

REDUCING POWER CONSUMPTION IN VACUUM PUMPS

FIELD OF THE INVENTION

The field of the invention relates to vacuum pumps, and to control of these pumps
5 to reduce power consumption particularly in a steady state standby mode.

BACKGROUND

In mechanical vacuum pumps such as positive displacement vacuum pumps,
total power consumption is a combination of useful power (used to move and/or
10 compress gas) and losses. Losses are mostly associated with electrical and
magnetic efficiency (motors and drives) and parasitic losses (gas leakage,
cooling fans, friction). Clearly there is potential to reduce losses through improved
design, but the power deployed in gas movement/compression is harder to
reduce.

15 In many applications, whether evacuating chambers or pumping a steady gas
flow at low pressures, vacuum pumps often spend at least some of their
operating time maintaining a vacuum and operating with little or no gas
throughput. During this mode an exhaust non-return valve is generally closed.
20 'Green' or 'standby' modes already exist, and they typically involve a reduction in
rotational speed to reduce frictional losses (power = torque x angular velocity,
and torque includes bearing frictional losses). Reduced speed results in a
different pressure distribution and a higher ultimate pressure, and the power
reductions may be quite modest, particularly when compared to the best saving
25 of all, which is to switch the pump off altogether.

It would be desirable to be able to reduce the power consumption of a vacuum
pump, particularly when operating in standby mode where for much of the time
there is little or no throughput of gas and the pump may be pumping at or close to
30 ultimate pressure.

SUMMARY

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A first aspect provides a method of controlling a mechanical vacuum pump to reduce power consumption of said pump during a standby mode, said method comprising: operating said pump by driving a pumping mechanism at a nominal speed; determining that said pump is to enter a standby mode in which an
5 exhaust non-return valve is closed; boosting a speed of said pumping mechanism for a predetermined time to reduce an amount of gas within said pump; and reducing said speed of said pumping mechanism and operating said pump in said standby mode with said exhaust non-return valve being closed.

10 Many mechanical pumps such as positive displacement pumps that operate as primary pumps and exhaust to atmosphere have non-return exhaust valves which mitigate the impact of failure modes and prevent the pump's return to atmospheric pressure in a short timescale. They also improve the efficiency of the pump, such that in steady state conditions with no throughput of gas the valve
15 will be closed. The mode where the valve is closed for some time and there is little or no throughput of gas may be termed a standby mode during which mode the pump simply maintains a vacuum in a space being pumped.

It was recognised that when in standby mode with the non-return exhaust valve
20 closed and with operation of the pump simply maintaining the pressure within the chamber being pumped, the gas inside the pump may be moved and/or compressed and then expand again with each cycle. This consumes energy. It was also recognised that were the amount of gas within the pump to be reduced during standby mode then the amount of energy required to provide this periodic
25 movement and/or compression of gas within the pump would be reduced. Thus, the invention provides the pump with a boost in speed prior to entering, or during this, standby mode so that the amount of gas within the pump is reduced and the energy required for the periodic movement and/or compression of the gas within the pump in this mode is correspondingly reduced. There is some increase in
30 power required for the boost in speed and the increase in speed will increase the wear on pump parts such as bearings, however, the increase in speed is only required for a short period of time such that overall power can be saved.

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In this way embodiments offer a way to achieve significant power savings when operating with no or very little gas throughput, without compromising pump inlet pressure.

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In some embodiments, said step of boosting a speed of said pumping mechanism comprises increasing a rotational speed of a motor driving said pumping mechanism.

10 By boosting a speed of the pumping mechanism, the volumetric capacity and in some cases compression of the pump is increased and the amount of gas within the pump is decreased.

In some embodiments, said predetermined time is more than 1 second,
15 preferably more than 3 seconds, in some cases more than 5 seconds.

In some embodiments, said predetermined time is less than 120, preferably less than 60 seconds.

20 In some embodiments, said increase in said rotational speed comprises an increase by more than 5%, preferably more than 10% of said nominal rotational speed.

In some embodiments, said step of reducing said speed of said pumping
25 mechanism comprises reducing said speed to said nominal speed.

In other embodiments, said step of reducing said speed of said pumping mechanism comprises reducing said speed to a reduced speed that is lower than said nominal speed.

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In some embodiments, said lower speed is more than 10% lower than said nominal speed.

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In standby mode where the exhaust non-return valve is closed it may be acceptable to operate the pump at a speed that is lower than the nominal speed and thereby reduce power consumption.

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In some embodiments, said step of determining that said pump is to enter a standby mode comprises at least one of: receiving a control signal from a user, receiving a control signal from a vacuum system associated with said pump and receiving a control signal from at least one sensor.

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The determining that the pump is to enter a standby mode may be made in response to a signal received from a user or a control signal from a vacuum system that the pump is evacuating and/or a control signal from a sensor associated with the pump or with the vacuum system.

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The sensor may be a power sensor sensing the power of the motor of this pump or of a secondary pump where this pump is backing a secondary pump.

Alternatively and/or additionally it may come from a pressure sensor sensing a pressure in the chamber or sensing a pressure within the pump or a pressure elsewhere within an associated vacuum system, and/or a sensor indicating that the exhaust non-return valve is closed and has remained closed for a predetermined time. The signal from the vacuum system may come from a control system controlling the vacuum system and/or the pump(s).

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In some embodiments, said step of determining that said pump is to enter a standby mode comprises receiving a control signal from at least one sensor sensing a power consumption of a motor, said sensor indicating said power consumption is at or close to value indicative of low or zero gas throughput, said method comprising a further step of determining a rate of increase of power consumption following said step of reducing said speed of said pumping

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mechanism and where a rate of increase of said power consumption is greater than a predetermined rate exiting said standby mode.

Where the entry to standby mode is triggered by detecting the power
5 consumption of the pump being at or close to a value indicative of no gas
throughput, then it may be that an additional step is performed once in the low
power mode, to verify that the pump had indeed reached the no gas throughput
condition. This additional step monitors the rate of rise of power consumption
and if this is higher than expected and exceeds a threshold then this provides an
10 accurate indication that the pump had not reached zero gas throughput. In this
case the pump may exit low power mode and resume normal operation. In effect
the power consumption of a pump at low gas throughput is dominated by
mechanical losses making the accurate detection of no gas throughput
challenging. However, once in low power mode a power sensor can accurately
15 detect that there is gas throughput as the rise in power consumption will be
relatively rapid. Thus, providing this additional check enables the low power
mode to be switched off where appropriate. As the boost in power is relatively
short and provides a power saving following it in any case, this trial and error type
approach has few disadvantages and can provide effective power savings.

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In some embodiments, said method comprises a further step performed during
said standby mode of: determining that said amount of gas within said pump is to
be reduced; boosting a speed of rotation of said pump for a predetermined time
to reduce an amount of gas within said pump; and reducing said rotational speed
25 and returning to operating in said standby mode.

The amount of gas within the pump during the standby mode may gradually
increase due to leakage of gas into the pump and in some cases the method may
include a step of determining this and in response performing the step of boosting
30 the speed again to reduce the amount of gas within the pump. In this way, the
amount of gas within the pump can be kept to a low level over a longer time

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period even where there is a small amount of gas flow, perhaps due to leakage into the system.

In some embodiments, said step of determining comprises at least one of:

- 5 determining that a power consumption of said pump or a secondary pump in a same system has increased by or to a predetermined amount, that a pressure has increased by or to a predetermined amount; that a predetermined time has elapsed since the speed was previously boosted; or that a signal is received from an operator or from a vacuum system.

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Determining that the amount of gas within the pump has risen and should be reduced may be done by monitoring increases in the power consumption of the pump or of a secondary pump in the same system, and/or in the pressure at an inlet and/ or monitoring an elapsed time since a previous boost and/or by

- 15 receiving a signal from an operator or control system.

In some embodiments, said step of determining comprises determining that a pressure within said pump, or within a chamber or associated vacuum system being pumped has increased by a predetermined amount.

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In some embodiments, said method further comprises determining a frequency with which said boosting is repeated during said standby mode and in response to determining said frequency has increased by more than a predetermined threshold amount, outputting a warning indication to an operator.

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The frequency at which the speed needs to be boosted in standby mode is an indication of leakage into the pump or vacuum system and thus, may be an indication of faults within the system. Thus, in some cases monitoring this frequency and seeing it rise above a predetermined level may be used as an

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indication of a fault in the system.

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A further aspect provides a computer program comprising computer readable instructions which when executed by a processor in a controller of a mechanical vacuum pump is configured to control said pump to perform a method according to one aspect.

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In some embodiments the computer program is stored on a non-transitory computer readable medium.

10 In some embodiments, said computer program comprises a PID (proportional-integral-derivative) control loop to tune the system response to the size of the system being evacuated and to provide a slower, smoother response for a larger volume system.

15 In some embodiments, said control loop is configured to determine said predetermined time to boost said pump speed for in dependence upon said size of said being evacuated. In some embodiments, said predetermined time is more than 1 second, preferably more than 3 seconds, in some cases more than 5 seconds. In some embodiments, said predetermined time is less than 120, preferably less than 60 seconds.

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The pumps may be used to evacuate different systems which may have different sizes. The amount of time that the speed of the pump should be boosted for may be dependent upon the system being evacuated, a larger system perhaps requiring a longer time and in some embodiments the computer program in the
25 controller of the pump may have a PID control loop operable to tune the pump to reflect the size of the system being evacuated and to provide a suitable boost period.

30 A yet further aspect provides a controller for a mechanical vacuum pump, said controller comprising: control circuitry configured to control a speed of a pumping mechanism of said pump, said control circuitry being configured to: control said pump such that said pumping mechanism is driven at a nominal speed; and in

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response to receipt of a signal indicating that said pump is to enter a standby mode in which said exhaust non-return valve is closed to control said pump to increase a speed of said pumping mechanism for a predetermined time to reduce an amount of gas within said pump; and after said predetermined time to reduce
5 said speed of said pumping mechanism and continue to drive said pumping mechanism in said standby mode with said exhaust non-return valve being closed.

In some embodiments, said step of reducing said pumping mechanism speed
10 comprises reducing said speed to said nominal speed.

In some embodiments, said step of reducing said pumping mechanism speed comprises reducing said pumping mechanism speed to a low power speed that is lower than said nominal speed.

15 In some embodiments, said signal is received from at least one of: a user, a control system or a sensor.

In some embodiments, the sensor may be a power sensor, a pressure sensor or
20 a sensor indicating the valve has closed and remains closed for a predetermined time.

In some embodiments, where said sensor is a power sensor, said sensor is further configured to determine a rate of increase of power consumption following
25 said pumping mechanism reducing said speed, and in response to a rate of increase of said power consumption being greater than a predetermined level, said control circuitry is configured to control said vacuum pump to exit said standby mode.

30 In some embodiments, said control circuitry is further configured in response to receipt of a signal during standby mode, said signal indicating that an amount of gas within said pump is to be reduced; to control said motor to boost a speed of

rotation of said pump for a predetermined time to reduce said amount of gas within said pump; and after said predetermined time to reduce said speed of said pumping mechanism and return to controlling said pump to operate in said standby mode.

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In some embodiments, said signal is generated in response to at least one of: a power consumption of said pump increasing by or to a predetermined amount, a pressure at an inlet to said pump increasing by or to a predetermined amount, a predetermined time having elapsed since the speed was previously boosted; or
10 an input from an operator or from a control system.

Another aspect provides a mechanical vacuum pump, comprising:

a motor for driving said pump;

a non-return exhaust valve; and

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a controller according to a yet further aspect for controlling operation of said mechanical vacuum pump.

In some embodiments, said pump comprises at least one sensor for sensing pressure at an inlet, or a sensor for sensing power consumption of a motor,
20 and/or a sensor for sensing a time elapsed since a previous boost in speed.

In some embodiments, said mechanical vacuum pump comprises one of a positive displacement or a regenerative vacuum pump.

25 In some embodiments, said positive displacement pump comprises a dry positive displacement pump.

In some embodiments said positive displacement pump comprise one of a scroll, a multi-stage Roots, a screw, a claw, a diaphragm, a reciprocating piston or a
30 rotary vane pump.

In some embodiments, said vacuum pump comprises a ported screw pump.

A vacuum pump according to an embodiment that has a non-return exhaust valve close to the pump provides a particularly effective power reduction as the reduction in the amount of gas within the pump resulting from the boost in speed to the pump mechanism increases with a decreasing volume of gas between the valve and the pump. Ported pumps such as a ported screw pump have the valve on a port at the exhaust of the pump and therefore have a very small volume between the valve and the pump.

It should be noted that some vacuum pumps may have impurities such as liquids and particles in the exhausted flow and these may clog the exhaust valve. One way of mitigating this is to provide a plenum into which the pump exhausts, this protects the valve from the impurities, but the increase in volume between the pump and valve makes the reduction in power by boosting the speed less effective. Dry pumps do not require such protection of the valves and therefore may have the valve closer to the pump. Scroll pumps are generally configured with a non-return exhaust valve close to the outlet of the pump and embodiments provide a particularly effective power reduction for these pumps.

In some embodiments, said vacuum pump comprises a regenerative vacuum pump, in some embodiments, said vacuum pump comprises a side channel blower.

The power consumption of a regenerative vacuum pump depends on the amount of gas circulating within the pump, and thus, in a similar way to a positive displacement pump, having a reduced quantity of gas within the pump when it is operating with a closed exhaust valve at substantially zero throughput reduces the power consumption of the pump.

A further aspect provides a vacuum system comprising a vacuum pump according to another aspect, said vacuum pump comprising a primary vacuum pump and said vacuum system further comprises a secondary vacuum pump,

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said secondary vacuum pump comprising a valve at an inlet, said controller being configured to close said inlet valve in response to receipt of said signal that said pump is to enter standby mode.

5 In vacuum systems comprising multiple pumps, power consumption may be reduced further if the amount of gas within both the secondary vacuum pump and the primary vacuum pump is reduced during substantially zero throughput operation. This may be done by closing an inlet to the secondary vacuum pump when ultimate pressure has been reached either prior to, during or immediately
10 following boosting the speed of the primary pump. Immediately following may be within 5 seconds, preferably 1 second of the boosting of the speed finishing. In such a scenario, sensors sensing the vacuum chamber being pumped may be required to indicate to the controller when pressure rises in the vacuum chamber such that the valves may be opened and the pump system become operational
15 again.

Further particular and preferred aspects are set out in the accompanying independent and dependent claims. Features of the dependent claims may be combined with features of the independent claims as appropriate, and in
20 combinations other than those explicitly set out in the claims.

Where an apparatus feature is described as being operable to provide a function, it will be appreciated that this includes an apparatus feature which provides that function or which is adapted or configured to provide that function.

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BRIEF DESCRIPTION OF THE DRAWINGS

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

Figure 1 shows a scroll pump and controller according to an embodiment;
30 Figures 2A and 2B schematically show the pressure distribution within a pump with no gas throughput with and without a boost in rotational speed;

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Figure 3 shows a flow diagram schematically illustrating steps in a method according to an embodiment;

Figure 4 shows how power consumption can vary with time with a vacuum pump according to an embodiment; and

5 Figure 5 shows a side channel blower according to an embodiment.

DESCRIPTION OF THE EMBODIMENTS

Before discussing the embodiments in any more detail, first an overview will be provided.

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Positive displacement pumps such as scroll vacuum pumps typically have a non-return valve at the outlet to prevent entry of atmospheric air. The valve is closed with a low-rate spring and its primary function is to prevent backflow of downstream gas into the user's system when the scroll pump is stopped, thereby preserving the vacuum even in the event of a power failure. An isolation valve at the pump inlet is an alternative technical solution but is more costly and introduces a gas conductance limitation.

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During steady-state operation with no or little gas throughput, this non-return valve is closed. The pump contains a finite trapped quantity of gas, and gas compression power at this ultimate condition is consumed in maintaining a pressure gradient between inlet and outlet. Most of the gas is in the last stages, where the pressure is close to atmospheric.

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If the trapped gas in the last stages can be ejected or isolated, the steady-state power requirement would reduce.

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Embodiments provide a solution where when gas throughput is substantially zero, the pump can be run briefly at a higher rotational speed than its normal rated speed (to improve performance and exhaust some additional gas), then returned to normal or a lower standby speed to take advantage of the reduced gas load.

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When the pump is operated with no gas throughput, a steady state is achieved. The gas within the pumping mechanism is distributed according to the pump's compression characteristic. The non-return valve at the outlet no longer opens
5 because the pressure in the last stage is insufficient to overcome the valve's spring.

If the pump's rotational speed is increased, the pump's ability to counter back-leakage improves and the pressure distribution is biased further towards the
10 outlet. Pressure in the final stage is sufficient to open the valve and more gas is pushed from the pump. After a short period, the pump can revert to the nominal speed – power requirement is now lower because pressure in the final stage has been reduced. (Note that the pump's all-round performance would be improved by operating continuously at a higher speed, but the increased load on bearings
15 would be detrimental in the longer term).

If the pressure in the final stage has been reduced then the internal leak rates through the other stage will also be reduced and it is possible to maintain a low ultimate pressure even if the pump speed is reduced below nominal, for a further
20 power saving. Note that such pumps typically already have an optional 'standby' reduced speed, but this results in a rise in inlet pressure. Embodiments seek to provide reduced power without eroding vacuum performance; if reduced performance is actually acceptable, then a preferred way to conserve power may be to slow the pump or stop it altogether.

25 In some embodiments, an existing pump may be retrofitted with suitable control circuitry enabling the pump to cycle through a sequence once gas throughput is reduced to zero or near zero. This allows a brief period (maybe just 30 seconds) of higher speed operation. This process may be manually controlled or it may be
30 automated. For it to be automated then the pump should recognise the no gas flow condition. If this is done using a power sensor, then this can be challenging as the power consumption at zero throughput is similar to the power consumption

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at a low gas throughput as it is dominated by mechanical losses. In some embodiments this is addressed by initiating the boost cycle and low power, standby mode once the power consumption has dropped to a certain value, in some cases only with the additional proviso that standby mode has not been
5 triggered for a predetermined time. The rate of rise of power consumption is then checked to determine whether it is larger than expected and where so this indicates that there is gas throughput, and thus, invoking power-saving is inappropriate. In this case the pump would be controlled to exit the power saving mode. A threshold value for the rate of increase indicating gas
10 throughput will depend on the type and size of pump and perhaps system being pumped and would be configured for a particular pump and set up.

Figure 1 shows a scroll pump 30 according to an embodiment. Scroll pump 30 comprises an exhaust non-return valve 20 which may be a spring loaded valve
15 that is configured to open under a pressure difference and to close when the pressure at the outlet to the pump is below atmospheric pressure. In this way, the pump may be sealed when it is no longer pumping gas, this may be when the pressure at the inlet has reached ultimate pressure. Scroll pump 30 has a motor 10 for driving the scroll pump and a controller 40 for controlling operation of the
20 motor. There is also sensor 42 which in this embodiment is associated with the motor 10 for sensing the power consumption of the motor. During operation controller 40 controls motor 10 to drive the scroll pump to evacuate a chamber and when steady state is reached which may at ultimate pressure at the inlet valve 20 closes and the sensor 42 indicates that this state has been reached and
25 controller 40 receives a signal from sensor 42 that the pump is to enter a standby mode. At this point controller 40 boosts the speed of operation of motor 10 by more than 10% from the nominal rotational speed for more than 5 seconds and less than 60 seconds such that the amount of gas within the pump is reduced. Controller 40 then controls the motor 10 to return to nominal or to a standby
30 speed which is less than nominal speed an exhaust valve 20 closes and pump 30 continues to operate but with no or very little gas flow. As the amount of gas in the pump has been reduced prior to entering standby state the amount of power

required for this operation is reduced and thus, the power expended in the standby mode is also correspondingly reduced.

In some embodiments, controller 40 may be configured to periodically boost the speed of the motor 10 in response to detecting that the amount of gas in pump 30 has risen. This may be due to leakage into the system and the repeated boost ensures that the power required for standby operation is maintained at or close to a lower level. The controller 40 may determine this in response to receipt of signals from a sensor such as the power consumption sensor 42 that determines that power consumption for driving the pump in the standby mode has increased above a predetermined amount. In some cases, the controller may also determine how frequently this boost in speed is required, that is the time elapsed between each boost cycle and where it is above a predetermined threshold then a warning indicator may be output by a controller 40.

Figures 2A schematically shows curves illustrating how the pressure varies within a pump with no gas throughput and the non-return exhaust valve closed at nominal rotational speed and at a lower standby rotational speed. The pressure varies from the inlet to the outlet, there being a lower pressure at the inlet which is connected to the vacuum system being evacuated and a higher pressure at the outlet. The pressure at the outlet is the pressure required to open the non-return exhaust valve, as if the pressure is above this the valve will open.

The power consumption is reduced in standby mode by slowing the rotational speed, this results in a different distribution of pressure within the pump with a higher pressure at the inlet and a lower pressure at the outlet. The area under the curve remains constant as the amount of gas in the pump remains unchanged.

Figure 2B shows the effect of a boost in speed of the pump. As can be seen this boost in speed changes the pressure distribution in the pump, so that the pressure at the inlet falls and the pressure at the outlet rises. The pressure at the

outlet rises to above the pressure required to open the non-return exhaust valve and this opens and gas is expelled from the pump. The non-return valve remains open until the pressure at the outlet falls below the opening pressure of the non-return valve whereupon it closes. The amount of gas expelled is schematically
5 shown by the shaded portion. When the pump returns to the nominal speed there is less gas in the pump and the pressure at both the inlet and the outlet is reduced, and the power consumption required to keep this pressure distribution is similarly reduced. A lower standby rotational speed would result in the pressure at the inlet rising and the outlet falling and additional power savings.

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As can be seen from the above, the overspeed works by removing gas from the mechanism and reducing the amount of gas within the pump. Once this is done, there is less power required to maintain a certain rotational speed and less impact on inlet pressure if pump rotation is slowed to further reduce power.

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Figure 3 shows a flow diagram schematically illustrating steps in a method according to an embodiment. In step S10 a pumping mechanism is driven at a nominal speed. At step S20 a signal is received that the pump is to enter a standby mode. This signal may be received from a sensor associated either with
20 the pump or with a vacuum system being pumped or from a user. It may also be received from a secondary pump located between the vacuum system and this pump. In response to this signal at step S30 the speed of the mechanism is boosted for a predetermined time to reduce the amount of gas in the pumping mechanism. At step S40 the speed of the pumping mechanism is reduced and
25 the pump is operated in standby mode with the exhaust non-return valve closed.

At step D5 it is determined whether the amount of gas in the pump has risen above a predetermined amount. This may be determined from a sensor such as a sensor sensing the power consumption of this pump or of a secondary pump
30 rising above a predetermined amount. If there is no indication that the amount of gas has increased unduly then operation in the standby mode continues. If it has increased then the method proceeds to step D15 where it is determined if the

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time since this increase in gas amount was last detected is less than a predetermined time. If it was then a warning indicator is output at S50 indicating the pump may not be functioning well, and the method returns to step S30 where the speed of the pumping mechanism is boosted. If it is not less than the
5 predetermined time then the method proceeds straight to step S30 where the speed of pumping mechanism is boosted.

Figure 4 schematically shows how the power use by the motor of the pump varies with time. Thus, there is a normal power consumption during normal operation.
10 Following an indication received, in this embodiment from the user, that the pump is to enter standby mode a boost of the pump speed is performed, which results in the temporary increase in power consumption shown in the graph. The pump then enters standby mode and the power consumption falls considerably. Here the amount of gas in the pump is low, there is no throughput of gas and the
15 power consumed is therefore significantly reduced. In some cases there may be some leakage of gas and the power consumption may gradually rise as the amount of gas increases, this is shown by the broken line. At a certain point a further boost may be performed where the speed of the pump is increased to again reduce the amount of gas in the pumping mechanism whereafter the power
20 consumption will again return to a low value. The power saving mode may be cancelled by a user indicating normal pumping operation is to resume. In other embodiments where the power saving mode is triggered automatically by a sensor, perhaps a power sensor, then the power saving mode may also be exited if it is determined that the initial rate of rise of power consumption is too high
25 indicating that the pump has entered power saving mode at an inappropriate time where there is still some gas throughput.

In summary embodiments use a temporary increase in rotational speed to expel more gas from the pumping mechanism, before returning to standard/normal
30 speed or perhaps an even lower standby speed. If there is no gas throughput, the amount of gas remaining in the mechanism (total product of pressure x volume) is lower than before, and the non-return valve in the pump outlet prevents or at

least impedes atmospheric gas from leaking back in. Gas pressures are lower so the power required to compress the gas is lower.

Figure 1 shows an embodiment with a scroll pump mechanism but other
5 embodiments with other primary vacuum pumps that can be fitted with a non-
return valve in the outlet such as multi-stage Roots, claw, diaphragm,
reciprocating piston, and rotary vane are also applicable to the technique.
Figure 5 shows a side channel blower 50 according to an embodiment. The side
10 channel blower is a type of regenerative pump which uses viscosity to entrain a
fluid flow 57 in a side channel 58 of the pump. In this embodiment, gas may
enter the pump at an inlet and an impeller 54 may rotate about a centre of
rotation 53 and blades 52 will confine gas between them in blade segments 56.
The impeller rotates in an anti-clockwise direction from the inlet towards the
15 outlet. The blades 52 do not reach the housing wall 53 and there is a side
channel 58. Gas within the side channel is entrained by viscosity to move with
the blades from the inlet towards the outlet. Adjacent to the outlet there is a
stripper 51 that closes or reduces the cross section of the side channel such that
gas within the side channel is pushed out via an outlet into an outlet channel 62.
20 There is a non-return exhaust valve 20 on the outlet channel 62 which is
controlled by control circuitry 40.

In operation when the control circuitry 40 determines, perhaps from a pressure
sensor reading, or from the motor characteristics, that the pressure at the inlet
has reached the desired or ultimate pressure then it sends a signal to the motor
25 driving the impeller 42 to boost the speed of rotation and reduce the pressure
within the pump further. Control circuitry 40 then closes the non-return valve 20
and controls the motor to return to nominal or to a standby speed which is less
than nominal speed. The impeller 42 continues to rotate but there is no or very
little gas flow through the pump. As the amount of gas in the pump has been
30 reduced prior to entering standby state the amount of power required for this
operation is reduced.

Although embodiments are particularly effective for the zero-throughput condition, they are also applicable to a low gas flow either into the pump inlet, or due to a leak within the pump. The proposed temporary speed increase would enable a power reduction despite the gas load, until the gas load eventually changed the pressure distribution back to its original state. If this happened quickly, due to a larger gas flow, the boost cycle would not be worth doing; but if the gas flow was small, it may be worth going through that cycle periodically. The flow amount at which the method would not be worthwhile would be dependent on the size and capacity of the pump.

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If the primary pump is part of a vacuum system that also includes a secondary pump such as a turbomolecular pump, then the trigger for the boost/standby cycle could come from the turbopump power consumption; and the trigger for a repeat cycle in the event of a small gas throughput or leak could also come from the turbopump power (this would be a particularly sensitive indicator).

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Where there is a vacuum system with a secondary pump, then in some cases, a valve at the inlet to the secondary pump could also be closed at or around the same time as the non-return exhaust valve, such that the boost cycle would reduce the pressure within the secondary pump too and provide a further power saving. In this case, the secondary pump power consumption would not provide an indication of a rise in pressure within the vacuum chamber and a separate sensor would be required to determine when the pump might be needed to pump the chamber again to maintain the required low pressure.

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The control algorithm for controlling the pump may include a PID (proportional-integral-derivative) control loop to tune the system response to the size of the system being evacuated with a slower, smoother response for a larger volume system.

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As noted above, once in the lower-power standby operational mode, a repeat boost/standby cycle can be invoked in response to a slow rise in system pressure

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(and pump power); by recognising this event, the pump could flag an error code to the user to alert them to the possibility of a vacuum leak.

5 Embodiments may provide a power-saving mode using a temporary boost cycle to eliminate some gas from the system, followed by a rotational speed reduction to reduce unnecessary work.

The mode may be triggered by manual intervention or manually-scheduled signal to the pump controller. The mode alternatively and/or additionally may be
10 automatically triggered by a system-level control signal that also stops gas throughput, or by a smart sensor that is monitoring a pump condition such as inlet pressure, or by a sensor measuring a power consumption of the pump.

The boost cycle can be repeated if required, for example to combat back-leakage
15 through the non-return valve. This could be a time-based response, whether needed or not or a sensor based response as a reaction to rising pressure or a reaction to rising power/current.

The computer program described above may be stored on program storage
20 devices, e.g., digital data storage media, which are machine or computer readable and encode machine-executable or computer-executable programs of instructions, wherein the instructions cause the processor to cause the controller to perform some or all of the steps of above-described methods. The program storage devices may be, e.g., digital memories, magnetic storage media such as
25 a magnetic disks and magnetic tapes, hard drives, or optically readable digital data storage media. The term non-transitory as used herein, is a limitation of the medium itself (i.e., tangible, not a signal) as opposed to a limitation on data storage persistency (e.g. RAM vs ROM).

30 Although illustrative embodiments of the invention have been disclosed in detail herein, with reference to the accompanying drawings, it is understood that the invention is not limited to the precise embodiment and that various changes and

modifications can be effected therein by one skilled in the art without departing from the scope of the invention as defined by the appended claims and their equivalents.

REFERENCE SIGNS

	10	motor
	20	non-return exhaust valve
	30	scroll pump
5	40	controller
	42	sensor
	50	side channel blower
	51	stripper
	52	blade
10	54	impeller
	56	fluid in blade segment
	57	side channel
	58	flow
	59	housing
15	60	gas flow at inlet
	62	outlet channel

CLAIMS

1. A method of controlling a mechanical vacuum pump to reduce power consumption of said pump during a standby mode, said method comprising:
5 operating said pump by driving a pumping mechanism at a nominal speed;
 determining that said pump is to enter a standby mode in which an exhaust non-return valve is closed;
 boosting a speed of said pumping mechanism for a predetermined time to reduce an amount of gas within said pump; and
10 reducing said speed of said pumping mechanism and operating said pump in said standby mode with said exhaust non-return valve being closed.
2. A method according to claim 1, wherein said step of boosting a speed of said pumping mechanism comprises increasing a rotational speed of a motor
15 driving said pumping mechanism.
3. A method according to claim 1 or 2, wherein said step of reducing said speed of said pumping mechanism comprises reducing said speed to said nominal speed.
20
4. A method according to claim 1 or 2, wherein said step of reducing said speed of said pumping mechanism comprises reducing said speed to a reduced speed that is lower than said nominal speed.
- 25 5. A method according to any preceding claim, wherein said step of determining that said pump is to enter a standby mode comprises at least one of: receiving a control signal from a user, receiving a control signal from a vacuum system associated with said pump and receiving a control signal from at least one sensor.
- 30 6. A method according to claim 5, wherein said step of determining that said pump is to enter a standby mode comprises receiving a control signal from at

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least one sensor sensing a power consumption of a motor, said sensor indicating said power consumption is at or close to a value indicative of low or zero gas throughput, said method comprising a further step of determining a rate of increase of power consumption following said step of reducing said speed of said pumping mechanism and where a rate of increase of said power consumption is
5 greater than a predetermined level exiting said standby mode.

7. A method according to any preceding claim, wherein said method comprises a further step performed during said standby mode of:
10 determining that said amount of gas within said pump is to be reduced;
boosting a speed of rotation of said pump for a predetermined time to reduce an amount of gas within said pump; and
reducing said rotational speed and returning to operating in said standby mode.

15 8. A method according to claim 7, wherein said step of determining comprises at least one of: determining that a power consumption of said pump or a secondary pump in a same system has increased by or to a predetermined amount, that a pressure has increased by or to a predetermined amount; that a
20 predetermined time has elapsed since the speed was previously boosted; or that a signal is received from an operator or from a vacuum system.

9. A method according to claim 6 to 8, said method further comprising determining a frequency with which said boosting is repeated during said standby
25 mode and in response to determining said frequency has increased by more than a predetermined threshold amount, outputting a warning indication to an operator.

10. A method according to any preceding claim, wherein said mechanical
30 vacuum pump comprises one of a positive displacement pump or regenerative pump.

11. A computer program comprising computer readable instructions which when executed by a processor in a controller of a mechanical vacuum pump is configured to control said pump to perform a method according to any preceding claim.

5

12. A controller for a mechanical vacuum pump, said controller comprising: control circuitry configured to control a speed of a pumping mechanism of said pump, said control circuitry being configured to:

control said pump such that said pumping mechanism is driven at a
10 nominal speed; and
in response to receipt of a signal indicating that said pump is to enter a standby mode in which said exhaust non-return valve is closed to control said pump to increase a speed of said pumping mechanism for a predetermined time to reduce an amount of gas within said pump; and
15 after said predetermined time to reduce said speed of said pumping mechanism and continue to drive said pumping mechanism in said standby mode with said exhaust non-return valve being closed.

13. A controller according to claim 12, wherein said step of reducing said
20 pumping mechanism speed comprises reducing said speed to said nominal speed.

14. A controller according to claim 12, wherein said step of reducing said
pumping mechanism speed comprises reducing said pumping mechanism speed
25 to a low power speed that is lower than said nominal speed.

15. A controller according to any one of claims 12 to 14, wherein said signal is received from at least one of: a user, a control system or a sensor.

30 16. A controller according to any one of claims 12 to 15, wherein said control circuitry is further configured in response to receipt of a signal during standby

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mode, said signal indicating that an amount of gas within said pump is to be reduced;

to control said motor to boost a speed of rotation of said pump for a predetermined time to reduce said amount of gas within said pump; and

5 after said predetermined time to reduce said speed of said pumping mechanism and return to controlling said pump to operate in said standby mode.

17. A controller according to any one of claims 12 to 16, wherein said signal is generated in response to at least one of: a power consumption of said pump
10 increasing by or to a predetermined amount, a pressure at an inlet to said pump increasing by or to a predetermined amount, a predetermined time having elapsed since the speed was previously boosted; or an input from an operator or from a control system.

15 18. A mechanical vacuum pump, comprising:
a motor for driving said pump;
a non-return exhaust valve; and
a controller according to any one of claims 12 to 17 for controlling
operation of said mechanical vacuum pump.

20 19. A mechanical vacuum pump according to claim 18, wherein said vacuum pump comprises one of a positive displacement pump or a regenerative pump.

20. A mechanical vacuum pump according to claim 18 or 19, wherein said
25 vacuum pump comprises a scroll pump.

21. A vacuum system comprising a primary vacuum pump according to any one of claims 18 to 20 and a secondary vacuum pump, said secondary vacuum pump comprising a valve at an inlet, said controller being configured to close said
30 inlet valve in response to receipt of said signal that said pump is to enter standby mode.