Dec. 4, 1962 J. W. BEAMS 3,066,849

HIGH VACUUM PUMP SYSTEMS

Filed Aug. 18, 1960 3 Sheets-Sheet 1

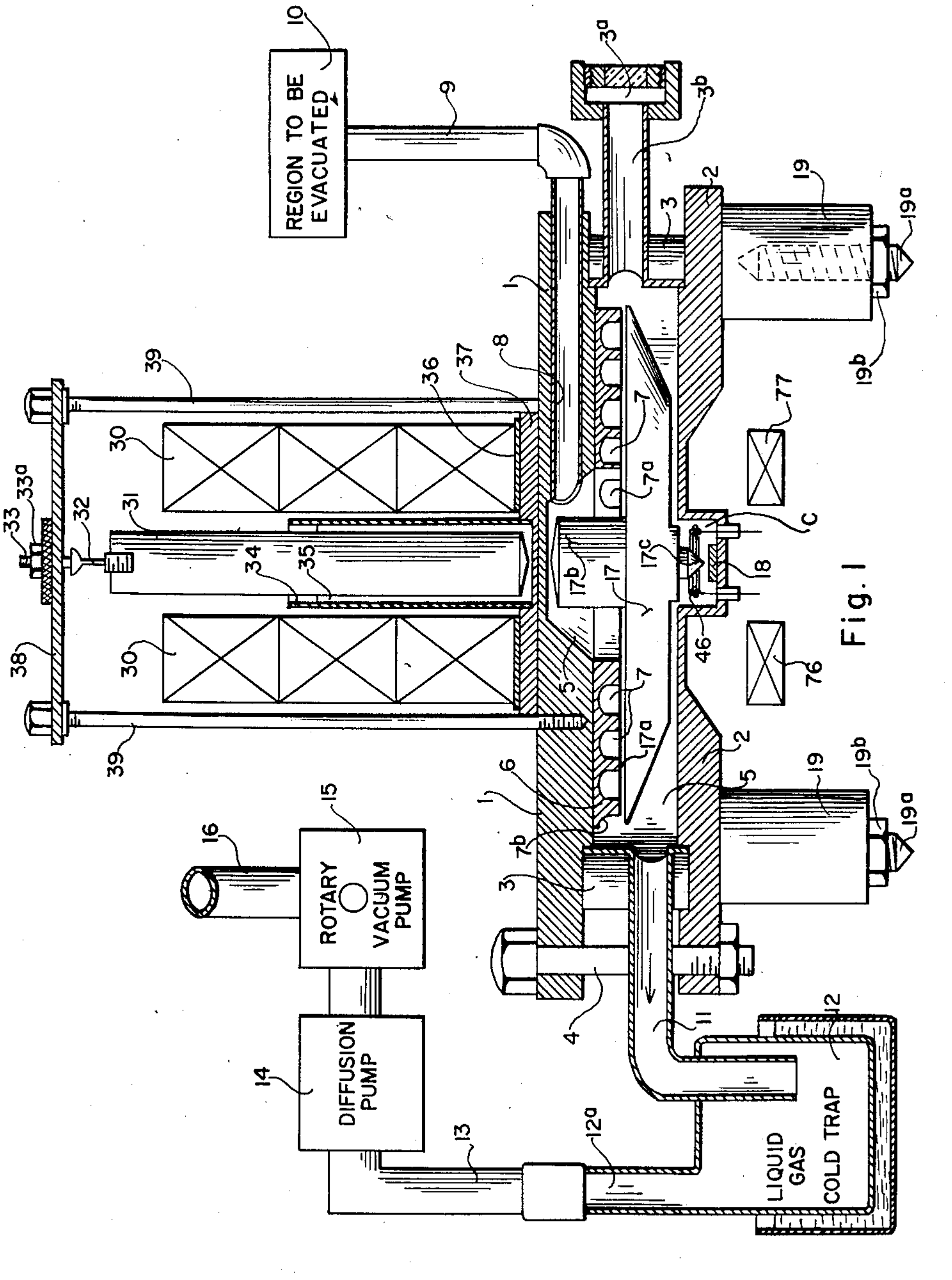

Fig. 1

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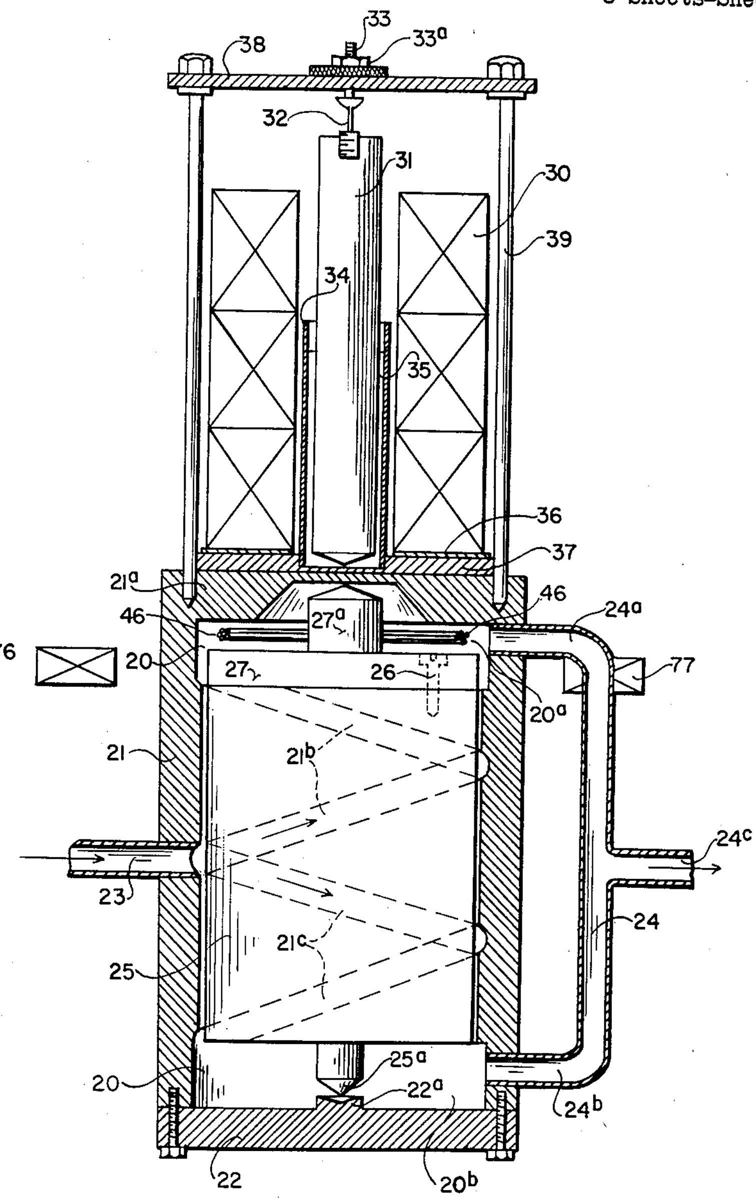

Fig. 2

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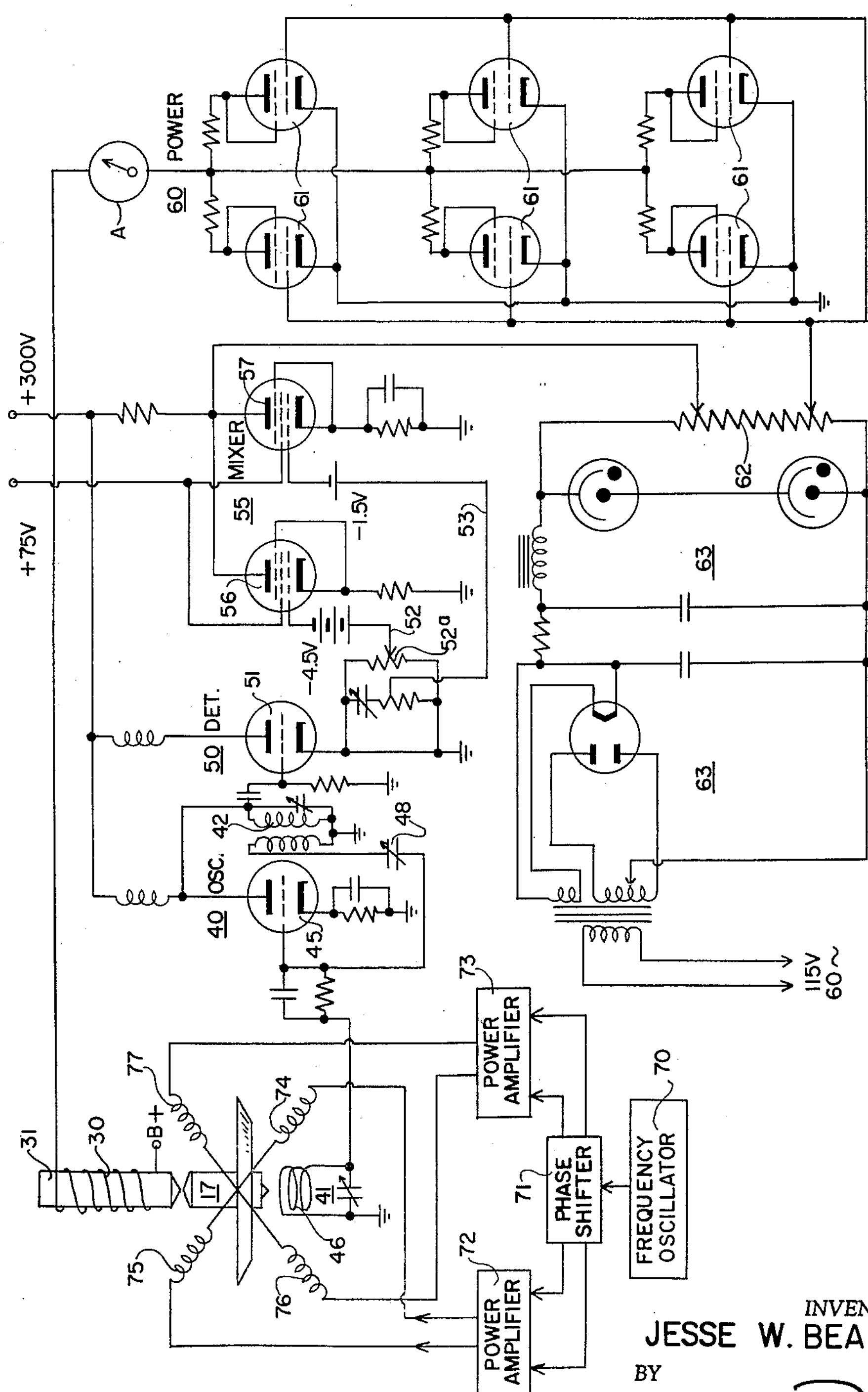

Fig. 3

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HIGH VACUUM PUMP SYSTEMS

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5 Claims. (Cl. 230—117)

This invention relates to pumps for attaining high vacua, and more particularly relates to improvements in molecular pumps in which the pumping rotor is magnetically suspended within the pumping chamber and therefore does not employ bearings when the pump rotor is up to speed.

Prior art molecular pumps employing bearing-mounted rotors produce relatively high vacua, but the best vacua attainable by such pumps have been limited either by the vapor pressure of the lubricant in the rotor bearings, or by the fact that the pump could not be baked out satisfactorily, or by both factors.

It is a principal object of the invention to provide a pump wherein the rotor is magnetically suspended in the pump chamber so that no bearings are required, and therefore bearing lubricants are eliminated and no vapor pressure therefrom is present to contaminate the pump chamber.

It is another object of the invention to provide a pump which can be baked out without resulting damage thereto and/or subsequently refrigerated, if desired, to increase its pumping efficiency.

Still a further important object of the invention is to provide an improved pumping structure resulting in improved efficiency, wherein the pumping takes place between the peripheral surface of a high-speed rotor and the stationary surface of a chamber whose pumping surfaces can be further improved by providing grooves spiraling from the intake duct of the chamber toward the discharge duct thereof in the direction of rotation of the rotor. In this type of pump, the gas molecules are driven toward the discharge-duct portion of the surface by frictional contact with the rotor surfaces traveling in that direction, and these molecules are entrapped between the rotor and stator where the clearance is very small, the clearance being of the order .05 centimeter or less.

Still a further object of the invention is to provide a magnetically suspended pump rotor capable of very high rotation rates, the rate being limited only by the highest speed at which the rotor can be turned without having it fly apart due to centrifugal forces, and the greatest speed attainable being further increased by the magnetic suspension of the rotor which eliminates mechanical bearing friction. In the pump according to the present invention, the surface speed of the rotor can easily be increased to twice the average molecular speed of the gas particles being pumped.

Another object of the invention is to provide a molecular pump suitable for use in tandem pumping systems which also employ diffusion-type vacuum pumps and/or rotary-type pumps. The diffusion pumps are especially efficient in pumping lighter molecules, whereas the present molecular pump is more efficient when pumping the heavier molecules, and therefore the two types of pumps when connected in tandem tend to complement each other.

Other objects and advantages of the invention will become apparent during the following discussion of the drawings, wherein:

FIG. 1 is a view of one embodiment of the pump according to the present invention, the pump of this embodiment being shown partly in cross-section and also being shown connected with other elements of a tandem pumping system;

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FIG. 2 is a view, partly in cross-section showing a modified form of the pump according to the invention, the pump being located below the coil of a magnetic rotor suspension device; and

FIG. 3 is a schematic diagram showing an electronic suspension and propulsion system suitable for use in suspending and driving the rotors of the pumps according to the present invention.

Referring now to the drawings, FIG. 1 shows a pump comprising a stationary housing including an upper plate **1**, a lower plate **2**, an annular wall **3** and bolt means **4** for securing the plates **1** and **2**, and the wall **3**, together to form a fluid-tight pump chamber generally designated by the reference numeral 5. Within the pumping chamber **5** is located a plate **6** having a series of spiraled grooves **7** which begin at the opening *7a* of the plate **6** and form a continuous spiral terminating at *7b* near the periphery of the pump chamber 5. The input to the pump chamber **5** includes the inlet tube **8** extending radially through the plate **1** and terminating near the center of the annular cavity 5. This tube **8** is connected by pipe means **9** with a region **10** to be evacuated. The discharge from the pump chamber takes place through the tube **11** which is connected into the outer periphery of the pump chamber **5** through the wall 3 and extends into a cold trap **12** having an outlet *12a* which is connected through suitable piping **13** with a diffusion pump **14** and ultimately with a rotary vacuum pump **15**, the pumped gas discharging through a pipe **16** into the atmosphere. The parts **12, 13, 14, 15** and **16** are all known per se and are not considered novel in themselves. These parts are merely included for the purpose of illustrating one possible use to which the pump according to the present invention can be put.

The actual pumping is carried out by a rotor **17** made of permeable material and having a disc-shaped pumping portion *17a* and a magnetic suspension center portion *17b*. In addition, the rotor has a small downwardly extending conical tip *17c* which lands on a bearing plate **18** when the rotor is at rest. The gas pumping, however, is carried out by the upper surface *17d* of the disc, which surface lies parallel with and closely spaced from the grooved surface of the pumping stator plate **6**.

The pump housing is supported on three or more feet **19** each of which includes an axially adjustable screw *19a* maintained at a proper elevation by a lock nut *19b*, and a window *3a* is supported at the end of a short tube *3b* secured in the side wall 3 of the pump housing.

The rotor **17** is suspended above the landing block **18** and is maintained in very close, but spaced proximity to the pumping stator **6** by a magnetic suspension system which forms a part of the novel combination of the present pumping system, but which is not per se novel. This magnetic suspension system is shown in FIG. 2 of Patent 2,733,857, which disclosure is substantially repeated to form a part of present FIG. 3 so as to illustrate one possible means for magnetically suspending the rotor **17**. As stated in the objects of this invention, the important improvement of providing a high-speed pump having no bearings and therefore no bearing lubricants is carried out according to the present invention by employing as a part of the present novel combination this magnetic suspension system.

The magnetic suspension system comprises a solenoid **30** which when energized by direct current establishes a unidirectional magnetic field, the solenoid comprising approximately 28,000 turns of #22 enameled copper wire. This number of turns provides an inductance of about 70 henries with a resistance of 1200 ohms. When its core **31** of magnetic material is in place the total current passed through this winding should be between 150 and 220 milliamperes. The core **31** is of circular cross-section and made of soft iron. It is suspended at its upper end on a flexible wire **32** which is attached to a stud **33** secured in adjustable position by a nut **33***a*. The core is located in axial alignment with the suspension portion **17***b* of the rotor **17** and the lower end of the core is contained within a cylindrical vessel **34** containing a relatively heavy motor oil **35** for damping any tendency which the core **31** may have to swing about the wire **32** on which it is supported. The vessel **34** is made of non-magnetic material.

The windings of the solenoid **30** are supported on a disc of asbestos **36** which rests upon a plate **37** located parallel with and below a brass plate **38** serving to support the upper end of the core. The plate **38** is in turn supported on studs **39** which are screwed into the upper plate **1** of the pump housing.

Referring to FIG. 3, the electrical suspension circuit comprises a high-frequency oscillator **40** tuned to a frequency of several megacycles by a tuned circuit **41** in the grid of the oscillator and a tuned circuit **42** in the plate of the oscillator. The triode **45** comprising the oscillator has a grid circuit which includes a coil **46** forming the inductance of the tuned circuit **41**. The output from the oscillator is taken from the tuned circuit **42** and is resistance-coupled with the grid of a detector tube **51**. The condenser **48** is connected in series with a tickler coil which is magnetically coupled with the tuned circuit **42**, and serves to couple sufficient feedback to the grid circuit of the oscillator to sustain oscillations. The coil **46** can also be seen in FIG. 1 located beneath the rotor **17** and has sufficient turns thereon that it can be tuned to the frequency of the oscillator **40** so that it can sense the position of the rotor **17** as will be described hereinafter. For present purposes, however, it is sufficient to note that the impedance of the coil **46** is decreased or increased as the rotor moves up or down with respect thereto and hence the tuning and output amplitude of the oscillator is dependent upon the vertical position of the rotor. It is the purpose of the rest of the circuit to amplify variations in the oscillator amplitude so that if the rotor rises, the current in the solenoid **30** will be decreased, and if the rotor descends the solenoid current will be increased.

The oscillator **40** is coupled to the detector **50** which comprises the tube **51** connected as a cathode follower for delivering a signal proportional to the amplitude of the RF signal which is delivered to the grid of the detector tube **51**. This output signal at the lead **52**, being proportional to the amplitude of the oscillation in the oscillator **40** can be used as an error signal for indicating the vertical position of the rotor **17**. A time-derivative signal is also taken at the output lead **53**. The error and time-derivative signals are combined in the mixer stages **55** which includes two pentodes **56** and **57** the anodes of which are connected in parallel and to the input of a power amplifier stage **60** shown as comprising six tetrodes **61** all connected in parallel. A power supply **63** is provided with a regulated output voltage appearing across the resistance **62**, and coupling is directly applied to the power amplifier **60** by connecting the grids of the power tubes **61** at appropriate points across the load resistor **62** which furnishes drive to the power tubes **61**. The resistor **62** is coupled with the tubes **56** and **57** of the mixer and serves as a load impedance therefor. The solenoid **30** comprises the load in the plate circuits of the six power stage tubes **61**, and the plate voltage to these power tubes is supplied from a separate high-voltage power supply (not shown). A voltage of about 800 volts has been found suitable for this purpose.

In addition to the suspension system, FIG. 3 also shows a rotor drive system comprising an oscillator **70** which drives a phase shifter **71** having two quadrature outputs driving power amplifiers **72** and **73**, respectively. The output of one power amplifier **72** is passed through one set of field coils **74, 75**, and the output of the other power amplifier **73** likewise drives another set of field coils **76, 77**. All of the field coils have their axes located in a common horizontal plane, and the axis of the aligned field coils **74, 75** is normal to the axis of the aligned field coils **76, 77**. These field coils provide a magnetic field in the vicinity of the rotor **17**, which field has a rotating component which rotates synchronously with the frequency of the oscillator **70** and thereby drives the rotor as a synchronous motor armature at a rate of rotation dependent upon the frequency of oscillator **70**. This rotation system is also known in the prior art and is not considered novel per se, although it forms a part of the novel combination of the present invention.

By reference to FIG. 1, it will be noted that the sets of drive coils are located below the rotor, in this instance the coils **76, 77** being visible.

Referring now to FIG. 2, this figure shows a modified form of pump structure, according to the present invention, which pump structure, however, is supported by a similar magnetic suspension system and is driven by a drive system which is also similar to that shown in FIGS. 1 and 3. Like parts are therefore similarly labeled in FIGS. 1 and 2.

The pump itself as shown in FIG. 2 comprises a cylindrical housing **21** closed at its upper end **21***a* and having tapped bores therein to receive the rods **39** by which the magnetic suspension unit is supported. The housing has a bottom plate **22** which is bolted thereto to form airtight closure of the cavity **20** of the pump. The intake duct **23** passes through the wall of the housing **21** and communicates with two spiral grooves which both pass in the same direction around the wall, the upper groove being labeled **21***b* and the lower groove being labeled **21***c*. The arrows shown on these grooves are both directed from the duct **23** in the same direction toward the upper and lower portions of the pump cavity **20**, respectively labeled **20***a* and **20***b*. Grooves **21***b* and **21***c* respectively discharge into these end cavities **20***a* and **20***b* which are then coupled by ducts **24***a* and **24***b* which communicate with a manifold duct **24** and with the output duct **24***c*. Therefore, it is apparent that the gas molecules being pumped enter through the duct **23**, pass around the spiral grooves **21***b*, **21***c* into the end cavities **20***a*, **20***b* and thence outwardly through the ducts **24***a*, **24***b*, **24** and **24***c*.

The rotor comprises an annular member **25**, made for instance of duralumin, and attached by means of a plurality of screws **26** which comprise a magnetic portion **27** of the rotor. This magnetic portion of the rotor also includes a suspension portion **27***a* which is located directly beneath the core **31** of the solenoid and is axially aligned therewith. At the lower end of the rotor is a small conical tip **25***a* which serves as a landing means to support the weight of the rotor when the system is turned off and the magnetic suspension is not present. This tip **25***a* engages the conical surface of a small boss **22***a* on top of the closure plate **22**.

Operation

In operation, the rotor of the pump according to the present invention is suspended entirely by the flux from the solenoid **30** and core **31** so that the pivot at the lower end of the rotor is raised off of the support therebelow. The flux which raises the rotor is produced by a direct current from the power amplifier **60**, and as the rotor moves vertically under the attraction of the flux, its proximity to the coil **46** is varied, and therefore the inductance of the coil **46** is varied so as to change the tuning of the oscillator **44**. The pickup coil **46**, by changing its inductance, changes the condition of tuning of the oscillator, and therefore raises or lowers the amplitude of oscillation of the tube **45**. A signal is coupled from the tune circuit **42** into the grid of the cathode follower detector stage **51** and a D.C. potential appears across the cathode resistor **52** which is proportional to the amplitude of oscillation appearing across the tune circuit **42**.

A portion of the potential is taken off of the resistance

52 and passed through a battery which serves to reduce the D.C. level thereof without decreasing the amplitude of signal variations. These signal variations are a direct error signal proportional to the vertical position of the rotor and are connected to one input of a mixer circuit **55**, comprising pentodes **56** and **57** having their plates connected in parallel.

In addition, an RC differentiating circuit is connected across the cathode resistor **52a** which gives a signal at the lead **53** which is proportional to the time-rate-of-change of rotor height. This derivative signal when mixed with the error signal provides a component which effectively damps any up and down motion of the rotor.

The error and derivative signals are separately amplified in the tubes **56** and **57** and mixed in their plate circuits and applied to the grids of six beam power pentodes **61** which regulate the current through the solenoid **30** while passing it through the milliammeter A so that an indication is present of the average current value. The magnitudes of the error signal and of the derivative signal can be individually adjusted and the mixed component thereof controls the current to the solenoid **30** in such a way that when the rotor approaches the coil **46** in FIG. 1, the amount of current in the winding **30** of the solenoid is increased and when the rotor rises higher above the coil **46**, the amount of current in the solenoid is decreased, and by proper adjustment an equilibrium can be had at which the rotor is suspended freely in space. Note that in FIG. 2 since the coil **46** is above the rotor **27** rather than below it, a different adjustment of the tune circuit **41** on the other side of resonance is necessary to provide the opposite operation from that just described above.

The horizontal position of the rotor is determined by the symmetrical magnetic field at the bottom of the core **31**. The rotor automatically seeks the strongest part of the electric field, which is at the center of the pole **31** and at the center of the rotor, but it is desirable to provide horizontal damping in order to prevent eccentric oscillations about the axis of rotation if the rotor is displaced in a horizonal direction. For this purpose, the cylindrical core **31** comprising the pole is hung on a wire **32** so that the core is supported like a pendulum, and the bottom end of the core is immersed in a dash-pot **34** of oil **35**. The mass and size of the rotor are so related to the dimensions and weight of the core that the core follows any eccentric motions of the rotor from the center position. However, the motion of the core **31** is damped by the oil **35** in the horizontal direction and therefore the oscillations of the rotor are also damped by the oil **35**. When properly adjusted, no movement, either horizontal or vertical, can be observed in the equilibrium position of the rotor.

With the rotor thus suspended, the oscillator **70** provides the energy of rotation by passing quadrature currents through the two sets of windings **75**, **74** and **76**, **77** of the field. As stated above, since quadrature currents are applied to these field windings, the rotor automatically locks into step with the rotating field of these windings and operates in the same way as the armature of a synchronous motor.

Thus it will be seen that I have provided an improved combination of elements which can pump gas molecules to achieve a very much increased vacuum without contamination of the evacuated region by vapor from such lubricants as have heretofore been necessary to lubricate the bearings of prior art pumps. Moreover, it will be observed that there is nothing in the pump body per se, including the rotor, the stator, and the pump housing, which can not be baked out at relatively high temperatures, such as 400 degrees F. for long periods of time, i.e. several hours or so. This baking out is extremely important, and can be sufficiently done only where no lubricant is required in the pump, since the lubricant tends to vaporize at the elevated bake-out temperatures.

I do not limit my invention to the precise forms illustrated in the drawings, for obviously changes may be made therein within the scope of the appended claims.

I claim:

1. A molecular gas pump comprising a housing having a cavity; inlet and outlet duct means communicating with said cavity; a stator surface in the cavity, a rotor in the cavity having an annular portion of magnetic material disposed along the axis of the rotor and having a rotor pumping surface substantially coextensive with said stator surface and located in closely spaced proximity thereto; magnetic suspension means located outside of said housing and coacting with said magnetic material for suspending the rotor freely in space within the cavity; and rotating-field generating means located outside of said housing and magnetically coupled with said annular portion of magnetic material for imparting rotation to the rotor.

2. In a pump as set forth in claim 1, the housing having an opening therein; a transparent window in said opening; and means to seal the window therein.

3. A molecular gas pump comprising a housing having a cavity; inlet and outlet duct means communicating with said cavity; a stator surface in the cavity; a rotor in the cavity having a rotor pumping surface substantially coextensive with said stator surface and symmetrically disposed about its axis of rotation; magnetic means located outside the housing and coacting with the rotor for suspending the rotor free of all contact with other elements of the pump for rotation about said axis; rotor-position sensor means adjacent the rotor and controlling said magnetic means for maintaining the rotor pumping surface located in close proximity to said stator surface, the gas molecules passing between said surfaces in transit from the inlet duct means to the outlet duct means; and drive means located outside of the housing and coacting with the rotor for imparting rotation to the rotor.

4. In a pump as set forth in claim 3, the housing having an opening therein; a transparent window in said opening; and means to seal the window therein.

5. In a vacuum pumping system, the combination of a pump having a housing including a cavity connected with a region to be evacuated and a discharge duct leading out from said cavity, and the pump including rotor means located within said chamber for impelling gas molecules toward said discharge duct and the rotor means having an axially disposed portion of magnetic material; magnetic suspension means located outside of and separable from said pump for coacting with and suspending the rotor freely in space within said cavity; and rotating field generating means located outside of the pump and magnetically coupled with said portion of magnetic material for imparting rotation to the rotor.

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