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3,306,375

HIGH-SPEED HANDPIECE

Original Filed June 16, 1960

2 Sheets-Sheet 1

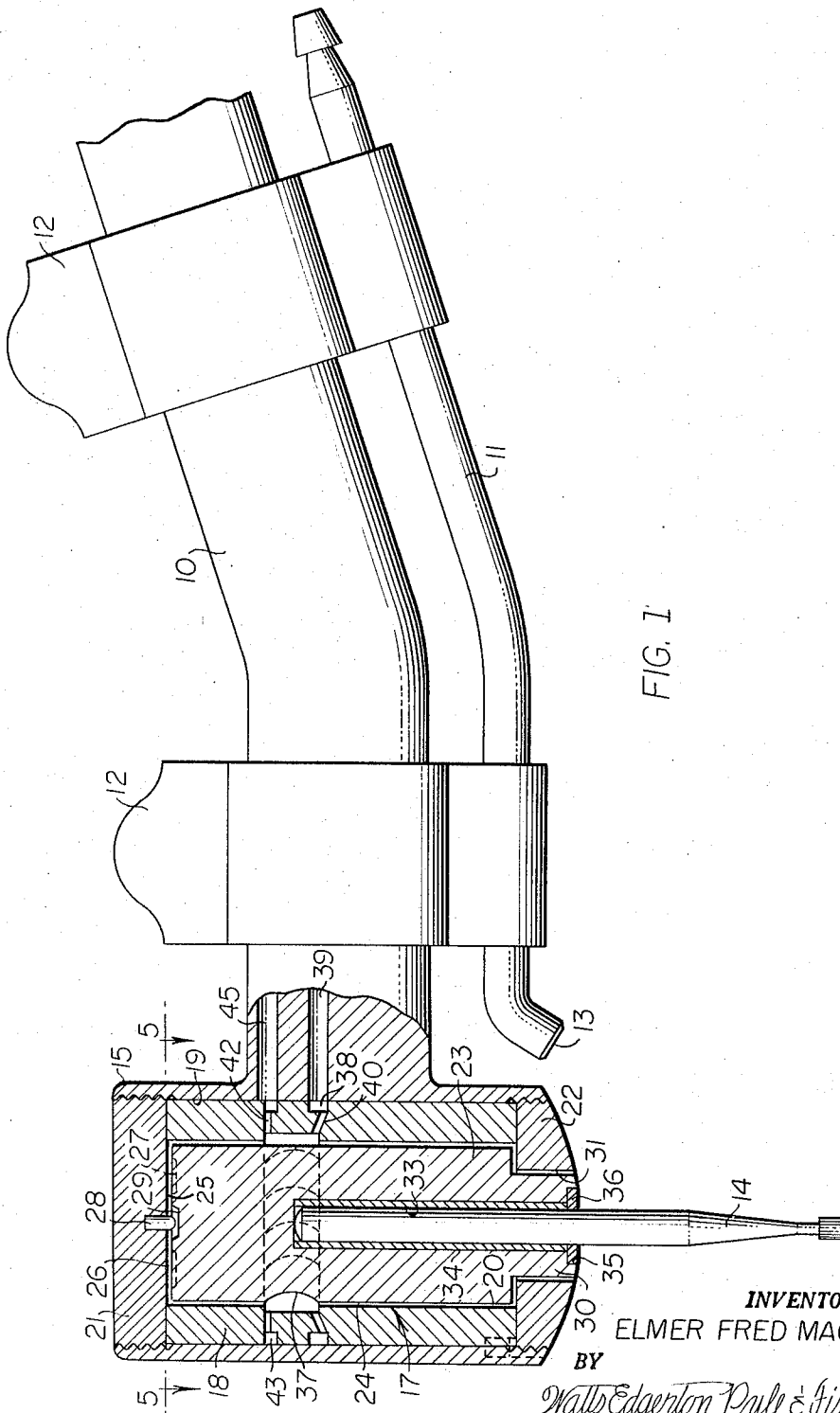


FIG. 1.

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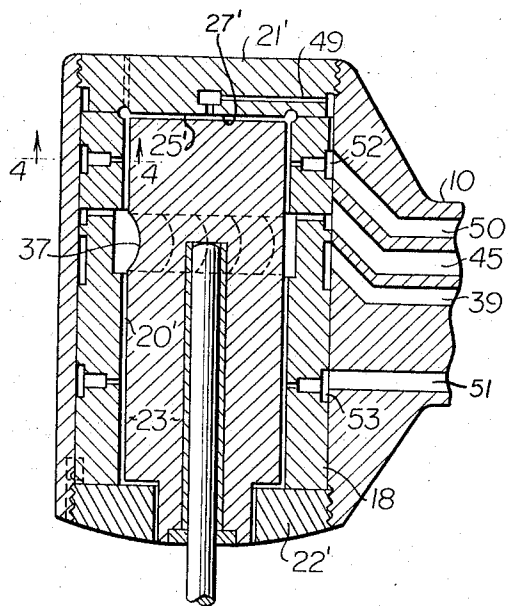


FIG. 2

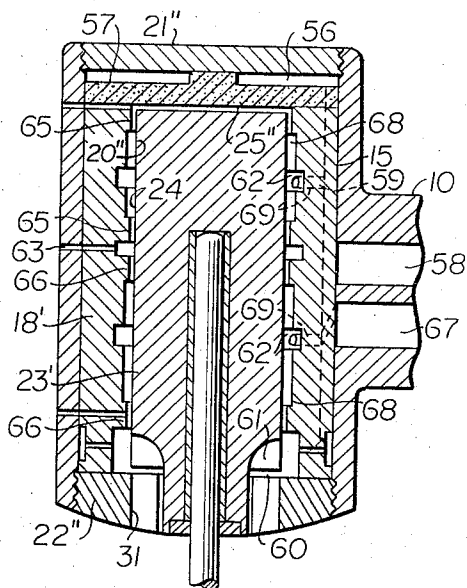


FIG. 3

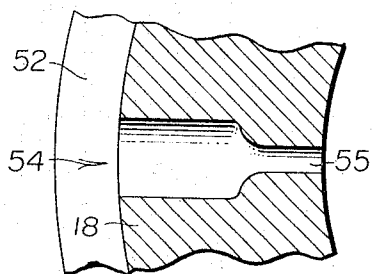


FIG. 4

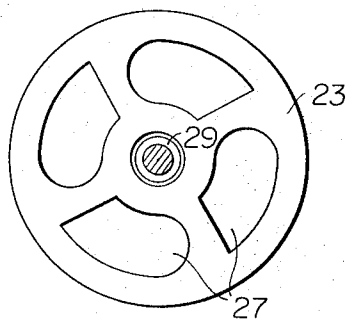


FIG. 5

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HIGH-SPEED HANDPIECE

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Continuation of application Ser. No. 36,513, June 16, 1960. This application Jan. 9, 1964, Ser. No. 338,282
19 Claims. (Cl. 173-59)

This application is a continuation of application Serial No. 36,513 filed June 16, 1960, under the title, High-Speed Handpiece and now abandoned.

This invention pertains to cutting tool holders and more particularly to a very high speed simplified drive and holder for grinding and drilling burrs and the like.

In many cutting operations such as industrial and dental drilling, burr removing, grinding, and the like, it is desirable to have a very small, compact high speed tool holder. The present invention pertains to a tool holder for such functions which operates at up to 500,000 r.p.m.

The provision of a tool for operation at such speeds creates a number of difficult problems. Among these is that it is difficult and in fact practically impossible, with present techniques, to manufacture a rotating assembly that is dynamically balanced at these speeds. Other problems are encountered because of the extremely close tolerances required. Maintaining the assembly free of dirt is difficult. Further, service of such a mechanism is also difficult because of the contamination problem. In such applications as dentistry the unit must be sterilizable.

With the present invention all of these difficulties and others are overcome through the provision of a compact, integrated unit which incorporates gas-film lubricating means to carry both radial and thrust load and which, in its preferred form, incorporates an air-driven rotor to impart the torque and speeds required for these operations.

Accordingly, one of the principal objects of this invention is to provide a novel and improved high speed tool holder which is an integrated assembly which incorporates gas-film lubrication as a part of the assembly.

Another object of this invention is to provide an improved high-speed tool holding assembly which is smooth and quiet in operation, has long life and great reliability, and which at the same time is safe to operate.

A further object of this invention is to provide a novel and improved gas-film supported rotor assembly which is driven by an air-turbine to provide a mechanism which will slip when some obstacle is encountered, thereby preventing damage to the mechanism or the work.

An additional object of this invention is to provide a novel and improved gas-lubricated tool-holding rotor assembly which eliminates the need for supplying oil or other lubricants and at the same time provides a unit which is readily sterilizable.

An additional object of this invention is to provide a novel and improved light-weight, compact unit which has improved efficiency of operation, affords greater life for burrs and other cutting tools, and which is simple to operate.

Still another object of this invention is to provide a novel and improved tool which, when used as a dental tool holder, affords greater patient comfort than prior known dental hand pieces.

Other objects and a fuller understanding of the invention may be had by referring to the following description and claims, taken in conjunction with the accompanying drawings, in which:

FIGURE 1 is a foreshortened sectional view of one of the novel and improved hand-piece embodiments of the invention showing the head thereof in section;

FIGURE 2 is a sectional view of an alternate construction of one of the novel and improved heads;

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FIGURE 3 is a sectional view of another modified construction;

FIGURE 4 is a fragmentary enlarged sectional view of an orifice incorporated in the modification of FIGURE 2 as seen from the plane indicated by the line 4-4 of FIGURE 2; and,

FIGURE 5 is a sectional view of the device as seen from the plane indicated by the line 5-5 of FIGURE 1.

Referring now to the drawings, and to FIGURE 1 in particular, a handle of a hand piece is shown generally at 10. As environment, and to show one application of the invention, the disclosed hand piece is a dental hand piece. In this application a coolant tube 11 is secured by clips 12 to the handle 10. The coolant tube 11 has a spray orifice at 13 for emitting a finely atomized water spray on the head of a dental burr 14. It will be recognized that the coolant tube 11 could be contained within the handle 10.

A head 15 is disposed transversely of and secured to the end of the handle 10. As will be described in greater detail below, the head 15 houses a tool spindle 17 which supports and drives the burr, or other cutting tool, 14.

In the embodiment of FIGURE 1, a tubular housing sleeve 18 is positioned within a bore 19 formed by the head 15. The housing sleeve 18 has a through cylindrically contoured inner bore 20. The bore 20 is closed at its upper end by a disc-like thrust end cap 21 which is threaded into the head 15. An annular lower end cap 22 is threaded into the head 15 adjacent the other end of the housing bore 20 to partially close the other end.

The spindle 17 includes a cylindrically contoured bearing portion 23 which is disposed within and substantially fills the housing sleeve 18. The bearing portion 23 includes a cylindrically contoured outer surface 24. Surfaces 20, 24 are complementary and closely spaced with a diametral clearance in the neighborhood of 0.0002 inch where the bearing portion has a diameter of 1/4 to 1/8 inch.

In the mechanism of FIGURE 1, the surfaces 20, 24 coact to define a pneumodynamic bearing therebetween. A pneumodynamic bearing is a gas bearing of the type in which the load carrying film is generated by the coaction of the two surfaces upon relative rotation.

End thrust loads imposed by the cutting tool 14 in either direction are absorbed by a thrust bearing at the inner end of the bearing portion 23. Because there is a relatively small quantity of air trapped between the cap 21 and the spindle, suction inhibits outward movement of the spindle. A gas bearing which absorbs thrust loads imposed in an inward direction is defined by the coaction of an inner surface 25 of the end cap or wall 21 and end surface 26 of the bearing portion 23. One of the surfaces 25, 26, the surface 26 of FIGURE 1, has a plurality of stepped convergent recesses 27 formed therein to provide the thrust load carrying ability of the thrust bearing. These recesses may be reversible or one of the other types disclosed in greater detail in my copending application for patent, Serial No. 594,026, filed June 26, 1956, and entitled, "Fluid Dynamic Bearing and Method of Making Same," now Patent No. 2,996,340, issued August 15, 1961.

As a protection against shock thrust loads which may well be encountered in drilling operations, a pivot overload pin 28 is carried by the end cap 21 and disposed along the axis of the head 15. A recess 29 is formed in the end of the bearing portion 23 to coact with the pivot overload pin 28. Normally the gas thrust-load carrying film generated between the surfaces 25, 26 will maintain sufficient spacing to keep the pivot overload pin 28 and the base of the recess 29 out of contact. However, when shock loads are imposed on the tool 14 the coaction of

the pivot pin and recess 28, 29 will prevent contact of the surfaces 25, 26.

The spindle 17 includes a shank portion 30 which is of reduced diameter with respect to the bearing portion 23 and which is offset with respect to the bearing portion 23. The shank portion 30 projects into an aperture 31 in the annular lower end cap 22. The space between the shank portion 30 and walls of the aperture 21 provides an annular air passage for escaping air. This escaping air blows any foreign particles away from the shank and keeps dirt from entering the bearing regions.

A tool support bore 33 is provided which extends from the shank portion inwardly into the bearing portion. A tubular tool holding sleeve 34 is positioned in the tool-holding bore 33. This sleeve may be formed of a variety of materials to serve as a chuck for the bit. Polyethylene is the material which is preferred for this application.

The bore 33 is counterbored at 35. An annular centering collar 36 is disposed in the counterbore 35 to prevent lateral displacement of the shank of the cutting tool 14 and thereby inhibit bearing whirl in the front or lower portion of the bearing.

In the embodiment of FIGURE 1 the spindle 17 includes a plurality of recesses in the form of turbine blades 37. An annular drive manifold 38 is formed in the periphery of the housing sleeve 18. The handle 10 has an air inlet passage 39 which supplies the drive manifold 38. Air passes from the drive manifold 38 through one or more jets 40 which direct pressurized air onto the turbine blades 37 to cause rotation. Outlet passages are provided at 42 which communicate with an exhaust manifold 43, also formed in the periphery of the housing sleeve 18. An air outlet passage 45 is provided in the handle 10 to conduct exhaust turbine air from the exhaust manifold 43.

In the embodiment of FIGURE 1 the entire rotating assembly is supported by pneumodynamic (or self-acting) gas-film lubrication. The gas used to drive the turbine and thus provide the ambient environment for the pneumodynamic bearings may be air, or an inert gas such as nitrogen may be used. An inert gas may be desirable in certain dental, medical or industrial applications to inhibit oxidation.

The embodiment of FIGURE 1 may utilize the features described below and in my copending application for patent Serial No. 786,856, filed January 14, 1959, entitled "Non-Contacting Dirt Seal" now Patent No. 3,121,179, issued February 11, 1964, and the teachings of the other patents and applications referenced there.

The structure which permits practical and economic use of the gas-film lubrication embodies unit bearing support surfaces which are part of the mechanism, as opposed to two or more individual bearings. Such unit support surfaces are employed for radial loads thus eliminating alignment problems and minimizing assembly, manufacturing and cost problems associated with the close tolerances of gas-film lubricating mechanisms. The integral-unit, gas-film bearing surface structure also permits increased reliability and facilitates frequent disassembly and assembly as might be required for sterilization in dental and medical applications.

Speeds from 50,000 r.p.m. to 500,000 r.p.m. are useful depending upon the diameter and type of cutting, grinding, or drilling tool employed. The speed is adjusted by controlling the turbine drive-air pressure. Pneumodynamic bearing instabilities may be inhibited over a wide speed range by incorporating stabilizing concepts already well known, for example a bleed to atmosphere from the gas-lubrication film in the form of a small hole in the low pressure circumferential region of the bearing (0.0001 inch deep) or by providing recesses in the bearing surfaces. Such surfaces are then referred to as "anti-whirl" pneumodynamic bearing surfaces and permit stable operation over wide speed ranges.

In FIGURE 2 the construction is slightly modified to provide one form of pneumostatic journal bearing. Here a pair of bearing gas inlet passages 50, 51 are formed in the handle 10. The passages 50, 51 communicate respectively with the annular bearing manifolds 52, 53 formed in the periphery of the housing sleeve 18. A plurality of orifice compensated passages connect the bearing manifolds 52, 53 with the interior bore 20 of the housing sleeve 18. Typically there may be six metering orifice passages connecting each bearing manifold to the interior of the bore. These metering orifice passages meter the flow of air from manifolds 52, 53 to the interior of the housing sleeve 18. The details of one such passage are shown at 54 in FIGURE 4. An orifice of 0.006 inch in diameter and about 0.010 inch in length is provided at 55 for a spindle diameter of $\frac{3}{8}$ -inch and a diametral clearance of 0.0002 inch. For somewhat greater load capacity the several orifices may each fill a very shallow recess—see copending application Serial No. 580,133, filed April 23, 1956, and entitled "Fluid Supporting Rotor" now Patent 3,004,180 issued October 10, 1961.

The orifice compensation principle is now well known in the art as one of several forms of fluid compensation. With any of several forms of fluid compensation, the flow of fluid through a foraminous wall is metered by restricting passages. Since the passages restrict the flow of fluid, there is little obstruction to the fluid flow from the passage. When an object is in close confrontation with the outlet, as when the spindle 17 moves close to one of these orifices, the restriction reduces the rate of flow and therefore immediately reduces the pressure drop. This reduction in pressure drop causes an increase in the pressure of the film to inherently support the bearing loads.

In FIGURE 2 a novel gas thrust bearing is shown. Here the opposing bearing surfaces 25', 27' on the cap 21' and the spindle 17' are both flat and smooth. The bearing surfaces are separated by a film of gas from the single-face thrust bearing, even though thrust loads are in both directions. This thrust bearing may be referred to as a single-face, two-directional, compressible, viscous, fluid thrust bearing which operates on the Bernoulli principle. If the total axial clearance is limited to approximately 0.001 to 0.002 inch (depending on the size of the spindle) then the single-face thrust bearing will provide load carrying capacity in both axial directions. With a plus thrust load, that is, one urging the surfaces toward one another, a positive pressure develops in the gas lubricating film. With a negative thrust load, that is, one tending to separate the surfaces 25', 27', a negative pressure (or suction) develops which serves to support the reversed load. The combined action develops from the change in velocity of the gas flowing through the load carrying film.

Air under pressure is supplied to the region between the surfaces through one or more orifices 48. Air is supplied to the orifices 48 through a passage 49 which is connected to the manifold 32. As an example with a 1.555 square inch area (a larger application) at 100 p.s.i. inlet air pressure the suction is $3\frac{3}{4}$ pounds using number 64 jets and $4\frac{1}{2}$ pounds using number 56 jets; however, approximately the same positive thrust load is developed in each case. In the smaller applications, negative and positive thrust loads of several ounces in each direction result at speeds from 0 to several hundred thousand r.p.m. with air inlet pressures below 100 p.s.i.

In FIGURE 3 a form of combined pneumostatic-pneumodynamic radial bearing is shown. The bearing type illustrated is referred to as a "modified-step" bearing. In the surface 20" spaced annular recesses 68 are provided. The recesses 54 extend around the entire circumference and communicate with gas inlet passage 59 through orifices 69 and circumferential grooves 62. The depth of the recesses is of the order of one-half the diametral clearance. In the case of a $\frac{3}{8}$ -inch diameter spindle with a diametral clearance of 0.0002 inch, the recess depth is of the order

of 0.0001 inch. The width of the circumferential groove 62 may be varied and in fact determines the maximum load-carrying capacity as does the step length between recesses which for the foregoing application is of the order of $\frac{1}{16}$ -inch and 0.050 inch length at 65, 66 respectively. A bleed passage 63 to the atmosphere may be employed to provide load stability. Pressurized fluid is directed to the journal bearing as well as the thrust bearing through conduit 58, while pressurized fluid for turbine-drive purposes is directed through conduit 67. A common inlet conduit may be employed for those applications where bearing support and turbine drive fluid pressures are matched.

In FIGURE 3 another form of fluid compensation is shown for the thrust bearing. There the end cap 21' includes a thrust bearing supply pressure chamber 56. A foraminous disc such as a sintered metal plate 57 permits a limited flow of air from the chamber 56 to the thrust bearing surface 25'. Air is supplied to the chamber 56 through an air inlet passage 58 in the handle 10 which communicates with the chamber 56 through the passage 59. The passage 59 is provided by forming a groove in the peripheral surface of the housing sleeve 18'.

In the embodiment of FIGURE 3 another refinement is shown. Here instead of forming the turbine blades at a location intermediate the ends of the bearing portion 23, the turbine blades are formed adjacent outer end 60 of the bearing portion 23'. In this embodiment the turbine blades are designated by the numeral 61. It will be seen that the blades 61, like turbine blades 37, are disposed within the contour generated by the bearing portion 23. Thus, though the turbine blades 37 separate the journal bearing of FIGURE 1 into two sections, they have, in effect, the simplicity of construction of the unit bearing design of FIGURE 3. In either instance, the complementary surfaces 20, 24 are each machined in a single operation, eliminating any need for alignment of journal bearings as is the more conventional construction. It is for this reason that the preceding discussions have often referred to the journal bearing sections of FIGURE 1 as if they were one. For manufacturing and assembly purposes, the surfaces are one.

In FIGURE 3 another refinement is provided in that the annular orifice defined by the aperture 31 and the shank portion 30 is rather large to accommodate the exhaust air from the turbine. A portion of this exhaust air may be bled back through the handle if desired, by providing appropriate passages and restrictions.

In each of the described embodiments, it will be seen that all radial loads are carried by what is essentially a single or unit journal bearing. With this construction, alignment problems are eliminated and the entire rotating assembly is left free to rotate about its center of mass.

Because of the high speeds of operation which may go as high as 500,000 r.p.m. balancing is of course important, certain manufacturing errors in balance are compensated for by this unique design. The rotating assembly being permitted to rotate about its own center of mass may actually rotate about an axis which is spaced from, and distinct from its geometric axis. This freedom of rotation is believed to contribute greatly to the mitigation of bearing whirl which is characteristic in high-speed gas bearings. It is also believed to contribute to the vibration-free, quiet operation of this device.

While the invention has been described with a great deal of detail it essentially comprises a tool holder having a cylindrically contoured bore in a housing, a drive spindle in the bore and having a cylindrically contoured outer surface coacting with the bore to define a fluid journal bearing, other surfaces between the spindle and housing to define a fluid thrust bearing and means to cause high speed relative rotation of the spindle and the housing, the preferred lubricating and drive to be a gas.

Although the invention has been described in its pre-

ferred form with a certain degree of particularity, it is understood that the present disclosure of the preferred form has been made only by way of example and that numerous changes in the details of construction and the combination and arrangement of parts may be resorted to without departing from the spirit and the scope of the invention as hereinafter claimed.

What is claimed is:

1. An assembly for driving a cutting tool comprising, a housing having an internal surface defining a cavity, said housing surface including a cylindrical portion, said housing including first and second spaced end walls defining the ends of the cavity, said first end wall including a through bore in axial alignment and communicating with the cavity, a tool drive spindle adapted for a tool, said spindle having a spindle section substantially filling said cavity and a shank section projecting through said bore, said spindle section having a peripheral surface including a cylindrically contoured portion, said housing and said spindle cylindrical surface portions being complementary and spaced apart to define a radial load carrying gas bearing therebetween, said spindle having an end wall at the end opposite said shank section, said spindle end wall and said housing second end wall being complementary coacting thrust surfaces defining a gas thrust bearing therebetween, and said spindle and housing including coacting means to cause rotation of the spindle in the housing by gas under pressure, a portion of said shank section and said first end wall defining a space for directed escape of the gas under pressure therethrough to clear the area on which the tool is operating.

2. The device of claim 1 wherein the gas thrust bearing includes a mechanical pivot overload means disposed along the axis of said bore.

3. The device of claim 1 wherein at least one of said thrust surfaces includes a plurality of circumferentially disposed stepped convergences.

4. The device of claim 1 wherein means are provided to introduce gas under pressure into said cavity to maintain the internal cavity wall and spindle cylindrical surfaces in spaced relationship so that the radial bearing is pneumostatic.

5. The device of claim 1 wherein the radial bearing is pneumodynamic and the radial load carrying gas bearing film is produced upon relative rotation of the spindle and the cavity.

6. A cutting tool drive comprising, a housing member having a cylindrically contoured surface defining the wall of a bottomed bore, a drive spindle member having a bearing portion, said bearing portion having a cylindrically contoured circumferential surface and first and second ends, said bearing portion being disposed in and substantially filling said bore, said spindle member having a shank portion offset from the bearing portion and extending from said first end, an annular end cap surrounding said shank portion and overlying said first end, said cap being secured to said housing member to retain the members together, said cylindrical surfaces being smooth and spaced closely apart to define a radial load carrying gas bearing therebetween, said second end and the bottom of said bore having complementary transversely disposed surfaces defining a gas thrust bearing therebetween, said members including coacting means to cause relative rotation of the members, one of said members including at least one gas conducting passage, and said one member including fluid compensation means connecting the passage with the radial load carrying bearing.

7. A tool holder and drive assembly comprising, a housing having a smooth cylindrically contoured bore extending from a first end to a bottom at a second end, the housing having a plurality of air conducting jets disposed between the ends of the bore and in communication therewith, the housing also including a drive manifold, each of the jets being disposed transversely of the bore and extending from the manifold to the bore, the

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housing also including an air supply passage in communication with the manifold, a spindle having a cylindrically contoured bearing portion disposed in the bore and coacting with and spaced from the bore to define a radial load carrying air bearing therebetween, said bearing portion including a plurality of turbine blades in the peripheral surface thereof and aligned with said jets, said bearing portion having a transversely disposed inner end surface, the inner end surface and the bottom of said bore together defining an end load thrust bearing, said spindle including a reduced diameter shank extending from the outer end of the bearing portion, and an annular end cap surrounding the shank and secured to the housing, said cap overlying the shank and having an opening therein so that the bottom end of the shank communicates with the outside of said housing, said shank being formed to accept a tool.

8. The device of claim 7 wherein an exhaust manifold is adjacent the drive manifold and in communication with the interior of the bore, and wherein the housing includes an air outlet passage communicating with the outlet manifold.

9. The device of claim 7 wherein the turbine blades are within the contour generated by said spindle cylindrically contoured bearing portion, and wherein the turbine blades are spaced from the thrust bearing.

10. The device of claim 7 wherein the turbine blades are formed adjacent said outer end of said bearing portion.

11. A hand tool comprising, a handle having at least one through air passage therein terminating at an outlet at one end of the handle, a head secured to said handle end and having a bore therein transverse to said handle and in communication with each such air passage, a spindle in the bore and having a shank portion projecting therefrom, an end cap surrounding the shank portion and secured to the head to retain the spindle therein, said spindle and head including smooth cylindrically contoured surfaces defining a radial load air bearing therebetween, and said head and spindle having thrust surfaces disposed transversely to said bore at the inner end thereof and defining an air thrust bearing therebetween.

12. A tool holder comprising a handle, a body connected to the handle and having a through bore, said handle having at least one gas passage formed therein and communicating with the bore for supplying gas under pressure thereto, a sleeve having an inner surface defining at least segments of a cylindrical contour and at least one groove formed in its outer surface, said sleeve being disposed in said bore with each such groove communicating with one such passage, said sleeve including at least one through hole connecting each such groove with the inner surface of the sleeve, first and second end closure means covering the opposite ends of the bore, a spindle having first and second ends and a first portion disposed within the sleeve, said first portion having a peripheral surface complementary to and spaced from said sleeve inner surface to define a radial gas load carrying bearing therebetween, said spindle first end and said first end closure means having complementary surfaces defining a thrust bearing, the second end closure means being annular with a through opening, said spindle having a reduced diameter portion projecting into said second end closure means opening, and tool holding means carried by the spindle adjacent its second end.

13. A tool holder comprising a handle, a body connected to the handle and having a through cylindrical bore, said handle having at least one gas passage formed therein and communicating with the bore for supplying gas under pressure thereto, a tubular sleeve having an inner surface defining at least segments of a cylindrical contour and at least one groove formed in its outer surface, said sleeve being disposed in said bore with each such groove communicating with one such passage, said sleeve including a through hole connecting each such

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groove with the inner surface, first and second end closure means covering the opposite ends of the bore, a spindle having first and second ends and a cylindrically contoured portion disposed within the sleeve, said contoured portion being complementary to said sleeve inner surface and spaced therefrom to define a radial load carrying bearing, said spindle having a thrust surface at its first end normal to the axis of the contoured portion, said thrust surface and the inner surface of said first end closure means being complementary surfaces defining a gas thrust bearing, the second end closure means being annular with a through opening, said spindle having a reduced diameter circular portion in axial alignment with the contoured portion and projecting into said second end closure means opening, said second end closure means being spaced from the reduced diameter circular portion to define a gas escape passage therebetween which is in communication with the radial gas load carrying bearing, and tool holding means carried by the spindle adjacent its second end.

14. An assembly for driving a tool comprising a housing having at least one internal surface defining a substantially cylindrical cavity, said housing including first and second spaced end walls defining the ends of the cavity, said first end wall including a through bore, and a tool drive spindle adapted for carrying a tool, said spindle having a portion substantially filling said cavity and means for holding a cutting tool which extends through said through bore, said spindle portion also having a cylindrically contoured outer peripheral surface, said spindle and housing including coacting means to cause rotation of the spindle in the housing by the use of gas under pressure, said housing and said spindle cylindrical surfaces being complementary and spaced apart to define a radial load carrying gas bearing therebetween, a radial load carrying film of gas being dynamically produced by the relative rotation of said spindle and said housing, said spindle having an end wall at the end opposite said bore, said spindle end wall and said housing second end wall being complementary coacting thrust surfaces defining a gas thrust bearing therebetween, said gas thrust bearing also being dynamically produced during rotation of the spindle with respect to the housing.

15. In a high speed handpiece, the combination of:

- (a) a housing having surfaces defining a spindle receiving chamber;
- (b) a spindle in the chamber and having a projecting tool holding shank;
- (c) the spindle having surfaces complementary with the housing surfaces to define gas radial and thrust bearings;
- (d) said spindle having circumferentially spaced turbine blade surfaces formed therein;
- (e) said housing having a gas emitting jet aperture oriented to emit a rotation producing gas stream against said blade surfaces;
- (f) the housing also having a gas supply passage communicating with the jet aperture to supply gas under pressure for the stream;
- (g) an annular end cap secured to the housing and overlying portions of the spindle to maintain the spindle in the chamber; and,
- (h) said cap surrounding and being spaced from the shank to provide gas escape passage therebetween, said shank and cap being shaped to direct a flow of gas escaping through the gas escape passage against a tool carried by the spindle and against a workpiece.

16. The device of claim 15 wherein said jet is defined by a tubular sleeve and the sleeve is removable from the housing for sterilization when said annular end cap is removed.

17. In a high speed handpiece, the combination of:

- (a) a housing having a head with a through bore and a tubular sleeve within the bore, the sleeve having surfaces defining a spindle receiving chamber;

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- (b) a spindle in the chamber and having a projecting tool holding shank;
- (c) the spindle having surfaces complementary with the sleeve surfaces to define gas radial and thrust bearings; 5
- (d) said spindle having circumferentially spaced turbine blade surfaces formed therein;
- (e) said sleeve having an annular external manifold and a gas emitting jet aperture extending from the manifold into the chamber and oriented to emit a rotation producing gas stream against said blade surfaces; 10
- (f) the housing also having a gas supply passage communicating with the manifold to supply gas under pressure for the stream; 15
- (g) an annular end cap threaded into one end of the housing bore and overlying portions of the spindle and the sleeve to maintain the spindle and the sleeve in the chamber; and,
- (h) a second end cap threaded into the other end of the housing bore to maintain the spindle and sleeve in the bore. 20

18. The device of claim 1 wherein a compensated gas passage communicates with said housing and wall to provide gas under pressure to said thrust bearing and wherein said thrust bearing is bi-directional. 25

19. In an article of manufacture, the improvement comprising:

- (a) a housing member having a chamber closed at one end; 30

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- (b) a spindle member within the chamber;
- (c) said members having first complementary, cylindrical surfaces defining a radial load carrying gas bearing between said closed end and said other end, said radial gas bearing providing a gas flow inhibiting passage between the ends of the members;
- (d) rotation producing means operatively connected to the members to cause relative rotation therebetween;
- (e) said members having second complementary surfaces defining a bi-directional load carrying gas thrust bearing at said closed end; and,
- (f) one of the members including a fluid compensated passage communicating with said thrust bearing to supply gas under pressure to said thrust bearing.

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