

Description

Title: Vacuum pump and method for controlling heating

5 Technical field of the invention

[0001] The invention relates to a vacuum pump, such as a dry vacuum pump or a turbomolecular vacuum pump. The invention further relates to a method for controlling the heating of a vacuum pump.

Technical background

[0002] The thermal management of vacuum pumps is critical. Gases and evaporated substances of different chemicals can circulate in the vacuum pumps and, due to changes in temperature or pressure conditions, can be deposited on the internal surfaces of the vacuum pump and cause clearance limitations which can lead to a seizure or breakdown of the vacuum pump.

[0003] It is known to heat the vacuum pump to prevent the condensation or solidification of reaction products and thus to limit the formation of deposits.

[0004] In order to achieve this, a central unit of the vacuum pump controls the electrical power supply of heating elements, by changing the electrical power of the electrical network to which the vacuum pump is electrically connected.

[0005] More specifically, vacuum pumps are installed across the entire globe and the voltage ranges and the

quality of the electrical networks to which they are connected are very varied.

[0006] The manufacturers of vacuum pumps are thus forced
5 to manage several different types of heating elements,
each adapted to the voltage of the electrical network of
the country in which the vacuum pump is designed to be
used. This can be costly, in particular due to the
significant number of certifications which can be
10 required.

[0007] A further drawback is that the heating depends
on the quality of the electrical network. Power outages,
voltage dips or voltage surges can arise more or less
15 frequently on certain electrical networks. The voltage
losses can lead to a reduction in the quality of the
heating, the temperature setpoint possibly being more
difficult to reach or take longer to reach, in particular
in low-voltage countries. Voltage surges can be dangerous
20 for people or can damage the heating elements.

Summary of the invention

[0008] An object of the present invention is to propose
25 a vacuum pump which at least partially remedies the
drawbacks of the prior art.

[0009] To this end, the subject of the invention is a
vacuum pump comprising:

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- a motor and at least one rotor which is configured to
be driven in rotation by the motor in a stator of said
vacuum pump,

- a heating module comprising at least one electrical heating element which is configured to heat the stator of the vacuum pump when it is electrically powered,

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- at least one temperature sensor which is configured to measure the temperature of the at least one rotor or the stator,

10 characterized in that the heating module further comprises a heating control unit comprising:

- a measuring device which is configured to measure the value of a parameter representative of the voltage of the electrical network to which the vacuum pump is electrically connected, and

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- a control unit which is configured to supply a supply voltage to the at least one heating element by adapting the electrical power of said electrical network by taking into account the measurement from the temperature sensor and the value of the parameter representative of the voltage of said electrical network measured by the measuring device, in order to reach a predetermined setpoint temperature.

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[0010] Thus, instead of adapting the supply voltage of the heating elements to control the temperature of the stator from an assumed voltage of the electrical network, the heating control unit measures a parameter representative of the voltage of the electrical network and deduces therefrom a suitable supply voltage of the heating elements, taking into account the actual value

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of the electrical network and thus possible voltage drops or voltage surges. In the event of a drop in the voltage of the network, a temperature control taking account of the measured voltage of the network enables the power to be increased more rapidly than waiting for a return of the control by measuring the temperature which would be slower, the power increments thereof being unsuitable and thus also slower before the setpoint is reached. In the event of an oversupply of the voltage of the network, the temperature control taking account of the measured voltage of the network makes it possible to avoid potential damage to the heating elements more or less over the long term. The temperature control can thus be adapted automatically to the voltage fluctuations of the electrical network and thus be more efficient and more robust. This makes it possible to ensure that the heating elements are correctly supplied with power and thus that the temperature of the stator can be controlled.

[0011] The vacuum pump can also comprise one or more of the following features which are described below, taken individually or in combination.

[0012] The heating control unit can also be configured to receive operating information of the vacuum pump and to take it into account in order to determine the supply voltage of the at least one heating element.

[0013] The operating information can be the setpoint at which the user wishes to control the temperature of the stator and/or the type of heating element, i.e. for example resistive or inductive or radiative and/or the rated supply voltage.

[0014] The operating information of the vacuum pump can be an operating state: in normal operation (nominal rotational speed) at a standstill/on standby (reduced rotational speed).

[0015] The heating control unit can also be configured to identify the control algorithm of the at least one heating element to be applied as a function of the type of heating element of the heating module of the vacuum pump.

[0016] The at least one heating element of the heating module comprises, for example, an electrical resistor and/or a radiative and/or inductive element.

[0017] According to one exemplary embodiment, the heating module comprises:

- at least one pair of heating elements comprising a first and a second electrical resistor, the electrical resistors having the same ohmic values, and
- an electrical circuit comprising a first circuit connecting the heating elements in parallel, a second circuit connecting said heating elements in series, and a controllable switching device.

[0018] The heating control unit is configured to control the switching device to supply the supply voltage to the terminals of one or other of the first circuit or the second circuit as a function of the voltage of the electrical network.

[0019] Thus it is possible, from the same components, to adapt the electrical circuit of the heating module so that the heating elements are suitable for the voltage of the electrical network. The same heating module comprising the heating elements having a low supply voltage can thus be used on vacuum pumps which can be connected to a wide range of electrical networks. Moreover, since this operation is automatic, possible connection errors which could damage the heating elements are avoided.

[0020] A further subject of the invention is a method for controlling the heating of a vacuum pump as described above, characterized in that it comprises the following steps:

- measuring the value of a parameter representative of the voltage of the electrical network to which the vacuum pump is electrically connected,

- supplying a supply voltage to the at least one heating element by adapting the electrical power of said electrical network by taking into account the value of the parameter representative of the measured voltage of said electrical network, in order to reach a predetermined setpoint temperature.

Brief description of the figures

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[0021] Further advantages and features will become apparent from reading the description of the invention, as well as the accompanying drawings in which:

[0022] [Fig. 1] figure 1 shows a highly schematic view of a vacuum pump.

5 [0023] [Fig. 2] figure 2 shows a wiring diagram of a heating module of the vacuum pump of figure 1 having a switching device in a first switching state.

[0024] [Fig. 3] figure 3 shows a diagram similar to
10 figure 2 for a second switching state of the switching device.

[0025] [Fig. 4] figure 4 shows a flow chart of a method for controlling the heating of the vacuum pump of figure
15 1.

[0026] In these figures, identical elements bear the same reference numerals.

20 Detailed description

[0027] The following embodiments are examples. Although the description refers to one or more embodiments, this does not necessarily mean that each reference relates to
25 the same embodiment or that the features apply only to a single embodiment. Individual features of different embodiments can also be combined or interchanged in order to provide further embodiments without departing from the scope of the invention as defined by the claims.

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[0028] Figure 1 shows an example of a vacuum pump 1.

[0029] The vacuum pump 1 comprises a motor 2 and at least one rotor 3 which is configured to be driven in rotation by the motor 2 in a stator 4 (or pump body) of said vacuum pump 1. The vacuum pump 1 is configured to be electrically connected, in particular for the electrical power supply of its motor 2, to an electrical network.

[0030] The vacuum pump 1 can be a so-called dry vacuum pump (figure 1) or a turbomolecular vacuum pump.

[0031] A dry vacuum pump 1 is a volumetric vacuum pump which is configured, by using two rotors 3, to suction, transfer and then discharge the gas to be pumped at atmospheric pressure or above. It is, for example, a multistage primary vacuum pump which comprises between two and ten pumping stages (five in the illustrated example) or a Roots compressor which comprises one to three pumping stages. Each pumping stage of the stator 4 is formed by a pumping chamber receiving two combined rotors 3, the pumping chambers respectively comprising an inlet and an outlet. The successive pumping stages are connected in series one after the other by respective inter-stage channels connecting the outlet of the preceding pumping stage to the inlet of the following stage. During rotation, the gas suctioned from the inlet is captured in the volume created by the rotors 3 and the stator 4, and then driven by the rotors 3 to the following stage. The vacuum pump 1, in particular, is called "dry", since during operation the rotors 3 rotate inside the stator 4 without any mechanical contact with one another or with the stator 4 which makes it possible not to use any oil in the pumping chamber(s).

[0032] According to a further example, the vacuum pump 1 is a turbomolecular vacuum pump and comprises a single rotor 3 (not shown). The rotor 3 is configured to be driven in rotation by the motor 2 at high speed in the stator 4, for example at more than twenty thousand revolutions per minute. The rotor 3 is guided laterally and axially by magnetic or mechanical bearings. During operation, the discharge port of the turbomolecular vacuum pump 1 is connected to a primary vacuum pump. The turbomolecular vacuum pump 1 can comprise only one turbomolecular stage or one turbomolecular stage and one molecular stage downstream of the turbomolecular stage in the direction of flow of the gases. In the turbomolecular stage, the rotor 3 comprises at least two blade stages and the stator 4 comprises at least one fin stage. The blade and fin stages axially follow one another along the axis of rotation of the rotor 3. According to one exemplary embodiment, the rotor 3 comprises a Holweck skirt in the molecular stage formed by a smooth cylinder, which rotates opposite helical grooves of the stator 4.

[0033] The vacuum pump 1 can also comprise a central control unit 7 such as an electronic card, comprising one or more controllers or microcontrollers or processors and a memory. The central control unit 7 is configured to execute sequences of program instructions making it possible, in particular, to control the rotational speed of the at least one rotor 3 and to receive and provide operating information of the vacuum pump 1, so as to provide a setpoint temperature, for example, received by a user interface, or provide signals for measuring the

temperature of the stator 4 or the at least one rotor 3, from at least one temperature sensor 20 of the vacuum pump 1, such as an infrared sensor, a magnetothermal sensor, a positive temperature coefficient probe, a thermocouple or a thermistor.

[0034] The vacuum pump 1 also comprises a heating module 5 comprising at least one electrical heating element 6 such as an electrical resistor and/or a radiative or inductive element, which is configured to heat the stator 4 of the vacuum pump 1 when it is electrically powered. The heating elements 6 can be configured to receive a low supply voltage, such as a single-phase voltage, for example between 100 V and 240 V, or they can be configured to be powered with a high supply voltage, such as a three-phase voltage, for example between 180 V and 530 V, this value range taking into account a safety margin of 20% on the lower terminal and 10% on the upper terminal to take into account fluctuations in the electrical network.

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[0035] The heating module 5 also comprises a heating control unit 8 such as an electronic card, which comprises one or more controllers or microcontrollers or processors and a memory, in order to execute sequences of program instructions, making it possible to implement a method for heating the vacuum pump 1.

[0036] The heating control unit 8 and the central control unit 7 can be part of the same electronic card or can be independent electronic cards. Units 7, 8 which are physically independent from one another make it possible to be able to standardize the central control

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units 7 of the vacuum pumps 1 by having the possibility of adding a heating module 5 thereto or not.

[0037] The heating control unit 8 comprises:

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- a measuring device which is configured to measure the value of a parameter representative of the voltage of the electrical network to which the vacuum pump 1 is electrically connected, such as the voltage of the electrical network, and

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- a control unit which is configured to supply a supply voltage U to the at least one heating element 6 by adapting the electrical power of the electrical network, by taking into account the measurement of the temperature of the stator 4 or the at least one rotor 3 from the temperature sensor 20 and the value of the parameter representative of the voltage of said electrical network U_{res} measured by the measuring device, in order to reach a predetermined setpoint temperature.

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[0038] The electrical network is the distribution network designed to supply the electrical power which makes it possible to power a set of electrical machines including the vacuum pump 1. By way of illustration, the voltage of the electrical network can be:

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Country	Single-phase	Three-phase
Japan	100 V or 200 V	200 V or 415 V
Taiwan	110 V	220 V or 380 V
USA-Canada	120 V or 240 V	240 V or 480 V
Mexico	127 V	220 V

Europe-China-South Korea	220 V - 240 V	380 V and 400 V
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[0039] The supply voltage to be supplied to the heating elements 6 is determined from a temperature setpoint, a temperature measurement of the stator 4 and a control algorithm, in particular a closed-loop control. The heating control unit 8 receives, for example, the temperature setpoint from the central control unit 7 and temperature measuring signals, either from the central control unit 7 or directly from temperature sensors of the vacuum pump 1.

[0040] The possible control algorithms are, for example, closed-loop on-off, proportional or PID (proportional, integral, derivative) controls.

[0041] In a manner known per se, in the on-off control algorithm, the heating elements 6 are supplied with power when the measured temperature is lower than the temperature setpoint and the power supply is cut off when the measured temperature is greater than the setpoint. In the proportional or PID control algorithm, the power supply to the heating elements 6 is increased or reduced as a function of the difference observed between the temperature setpoint and the measured temperature with a proportional, integral and derivative component.

[0042] The supply voltage U of the heating elements 6 thus determined is thus obtained by adapting the voltage of the electrical network U_{res} (function shown schematically by the block 15 in figure 4), for example

by transforming the supply voltage measured in a succession of intervals, the duration and/or the frequency thereof being varied so as to reach the supply voltage U determined by the control algorithm.

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[0043] The measuring device is configured, for example, to measure the voltage of the electrical network U_{res} in the region of a supply phase of the vacuum pump 1.

10 **[0044]** The measurement of the parameter representative of the voltage of the electrical network can be carried out periodically, for example with a period of less than 1 second, such as every 500 msec, so that the supply voltage to be supplied to the heating elements 6 can be
15 regularly recalculated and controlled to the temperature measurement of the stator 4.

[0045] Thus instead of adapting the supply voltage U of the heating elements 6 in order to control the
20 temperature of the stator 4 from an assumed voltage of the electrical network, the heating control unit 8 measures a parameter representative of the voltage of the electrical network U_{res} and deducts therefrom a suitable supply voltage U of the heating elements, taking into
25 account the actual value of the electrical network and thus possible voltage drops or voltage surges. The temperature control can thus be automatically adapted to the fluctuations in voltage of the electrical network. This makes it possible to ensure that the heating
30 elements 6 are correctly supplied with power and thus that the temperature of the stator 4 can be controlled.

[0046] According to one exemplary embodiment, the heating control unit 8 is also configured to receive operating information Ifon of the vacuum pump 1, provided by the central control unit 7, and to take this into
5 account in order to determine the supply voltage U of the heating elements 6 (figure 1).

[0047] The operating information Ifon of the vacuum pump 1 can be the setpoint at which the user wishes to control
10 the temperature of the stator 4 and/or the type of heating element 6, i.e. for example resistive or inductive or radiative and/or low or high supply voltage.

[0048] The operating information Ifon of the vacuum pump
15 1 can be an operating state: during normal operation (nominal rotational speed)/at a standstill/on standby (reduced rotational speed). The method can also modify the setpoint temperature, for example to cut off the heating if the vacuum pump 1 is at a standstill or on
20 standby, which makes it possible to make energy savings.

[0049] The heating can thus be finely controlled as a function of the operating conditions of the vacuum pump
1.

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[0050] According to one exemplary embodiment, the heating control unit 8 is also configured to identify the control algorithm of said at least one heating element 6 to be applied as a function of the type of heating element
30 6 of the vacuum pump 1.

[0051] In order to identify the control algorithm of the at least one heating element 6 to be applied, the heating

control unit 8 can firstly identify the type of heating element 6 of the heating module 5, then select a suitable algorithm from a database of algorithms previously stored in the central control unit 7 or in the heating control unit 8.

[0052] The type of heating element 6, such as an electrical resistor and/or a radiative or inductive element and/or the rated supply voltage, can be stored in the heating control unit 8 and/or can be information provided by the heating elements 6 themselves.

[0053] In order to identify the type of heating element 6 of the heating module 5, the heating control unit 8 can be configured to measure a resistance between two terminals of an electrical circuit, for example arranged in the region of the heating element 6 or in the heating control unit 8, the value of the resistance defining the type of heating element 6.

[0054] Thus the heating control unit 8 can be an independent module of the central control unit 7, implemented with the heating module 5 in the vacuum pumps 1, irrespective of the type of heating elements 6 of the heating module 5. The heating control unit 8 can itself detect the type of heating element 6 implemented and select the control algorithm to be applied from the algorithm library. The control heating unit 8 can thus be standardized for any type of heating element 6.

[0055] According to an exemplary embodiment illustrated in figure 2, the heating module 5 comprises at least one pair of heating elements 6 and an electrical circuit.

[0056] The pair of heating elements 6 comprises a first and a second electrical resistor, the electrical resistors having the same ohmic values.

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[0057] The electrical circuit comprises a first circuit 9 connecting the heating elements 6 of a pair in parallel, a second circuit 10 connecting said heating elements 6 in series, and a switching device 11 controllable by the heating control unit 9. If there is more than one pair of heating elements 6, the heating elements 6 of each pair are connected as in the first pair, the electrical circuits of each pair being connected in parallel.

15 [0058] The controllable switching device 11 comprises, for example, first relays 12a, 12b respectively arranged on each branch of the first circuit 9 connecting the heating elements 6 of the pair in parallel and a second relay 13 arranged on the branch of the second circuit 10 connecting the heating elements 6 of the pair in series.

[0059] The heating control unit 8 is configured to control the switching device 11 according to a first switching state (figure 2) or according to a second switching state (figure 3) to supply the supply voltage U to the terminals of one or the other of the first circuit 9 or the second circuit 10 as a function of the voltage of the electrical network U_{res} .

25 [0060] The heating control unit 9 is configured, for example, to compare the measured voltage of the electrical network U_{res} with a switching threshold and to control the switching device 11 as a function of the

result of the comparison. This comparison can be carried out by programming ("software") or by means of electronic components ("hardware").

5 **[0061]** According to one exemplary embodiment illustrated in figure 4, the electrical circuit of the heating module 5 comprises a comparator 14, an input thereof being connected to the measuring device providing a measurement of the electrical network U_{res} . The
10 measuring device can also comprise a step-down transformer 16 configured to filter, rectify and step-down the voltage of the electrical network U_{res} . The other input of the comparator 14 is connected to a reference voltage U_s . The output of the comparator 14
15 makes it possible to control the relays 12a, 12b, 13 of the switching device 11. The same comparison can be carried out by software programming.

[0062] If, for example, the control algorithm associated
20 with the type of heating element 6 recommends a low supply voltage as a single-phase voltage, for example 110 V, and the measured electrical network voltage U_{res} is a three-phase voltage, namely double the recommended voltage, for example 220 V, then the heating control unit 8 can control
25 the switching device 11 so that the supply voltage U is delivered to the terminals of the second circuit 10 connecting the heating elements 6 in series. Thus half of the supply voltage U can be delivered to the terminals of each heating element 6. This first switching state is
30 illustrated by figure 2, showing the first relays 12a, 12b of the switching device 11 open on the parallel branches of the first circuit 9 and the relay 10 closed on the branch of the second circuit 10.

[0063] If, however, the measured voltage of the electrical network U_{res} is equal to that of the voltage of the electrical network recommended by the control algorithm, then the heating control unit 8 can control the switching device 11 so that the supply voltage U is delivered to the terminals of the first circuit 9 connecting the heating elements 6 in parallel. Thus the supply voltage U can be delivered to the terminals of each heating element 6. This second switching state is illustrated in figure 3, showing the relays 12a, 12b closed on the parallel branches of the first circuit 9 and the relay 13 open on the branch of the second circuit 10 connecting the heating elements 6 in series.

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[0064] It is thus possible, from the same components, to adapt the electrical circuit of the heating module 5, so that the heating elements 6 are adapted to the voltage of the electrical network U_{res} . The same heating module 5, comprising the heating elements 6 having a low supply voltage, can thus be used on vacuum pumps 1 which are able to be connected to a wide range of electrical networks. Moreover, since this operation is automatic, possible connection faults which could damage the heating elements 6 are avoided.

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CLAIMS

[Claim 1] A vacuum pump (1) comprising:

- 5 - a motor (2) and at least one rotor (3) which is configured to be driven in rotation by the motor (2) in a stator (4) of said vacuum pump (1),
- 10 - a heating module (5) comprising at least one electrical heating element (6) which is configured to heat the stator (4) of the vacuum pump (1) when it is electrically powered,
- 15 - at least one temperature sensor (20) which is configured to measure the temperature of the stator (4) or the at least one rotor (3),
- characterized in that the heating module (5) further includes a heating control unit (8) comprising:
- 20 - a measuring device which is configured to measure the value of a parameter representative of the voltage of the electrical network to which the vacuum pump (1) is electrically connected, and
- 25 - a control unit which is configured to supply a supply voltage (U) to the at least one heating element (6) by adapting the electrical power of said electrical network by taking into account the measurement from the
- 30 temperature sensor (20) and the value of the parameter representative of the voltage of said electrical network (U_{res}) measured by the measuring device, in order to reach a predetermined setpoint temperature.

[Claim 2] The vacuum pump (1) as claimed in the preceding claim, characterized in that the heating control unit (8) is also configured to receive operating information
5 (Ifon) of the vacuum pump (1) and to take it into account in order to determine the supply voltage (U) of the at least one heating element (6).

[Claim 3] The vacuum pump (1) as claimed in one of the
10 preceding claims, characterized in that the heating control unit (8) is also configured to identify the control algorithm of the at least one heating element (6) to be applied as a function of the type of heating element (6) of the heating module (5) of the vacuum pump (1).

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[Claim 4] The vacuum pump (1) as claimed in one of the preceding claims, characterized in that the at least one heating element (6) comprises an electrical resistor and/or radiative and/or inductive element.

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[Claim 5] The vacuum pump (1) as claimed in one of the preceding claims, characterized in that the heating module (5) comprises:

25 - at least one pair of heating elements (6) comprising a first and a second electrical resistor, the electrical resistors having the same ohmic values, and

- an electrical circuit comprising a first circuit (9)
30 connecting the heating elements (6) in parallel, a second circuit (10) connecting said heating elements (6) in series, and a controllable switching device (11), the heating control unit (8) being configured to control the

switching device (11) to supply the supply voltage (U) to the terminals of one or other of the first circuit (9) or the second circuit (10) as a function of the voltage of the electrical network (Ures).

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[Claim 6] The vacuum pump (1) as claimed in the preceding claim, characterized in that the heating control unit (8) is configured to control the switching device (11) to supply the supply voltage (U) to the terminals of one or
10 other of the first circuit (9) or the second circuit (10) as a function of the voltage of the electrical network (Ures).

[Claim 7] A method for controlling the heating of a
15 vacuum pump (1) as claimed in one of the preceding claims, characterized in that it comprises the following steps:

- measuring the value of a parameter representative of the voltage of the electrical network to which the vacuum
20 pump (1) is electrically connected,

- supplying a supply voltage (U) to the at least one heating element (6) by adapting the electrical power of said electrical network by taking into account the value
25 of the parameter representative of the measured voltage of said electrical network (Ures), in order to reach a predetermined setpoint temperature.