United States Patent [19]

Shoulders

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[45] **July 13, 1976**

[54] **VACUUM PUMP**

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[73] Assignee: **American Optical Corporation,** Southbridge, Mass.

[22] Filed: **Aug. 1, 1974**

[21] Appl. No.: **494,016**

[52] **U.S. Cl.** **417/244;** 415/90; 415/100; 417/405; 250/311

[51] **Int. Cl.²** **F04D 19/04**

[58] **Field of Search** 415/90, 99, 100; 417/201, 244, 405; 250/311; 315/108

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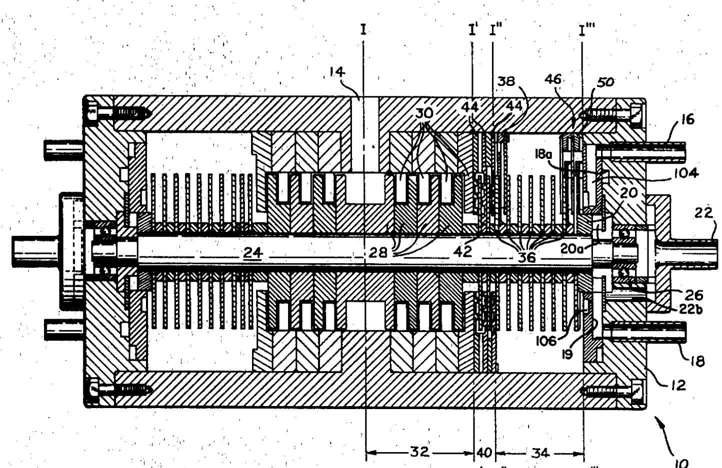
Attorney, Agent, or Firm—H. R. Berkenstock, Jr.; William C. Nealon

[57] **ABSTRACT**

An integral vacuum pump for producing ultra-high vacuums including, in combination, axial turbomolecular, centrifugal compressor and vortex diode pumping means.

4 Claims, 19 Drawing Figures



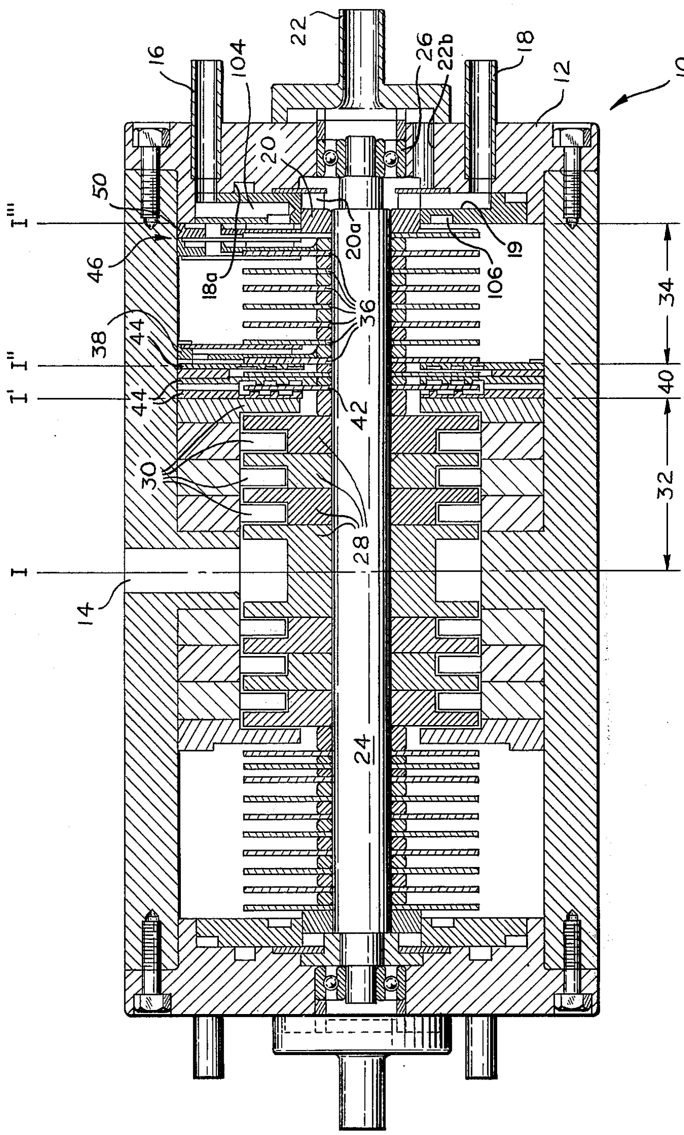

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FIG. 1

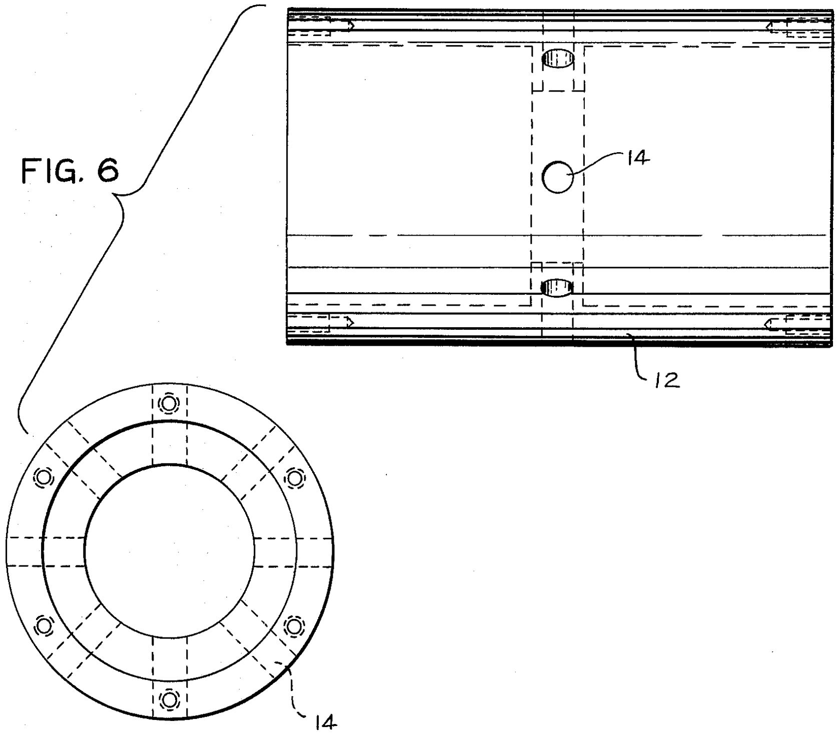

FIG. 6

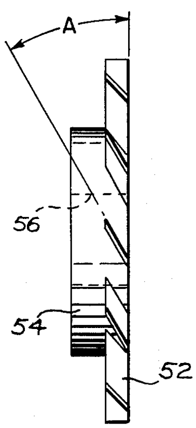

FIG. 2 b

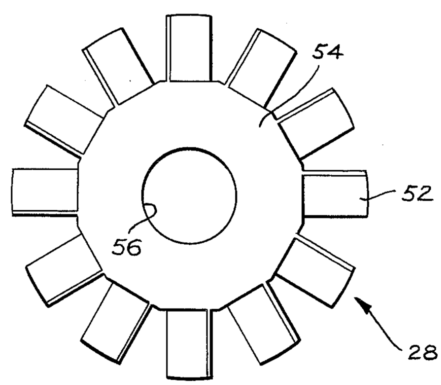

FIG. 2a

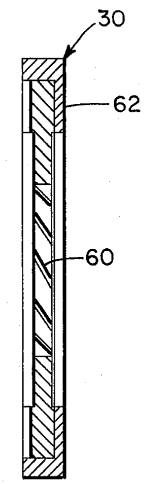

FIG. 2e

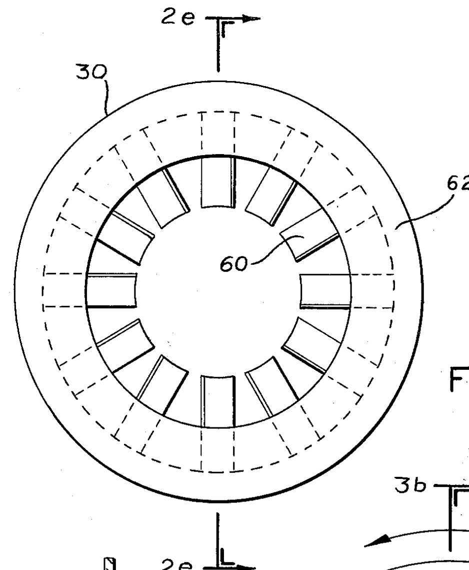

FIG. 2d

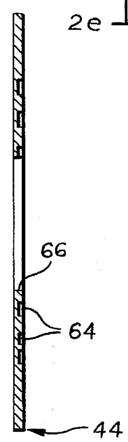

FIG. 3b

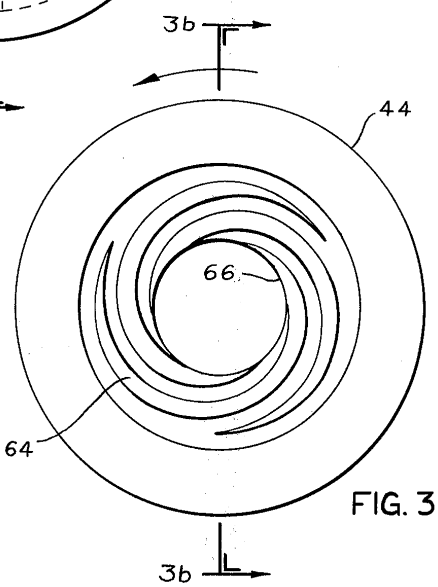

FIG. 3a

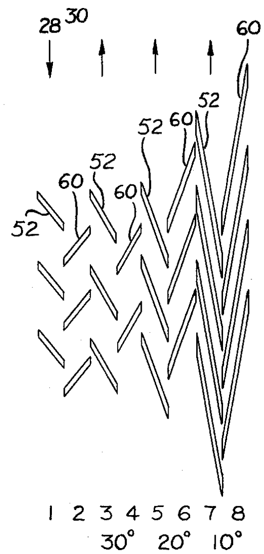

FIG. 2c

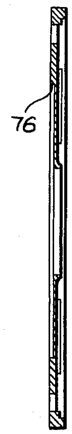

FIG. 4d

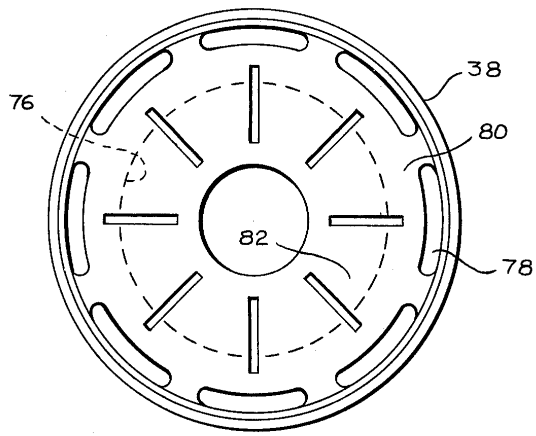

FIG. 4c

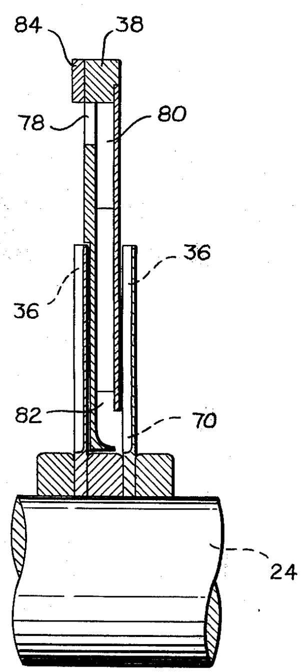

FIG. 4e

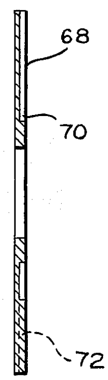

FIG. 4b

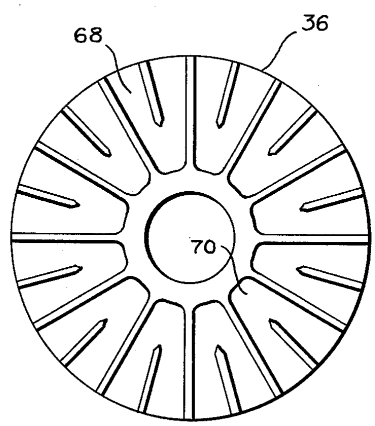

FIG. 4a

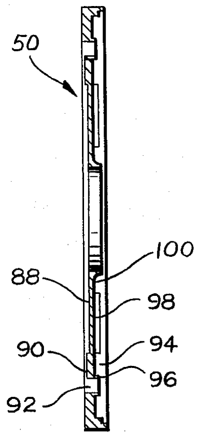

FIG. 5b

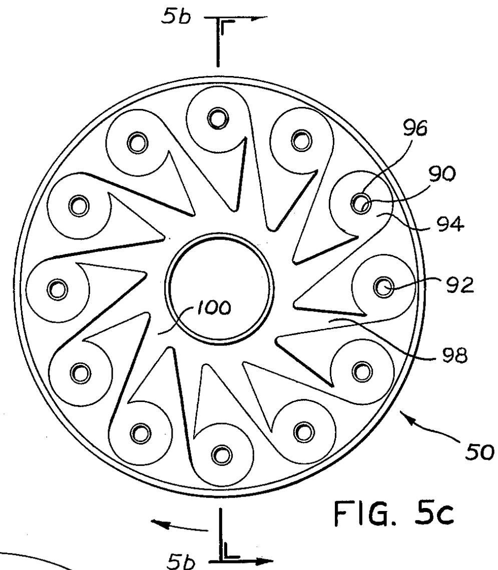

FIG. 5c

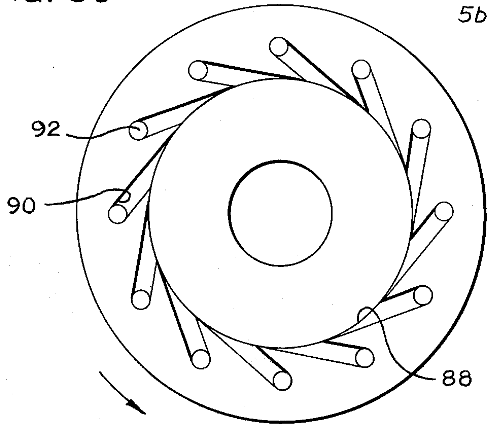

FIG. 5a

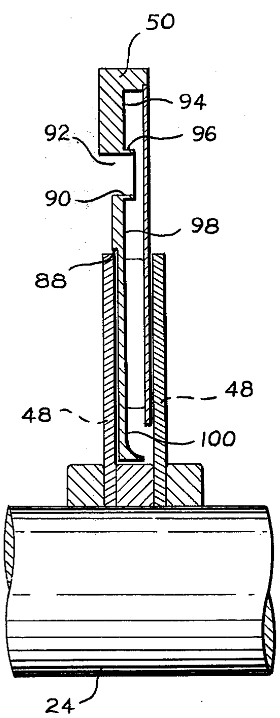

FIG. 5d

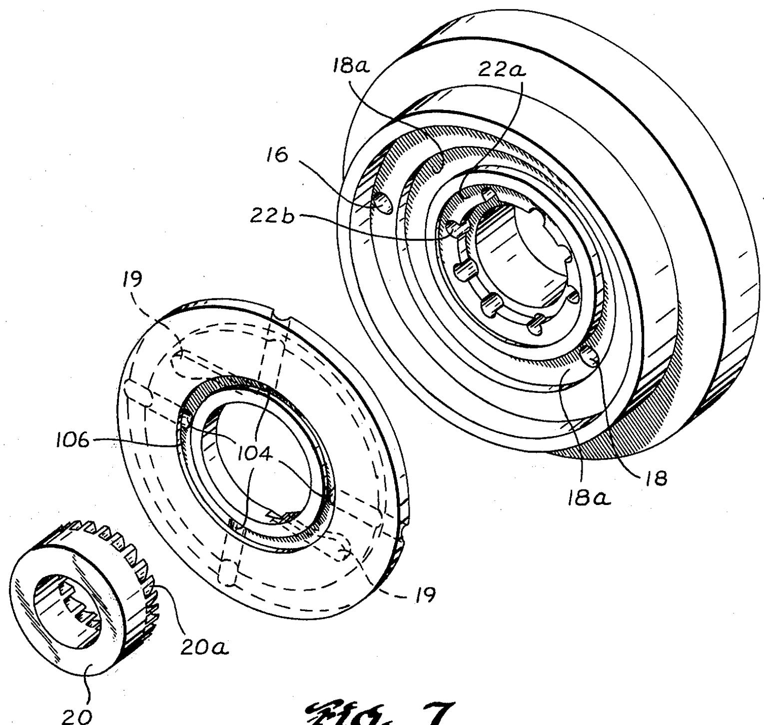

Fig. 7

VACUUM PUMP

BACKGROUND OF THE INVENTION

This invention relates to a vacuum pump of a type capable of producing high vacuums in closed chambers while avoiding hydrocarbon backstreaming. The disclosed invention incorporates principles of turbomolecular pumps; yet it is a unitary device not requiring a separate forepump.

While turbomolecular pumps are well known to the pumping art, their application has been limited in spite of their ability to produce high vacuum because of a number of considerations. Existing, commercially available turbomolecular pumps generally fall in the category of high capacity pumps having capabilities usually in the range of 150 to 650 liters/sec. of air. As may be appreciated, such units are comparatively large and complex devices and designed for pumping down large vacuum chambers and are adapted to be run over long operating cycles.

The nature of the turbomolecular pump is such that its effectiveness is quite dependent upon the ambient pressure to which it exhausts. Commonly, restrictions of an exhaust forepressure of 10^{-2} to 10^{-3} Torr are specified for the pump to reach its designed high vacuum capability. It should be immediately recognized that the specified low exhaust pressure thus requires a substantial forepumping by an auxiliary device. It is usual that oil-sealed rotating around pumps having a capacity of 100 to 200 liters are specified as forepumps adequate for turbomolecular installations.

There presently does not exist in the industry a relatively low cost, low volume, high vacuum pumping system adequate for intermittent duty cycling such as in scientific instrument applications. It is with the foregoing in mind that the present pump was invented.

In scientific instruments involving corpuscular beams, it is usual that evacuated chambers wherein these electron or ion beams are generated and directed upon a target, that backstreamed hydrocarbons can cause serious contamination within the chamber. Further, it is usual that the evacuated chamber is well sealed and of limited volume such that high capacity pumps are not required. However, it is also usual that the degree of evacuation required in many such scientific instruments is very high (eg. 10^{-9} Torr in the gun region of a field emission electron microscope). Thus, it must be recognized that a vacuum pumping system for such an instrument must be capable of producing high vacuum, while not necessarily being of great quantitative pumping capacity.

Further, in the case of a vacuum system suitable for a scientific instrument, the pump must be capable of reaching full operating characteristics in a relatively short time and over an often repeated duty cycle.

Thus, while the ultra-high vacuum capacity of turbomolecular pumps would seem to offer advantages to such as scientific instrument applications, their vast size and expense, as well as their dependence upon forepumps has led the industry to seek other alternatives, such as ion pumping and similar devices and to turn away from turbomolecular pumping. It was not until the present developments wherein the principles of turbomolecular pumps were combined with the characteristics of other pumping systems that an integral instrument of versatility and operability was provided to the scientific instrument industry.

SUMMARY OF THE INVENTION

In accordance with certain features of the invention there is herein presented a vacuum pumping system suitable for use in evacuating chambers such as exist in scientific instruments, and particularly electron microscopes. The vacuum system of the present invention is adapted to provide low vacuum pressures (in the order of 10^{-6} Torr or lower) from a single rotary device including principles of axial flow turbomolecular pumps. Included also in the integral device are a centrifugal compressor pumping means in combination with fluid diode means which together accomplish the objectives sought. Preferred embodiment includes also spiral molecular drag pumping means to further increase the effectiveness of the system.

DESCRIPTION OF THE DRAWINGS

FIG. **1** is a sectional view of the vacuum system according to the invention.

FIG. **2*a*** is a front elevation of an axial flow rotary stage included in the invention.

FIG. **2*b*** is a sectional view of the rotor of FIG. **2*a***.

FIG. **2*c*** is a plan view showing arrangement of several rotors and stators of the axial flow turbomolecular pumping stage of the invention.

FIG. **2*d*** is a front elevational view of a stator of the axial flow turbomolecular pumping stage of the invention.

FIG. **2*e*** is a sectional view of the stator of FIG. **2*d***.

FIG. **3*a*** is a front elevational view of a stator of the spiral molecular drag pumping stage of the invention.

FIG. **3*b*** is a sectional view of the stator of FIG. **3*a***.

FIG. **4*a*** is a front elevational view of a rotor incorporated in several pumping stages of the invention.

FIG. **4*b*** is a sectional view of the rotor of FIG. **4*a***.

FIG. **4*c*** is a front elevational view of a stator of the centrifugal compressor pumping stage of the invention.

FIG. **4*d*** is a partial sectional view of the stator of FIG. **4*c***.

FIG. **4*e*** is a partial sectional view of the elements of FIGS. **4*a–d*** in assembled relation.

FIG. **5*a*** is a rear elevational view of a stator of the vortex diode stage of the invention.

FIG. **5*b*** is a front elevation of the stator of FIG. **5*a***.

FIG. **5*c*** is a partial sectional view of the stator of FIGS. **5*a*** and **5*b***.

FIG. **5*d*** is a partial sectional view of the elements of FIGS. **5*a–c*** in assembled relation.

FIGS. **6*a*** and **6*b*** are respectively side and front elevations of the main housing for the pump of the present invention.

FIG. **7** is an exploded view of the turbine and exhaust members of the invention of FIG. **1.**

DESCRIPTION OF A PREFERRED EMBODIMENT

Referring now to the drawings and to FIG. **1** in particular, reference numeral **10** indicates generally the vacuum pump of the present invention. Included are housing **12** being generally cylindrical in shape and enclosing the working section of the pump, later described. Housing **12** includes inlet **14** adapted to be directly connected, in sealed relation, to a chamber to be evacuated (not shown) but understood to be such as the housing of an emission gun of an electron microscope. Disposed (flowwise) at the opposite end of the housing is outlet **16,** which in the present invention, exhausts to atmosphere.

Housing **12** also includes an inlet **18** for a drive turbine **20** (later described) and an associated exhaust outlet **22** therefor. Drive turbine **20** in the described embodiment is fixedly secured on shaft **24** which extends axially with housing **12** being disposed in bearing means **26** adapted for rotary motion.

It should be understood that as to the description of the preferred embodiment thus far, as well as that subsequent, pump **10** is symmetric left to right about central axis I—I. The pump section extending from center line I—I to I′—I′ includes alternate rotor elements **28** and stator elements **30** (as further illustrated in FIGS. **2***a* through **2***e*), being of the type the coaction of which, produces axial flow turbomolecular pumping. This section indicated by the bracket at **32,** and in the preferred embodiment, includes eight sections. These sections are arranged alternately being in the order of rotor section **28** and stator section **30,** which additionally are adapted to operate in the range of low pressure of 10^{-6} Torr or less. The determination of physical characteristics of the elements for operation at this range may be determined from reference to treatises on the art of molecular drag pumps.

Adjacent the axial flow, turbomolecular stage **32** is an axial flow centrifugal compressor section **34.** Centrifugal stage **34** is composed of, alternately, rotor elements **36** (such as the illustrated impeller) and stator elements **38** (such as the illustrated diffuser element). The above elements are further illustrated in FIGS. **4***a* through **4***e*. Centrifugal compressor stage **34** includes eight elements in the illustrated embodiment and is adapted to operate in the pressure range from atmospheric to about 10^{-2} Torr thus providing an advantageous operating environment for the turbomolecular stage **32.**

In the illustrated embodiment, an additional molecular pumping stage **40** is shown. This stage is of the spiral drag type and is disposed intermediate the axial flow turbomolecular stage **32** and the centrifugal compressor section **34.** This spiral drag stage includes alternating rotor elements, as impellers **42** which may be similar to the type illustrated in FIGS. **4***a* and **4***b* and such stator elements as spiral drag plates **44,** further illustrated in FIGS. **3***a* and **3***b*. The spiral drag stage is preferably disposed in the pump of the present invention since it provides a further isolation of the very low pressure axial flow turbomolecular stage **32** and the centrifugal compressor **34,** thus enhancing the function of the turbomolecular stage **32.**

It is a characteristic of such spiral drag pumps that they are capable of molecular pumping to low pressures, yet are less dependent upon a low fore pressure than axial flow turbomolecular pumps to provide effective pumping. Thus it may be seen that a spiral drag stage interposed between an axial flow stage and a centrifugal compressor stage provides an effective low pressure exhaust for axial flow stage **32** during normal operation and effective pumping during start up when centrifugal compressor **34** has not yet reached peak capacity.

The final stage disposed on shaft **24** in the illustrated embodiment is vortex diode stage **46.** This stage includes rotary impellers **48** alternately disposed with stator **50** (further illustrated in FIGS. **5***a* through **5***d*). One of the important considerations in the providing of an efficient pump is the minimization of input power or motive force when the apparatus is at normal operating condition. This is a particularly important requirement in pumps which must operate at very high rotary speeds as those which include molecular drag pumping stages. It has been recognized that, at normal operating condition, little work load is imposed on the molecular drag system since the volume of pumping is small with the well sealed chamber at high vacuum. The bulk of the pumping load has been recognized as being borne by the centrifugal section in the recirculation of fluid due to leakage losses and the like. Effectiveness of the present combination of stages is increased by the inclusion of a vortex diode stage which, by virtue of the exhausting flow, markedly increases the impedance for backflow, and thus improves the pressure ratio capabilities of the pumping sections preceding it. It is believed the inclusion of the vortex diode stage **46** also improves the start up performance of the present invention by further enhancing the pressure ratio performance of the centrifugal compressor during the high flow, initial evacuation of the pump housing and chamber to which it is attached.

Disposed on shaft **24** at opposite ends of pump **10** and adjacent exhaust parts **16** and **22** is drive turbine **20,** which in the preferred embodiment illustrated provides the motive power for shaft **24** and the plurality of various stage elements. In the application of vacuum pumps in scientific instruments, electrical motors and/or heavy gear drive trains may induce detrimental operational interferences. In the case of electrical motors (a common drive for rotary vacuum pumps), stray fields often cause serious internal interferences in instruments utilizing electron or ion probes. Likewise, the gear coupling utilized to drive rotors as from electro motors may introduce substantial vibrations which further degrade scientific instrument performance. This is particularly true for instruments wherein optical or electro-optical observations are being made. With the foregoing in mind, it has been decided to power the described embodiment by an integral air turbine, fixedly secured to the main shaft **24** of the pump. Low pressure compressed air is commonly available in installations where scientific instruments are used and the inclusion of a rotary, symmetrical drive has been found as an advantageous motive source. In the instant apparatus, compressed air is impressed upon the periphery of the air turbine wheel **22** from a central supply through inlet port **18.** The air is dumped into ring **18***a* and from there delivered to nozzles **19** (FIG. 7), and expanded, inwardly toward the shaft **24** and exhausted centrally of shaft **24.** Once expanded through the turbine blades **20***a*, the air is collected in exhaust ring **22***a*, exhausted through ports **22***b* to final exhaust port **22.**

Referring now to FIGS. **2***a* and **2***b*, the axial flow rotor elements **28** and axial flow stator elements **30** of axial flow turbomolecular stage **32** will be described. FIG. **2***a* shows front and side elevations of a rotor stage **28.** Rotor **28** includes blades **52** disposed in equal spacing circumferentially around hub **54.** Blades **52** are inclined at an angle A with respect to the axis of rotation depending upon the relative position in element sequence. It is customary in the art that blade angle A be large (50°) adjacent the inlet and be progressively decreased toward the pump exhaust (to, typically 10 to 20 degrees). FIG. **2***c* illustrates the typical relative relationship of successive elements **28** and **30.** Referring again to element **28** of FIG. **2***a*, hub **54** includes a base **56** to receive rotor **24** and to be fixedly secured thereto. Hub **54** has a thickness coordinated with the lateral extent of blades **52** and stator section **30** to accommodate blades **60** of stator **30.**

Referring to FIGS. **2***d* and **2***e*, stator **30** has blades **60** disposed in retaining ring **62.** Rings **62** are adapted to be fixedly received in housing **12** (FIG. **1**) in side-by-side relationship, with blades **60** registered in association with blades **52** and collectively forming the axial flow turbomolecular pumping stage **32.**

Referring now to FIGS. **3***a* and **3***b*, reference number **44** indicates the spiral drag stator for stage **40** immediately following the axial flow stage **32.** Stator is adapted with Archimedic spiral grooves **64**, which decrease in depth from center base **66** outwardly consistent with known principles. First stator **44'** is disposed adjacent the last stator **30** of stage **32,** as illustrated in FIG. **1,** being operationally associated with a disc impeller **42.** A second drag stator **44''** is disposed adjacent stator **42,** and adapted with grooves **64** spiralling inwardly, toward the center of the stage. Grooves **64** of second stator **44''** also decrease in depth, but from the periphery toward the center bore **66.** This decrease in depth of channel is generally in the direction of fluid flow.

As illustrated at **43** a combination of centrifugal compressor pumping and spiral drag may be employed in conjunction. The impeller **36** at **43** may be of the type illustrated in FIG. **4***a* wherein the rotational element is a disc including radial grooves **68** extending from a collection area **70** outwardly toward the periphery of the element. Vanes **72** are advantageously disposed centrally of the grooves **68** to enhance the centrifugal pumping. Rotor element **36** includes a bore, and is adapted to be fixedly secured to shaft **24.** As will be noted in FIG. **4***a*, the back side **74** of rotor **36** is non-grooved, as presents a disc rotor aspect. A spiral drag stator may be disposed adjacent the side **74** of rotor **36** and provide spiral drag pumping centrally toward the center of the pump (toward shaft **24**) where the stage is exhausted to a subsequent centrifugal compressor rotor **36.**

Alternatively, or in combination, centrifugal compressor stage **34** may include diffuser stators **38** interposed between impellers **36.** FIGS. **4***c* and **4***d* illustrate a preferred diffuser stator **38** wherein a cylindrical cutout **76** accommodates the disc portion **74** of impeller **36.** Disposed circularly adjacent the periphery of stator **36** are a plurality of collector slots **78** communicating with the collector side of stator **38.** Collector side **80** includes radially inwardly disposed channels **82** to exhaust the fluid pumped by impeller **36** to the collector area **70** of the subsequent centrifugal impeller. A spacer **84** provides additional spacing between stators **38** to accommodate successive rotors **36.** A cover plate **86** provides complete isolation for collector channels **82.** FIG. **4***c* illustrates the assembled relationship of rotor **36** and stator **38.**

The final operating stage, the vortex diode stage **46,** is illustrated in greater detail in FIGS. **5***a* through **5***d*. Diode stator **50** is adapted with a cylindrical relief **88** similar to that of **76** in the centrifugal pumping stage stator. Projecting outwardly from relief **88,** in a direction generally tangential thereto, are diffuser grooves **90** which terminate in a collector bore **92** extending through to the exhaust side of stator **50.** Bores **92** terminate in a collector basin **94,** wherein a walled section **96** of bore **90** extends well into collector basin **94.** Extending inwardly toward the center of stator **50** and from basin **94** are channels **98** which terminate in an exhaust pool **100,** which discharge to the next subsequent impeller **50.** Impellers **48** in the illustrated embodiment are similar to centrifugal impellers **36.** Upon exiting the final diode stage stator **50** at exhaust pool **106,** channels **104** (FIG. **1**) communicate with exhaust part **16,** (see also FIG. **7**).

Typically, a pump made accordingly to the present invention comprises the axial flow stage, a centrifugal compressor stage and a vortex diode stage. Preferred embodiments may include one or more of the varieties of spiral drag stages heretofore described. The number of stators and rotors may vary accordingly to the load or final pressure to be achieved. Typically, eight axial flow elements are used, seven centrifugal compressor elements, two to four spiral drag elements and two vortex diode stages.

It is to be recognized that angles, dimensions, and numbers of specific elements may be adjusted for particular performance characteristics; however, such variations from the specific illustrations herein are deemed to be within the spirit and scope of the invention subsequently claimed.

What is claimed is:

1. An integral vacuum pump for evacuating a fluid, such as air, from a sealed chamber as in a scientific instrument of the type of an electron microscope comprising:

a housing having an inlet to be connected in sealed relation to said chamber and an exhaust at an opposite end thereof;

a shaft axially disposed in said housing;

motor means for providing rotary motion to said shaft;

axial flow turbomolecular pumping means disposed in said housing, adjacent said inlet, and alternately including stators fixedly secured to said housing and rotors fixedly secured to said shaft, said rotors being in juxtaposed relation to said stators to provide turbomolecular pumping;

centrifugal compressor pumping means disposed in said housing intermediate said axial flow turbomolecular pumping means and said exhaust, including stators fixedly secured to said housing and rotor fixedly secured to said shaft, said rotors being in juxtaposed relation to said stators to provide centrifugal compressor pumping;

fluid diode pumping means disposed in said housing intermediate said centrifugal compressor pumping means and said exhaust including stators fixedly secured to said housing and rotors fixedly secured to said shaft, said rotors being in juxtaposed relation to said stators.

2. A vacuum pump according to claim **1** including spiral molecular drag pumping means disposed intermediate said axial flow molecular drag pumping means and said centrifugal compressor pumping means.

3. A vacuum pump according to claim **1** wherein said motor means is a turbine.

4. A vacuum pump according to claim **1** wherein said fluid diode pumping means is a fluidic vortex diode.

* * * * *