

June 11, 1968

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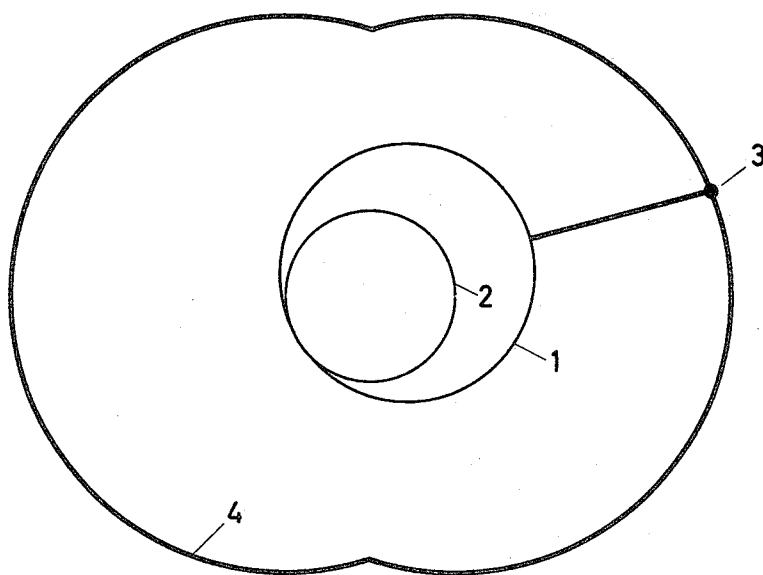
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ROTARY VACUUM PUMP

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5 Sheets-Sheet 1

Fig. 1A



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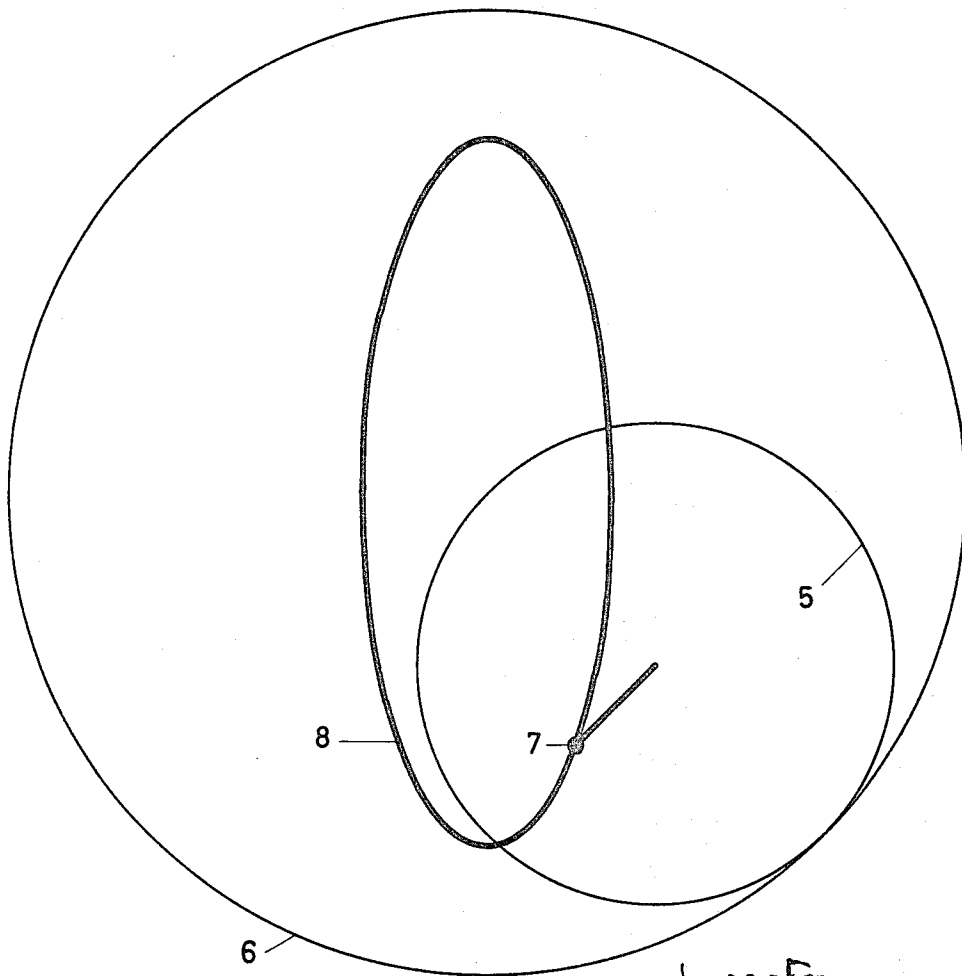
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ROTARY VACUUM PUMP

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Fig. 1B



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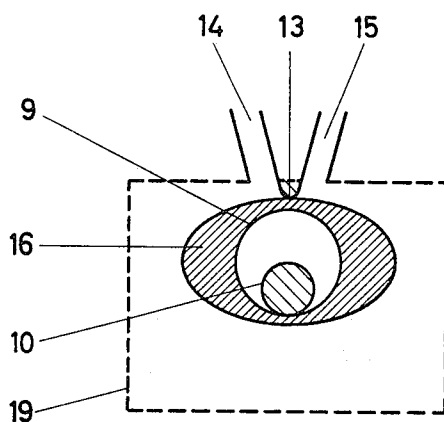


Fig. 2A

$i = 1:2$

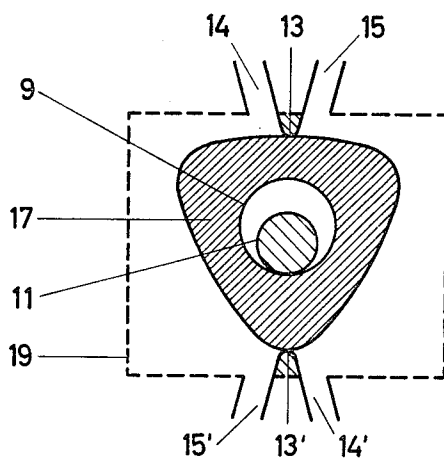


Fig. 2B

$i = 2:3$

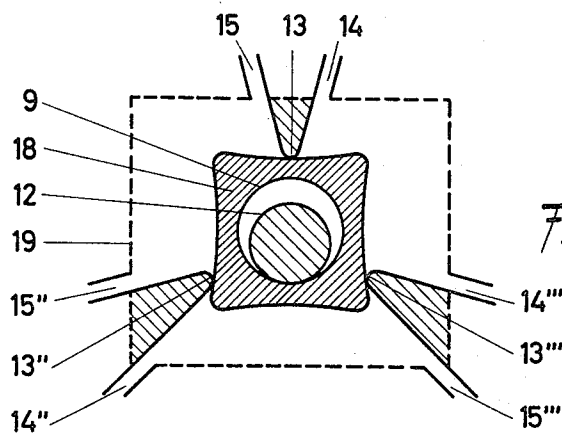


Fig. 2C

$i = 3:4$

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ROTARY VACUUM PUMP

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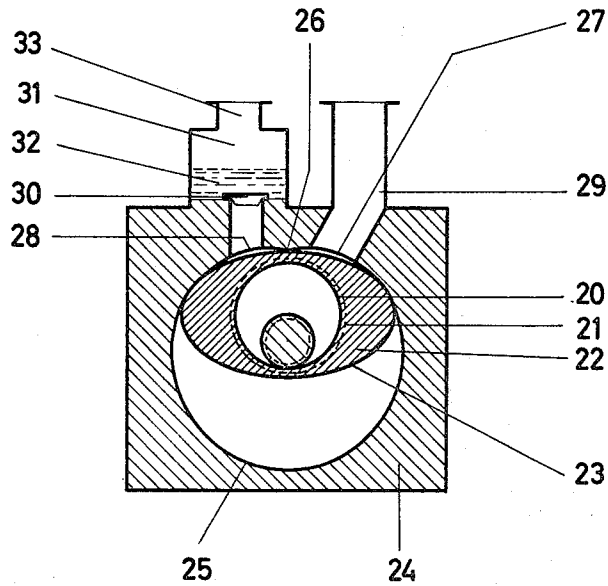


Fig. 3

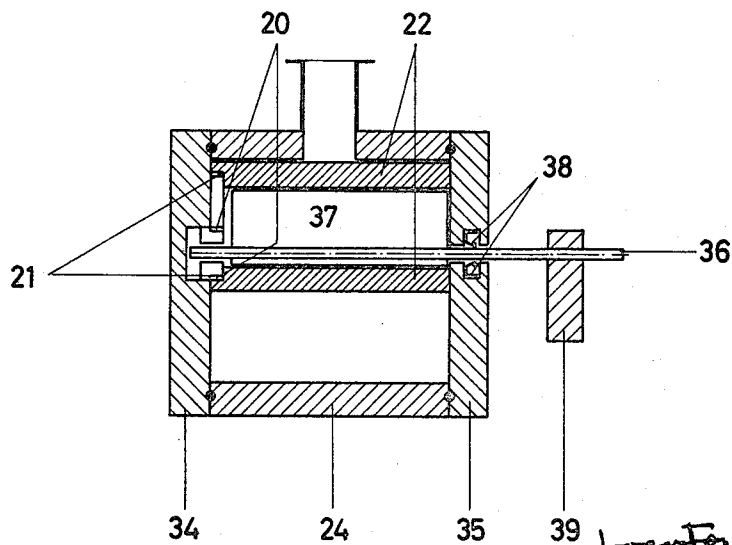


Fig. 4

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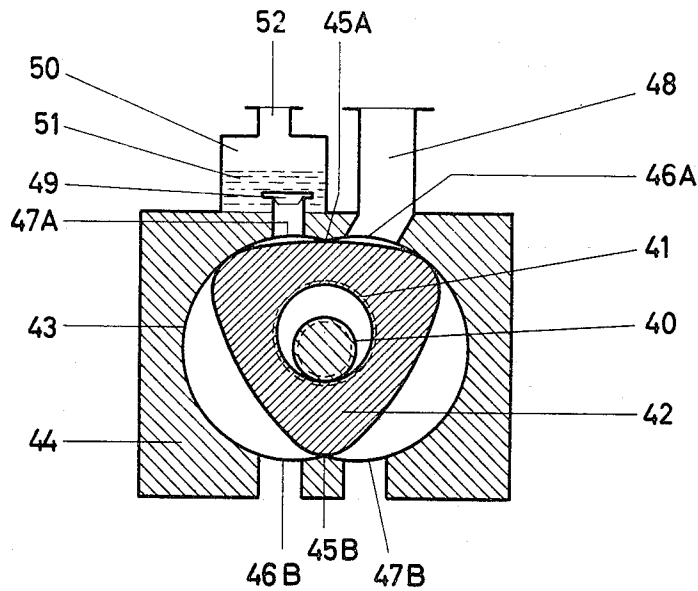
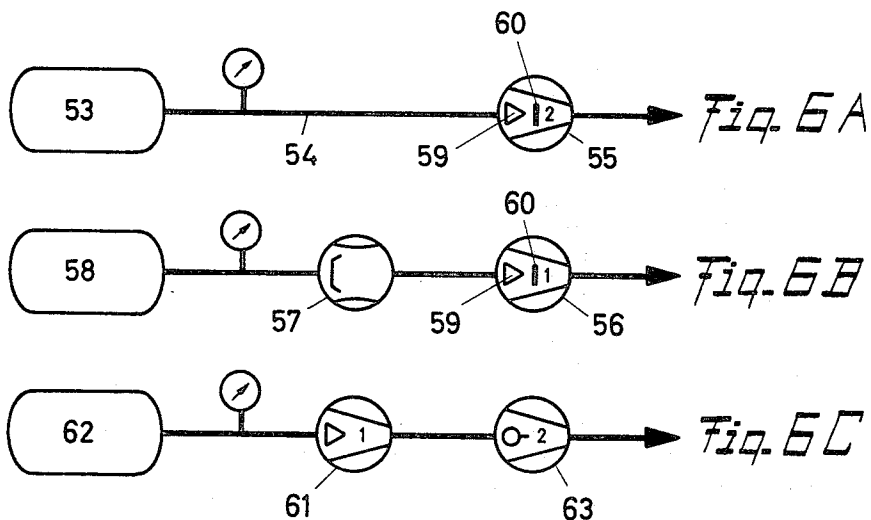


Fig. 5



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ROTARY VACUUM PUMP

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ABSTRACT OF THE DISCLOSURE

In a vacuum pump with a rotor revolving about a fixed point in a housing, the outer contour of the rotor being a hypotrochoid and the inner wall of the housing having the contour of an envelope of the revolving rotor contour. The housing wall contour has a fixed point contacting a point of the revolving rotor at all times, with an oil seal between the rotor surface and the fixed housing wall point separating the inlet from the outlet port.

The present invention relates to a rotary vacuum pump.

It is a fact well-known in the art that rotary vacuum pumps which when employed as forepumps should produce a pressure of less than 20 mm. Hg, preferably less than 10^{-1} mm. Hg, have to comply with very high requirements since they should be capable of producing a very high pressure ratio between the intake pressure and the atmospheric pressure which should, for example, amount to up to about 10^7 mm. Hg if the final vacuum to be attained should amount to 10^{-4} mm. Hg. The rotary vacuum pumps which are employed for this purpose are generally of the sliding vane type which, if these pumps are small run at a speed of up to approximately 1500 r.p.m., or they are of the rotary plunger type which run at a speed of about 500 r.p.m. In rotary vane pumps the vanes are pressed by spring force or by centrifugal force against the inner wall surface of the pump housing. Especially in view of the high speed of rotation of the pump, this results in a very strong wear upon the vanes and, if only a small amount of dirt collects in the pump, the vanes may also become wedged on the inner wall surface of the pump housing.

Rotary plunger pumps have the further disadvantage that, because of the reciprocating movements of the sliding plunger which also serves as an inlet for the gases which are to be drawn off, it is impossible to attain a complete dynamic mass balance. This prevents the pump from running at the highest desirable speed, and the suction output of such a pump of a certain size therefore cannot exceed a certain relatively small value. This is especially unfortunate since a rotary plunger pump is otherwise particularly suitable for being employed as a vacuum pump since it may be provided with an intake channel of a relatively large cross-sectional size. The movements of the revolving parts of such a pump also result in a relatively small wear since the sliding plunger is moved back and forth only within a bearing at a suitable tolerance, while the piston of the pumps revolves within its housing with a small clearance which is sealed tightly by oil. These desirable features of a sliding plunger pump cannot, however, be fully utilized because of the above-mentioned disadvantage of a considerable unbalance.

It is an object of the present invention to provide a rotary vacuum pump which eliminates the aforementioned disadvantage of the previously known rotary pumps. More particularly, it is an object of the invention to provide a pump which is tightly sealed by oil and has the smallest possible unbalance so as to permit the pump to operate at higher speeds and thereby to produce a higher suction output.

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A further object of the invention is to provide a vacuum pump which has an intake channel of a large cross-sectional area and is adapted to form the volume of the suction chamber or chambers practically from zero at every revolution.

In recent years, trochoidal machines such as the Wankel engines have been developed which because of their complete dynamic mass balance may be operated at very high speeds. Although when designed as an automobile engine, the three edges of each rotor of such a machine are sealed tightly relative to the inner wall of the engine housing by special sealing means, it would, of course, also be possible to design the rotor so as to permit it to rotate within the housing if between the rotor edges and the inner wall of the housing a small clearance exists which may be tightly sealed by oil.

Despite the advantages of these known trochoidal machines and even though some types of these machines have already been used as compressors, it has so far not been possible to design such machines so as to permit them to be employed as vacuum pumps. This is probably due to the fact that, while a compressor is only required to produce a compression substantially from an atmospheric pressure to a pressure of a few atmospheres, for example, 10 atm., a rotary vacuum pump when employed as a fore-pump has to produce a compression from at least 10^{-2} mm. Hg to about 760 mm. Hg, that is, a compression ratio of about 100,000:1.

It is therefore a further object of the invention to provide a trochoidal machine which is especially designed as a vacuum pump for producing such a high compression ratio.

The above-mentioned objects may be attained according to the invention by providing a trochoidal vacuum pump, the rotor of which has the shape of a hypotrochoid, while the inner wall surface of the pump housing forms an envelope curve of all rotor positions. Another feature of the invention consists in providing at least one point of engagement between the rotor and the pump housing, and in providing the intake opening at one side and the discharge opening at the other side of this point.

The present invention is founded upon the rather simple basis that for producing a sufficiently high compression ratio, it is necessary to separate the intake and discharge openings of the pump in such a manner that a short circuit of the gas current and thus a flow thereof in the reverse direction will be impossible. This requires what may be attained, for example, in rotary pumps of the sliding vane type, namely, that a point be provided in a fixed position on the housing which is sealed relative to the rotor and the housing either by a positive engagement between them or by means of oil, and which point is adapted to slide directly along the rotor during the rotation thereof.

It is the concept of the present invention that these considerations may be applied to certain trochoidal shapes, provided it is not the pump housing but the rotor which is made of such a shape and further provided that the rotor is made of the shape of a hypotrochoid. That this is true may be seen from a comparison of the four possible types or forms of a trochoidal machine; namely,

Type 1: The inner wall of the housing of the machine has the form of an epitrochoid;

Type 2: The rotor has the form of an epitrochoid;

Type 3: The inner wall of the housing has the form of a hypotrochoid;

Type 4: The rotor has the form of a hypotrochoid.

The above types Nos. 1 and 3 cannot be employed for producing a vacuum pump because it will be impossible to fulfill the requirement that there must be a fixed point on the housing which slides directly along the rotor during

the rotation thereof. This requirement may, however, be fulfilled if the types Nos. 2 and 4 are employed. However, when employing the type No. 2, the effect of the pump will be the same as that of a conventional piston pump since the intake and compression chamber does not revolve. Consequently, just as in a piston pump, it will then be impossible to avoid a so-called residual volume within the pump chamber. If the type No. 4 is employed, however, the intake and compression chamber will revolve together with the rotor, and such a pump may therefore be employed as a vacuum pump.

The features and advantages of the present invention will become more clearly apparent from the following detailed description thereof which is to be read with reference to the accompanying drawings, in which:

FIGURES 1A and 1B show the mathematical development of the curves of epitrochoids and hypotrochoids;

FIGURES 2A, B, and C show diagrammatic cross-sectional illustrations of rotors in the form of different hypotrochoids;

FIGURE 3 shows a diagrammatic cross section of a vacuum pump according to the invention which is taken along the line III—III of FIGURE 4;

FIGURE 4 shows a longitudinal section of the pump according to FIGURE 3;

FIGURE 5 shows a cross section of a vacuum pump according to a modification of the invention; while

FIGURES 6A, B, and C show diagrams of vacuum pump units in which trochoidal pumps are employed.

Solely for the purpose of attaining a better understanding of the following description of the invention, FIGURES 1A and 1B illustrates the manner of mathematically developing epitrochoids and hypotrochoids which often are also called epicycloids and hypocycloids, respectively.

If as shown in FIGURE 1A a circle 1 is rolled along the outside of a fixed smaller circle 2, a point 3 which is fixed on the rolling circle 1 will describe an epitrochoid 4. Closed simple curves will then be formed only if the ratio i between the diameters of the two circles 1 and 2 forms two successive integral numbers, for example, $i=1:2$ or $2:3$ or $3:4$, etc. If on the other hand, as shown in FIGURE 1B, a circle 5 rolls along the inside of a larger fixed circle 6, a fixed point 7 on the rolling circle 5 will describe a hypotrochoid 8. Closed simple hypotrochoids will be formed only if a ratio K between the diameters of the larger to the smaller circle forms integral numbers. If this ratio K amounts to $2:1$, the hypotrochoid has, for example, an elliptical shape; if it amounts to $3:1$, it has a shape similar to a triangle; and if it amounts to $4:1$, it has a substantially square shape.

Also solely for the purpose of explaining the invention, FIGURES 2A, B, and C illustrate rotors 16, 17, and 18, each of which has an outer shape of a different hypotrochoid, while its movement is determined by the two circles 9 and 10 or 9 and 11 or 9 and 12, respectively, which roll along each other. Since each point of the cross section of the rotors 16, 17, and 18 then describe an epitrochoid in accordance with FIGURE 1A, the ratio between the diameters of each pair of these circles has the value of two successive integral numbers and therefore corresponds to the above-mentioned symbol i . The larger circle 9 at the inside of each rotor 16, 17, and 18 is made of the same diameter in all three illustrations according to FIGURES 2A, B, and C, while the diameters of the inner circles 10, 11, and 12 differ from each other in accordance with the ratio i . If i has a value of $1:2$, as shown in FIGURE 2A, the diameter of the inner circle 10 amounts to one half of the diameter of the larger circle 9; if i has a value of $2:3$, as shown in FIGURE 2B, the diameter of the inner circle 11 amounts to two thirds of the diameter of the larger circle 9; and if i has a value of $3:4$, as shown in FIGURE 2C, the diameter of the inner circle 12 amounts to three fourths of the diameter of the larger circle 9.

In order to produce a rotor of the proper shape for a pump, a fixed point 13 is arbitrarily determined which

forms the sealing and separating point between an inlet 14 and an outlet 15. For kinematic reasons, the inner circles 10, 11, and 12 are held in stationary positions, while the outer circles 9 roll along these inner circles. This results in the development of the curved outer shape of the respective rotor, as illustrated in FIGURES 2A, B, and C. If the ratio i has a value of $1:2$, the rotor 16 according to FIGURE 2A has an elliptical shape; if it has a value of $2:3$, the rotor 17 according to FIGURE 2B has a shape of a triangle with rounded edges and outwardly curving sides; and if it has a value of $3:4$, the rotor 18 according to FIGURE 2C has a square shape with rounded edges and slightly inwardly curved sides. The outer shapes of the rotors which develop if the ratio i amounts to still higher values, such as $4:5$, $5:6$, etc., are not illustrated in the drawings. All of the rotors which are suitable for vacuum pumps have, however, in common that their outer shapes are those of hypotrochoids similar to the shapes of the rotors 16, 17, and 18.

In addition it should be pointed out that, while there is only one fixed sealing point 13 if the diametrical ratio i amounts to $1:2$, there will be an additional fixed sealing point 13' diametrically opposite to the sealing point 13 between another inlet 14' and another outlet 15' if the diametrical ratio i amounts to $2:3$, as shown in FIGURE 2B. Similarly, if the diametrical ratio i amounts to $3:4$ as shown in FIGURE 2C, there will be three sealing points, namely the points 13 and two further sealing points 13'' and 13''' between the inlet and outlet 14'' and 15'' and the inlet and outlet 14''' and 15''', respectively, and if the diametrical ratio i amounts to $5:6$, there will be five sealing points.

When designing a vacuum pump according to the invention, at first only the shape of the rotor and the location, shape and size of the sealing point 13 is determined. In order to produce the required pump chambers so as to attain an operative pump, it is still necessary to provide a pump housing 19 and to determine the shape of the inner wall surface thereof. This surface should have the shape of an envelope curve of all rotor positions and it will be provided with a single sealing point or inwardly directed "corner" if the diametric ratio amounts to $1:2$, or with two sealing points or "corners" if this ratio amounts to $2:3$, or with three sealing points or "corners" if the ratio amounts to $3:4$. In these cases, the respective rotor is therefore at first produced in the shape of a hypotrochoid which is determined by means of the three elements: (a) the large circle 9; (b) the small circle 10, 11, or 12 at the diametric ratio i to the circle 9 of $1:2$, $2:3$, or $3:4$; and (c) the selection of the position of the contactor sealing point 13.

For producing the desired shape of the rotor as well as the pump housing and especially the inner wall thereof, it may be assumed for the sake of illustration that the body of the rotor outside of the circle 9 as well as the body of the walls of the housing except for the sealing point 13 consist of a pliable material which hardens as soon as it has been molded to the desired shape. If the body of the rotor is then moved along the point 13 by rolling the outer circle 9 along the fixed inner circle 10, 11, or 12, it will be given the particular shape as illustrated in FIGURES 2A, B, or C, respectively. The shape of the inner wall of the pump housing is then determined by the envelope curve of all rotor positions of the respective revolving rotor.

In a previous part of this description, the four different possible types or forms of a trochoidal machine were listed. These four different types may be listed in a different manner and in greater detail as follows:

Type	Motor	Housing
1 -----	Inner envelope curve -----	Epitrochoid.
2 -----	Epitrochoid -----	Outer envelope curve.
3 -----	Inner envelope curve -----	Hypotrochoid.
4 -----	Hypotrochoid -----	Outer envelope curve.

A more detailed illustration of these four different types of trochoidal machines may be found, for example, in the article by E. Schmidt in the V.D.I.-Zeitschrift 102 (1960), No. 8, p. 293 etc., Figures 7 to 22.

The trochoidal machine known as a "Wankel engine" is designed in accordance with the above-mentioned type 1. The individual chamber volumes of this engine are sealed by sealing strips which are connected to and rotating with the rotor. Such a machine is unsuitable as a vacuum pump since such a pump requires one particular fixed point of the housing, i.e. the point 13, which is located between the intake and discharge openings to be sealed relative to the rotor. For the same reason it is also not possible to employ the above-mentioned type 3 as a vacuum pump.

A proper sealing action at a particular fixed point on the housing, for example, the point 13, may therefore be attained only by the above-mentioned types 2 and 4 in which the rotor forms a trochoid and the housing with at least one fixed sealing point forms an outer envelope curve. This sealing point forms an inwardly directed "corner" of the inner wall of the housing. In the case of the type 4, there is one such "corner" if the ratio i amounts to 1:2, there are two "corners" if the ratio i amounts to 2:3, and three "corners" if the ratio i amounts to 3:4.

The type 2 cannot be employed as a vacuum pump for the following reasons: Intermediate the sealing corners which amount to at least two in the most simple case of a ratio i of 1:2, the inner wall of the housing is provided with outwardly curved parts which are successively filled out completely or freed by the rotor. This is substantially in accordance with the movements of the piston in a piston pump and has also all of the disadvantages of such a pump, especially insofar as it possesses a residual pump volume. Such a residual volume would, however, absolutely prevent the function of such a pump as a vacuum pump with the required high compression ratio of more than 50,000 since it would only permit the production of a very poor vacuum. Each of these curved chambers which serve as pump chambers would like a piston pump require two valves, namely an intake valve and an exhaust or discharge valve. Furthermore, such a pump could also not produce a good vacuum for the reason that at the desired high rate of revolutions of the rotor an intake valve can only free a relatively small cross-sectional intake area at each revolution.

The above-listed machine type No. 4 differs fundamentally from the type No. 2 as last discussed. The free chambers between the rotor and housing of this machine are not produced again and again at the same points as in the case of the machine type No. 2, but these free chambers revolve and are therefore formed at one place, that is, at one side of the sealing point 13, while they disappear at the other side. Therefore, only this machine type No. 4 can possibly be employed for use as a vacuum pump. The present invention therefore consists in selecting from the four known machine types the type No. 4 in order to produce a high-duty vacuum pump by employing a rotor and housing of a known shape, i.e. a rotor of a hypotrochoidal shape and a housing, the inner wall of which is the outer envelope curve of the rotor.

An operative pump for a ratio i of 1:2 is illustrated in FIGURES 3 and 4. The two circles 9 and 10 of FIGURE 2A which roll along each other are provided in this case in the form of gear wheels 20 and 21. The smaller gear wheel 20 is secured in a fixed position on the housing wall 34, and the gear rim 21 with twice the number of inner gear teeth is adapted to roll along the smaller gear wheel 20 and thereby revolves the elliptical trochoidal rotor 22 to which this gear rim 21 is secured. The outer surface 23 of rotor 22 has the shape of a hypotrochoid of a ratio K of 2:1. The inner wall 25 of the surrounding body of the housing 24 is provided with a single "corner" or sealing point 26 which corresponds to the point 13 in FIGURE

2A and is either always in direct engagement with the outer surface 23 of the rotor or at least spaced only at a very small distance therefrom because of unavoidable tolerances of manufacture. The pump housing 24 is provided at one side of the sealing point 26 with an intake opening 27 which continues into the intake channel 29, and at the other side of point 26 with an exhaust or discharge opening 28 which may be provided with an outlet valve 30 which is mounted within a chamber 31 which contains sealing oil 32. The evacuated gases are then passed through an exhaust line 33 into a further line, not shown.

The longitudinal section of the pump according to FIGURE 3 which is illustrated in FIGURE 4 shows that the pump housing consists of the body 24 and the end walls 34 and 35. Rotor 22 is driven by the drive shaft 36 and an eccentric 37 which is rigidly secured to this drive shaft. Since the drive shaft 36 and the smaller gear wheel 20 which is secured to the end wall 34 are disposed coaxially to each other, shaft 36 may be extended through the gear wheel 20 so as to permit its end to be rotatably mounted in the end wall 34. In the other direction, drive shaft 36 extends through the other end wall 34 of the housing and is sealed relative thereto by conventional sealing means 38. The outer end of shaft 36 carries a counterweight 39 which compensates statically the eccentricity of the eccentric and the rotor. For dynamically compensating the eccentricity, it is possible to extend the drive shaft 36 through the end wall 34 and to mount another counterweight thereon.

Of course, in place of counterweights it is also possible to employ additional pump stages which are of a similar design as the pump according to FIGURES 3 and 4 and in which the length of the rotors and the phase relationship are determined in a conventional manner so that a complete dynamic mass equilibrium will be attained.

FIGURE 5 illustrates a further embodiment of the invention with a ratio i of 2:3 between the smaller and larger circles. The rotor has therefore a substantially triangular shape, that is, the shape of a hypotrochoid with a ratio $K=3:1$. The smaller gear wheel 40 is again mounted in a stationary position, while the larger gear rim 41 rolls along the gear wheel 40. The number of teeth on the two gears also have a ratio of 2:3 to each other. The gear rim 41 limits the cavity 43 within the housing 44. The two "corners" or sealing points 45A and 45B are located diametrically opposite to each other. Adjacent to each of them an intake opening 46A and 46B and a exhaust or discharge opening 47A and 47B may be provided. This discharge opening 47A may be provided with an outlet valve 49 which may again be mounted within a chamber 50 containing sealing oil 51. The evacuated gases are passed through the exhaust line 52 into a further line, not shown. The exhaust opening 47B and the intake line 46B may be connected to each other by a channel or chamber. The pump will in this case operate in two stages. It is, however, also possible to connect the exhaust channel 47B via a valve directly to the outside, in which case the pump will have a double action. Since the oil 51 in chamber 50 is in intimate contact with air, it is more advisable to design a two-stage pump not in the manner as illustrated in FIGURE 5, but to employ it as a double-acting pump and to provide a similar pump as a first pump stage. The pumps according to FIGURES 4 and 5 may also be provided with a gas ballast device as conventional in vacuum pumps.

Since a longitudinal section of the pump according to FIGURE 5 would substantially correspond to the section according to FIGURE 4, except for the details which are illustrated in FIGURE 5, it is not believed to be necessary to show it again.

The vacuum pumps as illustrated in FIGURES 3 and 5 operate with a conventional oil seal between the rotor and the inner wall of the housing and the valves 31 and 49 are also covered by oil 32 or 51. Such pumps are very

suitable as forepumps. The manner in which they are employed is illustrated diagrammatically in FIGURES 6A and 6B. FIGURE 6A shows a two-stage pump 55 according to the invention which evacuates a container 53 through the vacuum line 54. According to FIGURE 6B a one-stage pump 56 evacuates a container 58 by the cooperation with an oil diffusion pump 57. In order to indicate the use of a trochoidal pump, the symbol of a triangle 59 has been used in the pumps 55 and 56, while a thick transverse line 60 has been used as a symbol to indicate the oil seal and the outlet valve.

A trochoidal pump may also function without an oil seal and possibly also without an outlet valve. It belongs to the types of pumps which similarly to a Roots pump are driven at the highest possible speed in order to produce a high volumetric pump action. The gaps between the outer surfaces of the rotors and the inner surfaces of the housing which are not sealed by oil may be dynamically sealed sufficiently by a large free path of the molecules, provided the pump according to the invention is followed by a conventional forepump, as illustrated in FIGURE 6C. In this case, the one-stage or two-stage trochoidal pump 61 which may be, for example, valveless and not oil-sealed evacuates the container 62. This pump 61 is followed by a two-stage pump 63 of the plunger type, although it is of course also possible to employ an oil-sealed trochoidal pump 55 or 56, as indicated in FIGURES 6A and 6B, respectively.

Although my invention has been illustrated and described with reference to the preferred embodiments thereof, I wish to have it understood that it is in no way limited to the details of such embodiments but is capable of numerous modifications within the scope of the appended claims.

Having thus fully disclosed my invention, what I claim is:

1. In a vacuum pump comprising a housing having an inner wall defining a pump chamber, a rotor arranged to revolve in the pump chamber, an axis at a fixed distance from the inner housing wall about which the rotor is arranged to revolve, an intake port leading through the wall into the pump chamber and an exhaust port leading through the wall from the pump chamber: a gear on said

axis, an annular gear on the rotor in engagement with the first-named gear whereby the rotor may revolve thereabout, the diameter of the annular gear being larger than that of the first-named gear, the diameter ratios being determined by two successive integers, the rotor having a hypotrochoidal contour, the inner housing wall having a contour of an envelope of the revolving rotor contour, the inner housing wall contour having a fixed point between the intake and the exhaust port, said fixed point always contacting a point of the revolving hypotrochoidal contour of the rotor during each revolution, and an oil seal at the fixed point between the inner housing wall and the rotor contour, said seal separating the intake and exhaust ports.

2. In the vacuum pump of claim 1, means for rotating the first-named gear to revolve the rotor thereabout.

3. In the vacuum pump of claim 1, the two successive integers being 1 and 2.

4. In the vacuum pump of claim 1, the two successive integers being 2 and 3, and the inner housing wall having a second one of said fixed points.

5. In the vacuum pump of claim 1, an outlet valve in said exhaust opening.

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