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(54) Title: DETERMINING PRESSURE OF GAS PUMPED BY A TURBOMOLECULAR PUMP

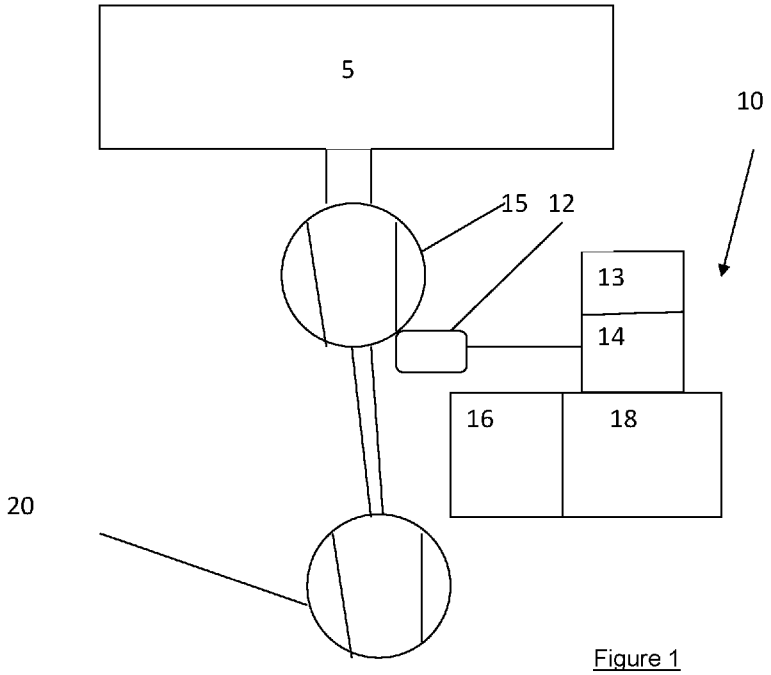


Figure 1

(57) Abstract: A turbomolecular pump and method of measuring pressure at the inlet of such a pump are disclosed. The turbomolecular pump comprises: control circuitry for controlling a motor for driving a rotor of the pump and a sensor for sensing a frequency of rotation of the rotor. The control circuitry is configured to initiate a pressure estimation by controlling the motor to interrupt driving the rotor; and the sensor is configured to sense a change in frequency of rotation of the rotor. The turbomolecular pump further comprises: processing circuitry configured to estimate a pressure of gas pumped by the turbomolecular pump in dependence upon deceleration of the rotor determined from the change in frequency of rotation detected by the sensor.

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DETERMINING PRESSURE OF GAS PUMPED BY A TURBOMOLECULAR PUMP

FIELD OF THE INVENTION

The field of the invention relates to turbomolecular pumps and in particular, to determining the pressure of a gas pumped by such a pump.

BACKGROUND

The operational inlet pressure of turbomolecular pumps (TMP) is generally in or below the high vacuum regime. Such low pressures are challenging to measure and conventionally ionisation type gauges have been used to measure these pressures. These gauges are not very robust, can be inaccurate and are expensive.

It would be desirable to provide an alternative way of determining the pressure at an inlet of a turbomolecular pump.

SUMMARY

A first aspect provides a turbomolecular pump comprising: control circuitry for controlling a motor for driving a rotor of the pump; a sensor for sensing a frequency of rotation of said rotor; wherein said control circuitry is configured to initiate a pressure estimation by controlling said motor to interrupt driving said rotor; and said sensor is configured to sense a change in frequency of rotation of said rotor; said turbomolecular pump further comprising: processing circuitry configured to estimate a pressure of gas pumped by said turbomolecular pump in dependence upon deceleration of said rotor determined from said change in frequency of rotation detected by said sensor.

The inventor of the present invention recognised that turbomolecular pumps have rotors that have relatively low inertia, rotate at high speed and are mounted such that frictional forces are low. This being the case, when the driving force driving

such rotors is interrupted the deceleration of the rotor that occurs is due for the most part and to a measurable degree to the pressure of the gas within the pump.

Although other factors, such as drag, frictional forces on the bearings and eddy currents may play a part, these will for the most part be constant for the pump and its frequency of rotation, so that with suitable calibration the amount of deceleration can be accurately linked to the pressure of the gas within or at the inlet of the pump.

Thus, measurement of this deceleration will provide a measure of the current pressure within the pump and an indication of the pressure at the inlet of the pump. In this way with the addition of some control and processing circuitry, the pump itself can be used as a pressure gauge, providing a low cost, practical means of determining the pressure at the inlet of a turbomolecular pump. In this regard, such pumps generally already have an accurate rotational frequency sensor.

In some embodiments, said processing circuitry is configured to estimate said pressure in dependence upon said determined deceleration and a frequency of said rotor.

The deceleration of the rotor as a fraction of the rotor frequency, be it average frequency, initial frequency or final frequency can be used as the indication of the pressure.

In some embodiments, said processing circuitry comprises a data store configured to store calibration data for said turbomolecular pump, said calibration data linking deceleration of said rotor to said pressure.

As noted previously other factors which affect the deceleration of the rotor are for the most part pump dependent and as such, storing suitable calibration data for

the pump within the circuitry associated with the pump allows the measured deceleration to be linked to the pressure of the gas within the pump or at the inlet to the pump.

In some embodiments, said calibration data is specific to a type of said turbomolecular pump.

The factors affecting deceleration that are pump dependent are generally fairly constant for any given type of pump and as such, each type of pump can have calibration data stored in storage circuitry within the pump enabling it to determine pressure from measured rotor deceleration.

In some embodiments, said calibration data is specific to a molecular weight of a gas being pumped.

Another factor that may affect the deceleration of the rotor is the molecular weight of the gas being pumped. In this regard it is a combination of gas pressure and its molecular weight that causes the rotor to slow. Where a pump is known to pump gases of different molecular weight different calibration data can be used to account for this.

In some embodiments, said calibration data comprises a plurality of sets of calibration data each set specific to a different molecular weight of a gas being pumped.

In some embodiments, said control circuitry is configured to initiate said pressure estimation in response to a pressure estimation request received from a user.

In some embodiments, said control circuitry is configured to initiate said pressure estimation periodically.

Determination of the pressure may be something that is performed periodically as part of the control of the system to maintain a desired pressure in a vacuum chamber being pumped, and/or it may be done in response to a user's request, perhaps where a user requires an indication of current pressure in such a chamber.

Although the deceleration of the rotor is an indication of the pressure of the gas within the pump, this is related to the pressure at the inlet of the pump and this can thus, be derived from the deceleration and is often the pressure that a user is interested in, where for example the pump is evacuating a process chamber.

In some embodiments, said control circuitry is configured to interrupt said driving of said motor for a predetermined time.

When performing the pressure measurements the driving of the rotor is interrupted and the deceleration measured. The control circuitry may be configured to control the interrupting of the driving of the rotor for a predetermined time. In this regard, interrupting the driving of the rotor will cause the rotor to decelerate and affect the pumping of the chamber, thus, it may be important to control the amount of time that this is done for so that the pressure in the chamber is not unduly affected but the deceleration is large enough to be accurately measured.

Although this system can be used to measure different pressures it is particularly effective for inlet pressures between 10^{-2} and 10^{-6} mbar and preferably inlet pressures between 10^{-5} and 10^{-6} mbar and outlet pressures of less than 10^{-2}mbar.

A second aspect provides a method of measuring the pressure of gas pumped by a turbomolecular pump, the method comprising: interrupting driving of a rotor of said pump; measuring deceleration of said rotor; estimating gas pressure from said measured deceleration; and outputting the estimated pressure.

In some embodiments, said step of interrupting said driving of said rotor is performed for a predetermined time.

In some embodiments, said step of estimating the pressure comprises comparing the deceleration of the rotor with stored calibration data for said pump.

In some embodiments, said calibration data links deceleration to a pressure at an inlet to said turbomolecular pump.

In some embodiments, said step of estimating the pressure comprises determining a molecular weight of a gas being pumped and comparing the deceleration of the rotor with stored calibration data specific for gas of said molecular weight.

As the deceleration of the rotor is dependent on both pressure and molecular weight of the gas, when determining the pressure the molecular weight of the gas may be taken into account. The molecular weight of the gas may be determined from an input signal received from circuitry associated with the vacuum chamber being evacuated or from a user input or form some other means of determining the nature of the gas being pumped.

A third aspect provides a computer program which when executed by a processor is operable to control said processor to perform a method according to the second aspect.

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 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.

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 vacuum pumping system comprising a turbomolecular pump according to an embodiment; and

Figure 2 shows a flow diagram illustrating steps of a method according to an embodiment.

DESCRIPTION OF THE EMBODIMENTS

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

Turbomolecular pumps rotate at high frequencies ~ 400-1500 Hz. These rotational frequencies can be measured to great precision. When a turbopump's power is disrupted this rotational frequency will reduce. The time based decrement of change is a function of pressure and relatively short-time power disruptions invoke measurable frequency changes. Measuring such frequency changes provides an indication of TMP inlet pressure

In this regard, measuring the pressures of high vacuums can be challenging, Ion Getter pumps for example, avoid the need for separate direct pressure measurments by exploiting the fact that the current drawn during operation provides an indication of pressure and thus, with suitable calibration can be used as a pressure measurement.

The inventor of the present techique recognised that when the power supply to a TMP is interrupted the deceleration of the TMP impeller (i.e. reduction in rotational frequency) is a function of the residual gas pressure. The frequencies

of rotation of production TMPs are routinely measured so a developed algorithm can be applied so that this dependency can be expolited to give an indication of pressure.

Eddy currents and magnetic losses also decelerate the impeller. Hence to improve the accuracy of the measurements pumps shoud be 'calibrated' or 'type-tested' for these effects. This also can be done for ranging inlet/exhaust pressure and where gases of differing molecular weights are to be pumped for these different gases.

Figure 1 shows a vacuum system comprising a turbomolecular pump 10 according to an embodiment. The vacuum system has a vacuum chamber 5 that is evacuated by turbomolecular pump 10. Turbomolecular pump 10 is backed by a backing pump 20. The turbomolecular pump 10 comprises a stator and rotor defining a pumping chamber 15. A sensor 12 senses the rotational frequency or speed of the rotor. There is a motor 16 which drives the rotor and is controlled by motor controller 18, which is connected to or is part of processing circuitry 14. Processing circuitry 14 has a data store 13 for storing calibration data.

The calibration data is specific to the type of pump and relates deceleration of the rotor to pressure within the pump or at the pump inlet. In some embodiments it may also be specific to the gas being pumped. In this regard the molecular drag force exerted on the rotor by the gas is proportional to the square root of its molecular mass. Thus, at a same pressure a heavier gas will have a greater effect on decelerating the rotor than a lighter gas will. Where the pump may be pumping different gases, or where the composition of the gas changes during a process, calibration data for the different gases may be stored to reflect this. The processing circuitry is configured to select the appropriate calibration data depending on the gas currently being pumped.

In embodiments, the vacuum chamber will be evacuated by the pumping system and the processing circuitry 14 will initiate pressure measurements either

periodically or in response to a user input. Processing circuitry 14 will initiate these measurements by sending a signal to motor controller 18 to control motor 16 to interrupt driving of the rotor of the turbomolecular pump. Sensor 12 will determine the changes in rotational frequency of the rotor when it is no longer driven and processing circuitry 14 will link the deceleration to the pressure in the pumping chamber 15 from calibration data stored in data store 13. As changes in rotational frequency are simple to measure accurately and as turbomolecular pumps will often have rotational frequency sensors associated with their rotors, a device that can estimate the pressure at the inlet can be provided often simply by the addition of some control and processing circuitry along with some calibration data.

Figure 2 shows steps in a method for estimating the pressure in a turbomolecular pump as shown in Figure 1. In a first step a pressure estimation request is received. This may be from a user, or it may be automatically generated, either at a predetermined time, or in response to a condition such as frequency of rotation, or predicted/ detected process changes in the vacuum processing chamber.

In response to receipt of the pressure estimation request, the driving of the rotor of the pump is interrupted and the deceleration of the rotor that is no longer driven is measured. This deceleration is compared to deceleration data stored in a calibration file and from this an estimate of the pressure of the gas at the pump inlet can be determined.

The calibration is specific to the type of pump. There may be several sets of calibration data each relating to a different gas and in some cases to different inlet pressures or ranges of inlet pressures. Where the turbomolecular pump pumps different gases, then prior to comparing the deceleration with the calibration data there may be an additional step performed of determining the gas currently being pumped and selecting calibration data related to the pumped gas.

Once the appropriate calibration data has been selected and the pressure estimated from this calibration data then the pressure can be output.

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

5	vacuum chamber
10	turbomolecular pump
12	rotational velocity sensor
13	data store
14	processing circuitry
15	turbomolecular pump pumping chamber
16	motor
18	motor controller
20	backing pump

CLAIMS

1. A turbomolecular pump comprising:

control circuitry for controlling a motor for driving a rotor of the pump,

a sensor for sensing a frequency of rotation of said rotor; wherein

said control circuitry is configured to initiate a pressure estimation by controlling said motor to interrupt driving said rotor; and

said sensor is configured to sense a change in frequency of rotation of said rotor;

said turbomolecular pump further comprising:

processing circuitry configured to estimate a pressure of gas pumped by said turbomolecular pump in dependence upon deceleration of said rotor determined from said change in frequency of rotation detected by said sensor.

2. A turbomolecular pump according to claim 1, wherein

said processing circuitry is configured to estimate said pressure in dependence upon said determined deceleration and a frequency of said rotor.

3. A turbomolecular pump according to any preceding claim,

wherein said processing circuitry comprises a data store configured to store calibration data for said turbomolecular pump, said calibration data linking deceleration of said rotor to said pressure.

4. A turbomolecular pump according to claim 3, wherein said calibration data is specific to a type of said turbomolecular pump.

5. A turbomolecular pump according to claim 3 or 4, wherein said calibration data is specific to a molecular weight of a gas being pumped.

6. A turbomolecular pump according to claim 5, wherein said calibration data comprises a plurality of sets of calibration data each set specific to a different molecular weight of a gas being pumped.

7. A turbomolecular pump according to any preceding claim, wherein said control circuitry is configured to initiate said pressure estimation in response to a pressure estimation request received from a user.

8. A turbomolecular pump according to any preceding claim, wherein said control circuitry is configured to initiate said pressure estimation periodically.

9. A turbomolecular pump according to any preceding claim, wherein said pressure estimated is an inlet pressure of said turbomolecular pump.

10. A turbomolecular pump according to any preceding claim, wherein said control circuitry is configured to interrupt said driving of said motor for a predetermined time.

11. A method of measuring the pressure of gas pumped by a turbomolecular pump, the method comprising:

interrupting driving of a rotor of said pump;

measuring deceleration of said rotor;

estimating gas pressure from said measured deceleration; and

outputting the estimated pressure.

12. A method according to claim 11, wherein said step of interrupting said driving of said rotor is performed for a predetermined time.

13. A method according to claim 11 or 12, wherein said step of estimating the pressure comprises comparing the deceleration of the rotor with stored calibration data for said pump.

14. A method according to any one of claims 11 to 13, wherein said step of estimating the pressure comprises determining a molecular weight of a gas being

pumped and comparing the deceleration of the rotor with stored calibration data specific for gas of said molecular weight.

15. A method according to any one of claims 11 to 14, wherein said step of interrupting driving of said rotor is performed at least one of periodically and at a request of a user.

16. A computer program which when executed by a processor is operable to control said processor to perform a method according to any one of claims 11 to 15.

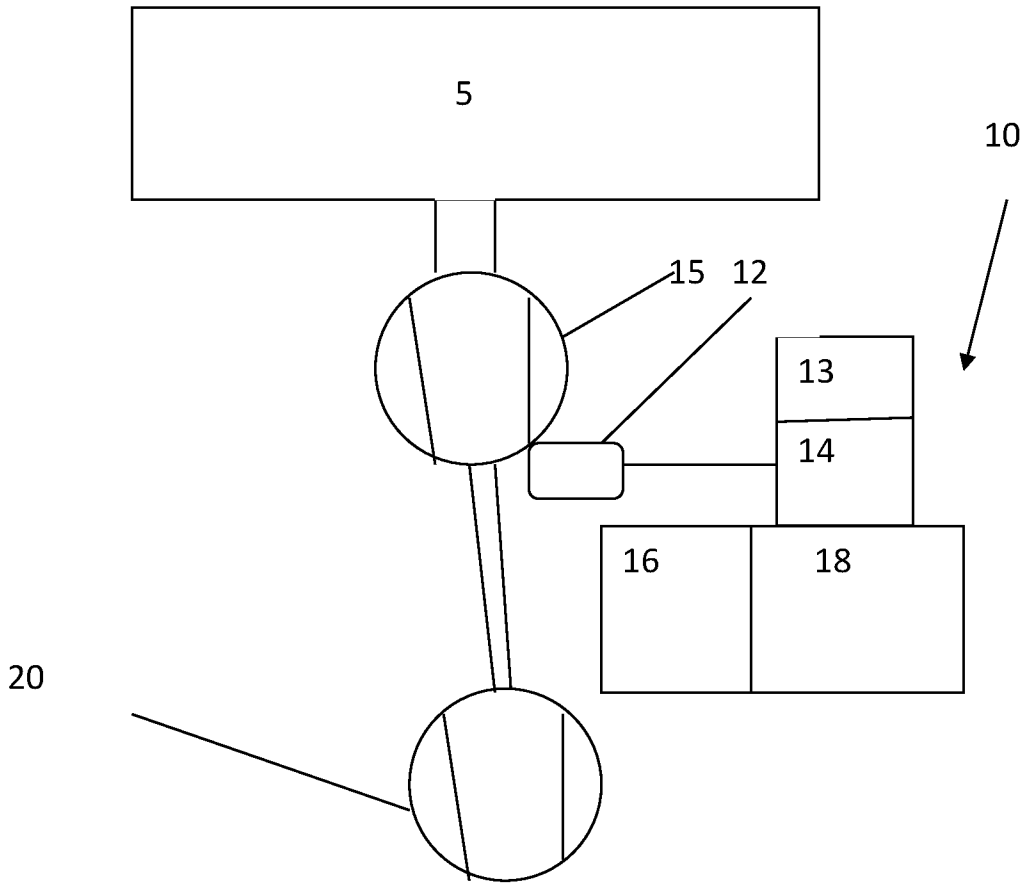


Figure 1

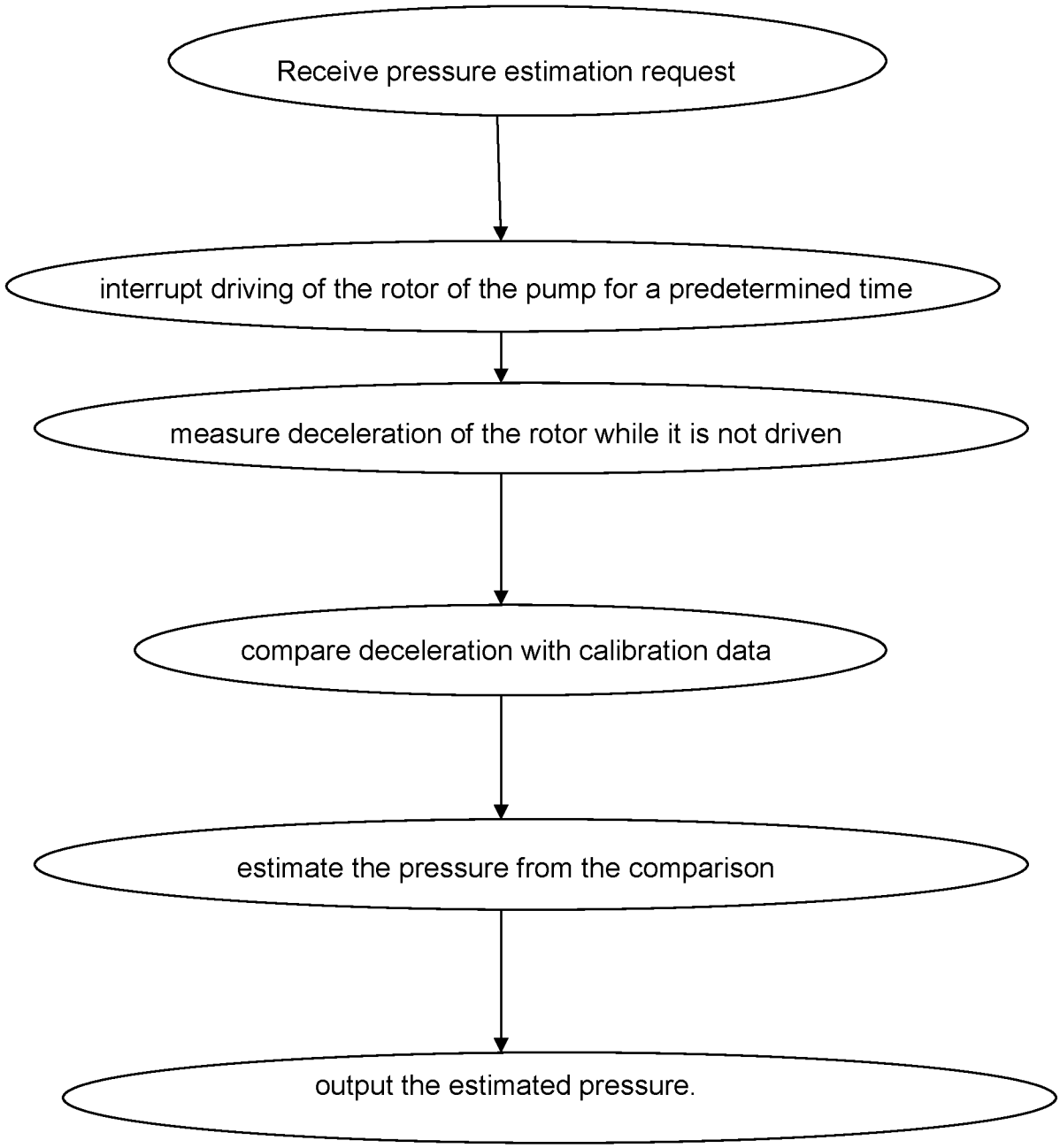

Receive pressure estimation request
interrupt driving of the rotor of the pump for a predetermined time
measure deceleration of the rotor while it is not driven
compare deceleration with calibration data
estimate the pressure from the comparison
output the estimated pressure.

Figure 2

INTERNATIONAL SEARCH REPORT

International application No
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A. CLASSIFICATION OF SUBJECT MATTER
INV. F04D19/04 F04D27/00 F04D27/02
ADD.

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)
F04D

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 practicable, search terms used)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2018 204437 A (SHIMADZU CORP) 27 December 2018 (2018-12-27) paragraphs [0002], [0006], [0009], [0011], [0012], [0015] - [0023], [0026] figures 1-3	1-16
A	US 2014/072452 A1 (TAHMASSEBPUR MOHAMMED [US] ET AL) 13 March 2014 (2014-03-13) paragraphs [0021], [0026], [0037] - [0042] figures 1-3	1-16
A	US 2013/186183 A1 (DOEBLER ULRICH [DE]) 25 July 2013 (2013-07-25) paragraphs [0014], [0018], [0019] figure 1 claims 1,5,6	1-16

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

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Date of the actual completion of the international search	Date of mailing of the international search report
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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/GB2020/050447

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