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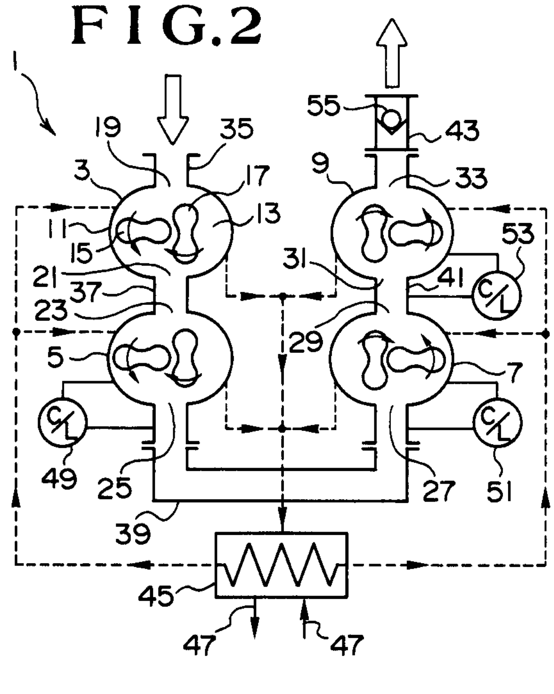
(54) **A multistage vacuum pump.**

(57) A multistage vacuum pump which provides a high ultimate vacuum at a low heat generation rate. The pump includes a plurality of Roots vacuum pump units (3, 5, 7 and 9) connected in series. The pumps in all stages have discrete casings (11). Pump chambers (13) are communicated with each other in series by connecting the outlet of the front-stage pump unit and the inlet of the rear-stage pump unit in each pair of adjacent Roots vacuum pump units by exhaust pipes (35, 37, 39, 41 and 43). Rotors (15 and 17) of the Roots vacuum pump units are carried on discrete driving and driven shafts so that the rotors can be driven to rotate at different speeds.

FIG.2

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BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to multistage vacuum pumps and, more particularly, to a multistage vacuum pump having a plurality of Roots vacuum pump units which are arranged so that the rotation speeds of the rotors of these pump units can be individually set.

2. Description of the Related Art

Vacuum environments are required in many systems such as a CVD system, a dry etching system, a sputtering system, etc. which are used, for example, in semiconductor producing processes. Vacuum pumps are used to produce vacuum environments. Oil-sealed rotary vacuum pumps are generally known as vacuum pumps which are capable of starting operation with the pump inlet placed under atmospheric pressure. However, since this type of pump uses oil in the pump chamber, the vacuum environment obtained with the pump may be contaminated with oil. Therefore, the oil-sealed rotary vacuum pumps are unsuitable for use in systems such as those described above. To meet the above-described demand, Roots vacuum pumps have recently been used as one type of dry-sealed vacuum pump. To obtain a high vacuum, a plurality of Roots vacuum pump units are disposed in series to form a multistage Roots vacuum pump.

Such a conventional multistage Roots vacuum pump is disclosed, for example, in Japanese Patent Application Public Disclosure (KOKAI) Nos. 04-8891 and 04-311696. In the conventional multistage Roots vacuum pump, the interior of a single casing is divided into a plurality of pump chambers, and a pair of rotors are disposed in each pump chamber. These rotors are fitted on mutual driving and driven shafts so as to rotate at the same speed of rotation. This type of pump will be referred to as "single-shaft multistage vacuum pump" in the following description.

In the above-described conventional single-shaft multistage Roots vacuum pump, since the pump chambers are in close proximity to each other, the heat generation in the pump chambers has a remarkable effect on the operation. Thus the pump efficiency is deteriorated and it is extremely difficult to control the temperature. Accordingly, it is likely that the shaft seal for each end portion of the driving and driven shafts will be impaired because of rise in temperature, causing lubricating oil for bearings or timing gears attached to the driving and driven shafts to enter the pump chambers, and thus disabling the pump from functioning as a dry-sealed vacuum pump.

Further, in the single-shaft multistage vacuum pump, a single mutual shaft is used as each of the driving and driven shafts, and therefore, the driving and driven shafts are long, as a matter of course. Accordingly, when the pump is run for a long time, particularly in a low-vacuum region where the heat generation rate is relatively high, the rotors are displaced to a considerable extent by the thermal expansion of the shafts, so that the rotors may contact the casing. Thus, the conventional single-shaft multistage vacuum pump cannot practically perform a continuous operation for a long time.

Further, in the conventional single-shaft multistage vacuum pump, an exhaust passage which connects each pair of adjacent pump chambers is formed in the casing which is integrated one for all the pump chambers as has been described above. In addition, three-lobe rotors, which have a complicated configuration, are used in order to raise the compression ratio. Further, it is necessary to vary the pump chamber size and the rotor size for each stage, in order to vary the pumping speed for each stage. Accordingly, the pump becomes extremely complicated in structure, large in size and remarkably high in cost. When the pump is to be repaired in the case of machine trouble, the whole pump system must be disassembled because of the single-shaft arrangement.

Incidentally, the amount of heat generated in a Roots vacuum pump is known to be proportional to the inlet pressure, the pumping speed and the compression ratio. It is also known that, in a relatively low-pressure region, no large amount of heat is generated even if the compression ratio is high, but a large amount of heat is generated at the high-pressure side. That is, in the conventional single-shaft multistage Roots vacuum pump, it is mainly at the rear-stage side that the heat generation gives rise to a problem.

Roots vacuum pumps are also used as superchargers for automotive engines. In such Roots vacuum pumps, two-lobe rotors having a simple configuration, that is, hourglass-shaped or cocoon-shaped rotors, are used. The whole structure is also simplified, and thus the quality is stabilized. We carried out an experiment using a Roots vacuum pump having two-lobe rotors and also having a pump capacity of 300 liters/minute when used as a supercharger to examine how the compression ratio would vary according to the speed of rotation of the rotors in each pressure region, and thus obtained results such as those shown in the graph of Fig. 1. As will be clear from the graph, the compression ratio varies according to the speed of rotation in each pressure region.

The present invention has been made to solve the problems of the conventional single-shaft multistage Roots vacuum pump on the basis of the above-described knowledge.

## SUMMARY OF THE INVENTION

An object of the present invention is to provide a multistage vacuum pump which is greatly improved in its pump efficiency, facilitates the temperature control, provides a high pumping speed and is capable of attaining a high ultimate vacuum.

Another object of the present invention is to provide a multistage vacuum pump which generates a minimal amount of heat and is capable of continuously operating for a long time.

Still another object of the present invention is to provide a multistage vacuum pump which facilitates repair and maintenance operations.

A further object of the present invention is to provide a multistage vacuum pump which is capable of starting operation with its inlet placed under atmospheric pressure and of attaining a high vacuum without the need for any auxiliary equipment.

To attain the above-described objects, the present invention provides a multistage vacuum pump which includes a plurality of Roots vacuum pump units each having a pair of rotors. The Roots vacuum pump units have respective casings which are formed as discrete structures. The pump units are disposed in series, and for each pair of adjacent pump units, the outlet of the front-stage pump unit and the inlet of the rear-stage pump unit are connected by piping for exhaust. The multistage vacuum pump is arranged so that the rotation speed of the rotors of each pump unit can be individually set, thereby enabling the rotors in each stage to be rotated at a desired speed.

In each pair of adjacent pump units which are connected to each other, the rotation speed of the rotors of the front-stage pump unit may be set higher than that of the rotors of the rear-stage pump unit.

The plurality of pump units used in the multistage vacuum pump may have the same pump capacity.

The rotors may be two-lobe rotors.

Preferably, the clearance between the rotors and the casing is not greater than 0.1 millimeter.

The above and other objects, features and advantages of the present invention will become more apparent from the following description of the preferred embodiments thereof, taken in conjunction with the accompanying drawings, in which like reference numerals denote like elements.

## BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a graph showing the relationship between the rotation speed and the compression ratio in each pressure region of a two-lobe rotor Roots vacuum pump.

Fig. 2 schematically shows the arrangement of one embodiment of the multistage vacuum pump according to the present invention.

Fig. 3 schematically shows the way in which an ultimate vacuum is measured at each stage.

Fig. 4 is a graph showing the ultimate vacuum measured at each stage.

## DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Specific embodiments of the present invention will be described below in detail with reference to the accompanying drawings. It should, however, be noted that the present invention is not necessarily limited to the specific arrangements of the embodiments described below.

Fig. 2 is a schematic view showing the arrangement of a multistage vacuum pump 1 according to one embodiment of the present invention. In this embodiment, the multistage vacuum pump 1 has four Roots vacuum pump units 3, 5, 7 and 9 which are disposed in series to form a 4-stage vacuum pump structure. Identical Roots pumps are used for the Roots vacuum pump units 3, 5, 7 and 9. That is, the pump units 3, 5, 7 and 9 have the same pump capacity.

Each Roots vacuum pump unit has a casing 11 which defines a pump chamber 13 in the inside thereof. A pair of two-lobe rotors (generally known as hourglass-shaped or cocoon-shaped rotors) 15 and 17 are carried on driving and driven shafts (not shown), respectively, in the pump chamber 13 so as to mesh with each other and rotate synchronously. End portions of the driving and driven shafts extend into a gear chamber (not shown) which is provided adjacently to each pump chamber 13. The end portions of the driving and driven shafts have timing gears fitted thereon which are in mesh with each other to rotate the driving and driven shafts synchronously. A belt pulley or other appropriate device is attached to the other end of the driving shaft so that the driving shaft is driven to rotate by a motor (not shown), causing the rotors 15 and 17 to rotate in opposite directions to each other, as shown in the arrows in the figure. Both the driving and driven shafts are sealed by mechanical seal or other sealing devices. Since the above-described Roots vacuum pump structure is known, and Roots vacuum pumps used in the multistage vacuum pump of the present invention may have such a known structure, illustration of specific arrangement thereof and further description thereof are omitted.

The inlet 19 of the first-stage pump unit 3 is communicated with a closed chamber (not shown) which is to be evacuated through an exhaust pipe 35. In each pair of adjacent pump units in the following stages, the outlet of the front-stage pump unit and the inlet of the rear-stage pump unit are connected by an exhaust pipe 37, 39 or 41. The outlet 33 of the fourth-stage pump unit 9 releases exhaust gas into the atmosphere through a pipe 43.

A heat exchanger 45 is equipped with an oil pump to circulate cooling oil, as shown by the dotted-line arrows in the figure, so that the cooling oil is sent to the gear chamber for the pump unit in each stage to cool the timing gears. The heat exchanger 45 is supplied with cooling water through a pipe 47 as shown by the solid-line arrow in the figure.

Intercoolers 49, 51 and 53 are disposed at the outlets25, 29 and 31 of the second-, third- and fourth-stage pump units 5, 7 and 9. A part of the exhaust gas cooled in each of the intercoolers 49, 51 and 53 is returned to the pump chamber 13 in each of the second, third and fourth stages, thereby suppressing heat generation from the rotors 15 and 17. Since such intercoolers have also heretofore been used, detailed description thereof is omitted. A check valve 55 is provided in the exhaust pipe 43 to prevent back-flow of the gas when the operation of the multistage vacuum pump 1 is suspended.

In this embodiment, the rotation speeds of the rotors 15 and 17 in each of the first-, second-, third- and fourth-stage pump units 3, 5, 7 and 9 can be set independently of each other. That is, unlike those in the above-described conventional single-shaft multistage vacuum pump, the driving and driven shafts in the pump units 3, 5, 7 and 9 are discrete from each other and capable of being rotated at different speeds. The device for individually rotating the driving and driven shafts may be realized in various forms. That is, the pump units 3, 5, 7 and 9 in the four stages may be driven by respective motors. Alternatively, a single motor is used, and the rotation speed of the pump unit in each stage is varied in an appropriate speed reduction ratio by using a combination of a belt and a belt pulley, or other appropriate motion transmitting device. It is also possible to use a gearbox, as a matter of course.

In this embodiment, the rotation speeds are set so that the rotation speed of the first-stage pump unit 3 is the highest, and the rotation speed reduces as the ordinal number of the stages increases. In this case, the generation of heat is low and gives rise to no significant problem at the upstream side of the multiple stages, that is, at the lower-pressure side where the degree of vacuum is relatively high, even if the pumping speed is raised to provide an extremely high compression ratio, as has been described above. Therefore, the rotation speeds may be set, for example, as follows: 3,600 rpm for the first-stage pump unit 3; 1,800 rpm for the second-stage pump unit 5; 1,170 rpm for the third-stage pump unit 7; and 765 rpm for the fourth-stage pump unit 9. Thus, the pumping speed of the first stage is set at an extremely high level, thereby enabling the multistage vacuum pump 1 to attain an extremely high ultimate vacuum. On the other hand, the rotation speed of the fourth stage is set at a relatively low level, and the compression ratio is set at 2 or lower, thereby enabling the generation of heat to be markedly suppressed.

Incidentally, we carried out an experiment using Roots pumps having a pump capacity of 300 liters/minute when used as a supercharger. The Roots pumps which were used in the first, second, third and fourth stages were run at 3,600 rpm, 3,600 rpm, 1,800 rpm and 1,800 rpm, respectively, and ultimate vacuums were measured at the exhaust pipes 35, 37, 39, 41 and 43 with vacuum gauges 57, 59, 61, 63 and 65, as shown in Fig. 3. As a result, values such as those shown in the graph of Fig. 4 were obtained. Thus, it was possible to obtain a high vacuum of $1.4/10^3$ Torr at the inlet 19 of the first-stage pump unit 3 in a state where the outlet 33 of the fourth-stage pump unit 9 was placed under atmospheric pressure. When the multistage vacuum pump was run with a fifth stage added thereto (although not shown), a vacuum of $5/10^4$ Torr was obtained.

Although in the foregoing embodiment the Roots vacuum pumps used in all the stages have the same capacity, Roots vacuum pumps having different capacities may also be used, as a matter of course. Roots vacuum pumps used in the present invention are not necessarily limited to two-lobe rotor pumps such as those described above. Three- or four-lobe rotor Roots vacuum pumps may also be used, as a matter of course.

In a case where a condensable or reactive gas is handled, a device for introducing an inert gas into the pump system or a trap can be readily attached to the piping for exhaust, not to the pump body.

Further, it is generally considered that Roots vacuum pumps per se cannot evacuate with the inlet thereof placed under atmospheric pressure, and an auxiliary pump or other equipment is required. However, it has been proved to be possible to start operation with the inlet of the pump placed under atmospheric pressure and to attain a high vacuum even with Roots vacuum pumps having two-lobe rotors, by providing a plurality of such Roots vacuum pumps in a multistage structure with the clearance between the rotors and the casing of each pump being set not greater than 0.1 millimeter, and by setting the rotation speed of the pump in each stage at an appropriate value, as described above.

It should be noted that it is convenient if a vacuum gauge is provided at a proper position in association with the pump in each stage to measure the vacuum obtained by the pump. For example, in the embodiment shown in Fig. 2, a vacuum gauge may be installed in the pipe between each pair of adjacent pump units, as shown in Fig. 3. By doing so, when a trouble occurs in the system during operation, the pump unit that has a failure can be instantaneously identified by the indication of the vacuum gauge associated with that pump unit. For example, if the first-stage pump unit 5 has a failure to evacuate, the vacuum gauge 59 gives an abnormal indication. In this case, the vacuum gauge 57 may also gives an abnormal indication.

As has been described above, in the present invention, the rotation speed of the rotors of the Roots vacuum pump unit in each stage can be individually set. Accordingly, the pump unit in each stage can be run at an optimal pumping speed, and efficient evacuation can be effected with minimal power supplied to the driving shafts. Thus, the overall pump efficiency can be improved, and the overall pumping speed can be increased. In addition, the ultimate vacuum of the multistage vacuum pump can be raised to a high level. In particular, if the pumping speed and temperature in each stage are controlled in view of the change of the compression ratio according to the speed of rotation, a multistage vacuum pump having extremely superior pump performance can be obtained. That is, a high pumping speed and a high ultimate vacuum are obtained by increasing the rotation speed of the pump unit at the higher-vacuum side, that is, in the first stage, where the heat generation rate is relatively low even if the compression ratio is high. On the other hand, at the lower-vacuum side, that is, the rear-stage side, particularly in the final stage, where heat is readily generated, the rotation speed of the pump is reduced to lower the compression ratio, thereby enabling the heat generation to be suppressed to a considerable extent. Accordingly, it is possible to eliminate the problems associated with the conventional multi stage vacuum pumps, such as the problem that the lubricating oil may enter the pump chamber because of destruction of the shaft seal. Unlike the casing of the conventional single-shaft multistage vacuum pump, the casings of the pump units in all the stages are discrete from each other, and therefore, the pump casings can be cooled advantageously. In this regard also, the temperature control is facilitated. Since the heat generation can be suppressed, the pump can be continuously run for a long time.

Unlike the conventional single-shaft multistage vacuum pump, the multistage vacuum pump of the present invention need not entirely be disassembled when it is to be repaired, but only the portion that needs repair may be disassembled.

Further, since discrete Roots vacuum pump units are connected in series by piping for exhaust, it is easy to install an inert gas supply device or a trap for coping with a condensable or reactive gas, which has heretofore needed complicated processing for installation on the pump body. In contrast to the conventional multistage vacuum pump that employs a large-sized integral casing, the present invention enables the degree of freedom of the pump configuration to be increased by appropriately drawing exhaust piping in accordance with the place for installation. Accordingly, it is possible to construct a pump system which is appropriate for each particular purpose.

Although the conventional multistage vacuum pump needs a substantial design change to obtain different pump performance, the present invention enables the pump performance to be readily modified by changing the speed of rotation, the pump capacity of pump units used, or the number of stages of pump units to be installed.

Further, since satisfactory pump performance can be obtained by using two-lobe rotor Roots vacuum pumps, which are easy to design and produce, it becomes possible to provide a multistage vacuum pump having stabilized quality in comparison to the conventional multistage vacuum pumps.

By setting the clearance between the rotors and the casing at 0.1 millimeter or less, operation can be started with the inlet of the pump placed under atmospheric pressure and a high vacuum can be attained, without the need for an auxiliary pump or other equipment which has heretofore been required for the conventional Roots vacuum pumps.

In addition, by installing a vacuum gauge in association with a pump unit in each stage, when the system has a failure, the pump that has caused the failure can be instantaneously identified. As has been described above, the multistage vacuum pump of the present invention includes a plurality of Roots vacuum pump units, and the Roots vacuum pump units are driven through respective discrete shafts. Accordingly, when repair is needed, it is only necessary to disassemble and repair the pump unit in the stage that has a failure. Therefore, the above-described advantage that the pump that is attributable to a system failure can be instantaneously identified is extremely useful from the viewpoint of repairs. Further, since the multistage vacuum pump of the present invention can be formed by using a plurality of pump units having the same pump capacity, if pump units of the same capacity are prepared as spares, when the system has a failure, the system operation can be immediately resumed simply by replacing the pump unit that has a failure with a spare pump unit.

Although the present invention has been described through specific terms, it should be noted here that the described embodiments are not necessarily exclusive and that various changes and modifications may be imparted thereto without departing from the scope of the invention which is limited solely by the appended claims.

## Claims

**1.** A multistage vacuum pump comprising:

a plurality of Roots vacuum pump units which are connected in series to form a multistage structure, each Roots vacuum pump unit having a casing which forms a pump chamber with an inlet and an outlet, a pair of rotors which are disposed in said pump chamber, and which are fitted on respective parallel shafts so as to mesh with each other and rotate synchronously, and a pair of timing gears which are fitted on respective end portions of said parallel shafts outside said pump chamber, and which are in mesh with each other to rotate said pair of rotors synchronously; and

exhaust piping for serially connecting together the outlet of a front-stage pump unit and the inlet of a rear-stage pump unit in each pair of adjacent Roots vacuum pump units so that said pump chambers of said plurality of pump units communicate with each other in series;

said casings of said plurality of Roots vacuum pump units being discrete from each other, and

said multistage vacuum pump being arranged so that a rotation speed of said rotors of each pump unit can be individually set.

**2.** A multistage vacuum pump according to claim 1, wherein in each pair of adjacent pump units which are connected to each other, the rotation speed of the rotors of the front-stage pump unit is set higher than that of the rotors of the rear-stage pump unit.

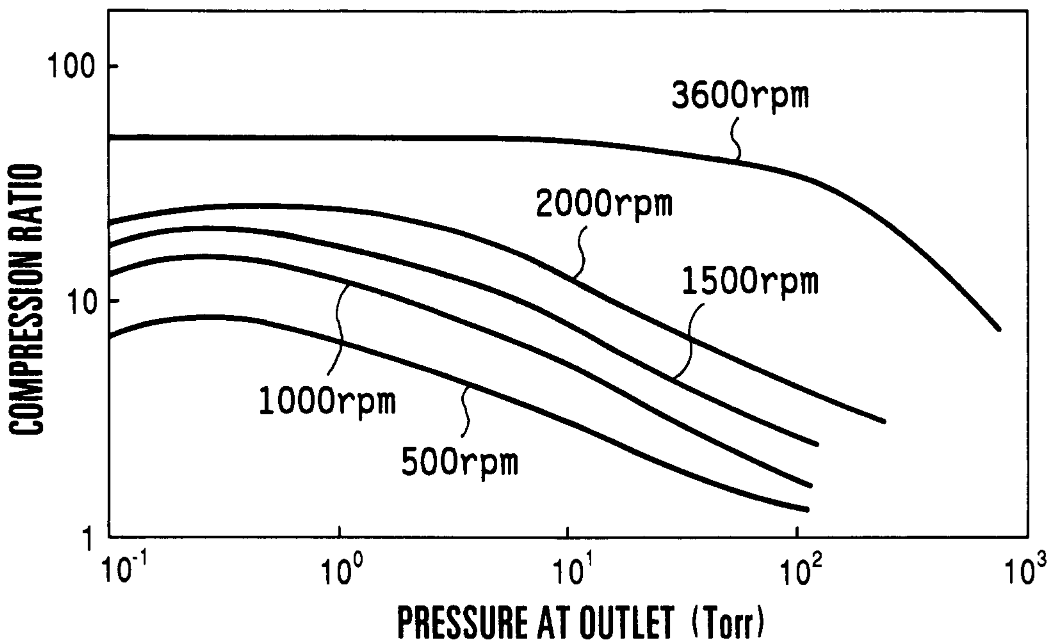
**3.** A multistage vacuum pump according to claim 1 or 2, wherein said plurality of pump units have the same pump capacity.

**4.** A multistage vacuum pump according to any one of claims 1 to 3, wherein said pair of rotors are two-lobe rotors.

**5.** A multistage vacuum pump according to any of claims 1 to 4, wherein a clearance between said casing and said rotors is not greater than 0.1 millimeter.

**6.** A multistage vacuum pump according to any one of claims 1 to 5, further comprising a vacuum gauge which is provided in association with the pump unit in each stage to measure a vacuum obtained by said pump unit.

# FIG.1



100
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COMPRESSION RATIO
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2000rpm
1500rpm
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500rpm
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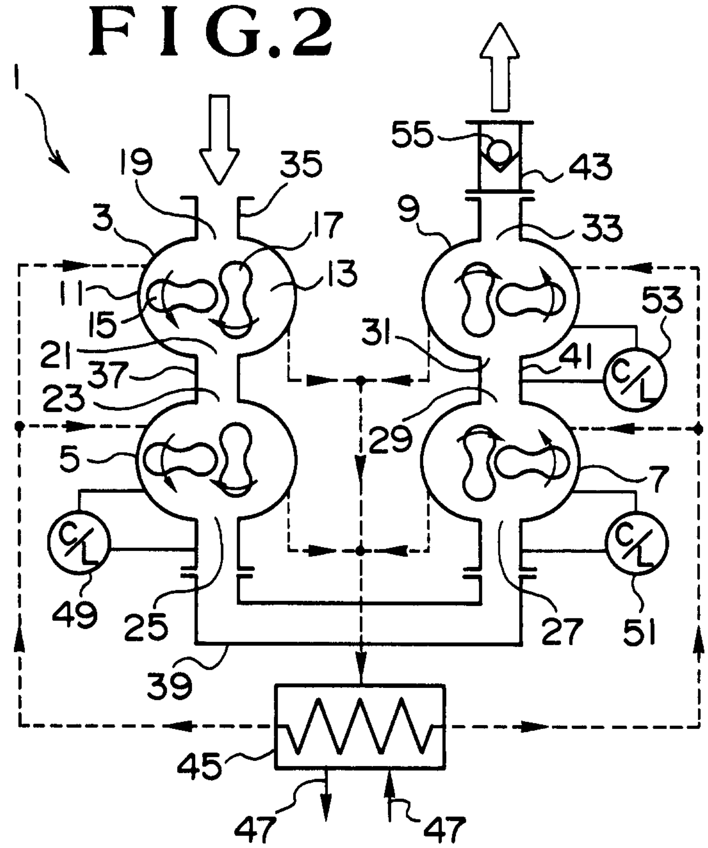
$10^{1}$
$10^{2}$
$10^{3}$
PRESSURE AT OUTLET (Torr)


# FIG.2



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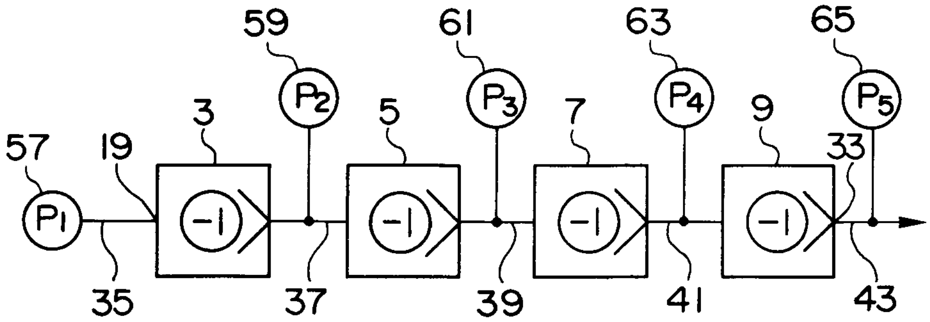
# FIG.3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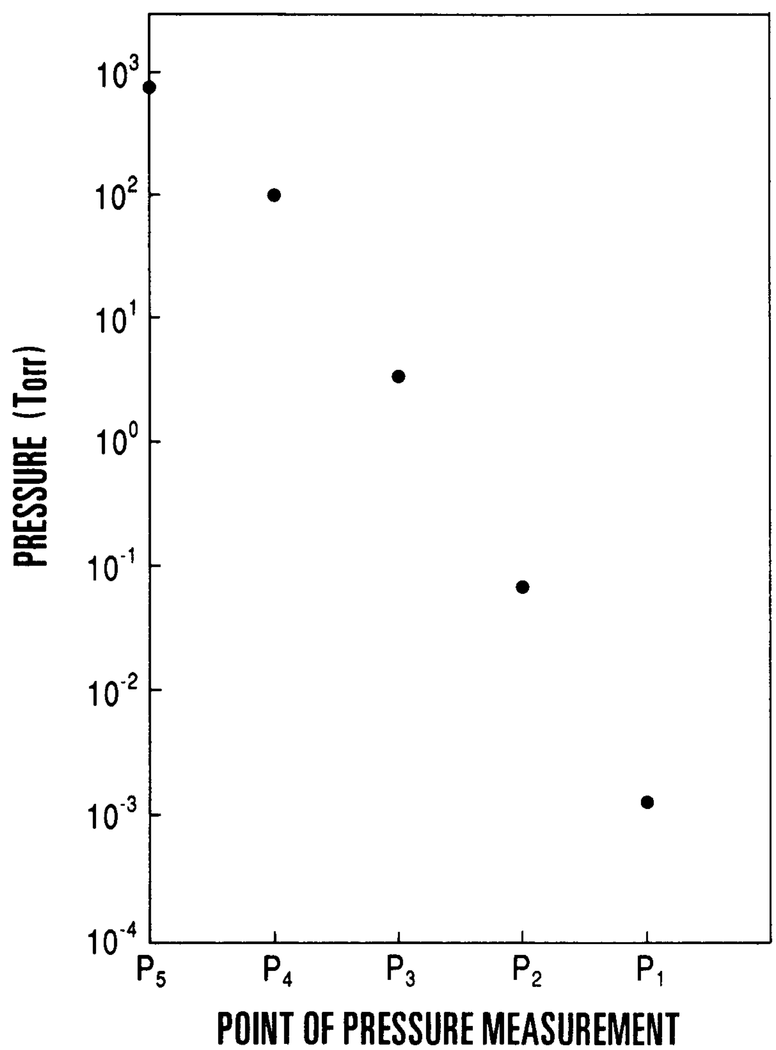
# FIG.4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$10^{-2}$
$10^{-3}$
$10^{-4}$
$P_5$
$P_4$
$P_3$
$P_2$
$P_1$
POINT OF PRESSURE MEASUREMENT

European Patent Office

# EUROPEAN SEARCH REPORT

Application Number
EP 95 10 3183

## DOCUMENTS CONSIDERED TO BE RELEVANT

| Category | Citation of document with indication, where appropriate, of relevant passages | Relevant to claim | CLASSIFICATION OF THE APPLICATION (Int.Cl.6) |
|---|---|---|---|
| Y | US-A-2 936 107 (BLACKBURN) * column 1, line 57 - column 2, line 71; figure * | 1,2,4,6 | F04C29/10 F04C23/00 |
| Y | DE-A-34 44 169 (LOEWE PUMPENFABRIK) * page 4 - page 7; figures * | 1,2,4,6 | |
| A | DE-U-93 06 559 (SIEMENS AG) * page 1 - page 4; figure * | 1,3,6 | |
| A | GB-A-809 443 (W.C.HERAEUS) * page 4, line 60 - line 103; figures 5-7 * | 1 | |

TECHNICAL FIELDS SEARCHED (Int.Cl.6)

F04C

The present search report has been drawn up for all claims

| Place of search | Date of completion of the search | Examiner |
|---|---|---|
| THE HAGUE | 13 June 1995 | Kapoulas, T |

CATEGORY OF CITED DOCUMENTS

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