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APPARATUS FOR REGULATING A TURBO-COMPRESSOR

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Fig. 1

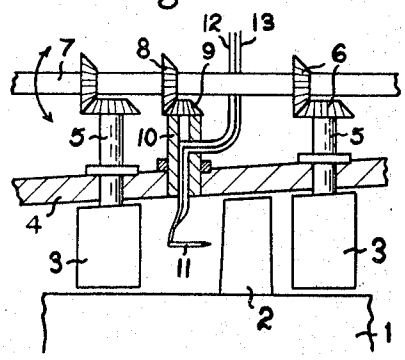



Fig. 2

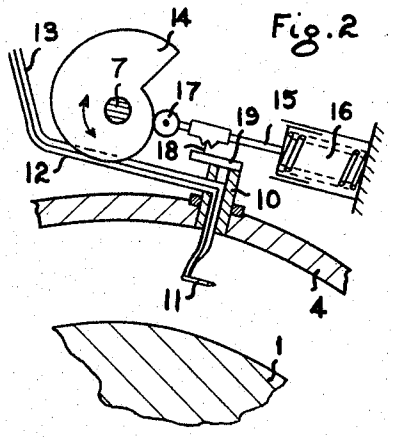



Fig. 5

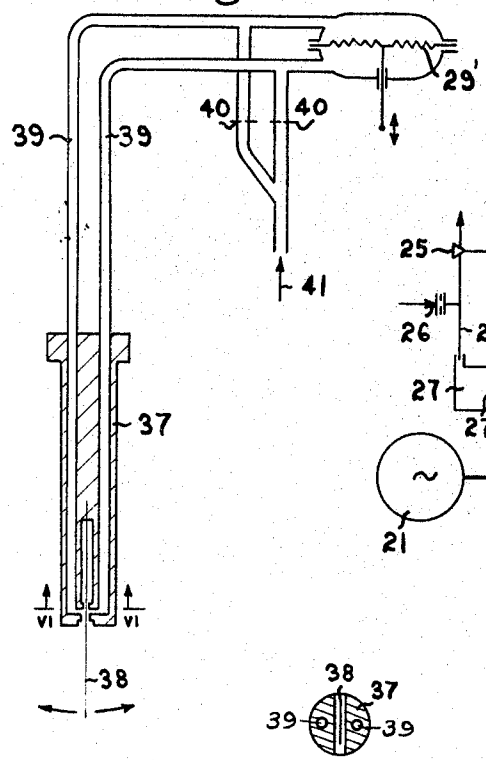
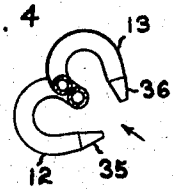



Fig. 4



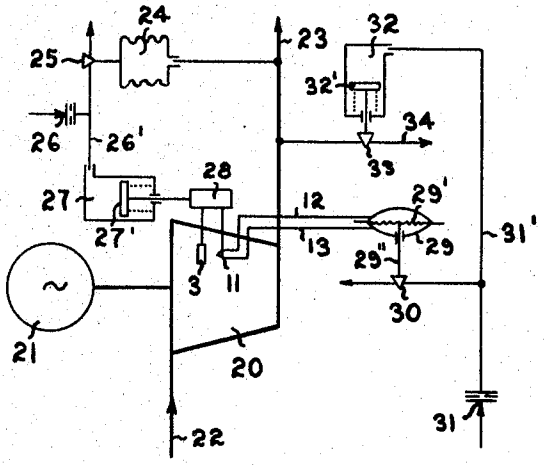




Fig. 3




Fig. 6

INVENTORS

Hans Baumann

Peter Schmidt-Theuner

BY Pierce, Scheffler & Parker

ATTORNEYS

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# APPARATUS FOR REGULATING A TURBO-COMPRESSOR

Hans Baumann and Peter Schmidt-Theuner, Nussbaumen, Aargau, Switzerland, assignors to Aktiengesellschaft, Brown, Boveri & Cie, Baden, Switzerland, a joint-stock company of Switzerland

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12 Claims. (Cl. 230—114)

The present invention relates to an improved apparatus for regulation of a multi-stage, axial flow turbo-compressor machine having a compressible operating medium flowing through it, preferably for preventing the machine from pumping. In accordance with the invention, the machine is provided with a rotationally adjustable probe which is inserted into the gap between adjacent rows or stages of the turbine blading for measuring the characteristic flow angle of the compressible operating medium, flowing through the machine, this measurement being transmitted to a regulator which functions to adjust the rotational position of the turbine blading, i.e. the blade angle, whenever the flow angle of the medium departs from a predetermined value. This rotational adjustment of the turbine blading can be applied to the rows of blading on the rotor or to the rows of otherwise stationary guide blading interposed between adjacent rows of rotor blading.

It is known to equip turbo-compressor machines with rotationally adjustable guide blading or rotor blading for purposes of regulation, so as to provide for a change in the blade angle to suit a particular operating condition. Adjustment of the blade angle enables the quantity delivered by the compressor and its pressure ratio to be adapted to any particular operating point which may be desired. This has proved to be satisfactory above all when the compressor is driven at constant speed. The operating point can approach the pumping limit up to the so-called aperture characteristic curve. This is approximately equidistant to the pumping limit with a relatively great quantity being delivered, at which quantity the compressor is still capable of working in stable fashion. If the operating point passes the aperture characteristic curve, for example if the quantity consumed becomes smaller, the compressor must be prevented from working in its unstable operating region. This is done by opening an outlet member in the pressure conduit of the compressor, with the result that the latter continues to work at a point on the aperture characteristic curve, and the excess quantity delivered is taken off.

The aperture characteristic curve has hitherto been determined as a characteristic value of the quantity delivered by a function of the terminal pressure of the compressor and a pressure difference in the flow path inside the compressor, or by linking one of these two measured values with a compressor-setting member such as may adjust the speed, aspirator-throttle flap or blades. A function corresponding to the desired aperture characteristic curve is formed in the regulator from these two measured values, for example by a cam-disc. Varying the shape of the cam-disc adapts the aperture characteristic curve to any individual compressor, regard being had to the particular operating conditions.

A further measured value is known as an input magnitude for the regulator, namely the absolute flow angle after a row of rotor blades of a turbo-compressor, measured by a built-in ram-pressure applicance. Since this measured value represents a characteristic magnitude of similarity, it may advantageously be used together with one of the above-mentioned magnitudes for determining



an operating characteristic curve. This flow angle also has the favorable property of being substantially constant for definite operating characteristic curves and types of regulation, for example when the speed or aspiration throttling is varied for a characteristic curve of optimum efficiency or for the aperture characteristic curve of the outlet member along the pumping limit. As a result, a single measured value is sufficient, and regulation is simplified since there is no need for a function to be formed.

If the compressor is regulated by blade-adjustment, this favorable property is no longer present. As an example of this, consideration will be given to the prevention of pumping in an axial compressor with rotatably adjustable guide blades. In this case, the absolute flow angle after the row of rotor blades varies in pronounced fashion along the pumping limit with guide blade adjustment, so that it has not hitherto been possible to use the advantage of making do with a single measured value for preventing pumping.

According to the invention, the measuring probe is now made adjustable, and its adjusting device is coupled to the device for rotationally adjusting the blades. As a result, it is possible in the case of the foregoing example to make use, for regulation purposes along the pumping limit, of the advantage of the absolute flow angle after the row of rotor blades being at least substantially constant relative to the guide blade setting.

Corresponding considerations may also be established for all other kinds of turbo-compressors and blade adjustments, and for definite operating characteristic curves, for example the characteristic curve of optimum efficiency.

Two example embodiments incorporating the invention concept are depicted, and their use diagrammatically illustrated, in the drawing, wherein

FIGURE 1 shows in axial section, a device for adjusting the measuring probe;

FIGURE 2 shows in radial section, another device for adjusting the measuring probe;

FIGURE 3 shows a regulation diagram;

FIGURE 4 shows a plan view of a measuring probe;

FIGURE 5 shows another measuring probe, in longitudinal section; and

FIGURE 6 shows the same measuring probe sectioned along VI—VI in FIGURE 5.

The same reference numerals are associated with the same parts in all the figures.

With reference now to the drawings, and to FIGURE 1 in particular, the rotor of the turbo-compressor is provided with several axially spaced rows of blading **2**, only one row of which is depicted. Each row of the rotor blading **2** lies between two rows of stationary guide blading **3** which project radially inward towards the surface of the rotor from a blade carrier housing **4**. The spindles **5** of the guide blading **3** are mounted for rotational adjustment about their axis in suitable bearings provided in housing **4** and each blade spindle is rotated by means of a pair of meshed bevel gears **6**, one of these gears being mounted on the blade spindle and the other mounted at a right angle thereto on a rotationally adjustable shaft **7**. The driving mechanism for rotating shaft **7** is not illustrated but the arrangement is such that the shaft may be rotated in either direction as indicated by the dual headed arrow.

Mounted on shaft **7**, which need not extend over all of the rows of blades, there is a further bevel gear **8** which is advantageosly located near the bladed part of the machine and which meshes with bevel gear **9**. The latter is secured upon a rotationally adjustable sleeve **10** parallel to spindles **5** and which is likewise mounted for rotation about its axis in suitable bearings provided in the housing **4**. Sleeve **10** carries a measuring probe **11** projecting

radially inward between blade rows 2 and 3, with associated measuring conduits 12 and 13 which expediently comprise movable or elastic parts outside of the sleeve so as to enable the latter to be rotationally adjusted in relation to the flow angle of the medium passing through the machine. When shaft 7 is adjusted in rotation, measuring probe 11 is simultaneously adjusted rotationally with the guide blading 3 either through the same angle as this blading, or in a linear dependence on their rotation, depending upon whether the bevel gears 8 and 9 have the same rotary drive transmission ratio as bevel gears 6, or a different ratio.

The apparatus in accordance with the invention enables the pressure difference in the two measuring conduits 12, 13 of measuring probe 11 to be maintained constant along the above-mentioned operating characteristic curves of the compressor, or to be maintained at a value of zero, if the zero method is used, and thus enables the compressor to be regulated in the desired manner. If the characteristic flow angle selected as the regulation magnitude departs from a predetermined value, which is indicated by a variation in the pressure difference measured by probe 11, the regulator will then act upon the blade angle setting mechanism for the guide blading 3 until the predetermined flow angle is restored.

FIGURE 2 illustrates a somewhat different embodiment of the invention for effecting a rotational adjustment of probe 11. Instead of a bevel gear drive, the blade angle adjuster shaft is provided with a cam disc 14 which when rotated actuates a push rod 15 which is guided by a resilient piston 16 and forced, via a roller 17 against the periphery of cam disc 14. A pin 18 fitted to push rod 15 engages lever 19 fastened to sleeve 10 so that as cam disc 14 is rotated in one direction or the other by rotation of shaft 7, the ensuing longitudinal displacement of push rod 15 will be converted into rotational displacement of sleeve 10 and probe 11 which are otherwise indentical to these two components in the embodiment of FIGURE 1.

Any desired function whatsoever between the rotary adjustment of flow angle measuring probe 11 and the rotary adjustment of guide blading 3 may be created by cutting the periphery of cam 14 to the proper contour. This is necessary if the flow angle along the operating characteristic curve is not constant, and the required value set up therefor is in need of correction.

FIGURE 3 shows, as an example of use, a regulation diagram for a compressor provided with means for adjusting the angle of the stationary guide blading 3, operation o fthe compressor being at a constant delivery pressure of the compressed gaseous medium, and pumping being prevented through means including measurement of the flow angle of the medium. The compressor indicated at 20 is driven by a motor 21 and delivers the operating gaseous medium from the aspiration conduit 22 at the compressor inlet to the delivery conduit 23 at the compressor outlet. A resilient bellows unit 24, the interior of which communicates with the pressure conduit 23, controls via a valve 25 the pressure of the oil in an oil pressure control system wherein oil is delivered into control line 26' from a pump source, not illustrated, through a controlled port 26. Connected into line 26' is the valve 25 and also the cylinder 27 which contains a spring loaded piston 27'. Movement of piston 27' in one direction or the other in response to a corresponding change in the oil pressure in line 26' as valve 25 is moved to a more open or more closed position to increase or decrease the flow of oil bled off from line 26' back to the sump from which the pump draws in oil, serves to produce a corresponding rotational movement in one direction or the other of the adjustment shaft 7 and hence also of the guide blading 3 and measuring probe 11. The rectangle 28 shown in FIGURE 3 thus corresponds to the mechanism shown in either FIGURES 1 or 2.



A differential pressure measuring device 29 includes a diaphragm 29' which separates the two pressure chambers of the device and these two pressure chambers are connected respectively with the two pressure measuring conduits 12, 13 associated with the measuring probe 11. A rod 29'' actuated by the diaphragm 29' controls a valve 30 which in turn controls the pressure of the oil in the oil pressure system wherein oil is delivered into another control line 31' from the same pump source, through a controlled port 31. Connected into line 31' is the valve 30 and also the cylinder 32 which contains a spring loaded piston 32'. Movement of piston 32' in response to a corresponding change in the oil pressure in line 31' as valve 30 is actuated to bleed off oil from line 31' back to the oil sump serves to actuate valve 33 in the blow-off conduit 34 from conduit 23 as soon as the flow angle on the aperture characteristic curve, and thus the pressure difference in the two measuring conduits 12, 13 reaches a definite limiting value. If the pressure in the measuring conduit 13 dominates, valve 30 opens, piston 32 is relieved of some pressure, valve 33 opens and the excess quantity of gaseous medium compressed by the compressor is allowed to blow off through conduit 34.

If the compressor is regulated in accordance with another operating characteristic curve, for example in accordance with a curve of optimum efficiency, the measured pressure difference acts on the device for rotating the compressor blades.

FIGURE 4 illustrates an intrinsically known two-hole angle-probe which may be used as the measuring probe 11. The open ends 35 and 36 of the measuring conduits 12 and 13 are as usual at right-angles to one another. If the operating medium impinges symmetrically on the probe, as indicated by the direction of the arrow, the ram pressure in both measuring conduits is of equal magnitude, and the pressure difference is zero. If the direction of flow departs from the plane of symmetry, the ram pressure in the two measuring conduits becomes different and a positive or negative pressure difference occurs, which difference may serve as the required value for regulation purposes, just as the zero value may. Multiple-hole angle-probes may be used in the same way.

A laminar probe particularly suited to carrying out the idea of the invention is depicted in FIGURES 5 and 6. The leaf-spring 38 is arranged in a slit in the body 37 of the probe between the constricted mouths of the measuring conduits 39, which are fed via control orifices 40 with clean air at constant pressure at 41. If the leaf-spring is in the middle position, both pressures at the mouths of the measuring conduits are equal. If the spring is deflected from the middle position by flow forces, the outflow cross-section of one mouth is increased, and that of the other reduced. This gives rise to a pressure difference which is substantially proportional to the bending of the leaf-spring, and thus to the angular departure of the flow. The pressure difference acts on the diaphragm 29, which is linked to a setting member in a system similar to FIGURE 3.

Instead of the embodiment with measuring conduits, the leaf-spring may be fitted with expansion-measuring strips, also known by the name of "strain gauges," to determine its bending, thus providing a delay-free electrical signal which serves as an input magnitude for the regulator.

As compared to ram-pressure measuring probes, the laminar probe exhibits greater sensitivity, is not liable to contamination, and in addition offers the advantage of giving an unambiguous and correct signal for regulation purposes even if reverse flow occurs in the compressor.

Adjustment may be imparted to the measuring probe by rotation, as illustrated in FIGURES 1 and 2, but also by radial displacement. Since the flow angle not only is affected by rotation of the blades, but also varies along a blade, the variation in flow angle when the blades are rotated can be compensated for by radial movement of

the measuring probe without there being any need to rotate it.

Coupling between the settings of the probe and the blades may be effected in various ways, for example mechanically, hydraulically, pneumatically or electrically. A special case arises when the measuring probe is constructionally combined with the rotatable blades.

The measuring probe may be built in after one row of guide or rotor blades, introduced from outside between the rows of blades, or arranged to rotate with them.

The method of regulation by measuring a characteristic flow angle of the operating medium, which method is also applicable for the first time to compressors with rotatable blades as a result of the present invention, confers simplification of regulating appliances with a resultant reduction in their cost, since there is no longer any need as hitherto to form a function from two measured magnitudes. It further offers the advantage that the measured flow angle represents a characteristic magnitude of similarity which is independent of aspiration pressure and aspiration temperature.

We claim:

1. The combination with a multi-stage turbo-compressor machine having rows of blading on the rotor alternating with rows of guide blading, of means for rotationally adjusting either the guide blading or the rotor blading, an adjustable measuring probe located in the space between a row of a guide blading and an adjacent row of rotor blading for measuring the characteristic flow angle of the gaseous medium passing therebetween, and regulator means responsive to the output of said measuring probe for actuating said blading adjusting means and simultaneously adjusting said measuring probe when the flow angle of said gaseous medium departs from a predetermined value thereby to restore said flow angle to the desired value and prevent pumping in said machine.

2. A multi-stage turbo-compressor machine as defined in claim 1 wherein said measuring probe is adjustable in a rotational manner.

3. A multi-stage turbo-compressor machine as defined in claim 1 wherein said measuring probe is adjustable in a radial manner.

4. A multi-stage turbo-compressor machine as defined in claim 1 wherein the adjustment of said measuring probe proceeds in linear dependence upon the rotational adjustment of said turbine blading.

5. A multi-stage turbo-compressor machine as defined in claim 1 wherein the adjustment of said measuring probe proceeds in accordance with a function dependent upon the rotational adjustment of said turbine blading.



6. A multi-stage turbo-compressor machine as defined in claim 1 wherein said measuring probe is located substantially in the middle of the bladed part thereof.

7. A multi-stage turbo-compressor machine as defined in claim 1 wherein said measuring probe is constituted by two inlet apertures located at an angle to one another.

8. A multi-stage turbo-compressor machine as defined in claim 1 wherein said measuring probe has a laminar sensing element.

9. A multi-stage turbo-compressor machine as defined in claim 8 wherein said laminar sensing element of said measuring probe function to increase the area of one inlet aperture and simultaneously decrease another.

10. A multi-stage turbo-compressor machine as defined in claim 8 wherein said laminar sensing element of said measuring probe is provided with a strain gauge to measure the deflection thereof.

11. A multi-stage turbo-compressor machine as defined in claim 1 wherein said measuring probe is of the pressure differential sensing type responsive to the angle of fluid flow, and said regulating means includes means for blowing off a portion of the compressed medium at the discharge side of said machine in accordance with the output of said probe, and means actuated in accordance with a change in pressure of said medium at the discharge side of said machine for effecting a simultaneous adjustment of said measuring probe and turbine blading.

12. A multi-stage turbo-compressor machine as defined in claim 1 wherein said measuring probe is of the pressure-differential sensing type responsive to the angle of fluid flow, and said regulating means including a diaphragm actuated in accordance with the pressure differential sensed by said probe, valve means controlled by said diaphragm for blowing off a portion of the compressed medium at the discharge side of said machine, and means actuated in accordance with a change in pressure of said medium at the discharge side of said machine for effecting simultaneous adjustment of said measuring probe and turbine blading.

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DONLEY J. STOCKING, *Primary Examiner.*

W. L. FREEH, *Assistant Examiner.*