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[33] **Japan**
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[50] Field of Search..... 32/3, 27;
308/9; 415/30, 49

[56] **References Cited**
UNITED STATES PATENTS
2,511,543 6/1950 Rawlings 253/3
3,255,527 6/1966 Staunt 253/2
3,304,051 2/1967 Calhoun 253/3
3,383,805 5/1968 Powell 253/3
3,386,702 6/1968 Krzysczuk 253/3

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[54] **APPARATUS FOR CONTROLLING THE**
ROTATION OF A HIGH-SPEED ROTATING
SPINDLE
6 Claims, 10 Drawing Figs.

[52] U.S. Cl..... 415/30,
32/27, 415/503, 415/49
[51] Int. Cl..... F01d 15/06,
A61c 1/10

ABSTRACT: An apparatus for controlling the rotation of a high-speed rotating spindle supported by gas bearings, the spindle being maintained in a floating state by a gas film interposed between the periphery thereof and the peripheries of the bearings and rotated by a gas turbine coaxially mounted therewith, the bearings and the turbine being driven by a gas which is supplied from one common supply source, including means for preventing the spindle from whirling.

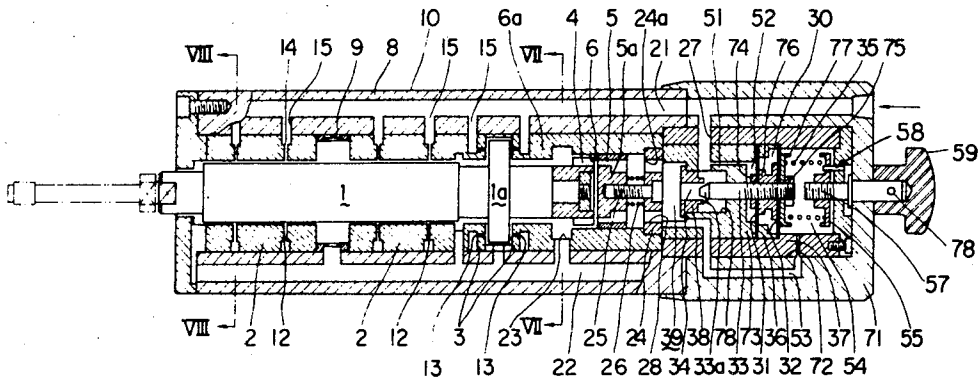


FIG. 3

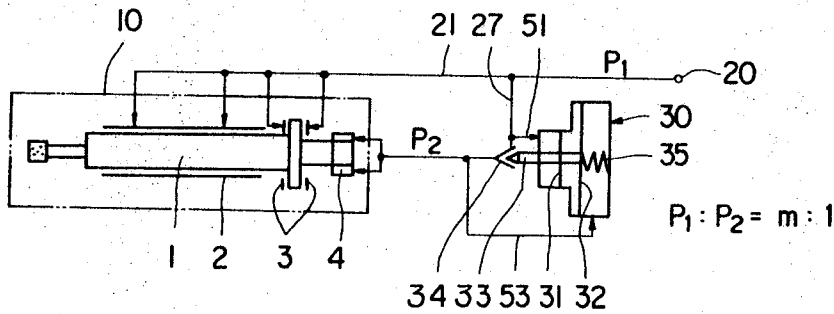


FIG. 4

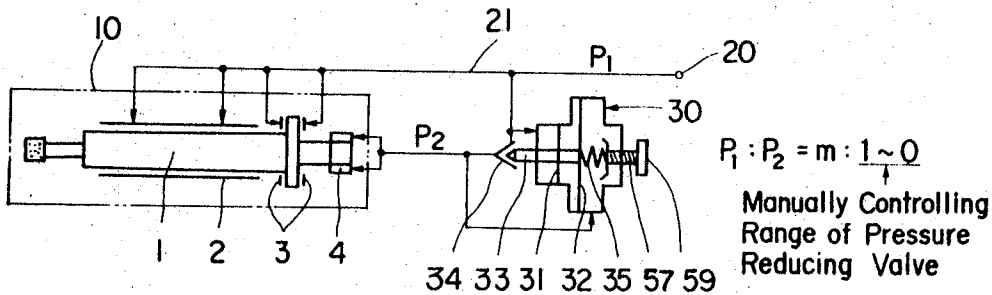
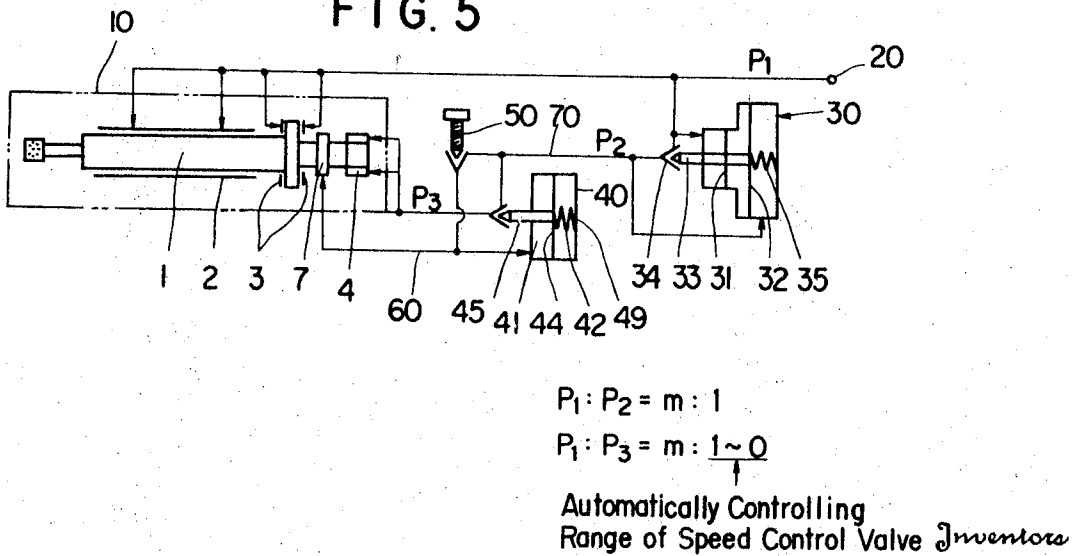


FIG. 5



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FIG. 9

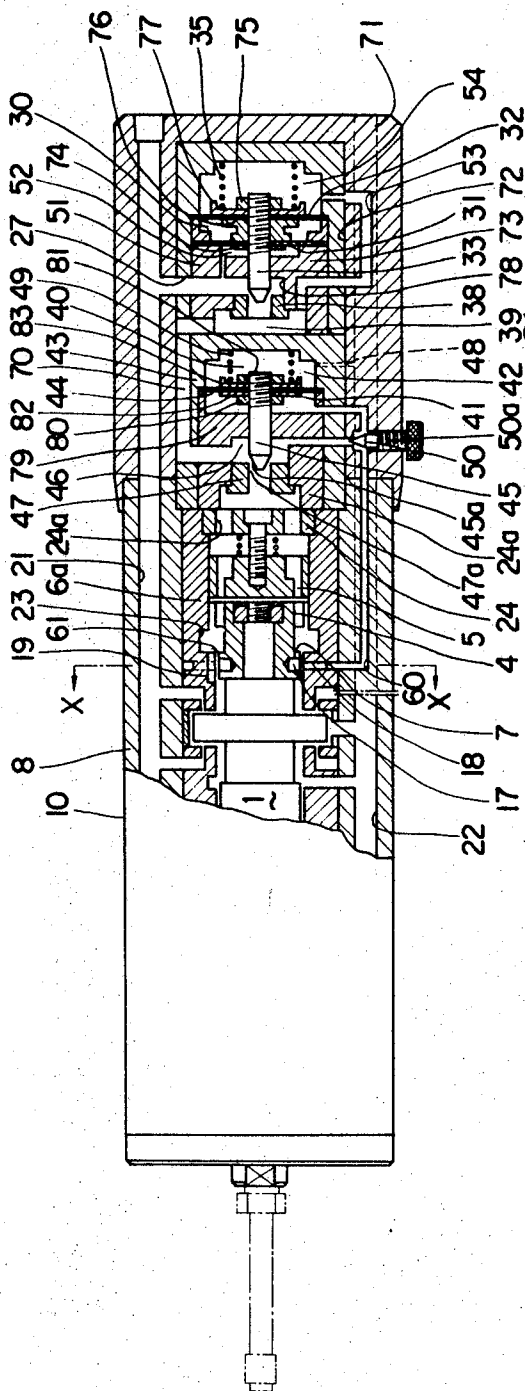
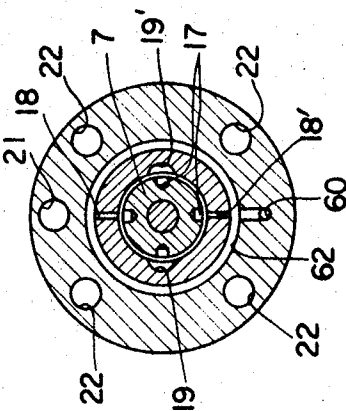


FIG. 10



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APPARATUS FOR CONTROLLING THE ROTATION OF A HIGH-SPEED ROTATING SPINDLE

BACKGROUND OF THE INVENTION

Generally speaking, in the high-speed rotation of a spindle for supporting tools and the like, it is common practice to provide the spindle with gas bearings, since such bearings possess extremely low frictional bearing characteristics and thereby afford an excellent bearing support for rotation of the spindle. It is also common practice to employ in high-speed rotation of this spindle provided with gas bearings a gas turbine drive which can produce a high revolution of the spindle.

For the purpose of driving both the gas bearings and the gas turbine it has been common practice to employ separate gas supply sources for supplying gas to the bearings and for supplying gas to the turbine. This is due to the fact that the gas pressure for driving the bearing is quite different from that utilized in driving the turbine. It is necessary for the bearings to be supplied with a gas of a relatively high pressure for maintaining proper and sufficient stiffness of the bearings, while for the turbine a gas in a relatively large quantity is needed but not one of a high pressure. Therefore, such prior art practices have conventionally operated at a disadvantage in that increased costs of construction, as well as operation and management, have occurred on account of the employment of separate installations of a gas source for a supply of high pressurized gas and a gas source for supply of low pressurized gas of a large volume.

Furthermore, the separate installation of gas supply sources has created an operational inconvenience in that it has required a troublesome adjustment of a pressurized gas supplied to the turbine for prevention of whirling of the rotating spindle.

If the spindle speed has increased high enough, the spindle which revolves on its axis whirls around at nearly half the speed of the rotation speed, thereby causing a whirling action of the spindle to take place, which will be described later. A whirling of the spindle causes initially an unstable rotation of the spindle and finally will result in serious failure in the apparatus due to frictional contact between the spindle and the bearings.

SUMMARY OF THE INVENTION

It is the general object of the present invention to provide an improved apparatus for controlling the rotation of a high-speed rotating spindle of the type which employs gas bearings maintaining the spindle in a floating state and which is driven by a gas turbine coaxially mounted with the spindle, with both the gas bearings and the gas turbine being operated by and from one common gas supply source, whereby the spindle is maintained free from any unstable movement.

Another object of the present invention is to provide an apparatus for controlling the rotation of a high-speed rotating spindle comprising gas bearings and a gas turbine both operated from a common gas supply source, and including at least one pressure reducing means for supplying the gas turbine with a gas at a lower pressure than that supplied to the bearings.

A further object of the present invention is to provide an apparatus for controlling the rotation of a high-speed rotating spindle which is simple in construction, easy in operation and relatively inexpensive to manufacture and maintain.

A still further object of the present invention is to provide an apparatus for controlling the rotation of a high-speed rotating spindle which is provided with means for protecting and preventing the bearing portion from a temperature rise by utilizing gas cooled by an adiabatic expansion through the gas turbine.

DESCRIPTION OF THE DRAWINGS

The foregoing and other objects of the present invention will become fully apparent from the following description of some preferred embodiments of the present invention with reference to the accompanying drawings, in which:

FIG. 1 is a schematic view of a path of an orbit of the spindle axis due to a whirling;

FIG. 2 is a diagram illustrating a critical limit to a whirling by way of showing a relation among pressures supplied to the gas bearings and the gas turbine and a rotating speed of the turbine;

FIGS. 3 through 5 inclusive are schematic views of different embodiments according to the present invention;

FIG. 6 is a cross-sectional view of a materialized structure of the second schematic embodiment of FIG. 4, the view being taken along the line VI-VI of FIG. 7;

FIG. 7 is a cross-sectional view taken along the line VII-VII of FIG. 6;

FIG. 8 is a cross-sectional view taken along the line VIII-VIII of FIG. 6;

FIG. 9 is a partially cutaway cross-sectional view of a materialized structure of the third schematic embodiment of FIG. 5; and

FIG. 10 is a cross-sectional view taken along the line X-X of FIG. 9.

DESCRIPTION OF THE INVENTION

Referring now to FIG. 1, a whirling of the spindle will be described. When the rotational speed of the spindle becomes so high, the rotating spindle tends to whirl around an equilibrium position E along an orbit having an eccentric radius e at nearly the speed of the axial rotation of the spindle ω . This condition will be hereinafter referred to as a "half-speed whirling" or simply a "whirling." Once the spindle axial rotation reaches a speed high enough to cause a half-speed whirling of the spindle, the rotation of the spindle falls into a critical state and thereafter in an unstable state. If the rotating speed is further increased, the amplitude of whirling of the spindle is increased rapidly until the spindle frictionally touches the bearings by shearing or breaking down the gas film interposed therebetween, with the result that it causes a serious failure or damage to the apparatus, such as bearing seizure. The half-speed whirling of the spindle occurs when the rotating speed of the spindle exceeds a certain critical speed as the onset-speed or the threshold speed of the half-speed whirling of the spindle. It was found that the onset-speed of the spindle largely depends upon the stiffness of the bearings, and accordingly that it increases or rises in accordance with an increased stiffness of the bearings.

A relation between stiffness of the bearings and the rotation speed of the turbine is shown in FIG. 2 by way of illustration of the relation between a gas pressure supplied to the bearings and a gas pressure supplied to the turbine. In FIG. 2, a curve A indicates the critical state of a half-speed whirling as a function of dimensionless numbers of the pressure supplied to the bearings and the number of the rotation of the turbine. The stable rotation of the spindle is generated below the curve A. The spindle rotation is extremely unstable above the curve A due to its half-speed whirling. The curve B indicates the spindle speed of rotation as a function of dimensionless numbers of the pressure supplied to the turbine.

The maximum pressure supplied to the turbine to the pressure supplied to the bearings is easily read from the diagram of FIG. 2. For instance, when P_1/P_0 as a factor of the pressure supplied to the bearings is set at 0.7, P_2 or P_3/P_e as a factor of the pressure supplied to the turbine reaches about 0.6 at the maximum, and N/N_0 as a factor of the turbine rotation speed falls about 0.9 at the maximum. P_e , P_0 and N_0 respectively represent constants as follows:

P_e : constant for the pressure supplied to the turbine P_2 or P_3

P_0 : constant for the pressure supplied to the bearings P_1

N_0 : constant for the spindle speed of rotation N

According to the present invention, it is most likely to apply the following actual values respectively to said constants as a preferred example:

P_e : 50 p.s.i.

P_0 : 100 p.s.i.

N_0 : 50,000 r.p.m.

It is an essential requirement to supply the turbine with a gas pressure lower than the threshold pressure of the half-speed whirling of the spindle, or otherwise, the apparatus would likely be subjected to heavy failure or damage.

Referring now to FIG. 3, the first embodiment according to the present invention is schematically shown. In FIG. 3, the portion enclosed by a phantom line 10 includes the bearing and turbine means. A rotating spindle 1, which has a gas turbine 4 coaxially mounted at one end of the spindle, is supported by suitable gas-lubricated radial bearings 2 and a thrust bearing 3. A common gas supply source 20 supplies the bearings 2 and 3, as well as the turbine 4, with a pressurized gas, either directly or indirectly via suitable conduits 21 or 27. The pressurized gas P_1 is supplied to the bearings 2 and 3 directly from the common gas source 20, while the gas turbine 4 is connected with the common gas source 20 via a pressure reducing valve 30 which serves to reduce the pressure supplied from the gas source 20 low enough to prevent the spindle 1 from reaching the half-speed whirling stage mentioned above. The pressure reducing ratio between the primarily supplied pressure P_1 and the secondarily reduced pressure P_2 , that is, the pressure supplied to the turbine 4, is kept constantly lower than that of the critical state to thereby prevent the whirling of the spindle, this being accomplished by means of the pressure reducing valve 30 being set at a ratio of $m:1$ as described in detail hereafter.

The pressure reducing ratio depends upon an effective diameter ratio between a smaller-diameter diaphragm 31 and a larger-diameter diaphragm 32, where the supply pressure P_1 is applied to the smaller-diameter diaphragm 31 via the radial conduit 27 and an axial conduit 51 and the reduced pressure P_2 is applied to the larger-diameter diaphragm 32 via a conduit 53. When the ratio between the supply pressure P_1 and the reduced pressure P_2 is other than the predetermined ratio, $m:1$, an equilibrium state of a throttle rod 33 fails. Thereupon the position of the throttle rod 33 is moved to change the throttling capacity at a throttle portion or throat 34 accordingly, so that the predetermined ratio $m:1$ is restored and maintained. That is, the pressure reducing ratio predetermined at $m:1$ is so maintained that the turbine 4 is supplied with the reduced pressure within a safety range in relation to the pressure supplied to the bearings 2 and 3 thus avoiding the half-speed whirling of the spindle even if the supply pressure P_1 is varied. According to the present invention, " m " of the pressure reducing ratio is preferred to be settled or selected at more than 2.

Referring now to FIG. 4, the second embodiment according to the present invention is schematically illustrated. This embodiment achieves a control of the turbine speed as well as the prevention of the whirling. In this modification the supply pressure P_1 from the gas pressure source 20 is controlled according to the same principle as in the first embodiment of FIG. 3 so as to be reduced to the pressure P_2 supplied to the turbine 4 and which is made variable within the safety range from the half-speed whirling. The means for controlling the pressure to the turbine 4 comprises a compression spring 35 and an adjusting screw 57 which may be turned by knob 59 and which adjustably compresses the spring 35. The spring 35 biases the throttle rod 33, fixed to the diaphragms 31 and 32, towards the left, as viewed in the drawings. An equilibrium position of the throttle rod 33 is shifted by manually adjusting the biasing force of the compression spring 35 by means of the screw 57, so that a throttling capacity at the throttle or throat portion 34 is so controlled to change within the safety range. Thus, the delivery pressure P_2 to the turbine 4 is changed within the safety range from the whirling. As the turbine speed is changeable arbitrarily within the stable range of the turbine rotation, the most favorable condition of rotation is obtained which is variable according to the kind of tool attached to the end of the spindle and the conditions present.

The third embodiment according to the present invention is schematically illustrated in FIG. 5. The general purpose of the third embodiment is to control the turbine speed of rotation to prevent the spindle from whirling. A more particular purpose

is to automatically keep the spindle speed of rotation nearly constant at a predetermined ratio of $m:1$, even if there are some changes of the load applied to the spindle 1. The pressure reducing valve is the same as shown in FIG. 3. The gas of the reduced pressure P_2 flows into a speed control valve 40 via a conduit 70 where it is further reduced in pressure before introduction into the turbine 4. To explain this in detail, the gas of the reduced pressure P_2 is introduced into a valve chamber 41 via line 70 and a throttle valve 50 which controls flow of the gas running therein. The pressure in the valve chamber 41 is regulated by the speed control valve 40 functioning to maintain constant the pressure responding to the volume of the gas flowing through the throttle valve 50 and the volume of the gas leaving or discharged from a speed detecting turbine 7. Assuming that the spindle speed of rotation is decelerated due to the load applied to the spindle 1, the amount of discharged gas leaving the speed detecting turbine 7 will decrease, whereby the pressure in the valve chamber 41 will rise. With this increase in pressure in chamber 41, a throttle rod 45, secured to a diaphragm 44, will move to the right increasing the valve opening to thereby increase the pressure P_3 supplied to the turbine 4 and to thereby restore the spindle speed of rotation. As above mentioned, it is the main feature of this third embodiment to maintain the spindle rotation at nearly a predetermined constant speed. The turbine speed of rotation is changeable and set manually by controlling an opening degree of the throttle valve 50, which will shift the equilibrium position of the throttle rod 45. The pressure to be supplied to the turbine 4 is thus so controlled that the turbine speed of rotation, which is determined and selected by adjustment of the throttle valve 50, is maintained.

FIG. 6 through FIG. 10 inclusive indicate actual structures of some of the foregoing embodiments. The materialized structure of the first embodiment is not explained here to avoid a double explanation in view of the fact that the first embodiment shown in FIG. 3 can be modified to the second embodiment shown in FIG. 4 if the former is combined with a control means comprising an adjust screw 57 and a knob 59, etc. as additional means.

The materialized structure of the second embodiment shown schematically in FIG. 4 is illustrated in FIGS. 6, 7 and 8. Radial bearings 2, radially spaced around the rotating spindle 1, and a thrust bearing 3, axially spaced around the peripheral sides of an enlargement 1a protruding radially from the rotating spindle 1, are integrally provided in an internal bore 9 of a spindle housing body 8. A plurality of radial apertures 12 and axial apertures 13 are respectively provided through the bearings 2 and 3 extending from the bearing surfaces and are connected to a supply conduit 21 via annular grooves 14 and radial conduits 15. The supply conduit 21 runs parallel to the spindle 1 and extends longitudinally along the spindle housing body 8 and a valve housing 71. The gas from the supply conduit 21 flows into a clearance between the peripheries of the bearings 2 and the periphery of the spindle 1 for supporting the spindle 1 in a floating condition and thence through discharge chamber 23 which leads to the atmosphere, via radial and axial conduits 22, exteriorly of the spindle housing body 8.

The turbine 4 is coaxially fixed to an end of the spindle 1 as previously stated. The conduits 22 also receive the gas leaving the turbine 4 which gas by expansion has been cooled to a lower temperature than the room temperature by 10 and more degrees Centigrade, thereby preventing the bearings from being overheated. Discharge conduits 22 extend parallel to the spindle 1 and are located circumferentially equal distance from each other so as to eliminate any local thermal deformations of the spindle housing body 8 and the bearings and to thus equalize the temperature distribution around the bearings.

A nozzle block 5a is slidably mounted in a bore 6 formed in a casing 6a and is provided with a plurality of axial nozzles 5. One side of the nozzle block 5a faces toward one side of the turbine 4 with a clearance that is changeable by a capscrew 25

and a compression spring 26 which eliminates the backlash of the capscrow 25. One end of the capscrow 25 is secured to a plate 24 mounted within the casing 6a, while the opposite end threadedly engages with the nozzle block 5a. The compression spring 26 normally biases the nozzle block 5a toward the left, with one end of the compression spring 26 bearing against the other side of the nozzle block 5a, while the opposite end of the spring 26 abuts a surface of the plate 24. The highest efficiency of the turbine 4 may be obtained by adjusting a clearance between the turbine 4 and the nozzle block 5a. The other side (left side) of the turbine 4 is open to the discharge chamber 23 which is in turn connected to the conduits 22 as mentioned above. The turbine 4 is rotated at high speed when the gas jet projected from the turbine nozzles 5 flows axially along the turbine blades.

While the turbine depicted in FIG. 6 is shown as an axial flow turbine, it will be appreciated that any other type of turbine may be applied.

A hollow valve housing 71 aligned with the spindle body 8 is coaxially fixed to one end of the spindle body 8 by means of capscrows (not shown). A pressure reducing valve 30 is contained within an outer sleeve 37 mounted within the inner surface 72 of the valve housing 71. As mentioned above the pressure reducing valve 30 is provided with a smaller diaphragm 31 and a larger diaphragm 32 which are of different effective diameters. The smaller-diameter diaphragm 31 is fixed or held at its rim between a ring 36 and an inner sleeve 73 which are mounted within and on the outer sleeve 37. The larger-diameter diaphragm is fixed or held at its rim by being clamped between the ring 36 and the outer sleeve 37. A throttle rod 33 slidably supported through an opening in the inner sleeve 73 is fixed to the diaphragms 31 and 32 by means of nuts 74 and 75 interposing therebetween a spacer collar 76 and a washer 77. A conical end 33a of the throttle rod 33 forms a variable throttle or throat portion 34 in cooperation with the valve seat 38. The valve seat 38 presenting its throat 34 in alignment with the throttle rod 33, is fixed to the inner sleeve 73. An inlet throttle chamber 78 is connected to the supply conduit 21 via a radial conduit 27. An outlet throttle chamber 39, connected to the inlet throttle chamber 78 through the throttle portion 34, is in turn connected to the nozzles 5 via the holes 24a perforated in the plate 24. A smaller chamber 52 formed by and between the diaphragm 31 and the inner sleeve 73 is connected to the inlet throttle chamber 78 via a passageway 51 extending axially through the inner sleeve 73 for introducing the supply pressure P_1 . A larger chamber 54 formed adjacent the larger-diameter diaphragm 32 is connected to the outlet throttle chamber 39 via a conduit 53 for introducing the reduced pressure P_2 . The throttle rod 33 is moved in response to the difference in the two pressures P_1 and P_2 applied respectively to the diaphragms 31 and 32 in order to keep the pressure reducing ratio constant. A compression spring 35 provided in the chamber 54 normally urges both the diaphragms 31 and 32 to the left via the collar 76. One end of the spring 35 bears against the washer 77, while the opposite end of the spring 35 abuts a washer 55 which is threadedly engaged with an adjustment screw 57 and retained therein by a pin 58 against rotation. The adjustment screw 57 is rotatably supported in the valve housing 71 and has one end protruding from the valve housing. A knob 59 is secured on the protruded end of the adjustment screw 57 by a pin 78 so that the same can be manually turned to control the compression force of the spring 35.

The gas with its pressure reduced from the supply pressure P_1 at the variable throttle portion 34, is introduced to the turbine nozzles 5 through the orifices or holes 24a in the plate 24, and thence flows axially along the blades of the turbine 4. After passing through the turbine the gas flows out into the chamber 23 which is connected to the discharge conduits 22, and it is thus adiabatically expanded, thus lowering its temperature to lower than the room temperature by 10° C. and more. The gas thus cooled prevents the bearing surfaces from undue temperature rise. The thrust bearing 3, which is most

likely to be subject to heat, is prevented from temperature rises by the annular chamber 23 being positioned adjacent thereto. The gas flowing through the discharge conduits 22, equally spaced from each other circumferentially along the radial bearings 2, can cool equally all the radial bearing peripheries, as well as the whole apparatus, to avoid any local thermal deformation.

The pressure reducing ratio at the valve 30 is variable in response to the compression of the spring 35 which is controllable through the screw 57 by a manual adjustment of the knob 59. The smallest compression of the spring 35 results in the pressure reducing ratio of the effective-diameter ratio between the diaphragms in which the highest pressure within the safety range is supplied to the turbine. The compression of the spring 35 is so determined that the reduced pressure P_2 supplied to the turbine does not exceed the threshold pressure to cause the half-speed whirling.

The equilibrium position of the throttle rod 33 is shifted in proportion to the compression force of the spring, and thereby the spindle speed is changeable arbitrarily within the safety range from the half-speed whirling by means of the knob 59.

Reading the diagram of FIG. 2, the critical pressure reducing ratio between the supply pressure P_1 and the reduced pressure P_2 may be decided according to the curve A. However, for the sake of safety the actual ratio is chosen below the curve A. For example, if the ratio is selected below the phantom line C, the spindle will never be rotated in an unstable state. The reducing ratio of the pressure reducing valve 30 is constant and keeps the reduced pressure P_2 from exceeding the critical pressure in spite of any changes in the supply pressure. Therefore, an operator can change the spindle speed of rotation with no trouble merely by turning the knob 59 as long as the spindle is currently free from the half-speed whirling.

Referring now to FIGS. 9 and 10, an actual adaptation and structure of the third embodiment schematically shown in FIG. 5 is illustrated. The structure of the bearing portion, the turbine and the pressure reducing valve 30, without the control means for changing the compression force of the spring 35, are the same as those in FIG. 6.

A speed control valve 40 is provided in series with the gas flow through conduit 70 of the reduced pressure P_2 coming for the pressure reducing valve 30, to automatically control the reduced pressure to be delivered to the turbine 4 for the purpose of maintaining the spindle speed of rotation almost constant in spite of differences in the loads applied to the spindle 1. The speed control valve 40 is located between the pressure reducing valve 30 and the plate 24 contained in the valve housing 71. An outer sleeve 43, closed at one end, the right end as viewed in the drawing, is mounted within the inner surface of the valve casing 71, and an inner sleeve 79 is mounted within the outer sleeve 43. A diaphragm 44, fixed between abutting surfaces of the outer sleeve 43 and the inner sleeve 79, separates a space formed by the sleeves into two chambers 41 and 42. A throttle rod 45 slidably supported through an opening in the inner sleeve 79 is fixed to the diaphragm 44 by means of nuts 80 and 81 interposing therebetween collars 82 and 83. A conical end 45a of the throttle rod 45 and a valve seat 47 mounted on the inner sleeve 79 form a throttle or throat portion 47a in a chamber 46. The chamber 46 is connected with the outlet throttle chamber 39 via a conduit 70. The gas under reduced pressure P_2 introduced from the pressure reducing valve 30 through the conduit 70 is further reduced in pressure at the throttle portion 47a on its way to the axial-flow turbine 4. The separated valve chamber 42 is opened to the atmosphere via an aperture 48. A compression spring 49 in the chamber 42 normally biases the throttle rod 45 toward the left. One end of the spring 49 bears against the end of the outer sleeve 43, while the opposite end of the spring 49 abuts the collar 83.

A throttle valve 50 includes a valve seat in a radial conduit opposite and leading to the chamber 46, the valve seat cooperating with a throttle rod 50a adjustably threaded through the valve housing wall 71. The other valve chamber

41 of speed control valve 40 is connected with the chamber 46 through the radial conduit and the throttle valve 50 and is also connected to a speed detecting turbine 7, coaxially fixed to the spindle 1, through the axial conduit 60. There is formed a small clearance between the internal periphery 61 of the sleeve 6a and the outer surface of turbine 7. A plurality of convex depressions 17 are provided on the periphery of the turbine 7 at an equal distance from each other. A pair of nozzles 18 and 18' oppositely extending from the periphery 61 of the inner sleeve 6a are connected to the chamber 41 via an annular groove 62 and the conduit 60 to detect the spindle speed of rotation. A pair of pockets 19 and 19' opening to the chamber 23 are provided on the periphery 61 of the inner sleeve 6a. The convex portions 17 on the turbine 7 carry the gas poured from the nozzle 18 or 18' to the pockets 19 and 19' in proportion to the turbine speed of rotation. The gas led to the speed detecting turbine 7 is limited by the throttle valve 50, so that the pressure in the valve chamber 41 is regulated according to the turbine speed of rotation.

Assuming that the spindle speed of rotation is decelerated by the loads applied to the spindle 1, the gas quantity flowing out of the speed detecting turbine 7 is decreased accordingly and thereby the pressure in the chamber 41 is increased resulting in moving of the throttle rod 45 to the right to open the throttle portion 47a to a greater degree and consequently increasing the spindle speed. When the spindle speed is accelerated, the gas quantity flowing out from the turbine 7 is increased and thereby the pressure in the chamber 41 is decreased, resulting in the moving of the throttle rod 45 towards the left, toward closed position, thus the spindle speed of rotation is decelerated. Thus, the pressure of the gas supplied to the turbine 4 is regulated automatically to maintain the spindle speed nearly constant. The speed control valve 40 cannot make the pressure to be introduced to the turbine 4 any higher than the reduced pressure P_2 even though the throttle rod 45 moved to the right the maximum distance, so that the function of the pressure reducing valve 30 to prevent the spindle from the half-speed whirling is still maintained and protected. The valve 40 controls the pressure supplied to the turbine 4 to maintain the spindle speed nearly constant without regard to the loads applied to the spindle 1. The throttle valve 50 permits manual change of a predetermined spindle speed by shifting an equilibrium position of the throttle rod 45 due to a pressure change within the valve chamber 41 controlled by the throttle valve 50.

As above mentioned, it is in the first embodiment that the pressure reducing ratio between the pressures to the bearings P_1 and to the turbine P_2 is maintained constant in order to prevent the spindle from the half-speed whirling. It is in the second embodiment that the pressure reducing ratio between the pressures P_1 and P_2 is controlled in order to prevent the spindle from the half-speed whirling and the pressure supplied to the turbine is changeable within the safety range from the half-speed whirling by manually turning the knob 59. It is in the third embodiment that the pressure supplied to the pressure reducing valve 30 is reduced with a constant ratio to prevent the half-speed whirling and the gas of the reduced pressure P_2 is supplied to the turbine 4 through the speed control valve 40 in order to keep the spindle speed nearly constant in spite of the changes of the loads applied to the spindle 1. The reduced pressure P_2 from the supply pressure P_1 is controlled automatically in accordance with the spindle speed within the range "0" to the maximum of the reduced pressure.

It is also possible to further modify the third embodiment with a means like the screw and the knob employed in the second embodiment to manually control the reduced pressure P_2 to be changeable within the safety range from the half-speed whirling.

While the foregoing description is concerned with the preferred embodiments of the present invention, it will be evident to those skilled in the art that various changes and modifications may be made therein without thereby departing from the basic principle of the invention, and the appended

claims are intended to cover all such changes and modifications as fall within the spirit and scope of the invention.

We claim:

1. An apparatus for controlling the rotation of a high-speed rotating spindle which comprises
 - a high-speed rotating spindle;
 - bearing means for supporting said rotating spindle in a floating condition by a gas film interposed between the periphery of said bearing means and the periphery of said spindle;
 - a rotatable gas turbine coaxially fixed to said spindle for rotating said spindle with a high-speed gas jet running therethrough;
 - a common gas source for supplying a pressurized gas directly to said bearing means and indirectly to said turbine; and
 - a pressure reducing means connected to said common gas source for reducing the pressure supplied from said common gas source on the way to the turbine to prevent unstable movement of said spindle during rotation thereof.
2. An apparatus for controlling the rotation of a high-speed rotating spindle as claimed in claim 1, which further comprises a control means for reducing the pressure to be supplied to said turbine within the safety range from the unstable movement of said spindle,
 - said control means including a spring means and a manually adjustable screw, said spring means being interposed between said screw and said pressure reducing means.
3. An apparatus for controlling the rotation of a high-speed rotating spindle as claimed in claim 1, which further comprises a rotatable speed detecting means coaxially fixed to said spindle for discharging a gas according to the spindle speed;
 - a throttle valve connected to said pressure reducing means for regulating the gas flow supplied from said pressure reducing means on the way to said speed detecting means; and
 - a speed control means for maintaining the spindle speed nearly constant in response to said speed detecting means in spite of changes in the loads applied to said spindle.
4. An apparatus for controlling the rotation of a high-speed rotating spindle as claimed in claim 3, which further comprises a control means for reducing the pressure to be supplied to the turbine within the safety range from the unstable movement of said spindle;
 - said control means including a spring means and a manually adjustable screw, said spring means being interposed between said screw and said pressure reducing means.
5. An apparatus for controlling the rotation of a high-speed rotating spindle as claimed in claim 1, wherein said pressure reducing means comprises
 - a pair of flexible diaphragms;
 - a throttle rod secured to said diaphragms;
 - a valve seat provided to form a throttle portion in cooperation with said throttle rod; and
 - two chambers separated by said diaphragms, one of said chambers receiving the pressure supplied from said common gas source and the other of said chambers receiving the pressure reduced at said throttle portion.
- Whereby the pressure supplied from said common gas source is controlled and reduced to the pressure to be supplied to said turbine in accordance with the movement of said diaphragms in response to the pressure difference between the pressures in said two chambers to thereby prevent unstable movement of said spindle during the rotation thereof.
6. An apparatus for controlling the rotation of a high-speed rotating spindle as claimed in claim 3, wherein said speed control means comprises
 - a flexible diaphragm;
 - a throttle rod secured to said diaphragm;
 - a valve seat to form a throttle portion in cooperation with said throttle rod; and

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two chambers separated by said diaphragm, one of said chambers being led to said speed detecting means and the other chamber being opened to the atmosphere.

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Whereby the spindle speed is maintained nearly constant in response to said speed detecting means in spite of changes in the loads applied to said spindle.

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