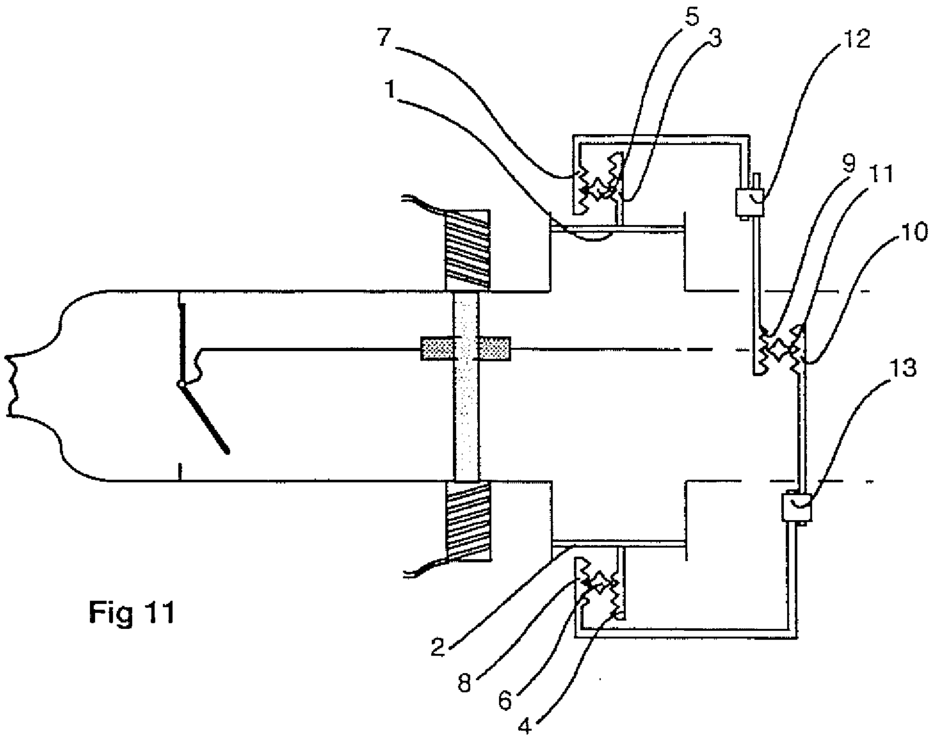

Fig 11

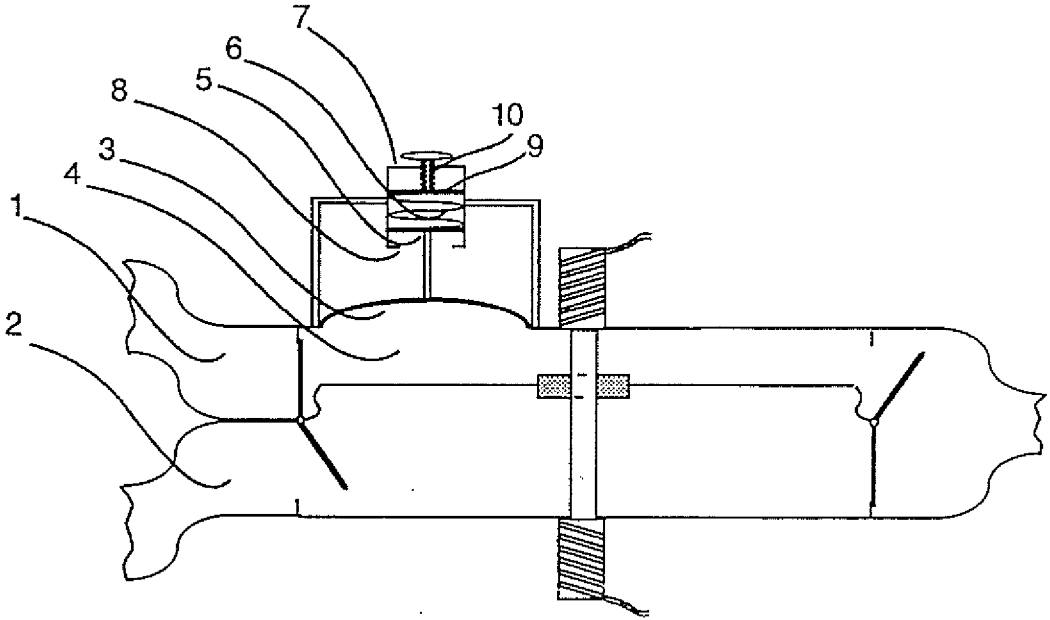

Fig 12

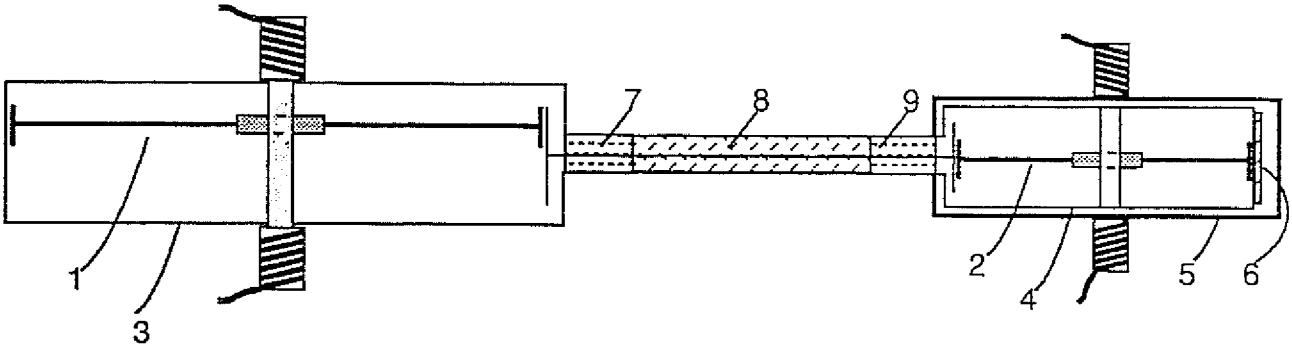

Fig 13

DISPLACEMENT PUMP

2273133

This invention relates to displacement pumps which receive their motive power from tubular linear motors.

An essential feature of these pumps is that the movable part of the motor, the runner is embedded in the crown of a piston or diaphragm so that when motivated it runs along a stator which passes through the crown.

Piston or diaphragm pumps which include a permanent magnet or armature in their crown are already known. These interact with magnetic fields produced by permanent or electromagnets external to the displacement volume. These pumps are limited to small displacements because the displacement volume, which must be penetrated by the magnetic flux has a low magnetic permeability. These small pumps have been used for example for artificial hearts and as automobile fuel pumps.

According to the current invention the low magnetic permeability region is limited to the small gap between the stator and the runner. This means that pumps with large displacement volumes can be constructed without a corresponding loss of efficiency.

The force on the crown is in the direction of the displacement, this eliminates side slap and associated lubrication problems.

This is an important consideration when selecting a pump for pumping fluids which are liable to be contaminated by lubricating oil or where the pumped fluid can be dissolved in the oil.

A second feature of the pumps to be described is that the volume swept out by both faces of the piston or diaphragm is used to displace fluid.

Thus the invention provides a dual chamber pump which offers two contributing pumping volumes, one on each side of the diaphragm or piston crown with the motive power driving the piston or diaphragm being at least one tubular linear motor with the tubular runner of the motor being attached to the crown and the motor stator, which performs an active magnetic function as part of the motor, taking the form of a shaft which passes through the centre of the runner and crown, with at least the runner or stator including one or more electromagnets which reverse in polarity at the end of each stroke in order to generate oscillatory diaphragm or piston movement.

The current invention has several other advantages over existing designs:

1) There is no necessity for an external piston shaft or other external moving parts.

2) The elimination of the piston shaft and the servicing of two chambers by one piston or diaphragm results in a compact design that is easily sealed.

3) The two chambers operate in anti-phase producing a fairly steady flow of fluid.

4) The operation of a number of pumps can easily be synchronised allowing them to be connected in series to increase the gain in pressure.

5) The pressure builds up on both sides of the crown along the stages of a series system reducing the stress on the crown, allowing operation at high pressures.

6) A cascaded system can be used as a lubricant free vacuum pump.

7) A peristaltic version of the pump can operate at high pressures and produce a fairly steady flow of fluid.

8) The pump can be used to mix two corrosive fluids.

9) The pump can be used to simplify Stirling cryocooler design.

Tubular linear motors in which the stator consists of current carrying conductors are well known to electrical engineers.
In what follows it is to be understood that this type of linear motor may be used.
For simplicity however the diagrams and descriptions will refer to a simple form of linear motor in which the runner takes the form of a permanent or electromagnet built into the crown of the piston or diaphragm and the stator consists of a soft ferromagnetic shaft connected to external magnets.

The principles of operation will be illustrated by reference to specific examples.

Figure 1 shows a side elevation of the pump.
This version of the pump has two chambers, 1 and 2 which are separated by the flexible diaphragm, 3.
4 is a permanent magnet embedded in the diaphragm. It takes the form of an annulus, encompassing a soft magnetic shaft, 5. The upper and lower sides of the magnet have opposite polarities.
6 and 7 are electromagnets external to the chamber and mounted on the ends of the shaft. They are connected to an alternating current supply which operates so as to produce like poles facing in towards the permanent magnet.

At a certain point in the current cycle the diaphragm moves upwards reducing the volume of the upper chamber and increasing the volume of the lower chamber. Half a cycle of the electricity supply later the polarities of the electromagnets are reversed and the diaphragm moves downwards.
8 and 9 are inlet valves, 10 and 11 are outlet valves. At the instant shown valves 8 and 11 are closed, 9 and 10 are open. This design of pump produces a fairly steady flow of fluid because when one chamber is in the induction phase the other chamber is in the delivery phase.

The chamber walls can be contoured to give a close fit with the shape of the diaphragm in the maximum displacement position, minimising the dead volume in each chamber.

A small amount of fluid can seep between the chambers via the gap between the stator and the runner. This causes a slight drop in pressure but also has a beneficial effect as it allows the pumped fluid to act as a lubricant.

Return springs may be added to prevent overshoot of the diaphragm at the end of the stroke. The elastic constant of the springs controls the cut off pressure of the pump.

If seepage of fluid between chambers is undesirable, for example if the fluid includes abrasive particles, then flexible sealing boots supported by helical return springs mounted spirally round the shaft may be added.

A feature of this design is that the absence of an external piston allows the pump to operate as a totally sealed unit.

The current source used is preferably alternating (a.c.), however a direct current source can be used if make-and-break mechanisms are included. The magnetic flux which leaks from the exposed ends of the ferromagnetic shaft may be used to operate two make and break devices. These can be connected to a suitably arranged battery of electricity cells or the like in order to produce both positive and negative going pulses of current to operate the pump during successive phases of the cycle. Those with a knowledge of electric circuits will be able to assemble the required circuit.

Figure 2 shows a variation on the design.
The view is at right angles to that shown in figure 1 so that the valves are not visible. The bi-polar magnet has been replaced with a tri-polar magnet, 1. This allows the external electromagnets to have poles of opposite signs facing inwards, enabling them to be linked with a soft magnetic yoke, 2. The arrangement increases the efficiency of the pump because it allows the electromagnets to produce the necessary magnetic flux density using smaller currents. It also allows the two sets of electromagnet windings to be replaced by a single set.

Figure 3 has a similar perspective to that in figure 2.
It shows an alternative configuration of the magnets. 1 and 2 are U shaped electromagnets carrying a.c. currents. 3 is a bar magnet. The directions of the currents are chosen in order to produce oscillation of the diaphragm at the current frequency. This configuration is suitable for pumps having diaphragms with larger surface areas than described above. The larger diaphragms may have a rigid central section, 4 and a flexible skirt or rim, 5. This arrangement can also be used with the North-South axis of the diaphragm magnet along the length of the pump or at any orientation in the plane of the diaphragm.

The magnet(s) embedded in the diaphragm may also be electromagnets, offering a higher pole strength/magnet mass ratio and overcoming possible coercivity problems.
Pumps offering this specification may advantageously be driven with the diaphragm magnet(s) carrying an a.c. current and the magnets in the walls of the chamber being d.c. electromagnets, or for basic designs, see figure 4, with permanent magnets in the chamber walls. The implications of these modifications in terms of reduced back e.m.f.s and reduced magnetic hysteresis losses will be apparent to those with a knowledge of a.c. circuits.

Figure 5 shows a two chamber arrangement with the diaphragm replaced by a sliding piston. The piston, 1 is a close tolerance fit but with sufficient peripheral gap to allow a small fraction of fluid in the chamber under compression to flow into the lower pressure chamber on the other side of the piston. The fluid in transition between the chambers acts, in this case as a lubricant. Those familiar with the arts of pump design will be aware of the fluids, materials and dimensional tolerances which will allow this design variation to be used to advantage. This design inherently requires less lubrication than a piston, shaft and flywheel arrangement because, unlike the latter arrangement there is no component of the driving force at right angles to the direction of piston travel, into the adjacent chamber wall.

Figure 6 shows an arrangement in which the permanent magnet mounted on the piston crown is replaced by an electromagnet, 1. The current can be fed to the electromagnet via the helical return springs 2 and 3. Any of the configurations described above can utilise appropriately arranged electromagnets instead of permanent magnets.

The pump may be used as a means of propulsion through water.
The thrust on the pump is equal in magnitude and opposite in direction to the thrust on the water ejected by the pump. This is advantageous compared with marine screw propellers which produce a useless tangential thrust on the displaced water in addition to the useful driving thrust.

Pump propulsion will be a particularly attractive option for craft on inland waterways which suffer erosion of adjacent banks as a result of the wash from passing craft.

For marine purposes the valve mechanisms are preferably modified so that the direction of flow of water through the valves can be reversed. For the convenience of the crew this adjustment is made by remote control means. Those with a knowledge of mechanical and electrical control systems will be able to make the necessary modifications.
The benefit of being able to reverse the thrust is that the direction of motion of the craft can be reversed. If two such pumps are used, one mounted on each side of the hull then the pumps may be used as a steering mechanism.

Two or more pumps can be linked in a multi-stage arrangement to increase the final exit pressure.

Figure 7 shows a two stage diaphragm pump suitable for use with compressible fluids.
The chambers in the second pump have a smaller volume than in the first because a given mass of gas decreases in volume as the pressure of the gas increases. The relative sizes of the chambers can be calculated by those with a knowledge of the gas laws.

The cascaded or series version of this pump can be used at higher pressures than traditional piston driven diaphragm pumps because although the absolute pressure builds up along the cascade the pressure difference across the diaphragm membranes does not. The fluid from the previous stage in the cascade provides a similar support to the whole of the diaphragm to that provided by the driving fluid in complex hydraulic diaphragm pumps.

This means that the multi-stage diaphragm version of the present pump can be used at pressures normally reserved for lubricated piston pumps or complex diaphragm pumps with hydraulic drivers. It could, for example be used as a compressor for a refrigeration system.

Figure 8 shows a peristaltic version of the pump.
The diaphragm is flexible and the alternating currents which relate to magnets 1, 2 and 3 are out of phase such that first magnet 1 is displaced upwards, then 2 followed by 3. The magnets then return to the equilibrium position in the same order, followed by a displacement down in this order.

Figure 9 is a graph showing a suitable profile for the alternating current delivered to one of the sets of electromagnets which motivate one segment of the diaphragm. Similar current profiles but with appropriate phase differences are applied to the other sets of magnets.

A number of such pumps can be connected in series, separated by valves.
The advantage of the series or cascaded version of the present pump compared with previously known peristaltic pumps is that it can be used at higher pressures because although the absolute pressure builds up along the cascade the pressure difference across the diaphragm membranes does not.

Figure 10 shows a device for generating rectangular current pulses with a defined phase difference between successive pulses. 1 is a battery of cells or other source of direct current which can be centre tapped to provide two terminal potential differences having opposite polarities. 2 and 3 are rotating slip rings which are connected by brushes 4 and 5 to the power supply. 6 is a rotating commutator which is driven by a motor or other means of producing rotation. 7 is a strip or sector of electrically conducting material, spirally laid along the cylinder which gives shape to the commutator. 7 is permanently electrically connected to one of the slip rings. A second conducting sector, similar to 7 is mounted out of sight on the far side of the cylinder and is connected to the second slip ring. The spirals are electrically isolated by insulating material. Brushes 8, 9, 10 and 11 connect to pump electromagnets 12, 13, 14 and 15 allowing phased pulses of current to pass through them.

Figure 10 shows an arrangement for providing phased current pulses to four electromagnets or other circuit components. This design can be used, with differing numbers of brushes in contact with the commutator to provide phase related currents to any two or more parts of the a whole pumping system. A similar phase relationship between currents can be achieved by a commutator design which incorporates parallel sided, straight edged conducting sectors and has the brushes for connecting the electromagnets to the commutator arranged in a spiral pattern along the length of the commutator.

Pumps or pump systems as described in this application can be used as components in vacuum systems.
At very low pressures the gas pressures involved may be insufficient to operate the valves promptly and efficiently. This deficiency is overcome if some or all of the valves are operated electromagnetically. The alternating signal required could be derived from the same source as the current supply for the electromagnets, but with a phase difference to produce the necessary synchronised opening and closing of the valves.

If a multi-stage vacuum system is used to evacuate a volume which is initially at atmospheric pressure to a very low pressure then the early stages of pumping will cause an unnecessary build up of pressure towards the end of the cascade. This is eliminated by adding a side valve to the first and if necessary later pumps in the cascade. The side valves are pressure loaded so that they will release gas directly to the local environment, without passing through the whole of the cascade if the pressure in the chamber exceeds the local environmental pressure.

The pumps described are oscillating systems which have a resonance frequency dependent on the parameters of the pump and fluid. One of the parameters which can be altered in order to tune the pump is the volume of the chambers as defined by the position of the outer walls. For example mechanisms may be incorporated into a single stage pump which allow the volume of each chamber to altered independently or in synchronization.

Figure 11 illustrates one version of the pump which can be tuned in this manner.
1 and 2 are close fitting pistons which can be moved to vary the shape and position of the side walls. Racks 3 and 4 engage with pinions 5 and 6. The pinions are normally locked in position during pump operation but can be unlocked and rotated for the purpose of independently altering the volumes of the chambers. A third rack and pinion mechanism, 7, 8 , 9, 10 and 11 allows both chambers to be adjusted simultaneously provided that clamps 12 and 13 are locked in order to ensure that racks 7 and 8 move in response to rotation of pinion 11.
The volume changes may be affected manually or electronically in response to feedback information from fluid flow sensors.

The essential dual chamber nature of this pump design means that the pump can be used for mixing and pumping two different fluids. This is an attractive option for mixing corrosive fluids because the present pumps can operate without being serviced by lubricating oil.

In order to allow the mixing of the fluids in different proportions the basic design needs to be modified to allow different throughputs for each chamber.

Figure 12 illustrates a version of the pump which includes this provision.
1 and 2 are inlet pipes which feed different fluids into the upper and lower pump chambers shown on the diagram. 3 is a sidewall diaphragm which can flex in response to pressure changes in the upper chamber, 4. By altering the amount of flex permitted for diaphragm 3 the pumping pressure for the upper chamber can be varied compared with the pressure generated in the lower chamber. When diaphragm 3 moves upwards a piston, 5 attached to 3 compresses a spring,6 enclosed in the open ended cylindrical housing, 7. Downward motion of the piston is restrained by a lip, 8 at the base of the housing. The housing is rigidly attached to the main body of the pump. The spring presses against a plate, 9 at the end of a threaded shaft, 10. The degree of flex of the sidewall diaphragm can be varied by changing the position of 9 by rotating the threaded shaft.
A similar sidewall diaphragm may be added to the lower chamber.

Some or all of the stages of any of the variations of the pump can include heating elements for the purpose of reducing the viscosity of the fluid. The diaphragm or piston driving mechanism may be designed to deliberately generate a measurable amount of thermal energy in order to provide this heat.

The inventive steps claimed in this patent application can also be used advantageously to modify reverse Stirling engines.

Stirling engines working in reverse to produce a cooling effect are well known to those with a knowledge of cryogenics. The essential elements of any Stirling cryocooler consist of two spaces with variable volumes which are connected through three heat exchangers, known to cryogenics experts as the cooler, regenerator and freezer. The inventive steps described in this patent application which may be applied to the Stirling engine design are the use of diaphragms or pistons with inbuilt driving mechanisms and the dual chamber arrangement.

A specific example will be described with reference to figure 13.
Those with a knowledge of Stirling engines will be familiar with the thermal energy exchange processes involved with Stirling cryocoolers so these will not be elaborated.
1 and 2 are sliding fit pistons which sweep out dual chambers 3 and 4. The pistons may be replaced with diaphragms to produce a similar effect. The driving mechanisms for the pistons or diaphragms are as described above. Dual chamber 3 is at approximately ambient temperature and is fitted with heat dispersal mechanisms. Dual chamber 4 is eventually driven to a lower temperature when the system is in operation.
Commonly,a Dewar insulation arrangement, 5 surrounds the cooler to minimise heat flow in from the surroundings.
6 is a representative circuit or detector which it is desired to cool. 7, 8 and 9 represent the cooler, regenerator and freezer.

The working fluid is a gas, for example helium. A small amount of the fluid can be deliberately allowed to flow between the pistons and the chamber walls. This provides the necessary natural lubrication for smooth action. A small drop in pressure occurs as a result of lubrication but the fluid is not lost from the system by this action, nor are there any significant heat exchange problems because each half of the dual chambers are approximately at the same temperature.
For the lower temperature pair of chambers there is a discontinuity in the high magnetic permeability shaft at the points where the magnetic circuit passes through the Dewar insulation.

For heat transfer to take place the two spaces of any Stirling system must vary in volume at the same frequency but out of phase. Typically the volume variation of the cool chamber leads the volume variation of the warm chamber by about 90°.
A merit of the present system is that if the piston/diaphragm driving mechanism is arranged to satisfy this condition then the cryocooler thus created is in effect two cryocoolers, extracting heat in the same direction between the chambers but acting in anti-phase. This produces a very compact design and also increases the efficiency of an appropriately designed regenerator.
The regenerator segment which services one pair of connected warm and cold chambers will be extracting heat from the working fluid when the regenerator segment serving the other pair of chambers is adding heat. This means that the regenerator is not called upon to store large quantities of thermal energy. Its role is simplified to that of placing the two sets of working fluids at different temperatures in thermal contact.

The choice of magnets for use in these Stirling refrigerator arrangements of the pump is a design variable. e.g. permanent magnets can be embedded in the pistons or diaphragms if working fluid contamination by the lacquer from electromagnet windings is a problem or if heat generation or seepage caused by installing electromagnets in the cool chamber piston is unacceptable. Superconducting magnets can also be incorporated into the design if sufficiently low temperatures are achieved.

Two or more cryocoolers of the type described can be linked in stages, along with suitable insulation to achieve lower final temperatures.

One widely known problem associated with actively varying the volume of the cooler chamber by an external force is that vibrations and electromagnetic noise are produced with undesirable consequences. Those with a knowledge of cryogenics will be aware that these problems can be overcome using a split Stirling cryocooler. The innovative steps described above can still be applied with benefit to these split systems in order to drive a pair of warm temperature chambers.

CLAIMS

1 A dual chamber displacement pump which offers two contributing pumping volumes, one on each side of the diaphragm or piston crown with the motive power driving the piston or diaphragm being at least one tubular linear motor with the tubular runner of the motor being attached to the crown and the motor stator, which performs an active magnetic function as part of the motor, taking the form of a shaft which passes through the centre of the runner and crown, with at least the runner or stator including one or more electromagnets which reverse in polarity at the end of each stroke in order to generate oscillatory diaphragm or piston movement.

2 A pump as in claim 1 in which the shaft is of a ferromagnetic material carrying a magnetic flux, with the flux being generated by one or more permanent or electromagnets coupled to the shaft.

3 A pump as in claim 2 with the magnetic flux created in the stator being alternating in nature.

4 A pump as in any of the above claims, the runner including one or more permanent magnets.

5 A pump as in any of the above claims, the runner including electromagnets carrying direct currents.

6 A pump as in any of claims 1-4, the runner including electromagnets carrying alternating currents.

7 A pump as in any of the above claims which is lubricated, in part at least, by a small fraction of the pumped fluid acting as a lubricant between the runner and stator and between the piston skirt and the adjacent chamber walls.

8 A pump as in any of the above claims which uses elastic components such as return springs to control the cut-off pressure.

9 A pump as in any of the above claims which includes a flexible boot to prevent fluid flow between chambers via the space between the stator and runner.

10 A pump as in any of the above claims and having inlet and outlet valves having roles which can be remotely changed so as to reverse the direction of fluid flow.

11 A pump as in any of the above claims in which a heating element is included or which utilises existing circuit components to produce a heating affect with the intention of heating the fluid being pumped.

12 A pump as in any of the above claims which has some or all of the internal components painted or otherwise surface treated in order to prevent corrosion and/ or aid the flow of fluid.

13 A pump as in any of the above claims which has a multiplicity of linear motors driving the piston or diaphragm.

14 A pump as in any of the above claims which is similar to a peristaltic pump in that the dual chambers are separated by a flexible diaphragm motivated by two or more cylindrical linear motors which operate out of phase such that during each cycle the shape of a chamber becomes constricted at the inlet valve end and the constriction then becomes more general, travelling towards the exit valve end of the pump, this state being followed by an equivalent phased expansion.

15 A pump as in any of the above claims which has electromagnetically operated valves which are synchronised to open and close at the necessary stages of the pumping cycle in order to allow the pump to operate with greater efficiency at low pumped fluid pressures.

16 A pump as in any of claims 1-14 which has inlet and outlet valves with the timing of the opening and closing of at least some of the valves being controlled by a cam or other mechanical device.

17 A pump as in any of the above claims which includes side valves which allow fluid to escape directly to the local environment when a pre-set pressure inside the chamber is exceeded.

18 A pump as in any of the above claims which can be tuned or adjusted by means of altering the positions of the electromagnets.

19 A pump as in any of the above claims which can be tuned or adjusted by means of altering the electromagnet currents.

20 A pump as in any of the above claims which include sensors for detecting magnetic field strength or rate of change of field strength.

21 A pump as in any of the above claims which include sensors for detecting magnetic field strength or rate of change of field strength and feed back mechanisms which allow the pump to correct itself if unequal forces or aging cause inefficient operation or malfunction of the pump.

22 A pump as in any of the above claims which includes chambers with movable walls that can be tuned mechanically or automatically in response to feedback signals in order to increase the efficiency of the pump.

23 A pump as in any of the above claims in which the containing walls of the pump are shaped to match with the shape of the piston or diaphragm in the maximum displaced position in order to minimise the volume of dead space inside each chamber.

24 A pump as in any of the above claims in which two different fluids have access to the respective chambers through two adjacent inlet ports.

25 A pump as in any of the above claims in which two different fluids have access to the respective chambers and which includes a mechanism for altering the relative pumping pressures of the two chambers in order to allow the fluids to be mixed in different proportions after emergence from the pump.

26 A pump as in any of the above claims which includes one or more make and break circuits or other electronic means for converting a direct current into a pulsed current supply to said electromagnets.

27 A pump as in any of the above claims which incorporates power supplies and a slip rings and brushes arrangement with two conducting sectors of a rotating commutator, the conducting sectors of the commutator and a second set of connecting brushes so arranged that potential differences can be provided to drive currents, via the brushes through two or more electromagnets, providing a set phase difference between the currents through the electromagnets.

28 A pump as in any of the above claims which is used to displace the working gas in a reverse Stirling refrigerator.

29 A pump assembly comprising at least two pumps as claimed in any preceding claim connected in series with successive pump chambers having progressively smaller volumes.