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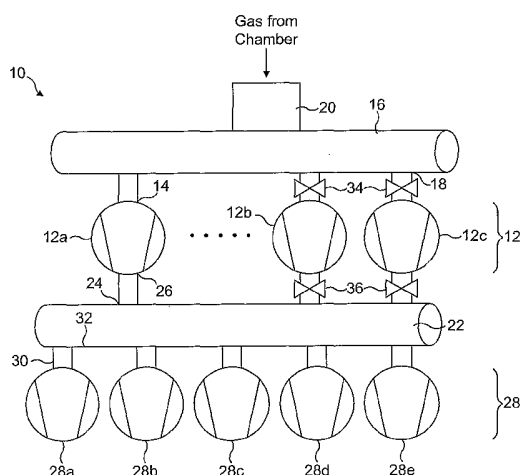
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(54) Title: VACUUM PUMPING ARRANGEMENT



(57) Abstract: A vacuum pumping arrangement for evacuating a chamber is described, in which the pumping arrangement comprises a plurality of booster pumps (12) connected in parallel to an inlet conduit (16) for receiving gas from the chamber (20), a plurality of backing pumps (28) connected in parallel to an exhaust conduit (22) for receiving gas exhaust from the first vacuum pumps (12), and a valve arrangement (34, 36) for selectively isolating at least one of the booster pumps (12) from the inlet conduit (16) and the exhaust conduit (18). In order to improve the rate of evacuation of the chamber, the valve arrangement (34, 36) is controlled so that gas flow through said at least one of the booster pumps (12) is inhibited during an initial stage of the evacuation of the chamber (20), and is permitted during a subsequent stage of the evacuation of the chamber (20).

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VACUUM PUMPING ARRANGEMENT

The present invention relates to a vacuum pumping arrangement and to a method of evacuating a chamber using a vacuum pumping arrangement.

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Vacuum processing is commonly used in the manufacture of semiconductor devices and flat panel displays to deposit thin films on to substrates. A processing chamber is evacuated using a vacuum pumping arrangement and feed gases are introduced to the evacuated chamber to cause the desired material to be deposited on one or more substrates located in the chamber. Upon completion of the deposition, the substrate is removed from the chamber and another substrate is inserted for repetition of the deposition process. Evacuated load lock chambers are used to transfer substrates to and from the processing chamber.

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Pumping arrangements used to evacuate load lock chambers to the desired pressure generally comprise at least one booster pump connected in series with at least one backing pump. Booster pumps typically have oil-free pumping mechanisms, as any lubricants present in the pumping mechanism could cause contamination of the clean environment in which the vacuum processing is performed. Such "dry" vacuum pumps are commonly single or multi-stage positive displacement pumps employing inter-meshing rotors in the pumping mechanism. The rotors may have the same type of profile in each stage or the profile may change from stage to stage. The backing pumps may have a similar pumping mechanism to the booster pumps, or a different pumping mechanism.

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In order to increase the speed of evacuation of processing and load lock chambers, rather than increase the size of the pumps it is cheaper to provide a pumping arrangement comprising a plurality of smaller booster pumps connected in parallel. Where a relatively high number of booster pumps are provided, two or more backing pumps may be provided in parallel. In such

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pumping arrangements, an inlet manifold has an inlet connected to the outlet from the chamber, and a plurality of outlets each connected to an inlet of a respective booster pump. An exhaust manifold has a plurality of inlets each connected to an outlet of a respective booster pump, and a plurality of outlets
5 each connected to an inlet of a respective backing pump for receiving the fluid exhaust from the booster pumps and exhausting the fluid at or around atmospheric pressure.

An asynchronous AC motor typically drives the pumping mechanism of a
10 booster pump. Such motors must have a rating such that the pump is able to supply adequate compression of the pumped gas between the pump inlet and outlet, and such that the pumping speed resulting is sufficient for the duty required.

15 In the pumping arrangement described above, frequent and repeated operation at high to intermediate inlet pressures may be required. For example, a load lock chamber is repeatedly evacuated from atmospheric pressure to a low pressure to enable a substrate located within the chamber to be transferred to a process chamber, and subsequently exposed to
20 atmospheric pressure to enable the processed substrate to be removed and replaced by a fresh substrate. The amount of gas compression produced by the booster pump, and the differential pressure generated between its inlet and outlet, may be limited by various means to control the amount of heat generated and to limit the risk of overheating. If the gas compression
25 produced by the booster pump is limited too severely, the resulting evacuation time of the large vacuum chamber may be undesirably slow. If the gas compression produced by the booster pump is not limited enough, whilst the resulting evacuation time of the vacuum chamber may be rapid the mechanical booster pump may overheat.

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For driving the motor of a booster pump, a variable frequency drive unit may be provided between the motor and a power source for the motor. The

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power supplied to the motor is controlled by controlling the current supplied to the motor, which in turn is controlled by adjusting the frequency and/or amplitude of the voltage in the motor. The current supplied to the motor determines the amount of torque produced in the motor, and thus determines the torque available to rotate the pumping mechanism. The frequency of the power determines the speed of rotation of the pumping mechanism. By varying the frequency of the power, the booster pump can maintain a constant system pressure even under conditions where the gas load may vary substantially.

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In order to prevent overloading of the booster pump, the drive unit sets a maximum value for the frequency of the power (f_{max}), and a maximum value for the current supplied to the motor (I_{max}). This current limit will conventionally be appropriate to the continuous rating of the motor, and will limit the effective torque produced by the pumping mechanism and hence the amount of differential pressure resulting, thereby limiting the amount of exhaust gas heat generated.

At the start of a rapid evacuation cycle, it is desirable to rotate the pumping mechanisms of the booster pumps as rapidly as possible to maximise the evacuation rate. Due to the high pressure, and thus relatively high density, of the gas at the start of the cycle, a large torque is required to rotate the pumping mechanisms at a frequency around f_{max} , and so there is a high current demand, which is generally greater than I_{max} . To protect the motors from damage, the frequency of the power supplied to the motors of the booster pumps is rapidly reduced to some level below f_{max} , resulting in a sharp reduction in the rotational speed of the pumps while limiting the differential pressure produced. As the evacuation progresses and the inlet pressure decreases, the drive units will ramp up the frequency towards f_{max} over a finite period to gradually increase the rotational speed of the booster pumps. While this protects the booster pumps from overheating at all inlet pressures, this period when the rotational speed is reduced may represent an

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undesirable extension of the time required to evacuate the chamber from atmospheric pressure to the desired low pressure (the "pump down" time).

It is an aim of at least the preferred embodiments of the present invention to
5 seek to solve these and other problems.

In a first aspect, the present invention provides a vacuum pumping arrangement for evacuating a chamber, the pumping arrangement comprising a plurality of first vacuum pumps connected in parallel to an inlet conduit for
10 receiving gas from the chamber, at least one second vacuum pump connected to an exhaust conduit for receiving gas exhaust from the first vacuum pumps, means for selectively isolating at least one of the first vacuum pumps from the inlet conduit and the exhaust conduit, and control means for controlling the isolating means such that gas flow through said at least one of
15 the first vacuum pumps is inhibited during an initial stage of the evacuation of the chamber, and permitted during a subsequent stage of the evacuation of the chamber.

By isolating at least one of the first vacuum pumps, or booster pumps, during
20 the initial stage of the evacuation of the chamber, these isolated pumps are not exposed to the relatively high pressure, and thus relatively high density, of the gas at the start of the evacuation cycle. Consequently, these booster pumps remain running at full speed during the initial stage of the evacuation cycle. When the isolation means is subsequently operated to permit gas flow
25 through these booster pumps at the end of this initial stage, the relatively low pressure in the inlet conduit means that a lower torque is required to rotate the pumping mechanisms of these booster pumps at a frequency around f_{max} , and so there is a lower current demand that would have been experienced by these booster pumps at the start of the evacuation cycle. In view of this, the
30 reduction in the frequency of the power supplied to the motors of these booster pumps, to prevent overheating, is significantly lower, and so the reduction in speed of these booster pumps is significantly lower, than would

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have been experienced at the start of the evacuation cycle. As a result, the pump down time of the chamber can be significantly reduced.

In one embodiment, the isolating means comprises, for each of said at least
5 one of the booster pumps, a respective first valve or other variable flow control device for selectively isolating that pump from the inlet conduit. A second valve may also be provided for selectively isolating that pump from the exhaust conduit. This can enable the number of booster pumps that are isolated at the initial stage of the evacuation cycle to be varied according to
10 the pumping requirements of the chamber. A further advantage is that one or more of the first and second valve pairs may be closed during the entire evacuation of the chamber. The booster pumps thus isolated from the gas stream can provide back-up booster pumps in the event that one of the operating booster pumps fails. Traditionally, when one booster pump fails,
15 the pumping performance of the pumping arrangement decreases. In view of this, all of the booster pumps are removed from the pumping arrangement for cleaning, incurring costly downtime. In contrast, the provision of one or more back-up pumps already connected to the pumping arrangement can enable a replacement pump to be rapidly exposed to the gas stream (by opening its
20 first and second valves) to replace a failed pump, thereby avoiding downtime and with no loss of pumping performance.

Therefore, in a second aspect the present invention provides a vacuum pumping arrangement for evacuating a chamber, the pumping arrangement
25 comprising a plurality of first vacuum pumps connected in parallel to an inlet conduit for receiving gas from the chamber, at least one second vacuum pump connected to an exhaust conduit for receiving gas exhaust from the first vacuum pumps, means for selectively isolating each of the first vacuum pumps from the inlet conduit and the exhaust conduit, and control means for
30 controlling the isolating means such that gas flow through at least one of the first vacuum pumps is permitted in the event of failure of one of the other first vacuum pumps.

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In one embodiment, the plurality of booster pumps comprises m booster pumps, where $m > 1$, and said at least one of the booster pumps comprises n booster pumps, where $n < m$. As a result, at least one booster pump can be permanently exposed to the gas stream entering the pumping arrangement from the chamber. As the gas exhaust from these pumps during the initial stage of the evacuation cycle is received by the all of the second vacuum pumps, or backing pumps, provided for receiving gas exhaust from all m booster pumps, the pressure at the exhaust of these booster pumps can be rapidly reduced during the initial stage of the evacuation cycle, thus enhancing the net pumping speed of these booster pumps.

In another embodiment, the isolating means comprises a first valve located within the inlet conduit, and a second valve located within the exhaust conduit. This can enable two or more booster pumps to be isolated by a single first and second valve pair. The pumping arrangement may comprise a by-pass conduit having an inlet for receiving gas from the chamber, a first outlet for exhausting gas to the inlet conduit and a second outlet for exhausting gas to the exhaust conduit, and a third valve located in the by-pass conduit between the first and second outlets. The control means may configured to control the third valve such that the third valve is open during the initial stage of the evacuation of the chamber, and closed during the subsequent stage of the evacuation of the chamber. The initial evacuation of the chamber can thus be performed by the backing pumps alone, so that when the booster pumps are exposed to the gas stream at the end of this initial stage of the evacuation cycle, the gas within the inlet conduit is at a relatively low pressure. As discussed above, this means that a lower torque is required to rotate the pumping mechanisms of these booster pumps at a frequency around f_{max} , and so there is a lower current demand that would have been experienced by these booster pumps at the start of the evacuation cycle.

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Thus, in this embodiment, where the plurality of booster pumps comprises m booster pumps, where $m > 1$, said at least one of the booster pumps may comprise n first vacuum pumps, where $n \leq m$.

5 A plurality of backing pumps may be connected in parallel to the exhaust conduit. Means may be provided for selectively isolating at least one of the second vacuum pumps from the exhaust conduit during both stages of the evacuation of the chamber. The backing pumps thus isolated from the gas stream can provide back-up backing pumps in the event that one of the
10 operating backing pumps fails. Thus, in a third aspect the present invention provides a vacuum pumping arrangement for evacuating a chamber, the pumping arrangement comprising a plurality of first vacuum pumps connected in parallel to an inlet conduit for receiving gas from the chamber, a plurality of second vacuum pumps connected in parallel to an exhaust conduit for
15 receiving gas exhaust from the first vacuum pumps, means for selectively isolating each of the second vacuum pumps from the exhaust conduit, and control means for controlling the isolating means such that gas flow through at least one of the second vacuum pumps is permitted in the event of failure of one of the other second vacuum pumps.

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The control means is preferably configured to receive input from at least one sensor for monitoring one or more states within the pumping arrangement, and to control said isolating means in dependence on the monitored states. For example, at least one sensor may be configured to supply a signal
25 indicative of a gas pressure within the pumping arrangement, the control means being configured to control the isolating means in dependence on the received signal. The control means may then be configured to permit gas flow through said at least one of the booster pumps when the pressure falls below a predetermined value. Alternatively, two sensors may be configured
30 to detect respective different pressures within the pumping arrangement, the control means being configured to control the isolating means in dependence on a relationship between the detected pressures. As another alternative,

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the control means may be configured to permit gas flow through said at least one of the booster pumps after the lapse of a predetermined time period from the start of the chamber evacuation. As a further alternative, the control means may be configured to monitor the speed of operation of at least one of the booster pumps, and to permit gas flow through said at least one of the booster pumps in dependence on the monitored speed. For example, the valves may be opened when the monitored speed, or the rate of change of the monitored speed, or other value derived from the monitored speed and rate of change of speed, reaches a predetermined value.

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In a fourth aspect, the present invention provides a method of evacuating a chamber, the method comprising the steps of connecting a plurality of first vacuum pumps in parallel to an inlet conduit for receiving gas from the chamber, connecting at least one second vacuum pump to an exhaust conduit for receiving gas exhaust from the first vacuum pumps, and selectively isolating at least one of the first vacuum pumps from the inlet conduit and the exhaust conduit during evacuation of the chamber such that gas flow through said at least one of the first vacuum pumps is inhibited during an initial stage of the evacuation of the chamber, and permitted during a subsequent stage of the evacuation of the chamber.

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Features described above relating to the apparatus aspects of the invention are equally applicable to the method aspect, and vice versa.

Preferred features of the present invention will now be described with reference to the accompanying drawings, in which:

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Figure 1 illustrates schematically a first embodiment of a vacuum pumping arrangement;

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Figure 2 illustrates schematically a control system for controlling the valves of the pumping arrangement of Figure 1;

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Figure 3 is a graph illustrating, for a number of different pumping arrangements, the variation with time of the pressure in a chamber during evacuation;

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Figure 4 is a graph illustrating the variation with time of the rotation speed of the booster pumps of the pumping arrangement of Figure 1 during evacuation of the chamber;

10 Figure 5 illustrates schematically a second embodiment of a vacuum pumping arrangement;

Figure 6 illustrates schematically a control system for controlling the valves of the pumping arrangement of Figure 5; and

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Figure 7 illustrates schematically a third embodiment of a vacuum pumping arrangement.

Figure 1 illustrates a vacuum pumping arrangement 10 for evacuating a chamber, such as a load lock chamber or other relatively large chamber. The pumping arrangement 10 comprises a plurality of booster pumps 12. In the illustrated embodiment, the pumping arrangement 10 comprises three booster pumps 12a, 12b, 12c, although any number m of booster pumps may be provided, where $m > 1$. The inlets 14 of the booster pumps 12 are connected in parallel to an inlet conduit 16, that is, each inlet 14 is connected to a respective outlet 18 from the inlet conduit 16. The inlet conduit 16 also includes an inlet 20 for receiving gas from the chamber to be evacuated using the pumping arrangement.

30 The pumping arrangement 10 also comprises an exhaust conduit 22 having a plurality of inlets 24 for receiving the gas exhaust from the exhausts 26 of the booster pumps 12. In the illustrated embodiment, a plurality of backing

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pumps 28 are connected in parallel to the exhaust conduit 22, that is, with each inlet 30 of the backing pumps 28 connected to a respective outlet 32 from the exhaust conduit 22. Each backing pump 28 has an exhaust that exhausts the gas drawn from the chamber to the atmosphere. In the
5 illustrated embodiment, the pumping arrangement 10 comprises five backing pumps 28a to 28e, although any number x of backing pumps may be provided, where $x \geq 1$.

Each booster pump 12 typically comprises a pumping mechanism driven by a
10 variable speed motor. Booster pumps typically include an essentially dry (or oil free) pumping mechanism, but generally also include some components, such as bearings and transmission gears, for driving the pumping mechanism that require lubrication in order to be effective. Examples of dry pumps
15 incorporating Roots and/or Northey mechanisms are commonly multi-stage positive displacement pumps employing intermeshing rotors in each pumping chamber. The rotors are located on contra-rotating shafts, and may have the same type of profile in each chamber or the profile may change from chamber to chamber. The backing pumps 28 may have either a similar pumping
20 mechanism to the booster pumps 12, or a different pumping mechanism. For example, the backing pumps 28 may be rotary vane pumps, rotary piston pumps, Northey, or "claw", pumps, or screw pumps. A backing pump motor drives the pumping mechanism of the backing pump.

25 The motor of each booster pump 12 may be any suitable motor for driving the pumping mechanism of the booster pump 12. In the preferred embodiment, the motor comprises an asynchronous AC motor. A control system for driving the motor comprises a variable frequency drive unit for receiving an AC power supplied by a power source and converting the received AC power
30 into a power supply for the motor. The drive unit comprises an inverter and an inverter controller. The inverter controller controls the operation of the

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inverter so that the power supply for the motor has a desired amplitude and frequency.

When the frequency of the power output from the inverter varies, the speed of rotation of the motor varies in accordance with the change in frequency. The drive unit is thus able to vary the speed of the booster pump 12 during the evacuation of the chamber to optimise the performance of the booster pump 12.

The inverter controller sets values for two or more operational limits of the drive unit; in particular, the maximum frequency of the power supplied to the motor (f_{max}), and the maximum current that can be supplied to the motor (I_{max}). As mentioned above, the value of I_{max} is normally set so that it is appropriate to the continuous rating of the motor, that is, the power at which the motor can be operated indefinitely without reaching an overload condition. Setting a maximum to the power supplied to the motor has the effect of limiting the effective torque available to the pumping mechanism. This in turn will limit the resulting differential pressure across the booster pump 12, and thus limit the amount of heat generated within the booster pump 12.

The inverter controller also monitors the current supplied to the motor. The current supplied to the motor is dependent upon the values of the frequency and amplitude of the AC power supplied to the motor by the drive unit. In the event that the current supplied to the motor exceeds I_{max} , the inverter controller controls the inverter to rapidly reduce the frequency of the power supplied to the motor, thereby reducing both the current below I_{max} and the speed of the booster pump 12.

Returning to Figure 1, a number of the booster pumps 12, in this embodiment booster pumps 12b, 12c, are each connected to the inlet conduit 16 and the exhaust conduit 22 via first and second valves 34, 36 respectively for selectively isolating the booster pumps 12b, 12c from the gas passing through

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the pumping arrangement 10. First valves 34 serve to isolate the booster pumps 12b, 12c from the inlet conduit 16 by inhibiting the flow of gas into the booster pumps 12b, 12c, and the second valves 36 serve to isolate the booster pumps 12b, 12c, from the exhaust conduit 22 by inhibiting the flow of gas from those pumps into the exhaust conduit 22. In the embodiment illustrated in Figure 1, two of the three booster pumps 12 can be selectively isolated from the gas flow, although any number n of booster pumps 12 may be selectively isolated, where $n < m$.

10 The first and second valves 34, 36 may be any suitable control valves which can be selectively opened and closed by a signal received from a controller 38, as shown in Figure 2, for controlling each of the valves 34, 36 of the pumping arrangement 10 (one pair only illustrated in Figure 2 for simplicity only). In the example shown in Figure 2, the controller 38 controls the valves 15 34, 36 in dependence on a gas pressure within the pumping arrangement. As illustrated, the controller 38 may receive a first signal indicative of the pressure at the inlet conduit 16 from a first pressure sensor 40. Alternatively, or in addition, the controller 38 may receive a second signal indicative of the pressure at the exhaust conduit 22 from a second pressure sensor 42. The 20 controller 38 may then control the valves 34, 36 in dependence on one, or both, of the first and second signals. As another alternative, the controller 38 may control the valves 34, 36 at a predetermined time during the evacuation of the chamber. As a further alternative, the controller 38 may control the valves 34, 36 in dependence on the speed of the booster pump 12a.

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In use, with all of the first and second valves 34, 36 initially closed to isolate the booster pumps 12b, 12c from the gas passing through the pumping arrangement, the booster pumps 12 and the backing pumps 28 are operated to evacuate the chamber. During an initial stage of the evacuation of the 30 chamber, the gas entering the pumping arrangement 10 from the chamber flows through the inlet conduit 16, booster pump 12a, exhaust conduit 22 and the parallel arrangement of backing pumps 28 before being exhaust to the

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atmosphere. At the end of this initial stage, as determined by the signals received from the first and/or second pressure sensors or after the lapse of a predetermined time period following the start of the evacuation, for example 20 seconds, the controller 38 opens the valves 34, 36. As a result, during the subsequent stage of the chamber evacuation, the gas entering the pumping arrangement 10 from the chamber flows through the inlet conduit 16, the parallel arrangement of booster pumps 12, exhaust conduit 22 and the parallel arrangement of backing pumps 28 before being exhausted to the atmosphere.

Figure 3 illustrates graphically the impact that such a control system has on the rate of evacuation of a chamber by such a pumping arrangement. Figure 3 illustrates the variation with time of a chamber when evacuated using four different pumping arrangements A to D, as summarised in the following table.

Pumping arrangement	<i>m</i>	<i>n</i>	<i>x</i>	Line in Figure 3
A	5	0	5	60
B	5	4	5	62
C	4	3	5	64
D	3	2	5	66

The first and second valves in the pumping arrangements B to D were each opened 20 seconds from the start of the evacuation of the chamber from atmospheric pressure. As can be seen from Figure 3, pumping arrangement D can provide a similar pumping performance to known pumping arrangement A employing no booster pump isolation, but with a reduced number of booster pumps 12 (three, instead of five), whereas pumping arrangements B and C offer a superior pumping performance.

The improvement in the pumping performance is explained with reference to Figure 4. Figure 4 graphically illustrates the variation with time of the rotation

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- speed of the booster pumps of the pumping arrangement of Figure 1 during evacuation of the chamber. Line 70 illustrates the variation with time of the pumping speed of booster pump 12a, and line 72 illustrates the variation with time of the pumping speed of booster pumps 12b, 12c, during the evacuation.
- 5 The valves 34, 36 are opened after 20 seconds. By way of comparison, line 74 illustrates the variation with time of the pumping speed of each of the three booster pumps 12 where valves 34, 36 are open during the entire pumping arrangement.
- 10 With reference first to line 74, due to the relatively high density of the gas in the inlet conduit 16 at the start of the evacuation, a large torque is required to rotate the pumping mechanisms of the three booster pumps 12 at a frequency around f_{max} , and so there is a high current demand, which is greater than I_{max} . To protect the motor from damage, the frequency of the power supplied to
- 15 each motor of the three booster pumps is rapidly reduced to some level below f_{max} , resulting in a sharp reduction in the rotational speed of the pumps. As the evacuation progresses and the pressure in the inlet conduit 16 decreases, the drive units will ramp up the frequency towards a finite period to gradually increase the rotational speed of the booster pumps. This results in a
- 20 relatively lengthy time required to evacuate the chamber from atmospheric pressure.
- In the pumping arrangement of Figure 1, with the valves 34, 36 initially closed, the booster pumps 12b, 12c continue to rotate at f_{max} during the initial stage of
- 25 the evacuation. Whilst booster pump 12a experiences a current demand greater than I_{max} , which results in the frequency of the power supplied to the motor of the booster pump 12a also being reduced to some level below f_{max} , the increased rate at which gas is drawn from the exhaust of the booster pump 12a by the backing pumps 28 (due to the isolation of the booster pumps
- 30 12b, 12c) means that the reduction in the rotational speed of the booster pump 12a is not as great as that experienced by the booster pumps 12 with no isolation. Consequently, booster pump 12a is able to maintain a

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significantly higher rotational speed than the booster pumps 12 during the initial stage of the evacuation, with the result that, during this initial stage, the evacuation rate of the chamber is not significantly different to that when no booster pump isolation is used.

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After 20 seconds, the valves 34, 36 are opened to permit gas to enter the booster pumps 12b, 12c. Whilst the booster pumps 12a, 12b, 12c experience a current demand greater than I_{max} , which results in the frequency of the power supplied to the motor of the three booster pumps 12 being
10 reduced to some level below f_{max} , the decreased pressure in the inlet conduit 16 means that the reduction in the rotational speed of the booster pump 12a is not significantly high, as shown in Figure 4. As there are now three, relatively fast, booster pumps contributing to the evacuation of the chamber, during this subsequent stage of the evacuation of the chamber, the
15 evacuation rate of the chamber is greater than that when no booster pump isolation is used. This leads to an overall improvement in pumping performance.

A second embodiment of a pumping arrangement 100 for evacuating a
20 chamber is illustrated in Figure 5. The pumping arrangement 100 comprises a by-pass conduit 102 which receives gas from the chamber, and has a first outlet 104 through which gas enters a booster pump inlet conduit 106 and a second outlet 108 through which gas enters a backing pump inlet conduit 110. Similar to the pumping arrangement 10, the pumping arrangement 100
25 comprises a plurality of booster pumps 112. In the illustrated embodiment, the pumping arrangement 100 comprises three booster pumps 112, although any number m of booster pumps may be provided, where $m > 1$. The inlets 114 of the booster pumps 112 are connected in parallel to the booster pump inlet conduit 106, that is, each inlet 114 is connected to a respective outlet
30 118 from the booster pump inlet conduit 106. The pumping arrangement 100 also comprises a booster pump exhaust conduit 122 having a plurality of inlets 124 for receiving the gas exhaust from the exhausts 126 of the booster

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pumps 112. The booster pump exhaust conduit 126 has an outlet 128 through which gas is conveyed into a second inlet 130 of the backing pump inlet conduit 110. In the illustrated embodiment, a plurality of backing pumps 132 are connected in parallel to the backing pump inlet conduit 110, that is, with each inlet 134 of the backing pumps 132 connected to a respective outlet 136 from the backing pump inlet conduit 110. Each backing pump 132 has an exhaust that exhausts the gas drawn from the chamber to the atmosphere. In the illustrated embodiment, the pumping arrangement 100 comprises five backing pumps 132, although any number x of backing pumps may be provided, where $x \geq 1$.

In this embodiment, a first valve 140 is located in the booster pump inlet conduit 106 for isolating the inlets 114 of n of the m booster pumps 112 from the by-pass conduit 102. In this embodiment, $n = m$, although n may be $\leq m$. A second valve 142 is located in the booster pump exhaust conduit 122 for isolating the exhausts 126 of the n booster pumps 112 from the backing pumps 132. A third valve 144 is located in the by-pass conduit 102 between the first outlet 104 and the second outlet 108.

The first, second and third valves 140, 142, 144 may be any suitable control valves which can be selectively opened and closed by a signal received from a controller 146, as shown in Figure 6, for controlling each of the valves 140, 142, 144 of the pumping arrangement 100. In the example shown in Figure 6, the controller 146 controls the valves 140, 142, 144 in dependence on a gas pressure within the pumping arrangement 100. As illustrated, the controller 146 may receive a signal indicative of the pressure in the by-pass conduit 102 from a pressure sensor 148. As alternative, the controller 146 may control the valves 140, 142, 144 at a predetermined time during the evacuation of the chamber.

In use, with the first and second valves 140, 142 initially closed to isolate the booster pumps 12 from the gas passing through the pumping arrangement,

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and with the third valve 144 open, the booster pumps 112 and the backing pumps 132 are operated to evacuate the chamber. During an initial stage of the evacuation of the chamber, the gas entering the pumping arrangement 10 from the chamber flows through the by-pass conduit 102 into the backing pump exhaust conduit 110, through the parallel arrangement of backing pumps 132 before being exhaust to the atmosphere. At the end of this initial stage, as determined by the signal received from the sensor 148 or after the lapse of a predetermined time period following the start of the evacuation, for example 20 seconds, the controller 146 opens the valves 140, 142 and closes the third valve 144. As a result, during the subsequent stage of the chamber evacuation, the gas entering the pumping arrangement 10 from the chamber enters the booster pump inlet conduit 106, and passes through the parallel arrangement of booster pumps 112 to enter booster pump exhaust conduit 122. From this conduit 122, the gas enters the backing pump inlet conduit 100, and passes through the parallel arrangement of backing pumps 132 before being exhausted to the atmosphere.

The backing pumps 132 alone thus perform the initial evacuation of the chamber. When the booster pumps 112 are exposed to the gas stream at the end of this initial stage of the evacuation cycle, the gas within the booster pump inlet conduit 106 is at a relatively low pressure. As discussed above, this means that a lower torque is required to rotate the pumping mechanisms of the booster pumps 112 at a frequency around f_{max} , and so there is a lower current demand that would have been experienced by these booster pumps 112 at the start of the evacuation cycle. Consequently, the reduction in speed of the booster pumps 112 when the valves 140, 142 are opened is significantly less than if the booster pumps 112 had been exposed to the gas stream at the start of the evacuation cycle. As a result, the net pumping speed of the booster pumps 112 can be improved, improving the overall pumping performance of the pumping arrangement 100.

Figure 7 illustrates a third embodiment of a pumping arrangement 200. This third embodiment is similar to the first, with the exception that each of the booster pumps 12 is provided with a pair of valves 34, 36 at the inlet and exhaust thereof, and now each of the backing pumps 28 is provided with a
5 controllable valve 210 at the inlet thereof. This can enable one or more of the booster pumps 12 and backing pumps 28 (identified in Figure 7 at 12s and 28s) to be selectively isolated from the gas stream during the entire evacuation of the chamber. These pumps 12s, 28s can thus provide back-up pumps in the event that one of the other booster pumps 12 or backing pumps
10 28 fails during use. In this event, the back-up pump can be rapidly exposed to the gas stream (by opening the valves 34, 36 or 210 as required) to replace the failed pump. The valve(s) associated with the failed pump can then be closed to enable the failed pump to be removed for service. The replacement of this failed pump by a back-up pump thus incurs no loss of pumping
15 performance and no downtime of the chamber under evacuation.

CLAIMS

1. A vacuum pumping arrangement for evacuating a chamber, the
5 pumping arrangement comprising a plurality of first vacuum pumps
connected in parallel to an inlet conduit for receiving gas from the
chamber, at least one second vacuum pump connected to an exhaust
conduit for receiving gas exhaust from the first vacuum pumps, means
for selectively isolating at least one of the first vacuum pumps from the
10 inlet conduit and the exhaust conduit, and control means for controlling
the isolating means such that gas flow through said at least one of the
first vacuum pumps is inhibited during an initial stage of the evacuation
of the chamber, and permitted during a subsequent stage of the
evacuation of the chamber.
15
2. An arrangement according to Claim 1, wherein the isolating means
comprises, for each of said at least one of the first vacuum pumps, a
respective first valve for isolating that pump from the inlet conduit.
- 20 3. An arrangement according to Claim 2, wherein the isolating means
comprises, for each of said at least one of the first vacuum pumps, a
respective second valve for isolating that pump from the exhaust
conduit.
- 25 4. An arrangement according to any preceding claim, wherein said
plurality of first vacuum pumps comprises m first vacuum pumps,
where $m > 1$, and said at least one of the first vacuum pumps
comprises n first vacuum pumps, where $n < m$.
- 30 5. An arrangement according to Claim 1, wherein the isolating means
comprises a first valve located within the inlet conduit, and a second
valve located within the exhaust conduit.

- 20 -

6. An arrangement according to Claim 5, comprising a by-pass conduit having an inlet for receiving gas from the chamber, a first outlet for exhausting gas to the inlet conduit and a second outlet for exhausting gas to the exhaust conduit, and a third valve located in the by-pass conduit between the first and second outlets.
5
7. An arrangement according to Claim 6, wherein the control means is configured to control the third valve such that the third valve is open during the initial stage of the evacuation of the chamber, and closed during the subsequent stage of the evacuation of the chamber.
10
8. An arrangement according to any of Claims 5 to 7, wherein said plurality of first vacuum pumps comprises m first vacuum pumps, where $m \geq 1$, and said at least one of the first vacuum pumps comprises n first vacuum pumps, where $n \leq m$.
15
9. An arrangement according to Claim 8, wherein $n = m$.
- 20 10. An arrangement according to any preceding claim, wherein said at least one second vacuum pump comprises a plurality of second vacuum pumps connected in parallel to the exhaust conduit.
- 25 11. An arrangement according to Claim 10, comprising means for selectively isolating at least one of the second vacuum pumps from the exhaust conduit during both stages of the evacuation of the chamber.
- 30 12. An arrangement according to any preceding claim, wherein the control means is configured to receive input from at least one sensor for monitoring one or more states within the pumping arrangement, and to control said isolating means in dependence on the monitored states.

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13. An arrangement according to Claim 12, wherein at least one sensor is configured to supply a signal indicative of a gas pressure within the pumping arrangement, and wherein the control means is configured to control the isolating means in dependence on the received signal.
- 5
14. An arrangement according to Claim 13, wherein the control means is configured to permit gas flow through said at least one of the first vacuum pumps when the pressure falls below a predetermined value.
- 10
15. An arrangement according to Claim 13, wherein two sensors are configured to detect respective different pressures within the pumping arrangement, and the control means is configured to control the isolating means in dependence on a relationship between the detected pressures.
- 15
16. An arrangement according to Claim 12, wherein the control means is configured to permit gas flow through said at least one of the first vacuum pumps in dependence of the speed of at least one of the plurality of first vacuum pumps.
- 20
17. An arrangement according to any of Claims 1 to 11, wherein the control means is configured to permit gas flow through said at least one of the first vacuum pumps after the lapse of a predetermined time period from the start of the chamber evacuation.
- 25
18. An arrangement according to any preceding claim, comprising, for each of the first vacuum pumps, an inverter for supplying a variable frequency power to a motor for driving the vacuum pump.
- 30
19. A method of evacuating a chamber, the method comprising the steps of connecting a plurality of first vacuum pumps in parallel to an inlet conduit for receiving gas from the chamber, connecting at least one

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5 second vacuum pump to an exhaust conduit for receiving gas exhaust from the first vacuum pumps, and selectively isolating at least one of the first vacuum pumps from the inlet conduit and the exhaust conduit during evacuation of the chamber such that gas flow through said at least one of the first vacuum pumps is inhibited during an initial stage of the evacuation of the chamber, and permitted during a subsequent stage of the evacuation of the chamber.

10 20. A method according to Claim 19, wherein said one of the first vacuum pumps is isolated until the lapse of a predetermined time period from the start of the chamber evacuation.

15 21. A method according to Claim 19, wherein said one of the first vacuum pumps is isolated until a gas pressure within the pumping arrangement falls below a predetermined value.

20 22. A vacuum pumping arrangement for evacuating a chamber, the pumping arrangement comprising a plurality of first vacuum pumps connected in parallel to an inlet conduit for receiving gas from the chamber, at least one second vacuum pump connected to an exhaust conduit for receiving gas exhaust from the first vacuum pumps, means for selectively isolating each of the first vacuum pumps from the inlet conduit and the exhaust conduit, and control means for controlling the isolating means such that gas flow through at least one of the first vacuum pumps is permitted in the event of failure of one of the other first vacuum pumps.

25 23. A vacuum pumping arrangement for evacuating a chamber, the pumping arrangement comprising a plurality of first vacuum pumps connected in parallel to an inlet conduit for receiving gas from the chamber, a plurality of second vacuum pumps connected in parallel to an exhaust conduit for receiving gas exhaust from the first vacuum

30

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pumps, means for selectively isolating each of the second vacuum pumps from the exhaust conduit, and control means for controlling the isolating means such that gas flow through at least one of the second vacuum pumps is permitted in the event of failure of one of the other
5 second vacuum pumps.

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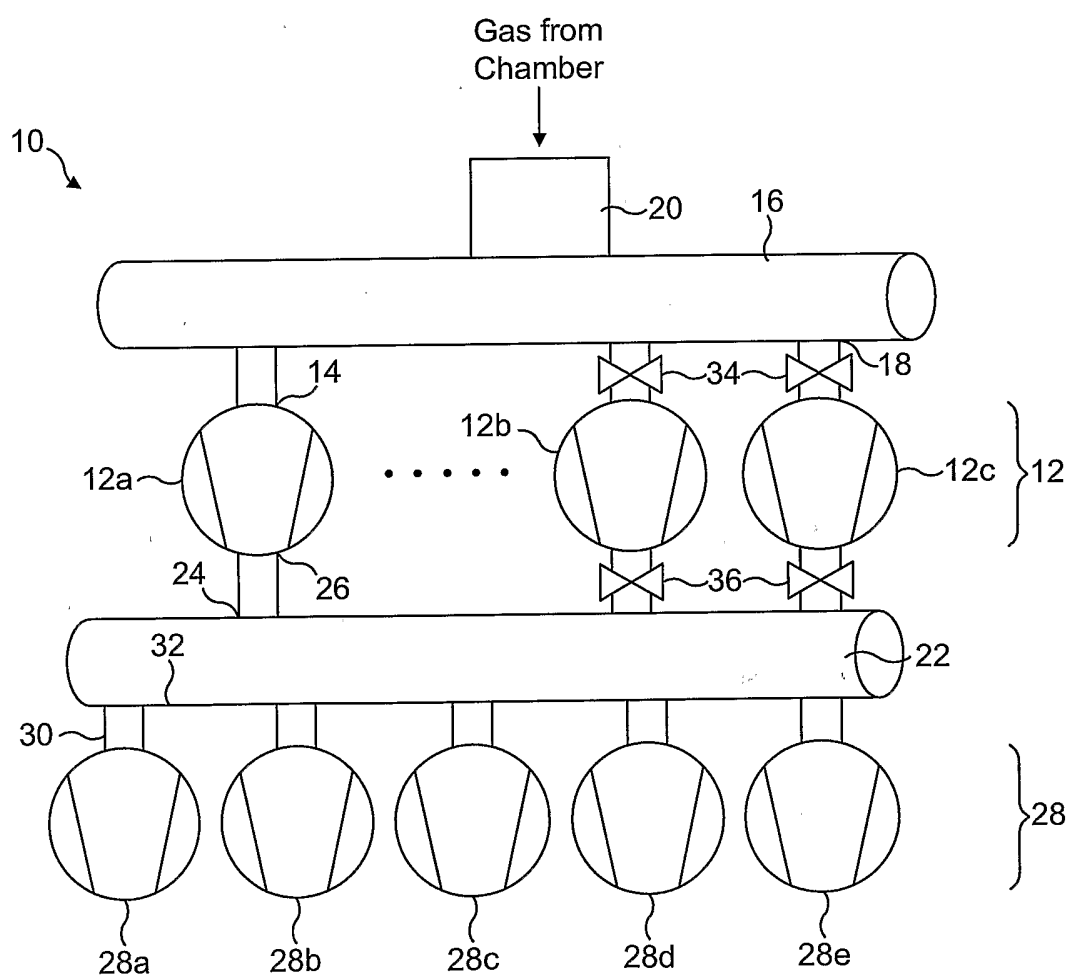


FIG. 1

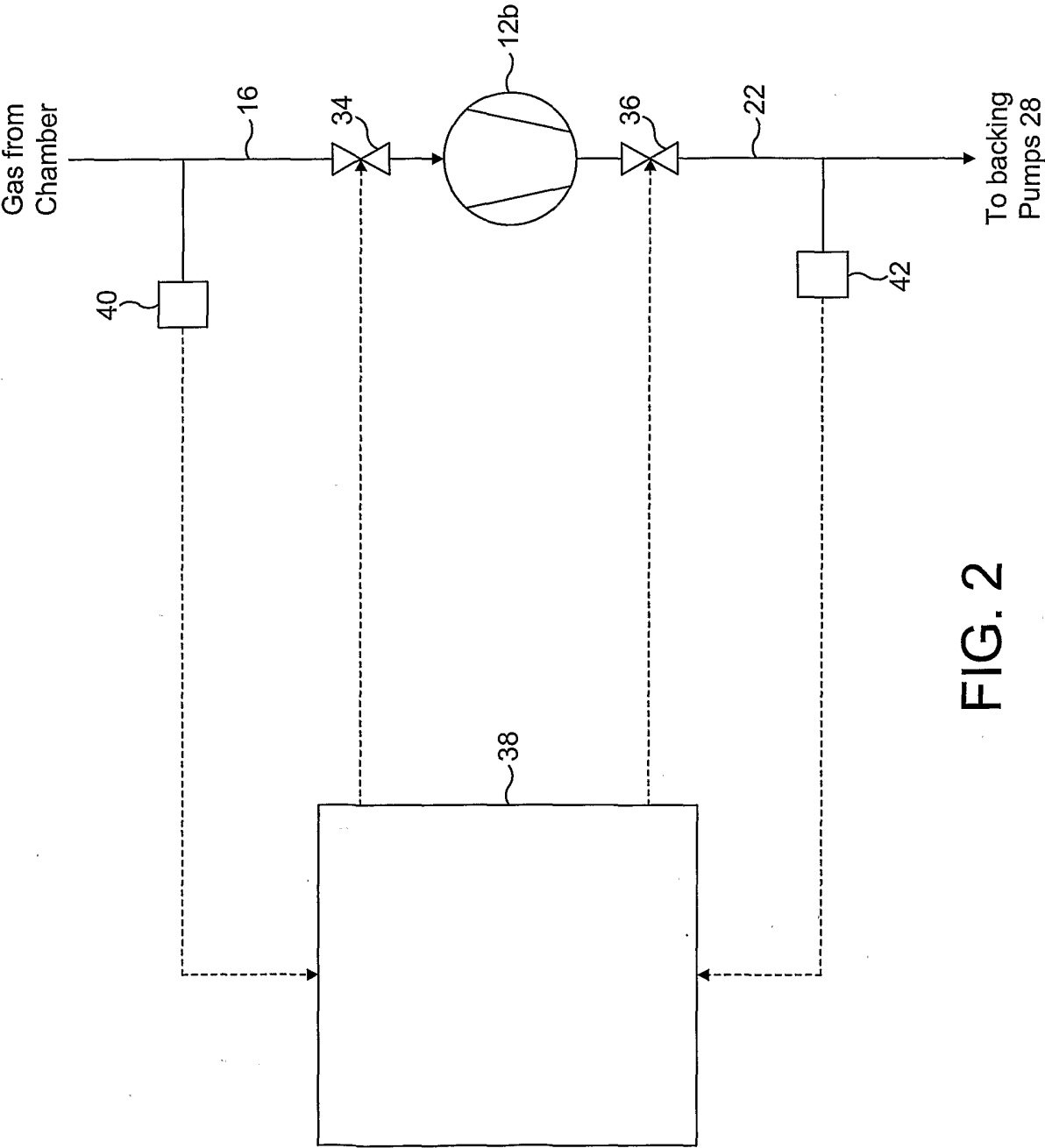


FIG. 2

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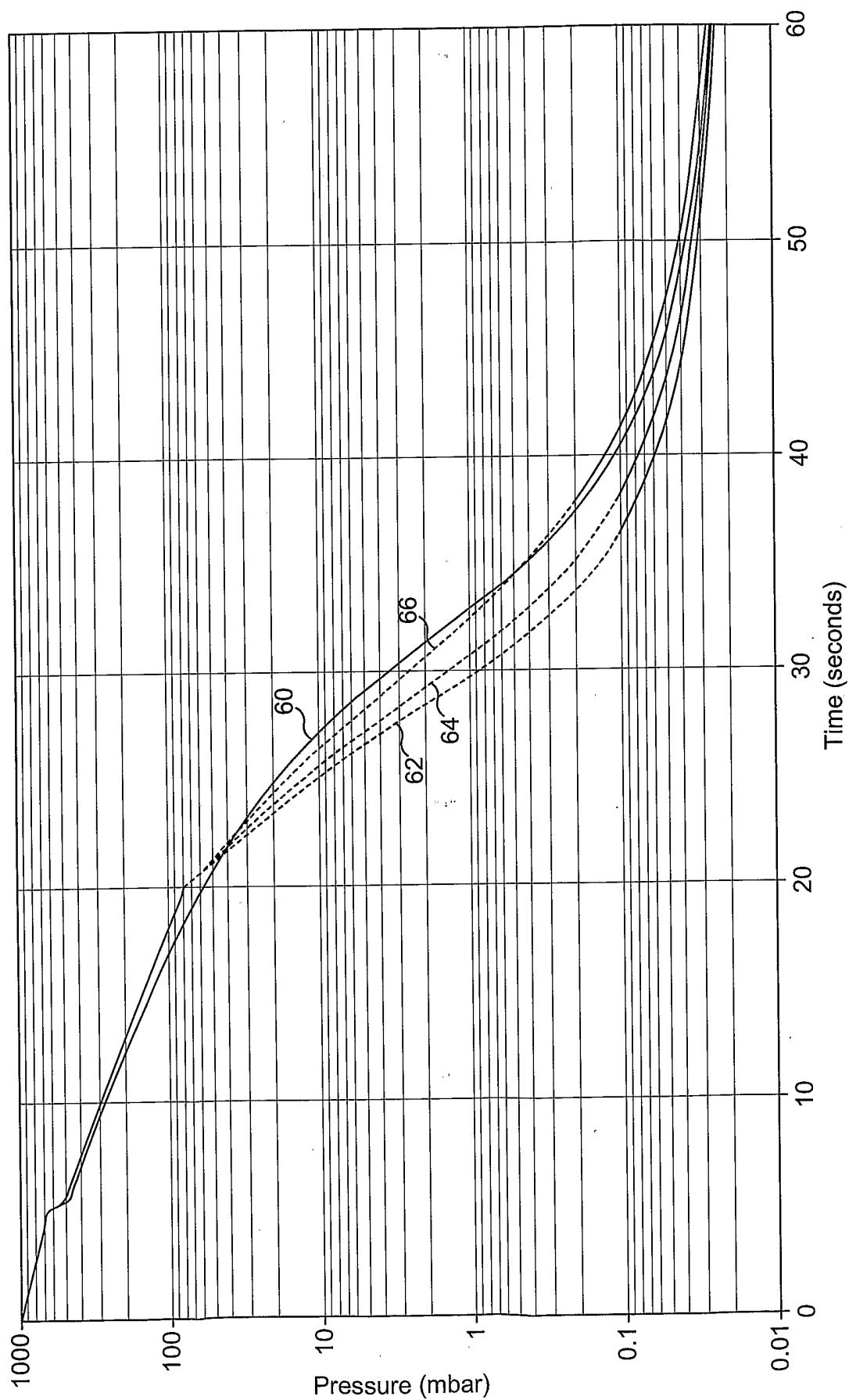


FIG. 3

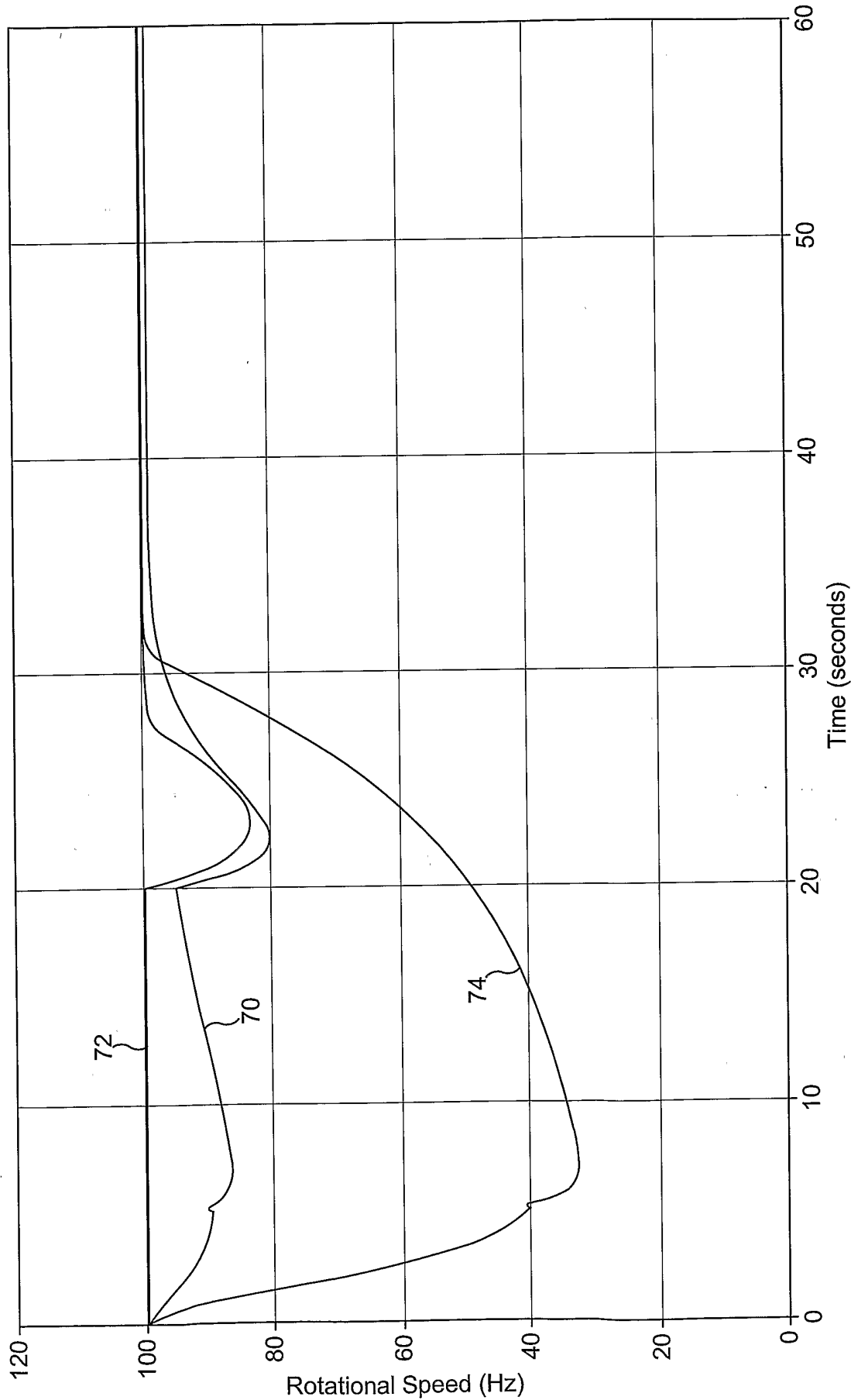


FIG. 4

5 / 7

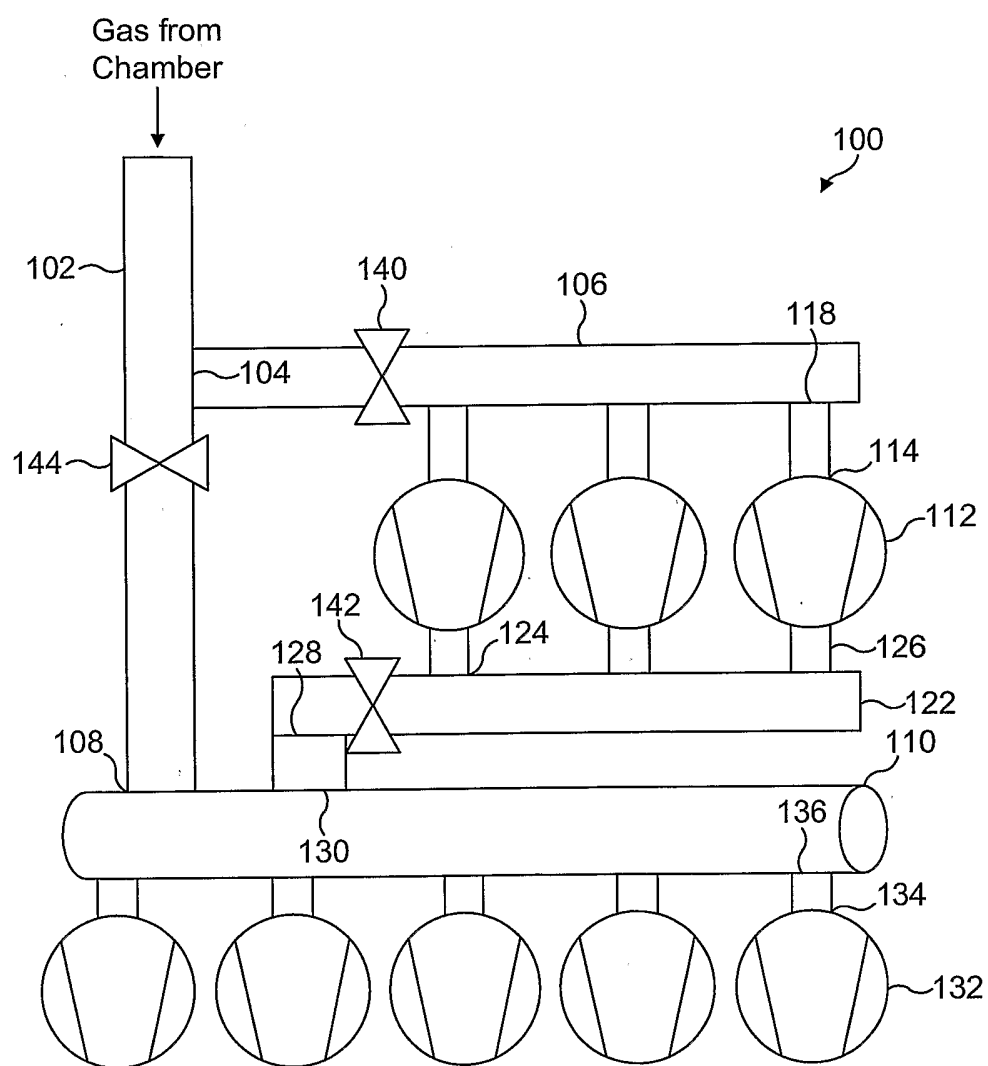
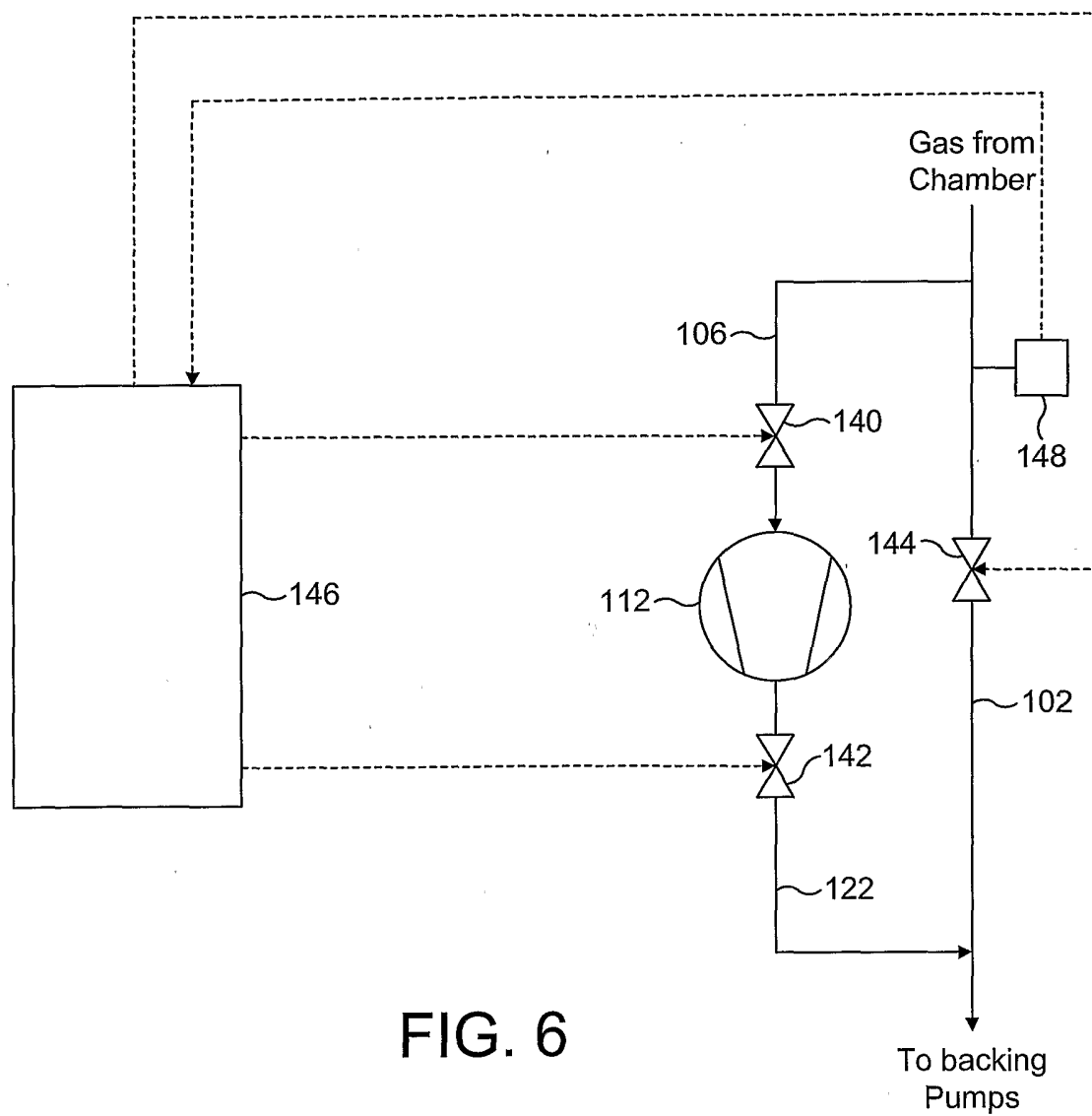


FIG. 5

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7/7

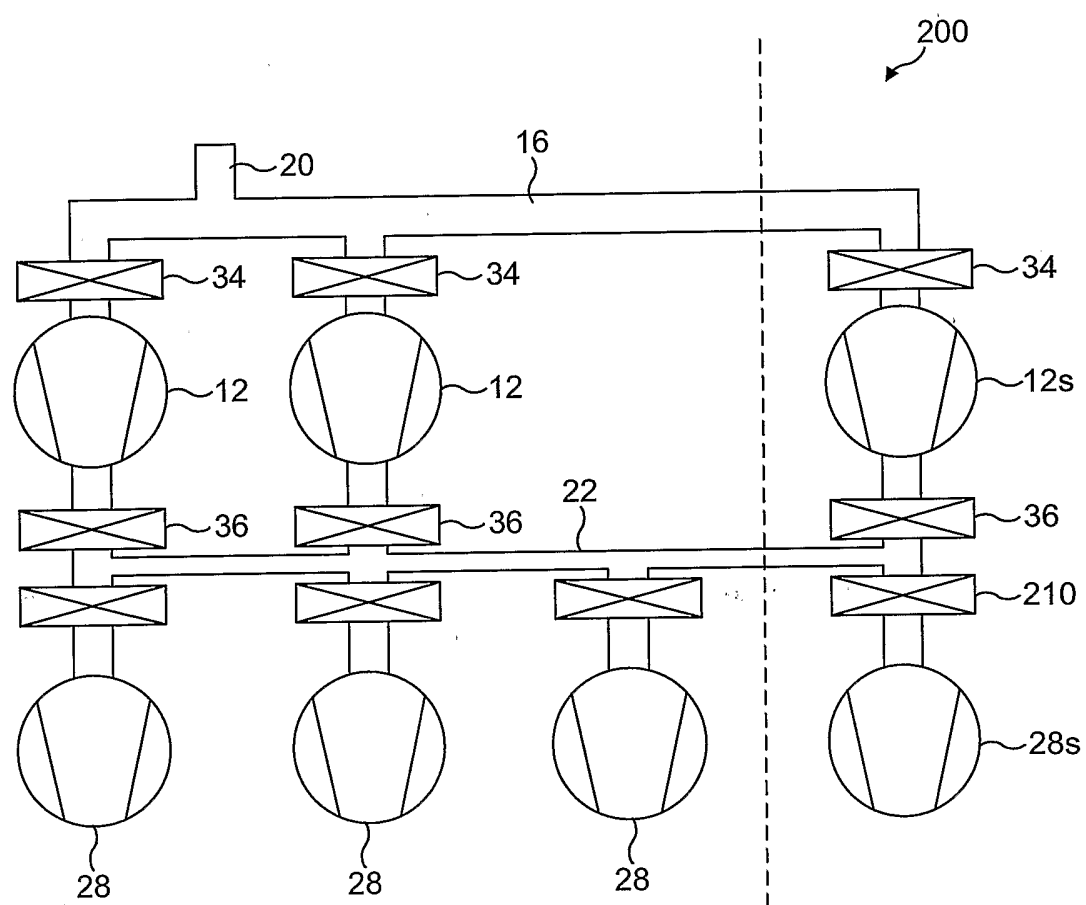


FIG. 7

INTERNATIONAL SEARCH REPORT

International application No

PCT/GB2006/000724

A. CLASSIFICATION OF SUBJECT MATTER

INV. C23C16/44 G01M3/20 F04D17/16

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)

G01M C23C F04D B01J F04B

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)

EPO-Internal, WPI Data, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2004/146410 A1 (CONRAD ARMIN ET AL) 29 July 2004 (2004-07-29) paragraph [0022]; figure 2 -----	1, 19, 22, 23
A	US 5 228 838 A (GEBELE ET AL) 20 July 1993 (1993-07-20) column 3, line 60 - column 4, line 5; figure 2 -----	1, 19, 22, 23



Further documents are listed in the continuation of Box C.



See patent family 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

27 June 2006

Date of mailing of the international search report

05/07/2006

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Authorized officer

Di Giorgio, F

INTERNATIONAL SEARCH REPORT

International application No.
PCT/GB2006/000724

Box II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This International Search Report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:
2. ☐ Claims Nos.:
because they relate to parts of the International Application that do not comply with the prescribed requirements to such an extent that no meaningful International Search can be carried out, specifically:
3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☒ As all required additional search fees were timely paid by the applicant, this International Search Report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this International Search Report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this International Search Report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest.

☒ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ .210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-21

A vacuum pumping arrangement (claims 1 to 18) for evacuating a chamber and corresponding method (claims 19 to 21), comprising a plurality of first vacuum pumps and one second vacuum pump, and control means for controlling isolating means such that gas flow through one first vacuum pump is inhibited during an initial stage of the evacuation of the chamber, and permitted during a subsequent stage of the evacuation of the chamber.

2. claims: 22, 23

Claim 22: a vacuum pumping arrangement for evacuating a chamber, comprising a plurality of first vacuum pumps and one second vacuum pump, and control means for controlling isolating means such that gas flow through one first vacuum pump is permitted in the event of failure of one of the other first vacuum pumps.

Claim 23: A vacuum pumping arrangement for evacuating a chamber, comprising one first vacuum pump and a plurality of second vacuum pumps, and control means for controlling isolating means such that gas flow through one second vacuum pump is permitted in the event of failure of one of the other second vacuum pumps.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/GB2006/000724

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2004146410 A1	29-07-2004	DE 10302764 A1 EP 1441128 A2	29-07-2004 28-07-2004
US 5228838 A	20-07-1993	DE 4213763 A1	28-10-1993