

United States Patent

Wetterstad

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[54] **METHOD AND DEVICE FOR PROVIDING A CONTROL OF THE VELOCITY PROFILE OF THE WORKING MEDIUM IN THE INLET OF FLOW MEDIUM**[72] Inventor: **Lennart Wetterstad**, Storegardsuagen 27, Trollhattan, Sweden[22] Filed: **Jan. 2, 1970**[21] Appl. No.: **307**[52] U.S. Cl. **137/13, 137/81.5, 415/116**[51] Int. Cl. **F15d 1/02**[58] Field of Search **137/81.5, 15.1, 15.2, 13; 415/116, DIG. 1**[56] **References Cited****UNITED STATES PATENTS**

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[57]

ABSTRACT

A method and apparatus for controlling the velocity profile of the working medium of fluid actuated or fluid impelling mechanisms, such as water and gas turbines, turbopumps, compressors, etc., having radial or axial flow patterns in which a control fluid of the same character as the working fluid is introduced tangentially into the working fluid at the working fluid inlet to impart a rotational motion to the working fluid either in the same direction as the direction of rotation of the rotor of the mechanism or in a direction opposite to the direction of rotation of the rotor, and at a substantial distance forward of the rotor, with respect to the direction of flow of working fluid, and the rotational movement is then amplified by restricting the flow path of the working fluid prior to its contact with the rotor. Preferably, the control fluid is introduced through a plurality of orifices or nozzles distributed along radially disposed conduits in the working fluid inlet and the control fluid is obtained from the outlet of the machine or from both the outlet and an external source and is passed through a control apparatus, such as a fluid amplifier system, to control the volume, pressure and distribution through the orifices or nozzles.

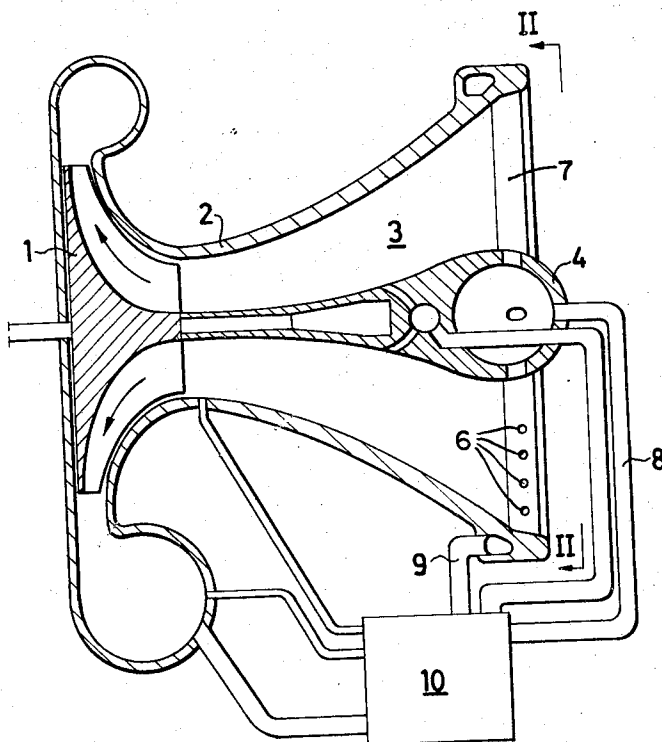
21 Claims, 8 Drawing Figures

Fig.1

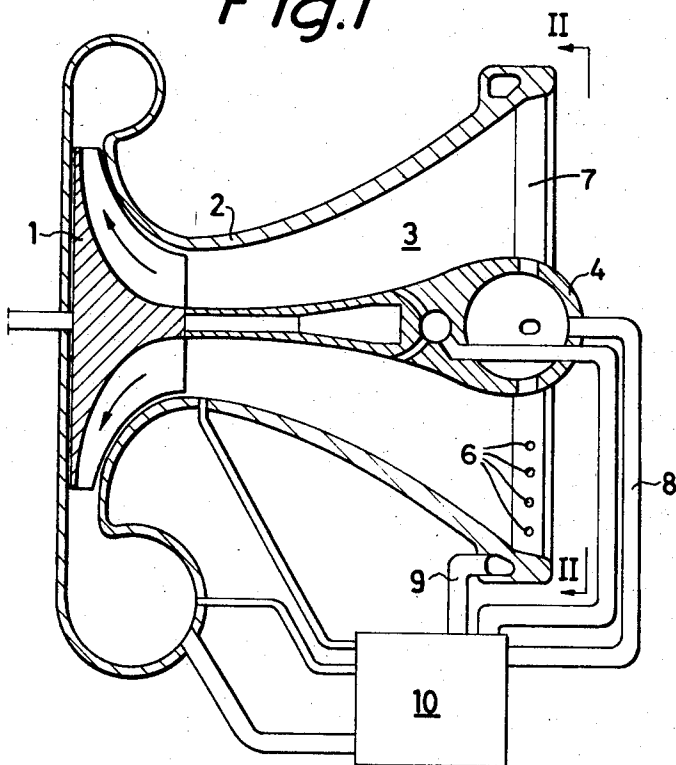
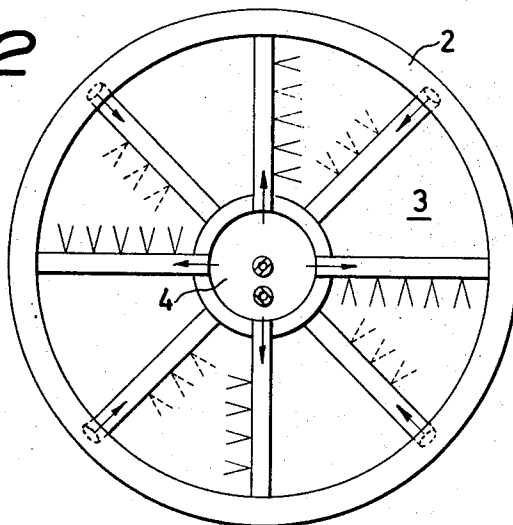


Fig.2



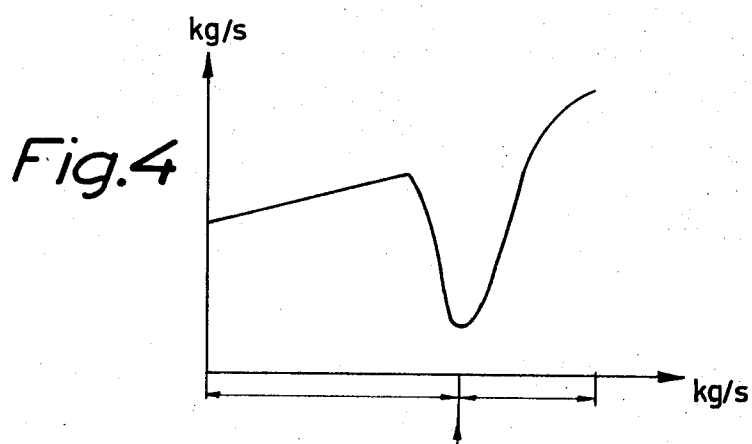
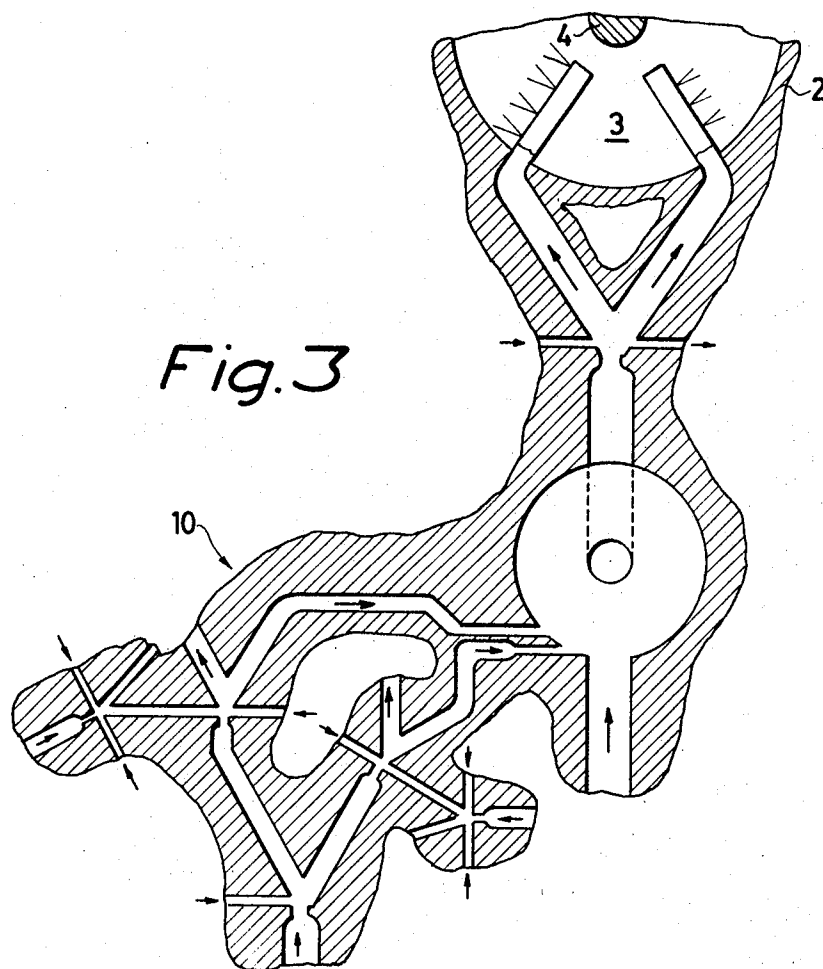


Fig.5

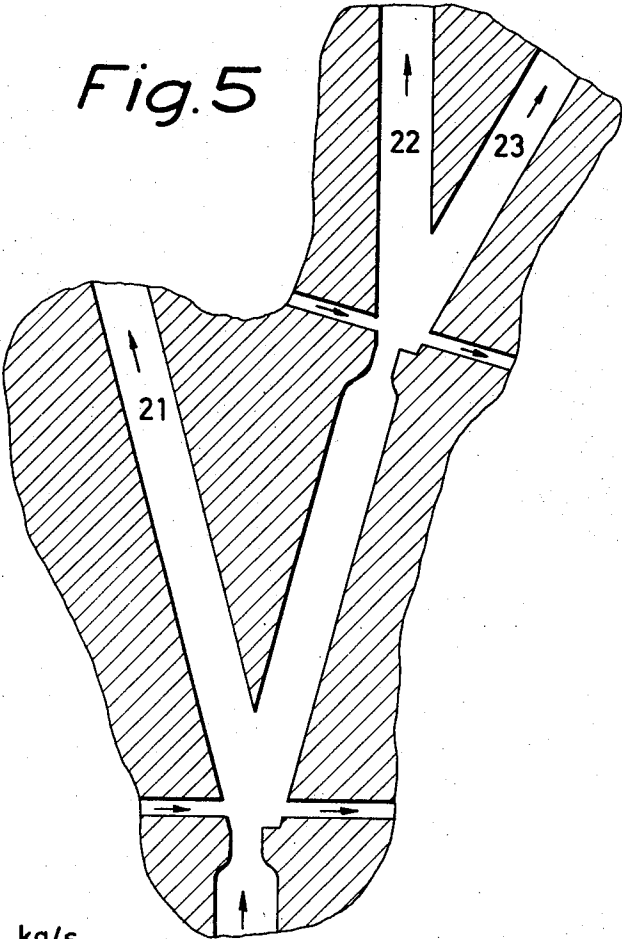


Fig.6

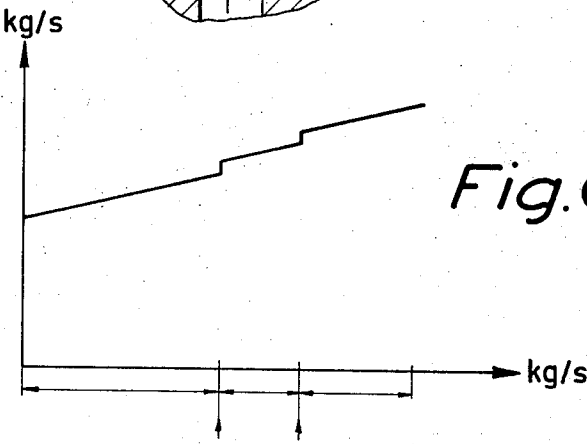


Fig. 7

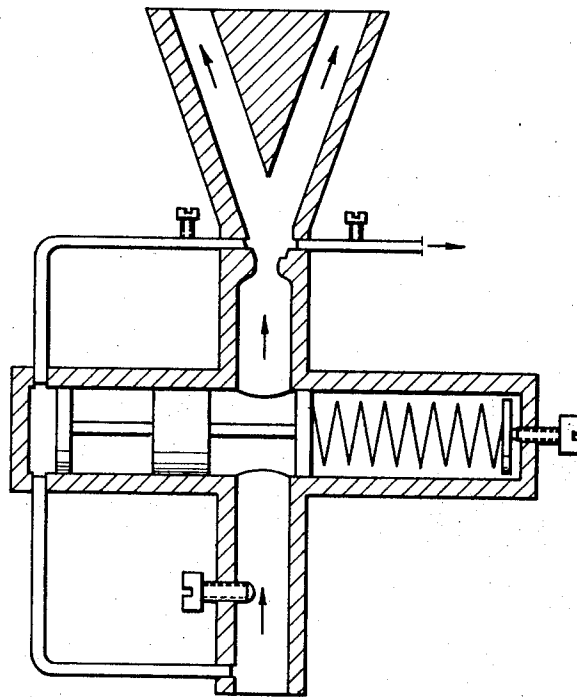
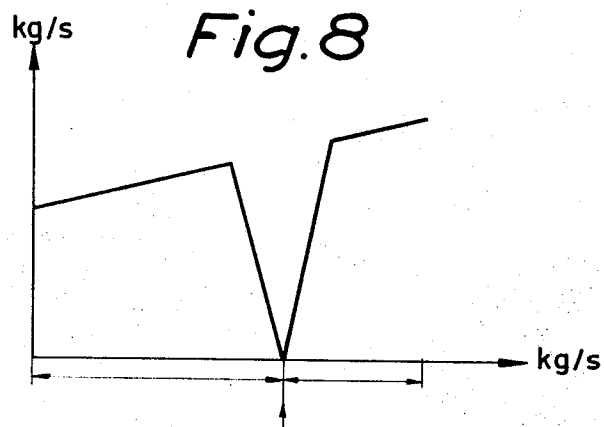


Fig. 8



METHOD AND DEVICE FOR PROVIDING A CONTROL OF THE VELOCITY PROFILE OF THE WORKING MEDIUM IN THE INLET OF FLOW MEDIUM

The present invention relates to a method and device for providing a control, preferably by fluid amplifier system, of the velocity profile of the working medium in the inlet of flow machines of radial as well as axial flow type, such as water and gas turbines turbopumps and compressors etc., for adaptation of the machine to optimum efficiency at other operational conditions than the design condition; in which a uni- or counter directional rotational movement relative to the rotor of the machine is applied to the working medium at the inlet of the machine by a control medium of the same kind as the working medium, which control medium is supplied from a separate source or constituted by a portion of the working medium drained from the outlet of the machine and which is introduced tangentially into the inlet of the radial or axial machine at a substantial distance forwardly of the rotor of the machine.

In all flow machines, radial as well as axial, i.e., water turbines steam turbines, gas turbines, air turbines, turbopumps, turbocompressors, fans etc., there exists an operational condition for which the machine is designed. When a machine working with a gaseous medium for various reasons is forced to operate at other pressures and throughputs than correspond to said operational condition, the blades will meet the flow at the wrong angle of attack. This causes reduction of efficiency and also flow separation from blades and walls. Flow separation also can cause unstable operation, in compressors called "pumping."

When the flow medium is a liquid, a similar problem occurs, namely cavitation. Cavitation is, at least in its lighter form, a border layer phenomenon which implies that it occurs closely adjacent the surfaces where the flow velocity is reduced and hence a somewhat longer time is required for the vapor forming process.

Pumping as well as cavitation can be substantially eliminated, however, if the velocity profile in the inlet of the machine is controlled in a suitable manner.

In previously known methods and structures for obtaining such a control, guide vanes have often been utilized, said guide vanes being mechanically adjustable. However, such structures are complicated and thus expensive and furthermore they give rise to flow losses even when they are not operating. Adjustable guide vanes are also rigid and their cross-sectional profile must be a compromise for the operating range within which they are to work. The difficulties will be still greater when the guide vanes are oriented to guide the medium, preferably air, both unidirectionally and counter-directionally. The guide vane then cannot be curved or even have a curved cross section but must quite simply have just the shape of an adjustable plane or an adjustable plane or an adjustable aerodynamically shaped wing.

An object of the present invention therefore is to eliminate the above-mentioned difficulties by means of a method substantially distinguished in that said control medium is introduced as a plurality of radially distributed separate jets at a position in the inlet of the rotor of the machine having relatively great radius, after which position said inlet then becomes narrowed and amplifies the rotational movement imparted to the working medium.

Another object of the invention is to provide a device for carrying out the method of providing a control, preferably by fluid amplifier system, of the velocity profile of the working medium in the inlet of flow machines, and having means for tangential introduction, uni- or counterdirectionally, into the axial or radial inlet of said machine of a control medium of the same kind as the working medium. Said device is distinguished, according to the invention, in that said inlet means consist of a plurality of radially spaced individual outlet orifices, said inlet being shaped convergent downstream of said control medium introduction so as to achieve an amplification of the imparted rotational movement of the working medium.

According to the invention there is provided a method and device which allows, in a very simple way, the provision of a control of the velocity profile of the working medium in the inlet of the machine, and this completely without utilizing guide vanes with all inherent drawbacks thereof. In applications with fluid working mediums the control medium can be controlled by simple reliable means and it is even possible to utilize advantageously a fluid amplifier system for said control, a minimum of movable parts of the control mechanism being required at the same time as high reliability of the latter is achieved as well as optimum efficiency of the actual flow machine.

By way of example, the invention will be further described below with reference to the accompanying drawings, in which FIG. 1 is a longitudinal section;

FIG. 2 a front end view of an exemplifying super charger assembly of an internal combustion engine of diesel type,

FIG. 3 is a diagrammatical section of a relatively complicated control system operating with a fluid amplifier system,

FIG. 4 is a diagram of the control function of said fluid amplifier system,

FIG. 5 is also a diagrammatical section of another and simpler but automatic fluid amplifier system with associated control curve illustrated in FIG. 6, and

FIG. 7 finally illustrates a fluid amplifier system combined with a mechanical valve and the associated control function is illustrated by the curve of FIG. 8.

As stated above, in the drawings the invention is illustrated as applied to a supercharger compressor, a flow machine operating with air in which very complicated operational conditions occur. It is obvious, however, that the invention can be applied on any flow machine for liquid as well as gaseous mediums, in which the indicated control difficulties are to be eliminated.

In the present application the supercharger turbocompressor of an internal combustion engine of diesel type has been selected as the supercharger assembly. For such an assembly, which in its air section usually is made as a single-stage radial compressor, the working medium ought to be introduced thereto, at low speeds, a unidirectional rotation in the inlet at a maximum of 40°-50° and at high speeds a counterrotation at a maximum of -20°. The angle in question is measured between the absolute vector of the inlet velocity and the center plane of the compressor wheel. Counterrotation is particularly used for limiting the rotational speed and, if desired, the pressure at the outlet of the compressor.

The above-stated nonpivotable guide vanes of the prior art provide a very disadvantageous velocity profile in the inlet which would be a particular drawback in an assembly of the last-mentioned kind. The prerotational movement generated by said guide vanes is namely greatest at the hub and decreases, outwardly towards the periphery, while, on the contrary, the inverse relation is desired. Moreover, the axial velocity profile is approximately constant along the radius. However, said axial velocity in some cases ought to be greater at the hub, since in small compressor wheels it is often difficult to keep the relative velocity high at that position due to the low peripheral velocity. As known, however, it is just the low relative velocity that promotes the occurrence of flow separation, and flow separation at the hub in its turn is one of the sources of the above-mentioned "pumping."

The present invention now makes it possible to easily eliminate said drawbacks. The supercharging turbocompressor illustrated in FIGS. 1 and 2 of the drawings comprises a radial or centrifugal compressor with a driven blade wheel 1 mounted in a casing 2 of well-known type. The casing 2 is formed with an inlet 3 for the working medium of the compressor, and centrally in the inlet is mounted a hub 4.

According to the invention, the compressor is provided in the inlet 3 with means 6 for introducing a control medium, of the same type as the working medium, tangentially into the inlet 3 at a place spaced upstream from the compressor wheel

1. Said control medium gives rise to a unidirectional or counterdirectional movement of the working medium entering into the inlet, before said medium reaches the blade wheel 1 of the machine. In the present case, where the working medium is air, the control medium also is gaseous and most preferably air. Said air can be supplied from any suitable individual source for pressurized air or it can be drained from the outlet side of the blade wheel 1. It is also obvious that analogous thereto a liquid can be used as a control medium in case the working medium is a liquid, and said liquid control medium then can be supplied from the outlet side of the blade wheel 1 as well as from any suitable individual source.

In the embodiment illustrated in the drawings the means 6 consist of a plurality of orifices or nozzles arranged in radial tubular struts 7, which furthermore serve as support members for the hub 4 centrally located in the inlet 3. Of course, said means 6 for introducing the control medium do not necessarily need to be orifices or holes but might as well be slots or have any other suitable form. In the present case, wherein unidirectional as well as counterdirectional movement is to be provided, some of the means 6 are directed opposite to the direction of rotation of the machine, while other means are directed along said direction, said means 6 thus being directed in a negative and positive sense, respectively. Preferably the arrangement is such that half the number of tubular supports 7 are provided with injection orifices 6 directed in a negative sense while the other half is provided with means 6 directed in a positive sense. Of course, other distributions between the means 6 can be used, if desirable, and the number of orifices or other injection means 6 on each tubular supports 7 as well as the area of said injection means and area variations of the injection means, if any, along one and the same tubular support 7 can be adapted to actual requirements. Finally, the means 6 also can be directed at various angles to the entering working medium.

The control medium is supplied to the means 6 on the supports 7 through conduits 8 and 9, in the present case the conduit 8 leading to the hub 4 for being connected to the supports 7 which are provided with means 6 directed in a positive sense, i.e., for unidirectional injection, while the conduit 9 extends around the casing 2 at the mouth of the inlet 3 and is connected to the rest of the supports 7, which have means 6 directed for counterrotation. The control medium which in the present case is air, drained from the pressure side of the compressor, is led to the conduits 8 and 9 through a control apparatus 10.

It is also advantageous to introduce the control medium at greatest possible distance from the longitudinal center line of the inlet 3 so as to obtain maximum impulse momentum. An important condition for the invention also is that the uni- or counterrotational movement of the medium in the inlet 3 is amplified by the fact that the inlet is made convergent towards the blade wheel 1.

In the exemplified assembly as well as in other embodiments, in which air and other gaseous mediums are working and controlling medium, it is indeed possible to obtain the required control of the control medium by means of mechanical or electrical valves of the kind known per se. Still much greater advantages can be achieved, however, by using a pure fluid amplifier control system, which is to be particularly described in the following with reference to the rest of the figures of the drawings.

In FIG. 3 it is first illustrated a complicated pure fluid amplifier system in which the main air is drained from the compressor. Monostable, bistable and proportional wall effect fluid amplifiers and vortex fluid amplifiers can be used. The first fluid amplifier in the train is monostable, i.e., it always chooses the left exit conduit. When the control flow increases, more and more of the main flow thereof is forced to go through the right conduit. The last fluid amplifier of the train, the output fluid amplifier, is bistable and will be further described below. The circular fluid amplifier is a vortex fluid amplifier having as its purpose to restrict the main flow. The more control flow

supplied to the vortex chamber, the more the main flow is reduced. The four remaining fluid amplifiers are proportional, i.e., the medium flows in both exit conduits of the fluid amplifier are proportional to the differential between the two control flows thereof. Also proportional fluid amplifiers having three or more exit conduits can be used and the control system can be more or less complicated dependent upon how sophisticated the control must be. The system can be controlled both with control air from the compressor or from any other pressure source, such as a booster system of the vehicle in which the engine is used. Also the vacuum in front of the compressor wheel can be utilized. The speed of the compressor, the throttle or various impulse sources on the diesel engine also can be used for the control but in such cases this is often accomplished through mechanical control linkages. The control curve will be in accordance with the illustration of FIG. 4.

FIG. 5 illustrates an automatic but simpler fluid amplifier system in which only two nonsymmetric bistable wall-effect fluid amplifiers are used. The nonsymmetry resides in that the right side has a small step at the primary nozzle which causes the air to initially flow from the left conduit, see FIG. 7. The bistable character means that the Coanda effect is utilized for adhering the jet to either the left or right side.

Also in this case air is drained from the pressure side of the compressor. The control impulses are taken from the pressure and suction side of the compressor. At low compressor pressure the air flows through a conduit 21 which leads to support means having orifices directed in positive sense. When the pressure rises, the first fluid amplifier shifts to conduit 22 at a certain pressure. Conduit 22 leads to an opening at the hub, where air can be introduced axially in uniflow. After further pressure increase the second fluid amplifier shifts to conduit 23 which leads the air to the tubular supports giving negative rotation in the compressor inlet. The control curve is illustrated in FIG. 6.

The fluid amplifier system can easily be combined with a mechanical valve for the second portion of the curve, if no compressor drainage should be desired in said operating range. Such a structure is disclosed in FIG. 7. Mechanical valves are preferably to be avoided, however, due to the cost and their sensitivity to wear and dirt. A pure fluid amplifier system is more dependable in its operation and less expensive since fluid amplifiers and conduits can be molded into the compressor casing.

A certain quantity of drained air can be allowed to flow constantly from the hub or any other place if the efficiency is increased thereby.

I claim:

1. A method for controlling the velocity profile of the working medium of a fluid flow machine having a motor comprising; introducing a control fluid of the same character as said working fluid tangentially into said working fluid at a substantial distance forward of the rotor of said machine, with respect to the direction of flow of said working fluid to impart a rotational motion to said working fluid and reducing the cross-sectional area of the flow path of said working fluid prior to contact of said working fluid with said rotor to amplify said rotational motion.

2. A method in accordance with claim 1 wherein the control fluid is introduced in the direction of rotation of the rotor.

3. A method in accordance with claim 1 wherein the control fluid is introduced in a direction opposite to the direction of rotation of the rotor.

4. A method in accordance with claim 1 wherein the control fluid is introduced in the direction of rotation of the rotor and in a direction opposite to the rotation of said rotor.

5. A method in accordance with claim 1 wherein at least a part of the control fluid is withdrawn from the pressure side of the machine.

6. A method in accordance with claim 5 wherein all of the control fluid is withdrawn from the pressure side of the machine.

7. A method in accordance with claim 1 wherein the fluid is introduced through a plurality of distributing means.

8. A method in accordance with claim 7 wherein the control fluid is adjusted to introduce said control fluid through a selected portion only of the distributing means.

9. A method in accordance with claim 7 wherein the control fluid is adjusted to introduce said control fluid at different pressures through different ones of the distributing means.

10. Apparatus for controlling the velocity profile of the working fluid of a fluid flow machine having a rotor and a working fluid inlet means, comprising: control fluid introduction means mounted in said inlet means a substantial distance from said rotor, with respect to the direction of flow of said working fluid, and oriented to introduce said control fluid tangentially into said working fluid and restricting means in said working fluid inlet means to reduce the cross-sectional area of said working fluid inlet means between said rotor and said control fluid introduction means.

11. Apparatus in accordance with claim 10 wherein the fluid flow machine is of the radial flow type.

12. Apparatus in accordance with claim 10 wherein the fluid flow machine is of the axial flow type.

13. Apparatus in accordance with claim 10 wherein the control fluid introduction means is oriented to introduce control fluid in the direction of rotation of the rotor.

14. Apparatus in accordance with claim 10 wherein the control fluid introduction means is oriented to introduce control fluid in the direction opposite to the direction of rotation

of the rotor.

15. Apparatus in accordance with claim 10 wherein the control fluid introduction means is oriented to introduce control fluid both in a direction opposite to the direction of rotation of the rotor and in the same direction as the direction of rotation of said rotor.

16. Apparatus in accordance with claim 10 wherein the control fluid introduction means is a plurality of conduits radially disposed in the working fluid inlet means and said conduits at a plurality of distributing means spaced therealong.

17. Apparatus in accordance with claim 10 wherein a fluid control means is connected to the control fluid introduction means.

18. Apparatus in accordance with claim 17 wherein the fluid control means is a fluid amplifier system.

19. Apparatus in accordance with claim 17 wherein the fluid control means is connected to the pressure side of the fluid flow machine.

20. Apparatus in accordance with claim 17 wherein the fluid control means is connected to an external source of control fluid and to the pressure side of the fluid flow machine.

21. Apparatus in accordance with claim 17 wherein the fluid control means is connected to an external source of control fluid.

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