(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) Publication number: **0 446 900 A1**

(12) # EUROPEAN PATENT APPLICATION

(21) Application number: **91103850.3**

(22) Date of filing: **13.03.91**

(51) Int. Cl.5: **F04D 29/44**, F04D 17/06, F04D 29/62

(30) Priority: **14.03.90 JP 60973/90**

(43) Date of publication of application: **18.09.91 Bulletin 91/38**

(84) Designated Contracting States: **CH DE FR IT LI**

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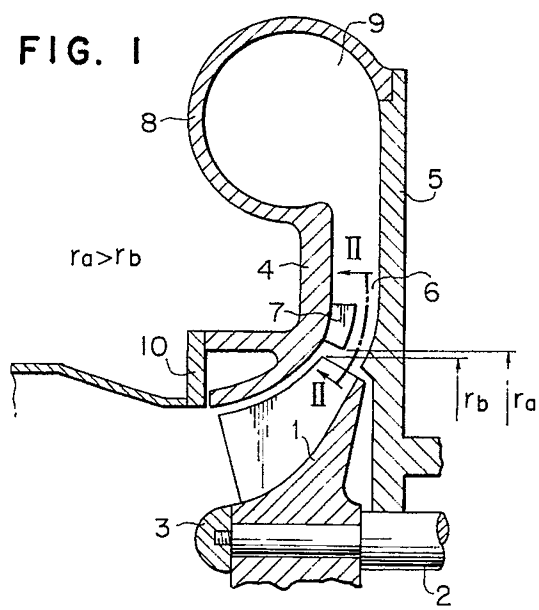
(54) **Mixed-flow compressor.**

(57) A compressor is disclosed wherein a diffuser flow path is curved in a radial direction in the vicinity of an outlet of a mixed-flow turbine (1), and guide vanes (7) each having a height larger than a maximum radius (r_b) at the outlet of the mixed-flow turbine (1) are arranged in the form of a circular wing row at the curved portion on a flow path surface of the diffuser plate (4) located toward a side plate. Thus, it is possible to keep uniform the flow within the diffuser (6) and to enhance the performance of the compressor. In addition, the axial length of the compressor may be shortened to thereby make the compressor compact in size.

FIG. I



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BACKGROUND OF THE INVENTION

FIELD OF THE INVENTION

The present invention relates to a mixed-flow compressor, and more particularly to a mixed-flow compressor suitable for enhancement of its performance and for compactness in size.

DESCRIPTION OF THE PRIOR ART

As disclosed in Proceedings of the Sixth Turbomachinery Symposium, pp 61 to 62 (October 1977), in a conventional mixed-flow compressor, a oblique or mixed flow diffuser (in which a flow-out direction is slanted from the radial direction) is not provided with guide vanes in the flow path. Also, if provided as disclosed in Japanese Utility Model Examined Publication No. 56-38240, the guide vanes are arranged on a core plate side. In addition, it is known in Japanese Machinery Association Papers, pp 16 to 20 (March 1987) that a diffuser is provided in the radial direction, but there is no guide vanes.

In general, if the specific velocity ns expressed in the following equation is high, a ratio between a diameter at an end of an inlet of a turbine and a diameter at an end of an outlet thereof is increased, so that the performance of the turbine is degraded due to the fact that the curvature is increased in case of the centrifugal turbine. Further, due to the increase in curvature, a secondary flow becomes remarkable within the turbine, so that the flow at the outlet of the turbine is deflected to the core plate side to thereby degrade the performance of the diffuser.

$$ns = N \cdot \sqrt{Q}/H_{ad}^{0.75}$$

where N is the revolutional speed (rpm), Q is the flow rate in volume (m^3/min) and Had is the adiabatic head (m).

In order to avoid this, in general, a mixed-flow turbine in which the outlet of the turbine is slanted from the radial direction is used. In the mixed-flow turbine, the curvature of a meridional plane flow path in a meridional plane (i.e., a cross section passing through the rotary shaft and vertical to the paper surface) (hereinafter referred simply to as a meridional plane flow path) is decreased, so that the flow may be kept substantially uniform in the widthwise direction at the outlet of the turbine, i.e., at the inlet of the diffuser. It is thus possible to prevent the generation of the flow deflected toward the core plate. However, if the flow having a volute component is introduced into the mixed-flow diffuser, the flow is deflected to the side plate from the intermediate portion to the outlet portion of the diffuser due to the curvature of right angle with respect to the flow path. In the extreme case, a reverse flow will be generated on the core plate side to largely increase the diffuser loss. In addition, in the mixed-flow compressor in which such diffuser without vanes is used, the length in the axial direction is increased to make the compressor large in size and to increase the friction loss in the flow path.

Furthermore, since the length of the rotary shaft is increased, the safety limit speed of the shaft system must be lowered.

In order to overcome these problems, guide vanes each having a height corresponding 10 to 50% of the width of the meridional plane flow path are provided on the core plate side of the diffuser. However, this could not sufficiently attain the object. There are still unsolved problems such as the increase in friction loss and a reduction in safety limit speed.

In order to overcome these problems, an object of the present invention is to provide an oblique flow compressor that is small in size and ensures a high performance.

SUMMARY OF THE INVENTION

This and other objects of the invention is attained by providing a mixed-flow compressor in which the outlet portion of the mixed-flow turbine, i.e., the diffuser is curved in the vicinity of the inlet portion of the diffuser, and guide vanes each having a height such that the inlet and outlet vane angles are substantially equal to the average flow angle of design at the outlet of the turbine are provided in the form of a circular wing row at the curved portion on the flow path surface on the side plate side of the diffuser.

According to another aspect of the invention, the diffuser flow path is curved in the radial direction just after the outlet of the turbine, and the guide vanes each having a height such that the inlet and outlet vane angles are substantially equal to the average flow angle of design of the turbine outlet are provided in the form of the circular wing row just after the inlet of the flow pat surface of the diffuser on the side plate side.

With such arrangements, the following advantages are ensured.

Since the guide vanes each having a certain height are provided at the curved portion on the flow path surface of the diffuser plate on the side of the side plate curved in the radial direction in the vicinity of the outlet of the mixed-flow turbine, and the inlet and outlet angles are equal to the average flow angle of the design point at the outlet of the turbine, the flow on the side of the side plate of the mixed-flow turbine outlet is introduced with almost no collision into the guide vanes. Then, since the fluid introduced into the guide vanes is forcibly led, the fluid will flow without separating away from the wall surface of the side plate and will reach the guide vane outlet portion. Since the vane angle is equal to the average flow angle at the design point at the guide vane outlet, i.e., the end of the curved portion, the flow angle of the fluid led by the guide vane is equal to the flow angle of the portion where guide vanes are not provided. Also, since at the end of the curved portion, the curvature of the meridional plane flow path is small, the meridional flow speed is also kept substantially uniform in the widthwise direction. After all, the flow may be kept uniform in the widthwise direction.

Also, since the guide vanes each having a height are provided on the surface of the flow path of the diffuser plate on the side of the side plate curved in the radial direction are provided just after the turbine outlet, and the inlet angle and the outlet angle are equal to the average flow angle of the outlet of the turbine, the fluid of the outlet of the mixed-flow turbine on the side of the side plate is introduced into the guide vanes with almost no collision. Then, since the fluid introduced into the guide vanes is forcibly led by the guide vanes, the fluid will flow without separating from the wall surface of the side plate and will reach the outlet portion of the guide vanes. Since at the outlet portion of the guide vanes, the vane angle is equal to the average flow angle of the design point, the flow angle of the fluid led by the guide vanes is equal to the flow angle at the portion where guide vanes are not provided. Also, the curvature of the meridional plane flow path .is small at the outlet of the guide vanes is small so that the meridional plane flow speed is also kept substantially uniform in the widthwise direction. After all, the flow is kept constant in the widthwise direction.

BRIEF DESCRIPTION OF THE DRAWINGS

In the accompanying drawings:

Fig. 1 is a longitudinal sectional view showing one embodiment of the invention;

Fig. 2 is a cross-sectional view taken along the line II-II of Fig. 1;

Fig. 3 is a graph showing a meridional plane velocity distribution in the widthwise direction at the end portion of the diffuser shown in Fig 1;

Fig. 4 is a graph showing a comparison in adiabatic efficiency ratio between the mixed-flow compressor according to the embodiment shown in Fig. 1 and a conventional mixed-flow compressor;

Fig. 5 is an assemblage illustration of the compressor shown in Fig. 1;

Fig. 6 is a longitudinal sectional view showing another embodiment of the invention;

Fig. 7 is a longitudinal sectional view showing still another embodiment of the invention;

Fig. 8 is a cross-sectional view taken along the line VIII-VIII of Fig. 7; and

Fig. 9 is a longitudinal sectional view showing still another embodiment of the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Fig. 1 is a longitudinal sectional view showing a mixed-flow compressor in accordance with an embodiment of the invention, in which a mixed-flow turbine 1 having a small curvature in a meridional plane flow path is fixed to a rotary shaft 2 by a nut 3. A pair of diffuser plates 4 and 5 each having a curvature in the vicinity of an outlet of the turbine 1 are provided outside of the turbine 1. The diffuser plates 4 and 5 define a diffuser 6 which has a curvature in the vicinity of the turbine 1. One of the diffuser plates 4 is located on a so-called side plate side, whereas the other of the diffuser plates 5 is located on a core plate side. Guide vanes 7 are arranged in the form of a circular wing row at the curved portion of the flow path surface of the diffuser plate 4. It is preferable that the guide vanes 7 are partially provided in the width-wise direction of the flow path and their height are ranged in 20 to 50% of the flow path width. In addition, an inlet vane angle α_1 and an outlet vane angle α_2 are equal to an average flow angle at a design point of the outlet of the mixed-flow turbine 1 (i.e., an average value of an angle defined by an absolute velocity of the turbine outlet at the design flow rate point with respect to a tangential direction (circumferential direction)). The reason why the height of the guide vanes is in the range of 20 to 50% is that the reverse flow preventing effect would be eliminated at the curved portion below 20% and the incidental loss at the flow rate point outside the design point (i.e., a loss generated due to the difference between the flow angle and the vane angle) is increased to degrade the performance of the compressor above 50%.

A minimum inlet radius r_a of the guide vanes 7 is larger than an maximum outlet radius r_b of the turbine 1.

A casing 8 is provided radially outwardly of the diffuser plates 4 and 5 to define an outlet flow path 9. A suction pipe 10 is fixed on a gas suction side of the diffuser plater 4.

The operation of the mixed-flow compressor with the above-described arrangement for compressing gas will be described.

The gas is pressurized and then sucked into the diffuser 6 from the turbine 1. The gas flow is decelerated within the diffuser 6 and is introduced into the casing 8. In general, since the curvature of the meridional flow path of the mixed-flow turbine 1 is small, the flow at the outlet of the turbine 1 becomes uniform in the widthwise direction. Accordingly, the flow angle of the fluid on the side of the diffuser plate 4 at the outlet of the turbine 1 is substantially equal to the average flow angle in the widthwise direction, so that the fluid on the side of the diffuser plate 4 is introduced into the guide vanes 7 with almost no collision. Since the introduced fluid is forcibly guided by the guide vanes 7, the fluid may flow without separating away from the wall surface of the diffuser plate 4 and reach the outlet portion of the guide vanes 7. Since the curvature of the meridional plane flow path is small at the outlet portion of the guide vanes 7, i.e., the terminal portion of the curvature, the flow is forcibly led by the guide vanes 7 (whose height is 40% of the diffuser 6) and becomes uniform in the widthwise direction as shown in Fig. 3.

Fig. 4 shows the specific advantage according to this embodiment and the adiabatic efficiency ratio between a conventional mixed-flow compressor using the diffuser without any radial movement vanes and the compressor according to the present embodiment. Curve F indicates the adiabatic efficiency ratio at each suction flow rate of the conventional mixed-flow compressor, and curve E indicates the adiabatic efficiency ratio at each suction flow rate of the mixed-flow compressor according to the present embodiment. The reference value is defined by regarding as 1.0 the maximum value of the adiabatic efficiency of the mixed-flow compressor according to the present embodiment. As is apparent from Fig. 4, it is possible to considerably improve the adiabatic efficiency ratio in comparison with the conventional mixed-flow compressor having the diffuser without vanes.

As described above, since according to the present embodiment, it is possible to prevent the separation of the flow at the curved portion of the diffuser, it is possible to considerably reduce the loss at the curved portion and to make uniform the flow in the widthwise direction at the outlet portion of the guide vanes, thereby largely enhancing the performance of the diffuser after the outlet portion of the guide vanes. In addition, since the meridional plane flow path of the diffuser is curved in the radial direction, the length of the flow path may be reduced in comparison with that of the conventional mixed-flow diffuser and the frictional loss may also be reduced. As a result, the performance of the mixed-flow compressor may be largely enhanced in comparison with the conventional compressor. Furthermore, since the rotary shaft of the compressor may be shortened, the limit speed of the shaft system may be increased.

Fig. 5 is an illustration of the assemblage of the compressor of the embodiment shown in fig. 1. First of all, the mixed-flow turbine 1 is fitted with the rotary shaft 2 by moving the turbine in the axial direction as indicated by the arrow A. Then, the turbine 1 is fastened to the rotary shaft 2 by the nut 3. The casing 8 integral with the diffuser plate 4 on which the guide vanes 7 are mounted are moved in the axial direction as indicated by the arrow B and is inserted into a fit portion 12 of the diffuser plate 5 which has been coupled with the rotary shaft 2 through a bearing. In this embodiment, since the minimum inlet diameter of the guide vanes 7 is larger than the maximum outlet diameter of the turbine 1, it is also advantageously easy to assemble the compressor.

Fig. 6 is a longitudinal view showing another embodiment. In this embodiment, in the same way as Fig. 1, the diffuser 6 is composed of a pair of diffuser plates 4 and 5 each having a curvature in the meridional plane and guide vanes 7 arranged in the form of a circular wing row at the curved portion on the flow path surface of the diffuser plate 4. The inlet angle and the outlet angle of the guide vanes 7 are substantially equal to an average flow angle at the design point of the outlet of the turbine. Also, for the same reason as that in Fig. 1, the height of the guide vanes 7 is ranged in 20 to 50% of the flow path width. Then, the inlet radius r_a of the guide vanes 7 is larger than the outlet maximum radius r_b of the turbine 1 and is kept constant in the widthwise direction.

Also in this mixed-flow compressor, in the same manner as in Fig. 1, the fluid on the side of the diffuser plate 4 at the outlet of the mixed-flow turbine 1 is led without separating away from the guide vanes 7 and reaches the outlet of the curvature portion. The flow is kept substantially constant in the widthwise direction at the outlet of the curvature. Accordingly, in the same manner as in Fig. 1, the performance of the diffuser 6 is considerably enhanced. Furthermore, since the meridional plane flow path is curved in the radial direction, the axial length of the compressor is shortened. Therefore, also in this embodiment, it is possible to make the mixed-flow compressor small in size and it is also possible to enhance the limit speed of the shaft system.

Furthermore, since the inlet radius of the guide vanes 7 is larger than the maximum outlet radius of the turbine 1 and kept constant in the widthwise direction, it is possible to facilitate the assemblage of the compressor and easier to manufacture the diffuser than the case of Fig. 1.

Fig. 7 is a longitudinal sectional view showing still another embodiment. Fig. 8 is a cross-sectional view taken along the line VIII-VIII of Fig. 7. In this embodiment, in the same way as in Fig. 1, the diffuser 6 is composed of a pair of diffuser plates 4 and 5 each having a curvature in the meridional plane and guide vanes 11 arranged in the form of a circular wing row on the flow path surface of the diffuser plate 4. The guide vanes 11 are provided not only on the curved portion of the flow path surface of the diffuser plate 4 but also on the parallel portion downstream of the curved portion. The inlet and outlet angles are substantially equal to the average flow angle at the design point of the outlet of the turbine 1. Also, for the same reason as that of Fig. 1, the height of the guide vanes 11 is ranged in 20 to 50% of the flow path width. The inlet radius r_a of the guide vanes 11 is larger than the outlet maximum radius r_b of the turbine 1 and is kept constant in the widthwise direction.

Also in this mixed-flow compressor, in the same manner as in Fig. 1, the fluid on the side of the diffuser plate 4 at the outlet of the mixed-flow vanes 1 is led without separating away from the guide vanes 11 and reaches the outlet of the curved portion. At the outlet of the curved portion, the flow is made substantially uniform in the widthwise direction. However, in the case where no guide vanes 11 are provided at the parallel portion downstream of the curved portion, it is possible that the stress of inlet flow is increased toward the downstream side. Accordingly, since the guide vanes 11 are provided to extend to the parallel portion to thereby keep uniform the flow along the parallel portion, it is also possible to enhance the diffuser performance, i.e., the performance of the mixed-flow compressor in comparison with the case shown in Fig. 1.

Incidentally, in this embodiment, since the meridional plane flow path of the diffuser 6 is curved in the radial direction, the axial length of the compressor may be reduced. It is therefore possible to make small the mixed-flow compressor and to enhance the limit speed of the shaft system also in this embodiment.

Furthermore, since the inlet radius of the guide vanes 11 is larger than the outlet maximum radius of the turbine 1 in the same manner as in Fig. 6, it is possible to facilitate the assemblage of the compressor according to this embodiment, and it is possible to facilitate the manufacture of the diffuser in comparison with the case of Fig. 1.

Fig. 9 is a longitudinal sectional view according to still another embodiment. In this embodiment, the diffuser 6 is composed of a diffuser plate 5 having a curvature in the meridional plane, a diffuser plate 4 curved in the radial direction immediately after the inlet thereof, and guide vanes 11 arranged in the form of a circular wing row on the flow path surface of the diffuser plate 4. The guide vanes 11 are provided at a section between the inlet and outlet of the diffuser 6. The inlet and outlet angles are substantially the same as the average flow angle at the design point of the outlet of the turbine. Also, for the same reason as that of Fig. 1, the height of the guide vanes 11 is in the range of 20 to 50% of the flow path width. The inlet radius r_a of the guide vanes 11 is larger than the outlet maximum radius r_b of the turbine 1 and is kept constant in the widthwise direction.

Also, in this mixed-flow compressor, in the same manner as in Fig. 1, since the fluid on the side of the diffuser plate 4 at the outlet of the mixed-flow turbine 1 is led without separating way from the guide vanes 11, the flow within the diffuser is kept substantially uniform in the widthwise direction. Accordingly, the performance of the diffuser 6 is largely improved. Furthermore, since the meridional plane flow path of the diffuser 6 is curved in the radial direction immediately after the inlet, the axial length of the compressor is shorter than that shown in Fig. 1. Accordingly, it is possible to make smaller the mixed-flow compressor and to enhance the limit speed of the shaft system in this embodiment.

In addition, since the inlet radius of the guide vanes 11 is larger than the outlet maximum radius of the turbine 1 and is kept constant in the widthwise direction, it is possible to facilitate the assemblage of the compressor and to simplify the manufacture of the diffuser in comparison with the case of Fig. 1.

Claims

1. In a mixed-flow compressor having a mixed-flow turbine (1) in which a flow-out direction in a meridional plane of the turbine (1) is slanted from a radial direction, and a pair of diffuser plates (4, 5) provided downstream of the mixed-flow turbine (1), wherein a diffuser flow path is identical with the flow-out direction of said mixed-flow turbine (1) at an inlet portion and is directed in the radial direction at an outlet portion, the improvement wherein the diffuser flow path is curved in the radial direction in the vicinity of the outlet of said mixed-flow turbine (1), and guide vanes (7) each having a height such that a minimum inlet radius (r_a) thereof is larger than a maximum radius (r_b) at the outlet of said mixed-flow turbine (1) are arranged in the form of a circular wing row at the curved portion on a flow path surface of the diffuser plate (4) located toward a side plate.

2. In a mixed-flow compressor having a mixed-flow turbine (1) in which a flow-out direction in a meridional plane of the turbine (1) is slanted

from a radial direction, and a pair of diffuser plates (4, 5) provided downstream of the mixed-flow turbine (1), wherein a diffuser flow path is identical with the flow-out direction of said mixed-flow turbine (1) at an inlet portion and is directed in the radial direction at an outlet portion, the improvement wherein the diffuser flow path is curved in the radial direction in the vicinity of the outlet (9) of said mixed-flow turbine (1), and guide vanes (11) each having a height such that a minimum inlet radius (r_a) thereof is larger than a maximum radius (r_b) at the outlet of said mixed-flow turbine (1) are arranged in the form of a circular wing row over the whole flow path surface of the diffuser plate (4) located toward a side plate.

3. In a mixed-flow compressor having a mixed-flow turbine (1) in which a flow-out direction in a meridional plane of the turbine (1) is slanted from a radial direction, and a pair of diffuser plates (4, 5) provided downstream of the mixed-flow turbine (1), wherein a diffuser flow path is identical with the flow-out direction of said mixed-flow turbine (1) at an inlet portion and is directed in the radial direction at an outlet portion, the improvement wherein guide vanes (11) each having a height such that a minimum inlet radius (r_a) thereof is larger than a maximum radius (r_b) at the outlet of said mixed-flow turbine (1) are arranged in the form of a circular wing row over the whole flow path surface of the diffuser plate (4) located toward a side plate.

4. The compressor according to one of the claims 1 to 3, wherein an inlet angle (α_1) and an outlet angle (α_2) of said guide vanes (7, 11) are equal to an average flow angle at a design point of the outlet of said mixed-flow turbine (1).

5. The compressor according to claim 4, wherein the height of said guide vanes (7, 11) is ranged in 20 to 50 % of a width of the flow path.

6. The compressor according to claim 5, wherein a radius of an inlet of said guide vanes (7, 11) is kept constant.

FIG. 1

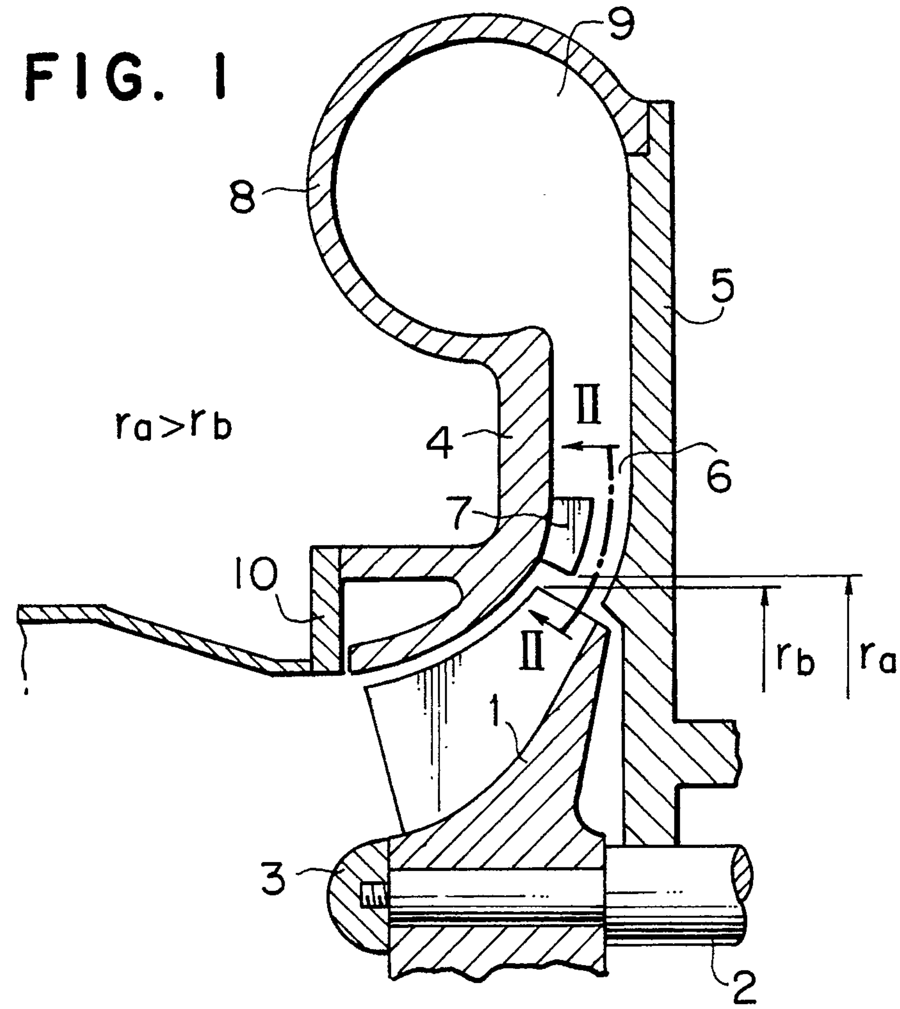


FIG. 2

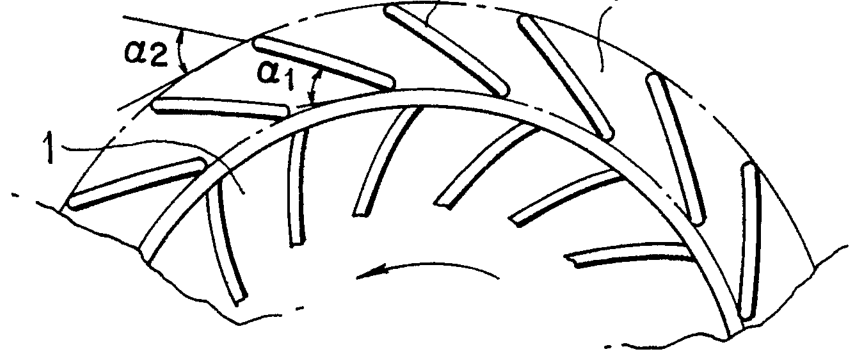


FIG. 3

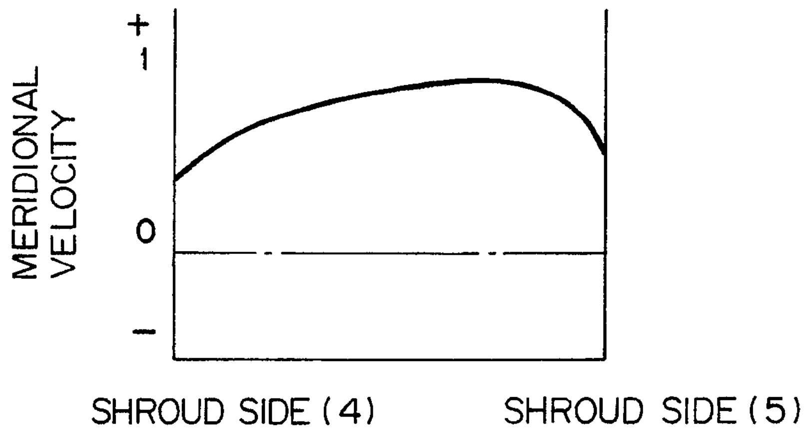

MERIDIONAL
VELOCITY
+
1
0
−
SHROUD SIDE (4)
SHROUD SIDE (5)

FIG. 4

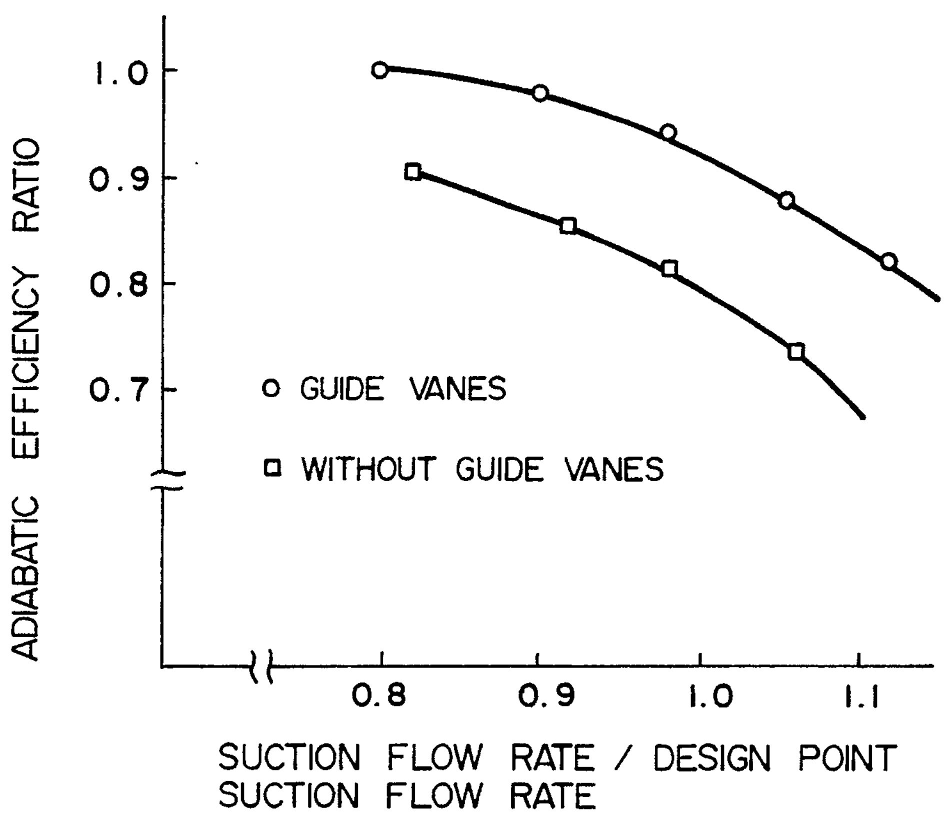

ADIABATIC EFFICIENCY RATIO
1.0
0.9
0.8
0.7
GUIDE VANES
WITHOUT GUIDE VANES
0.8
0.9
1.0
1.1
SUCTION FLOW RATE / DESIGN POINT
SUCTION FLOW RATE

FIG. 5

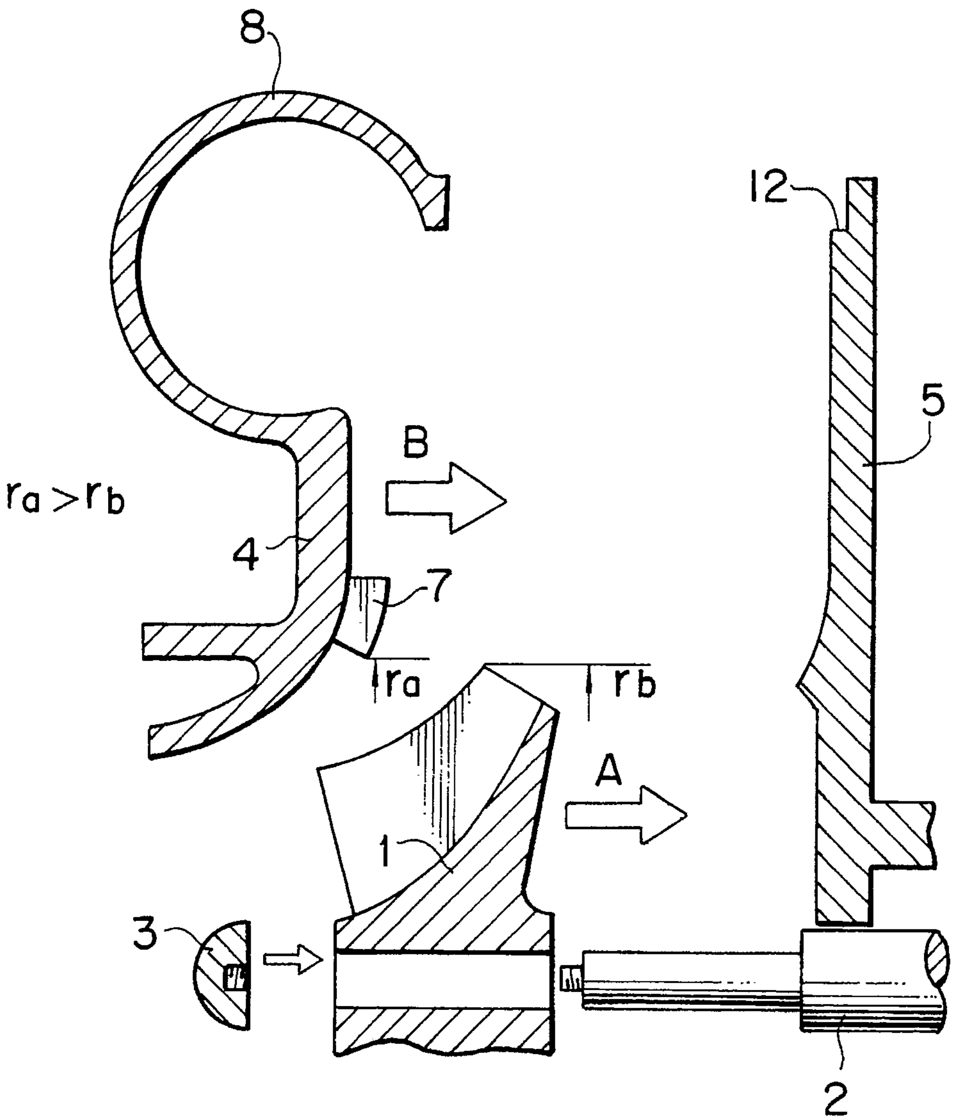


FIG. 7

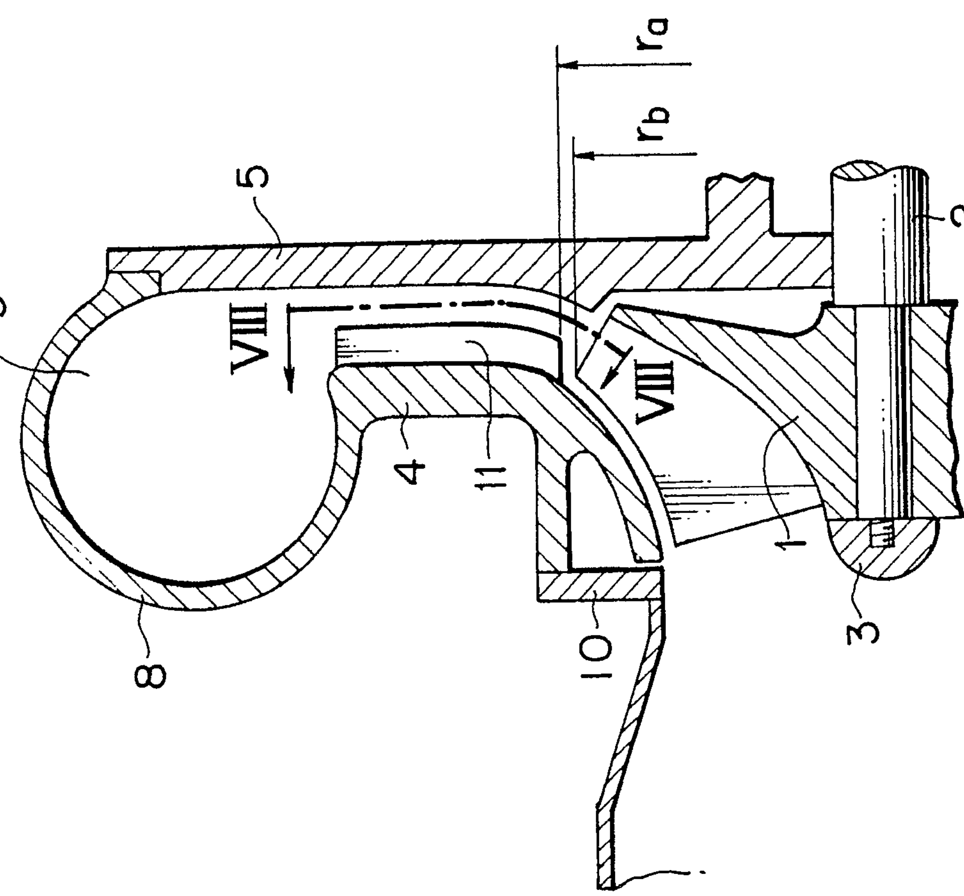


FIG. 6

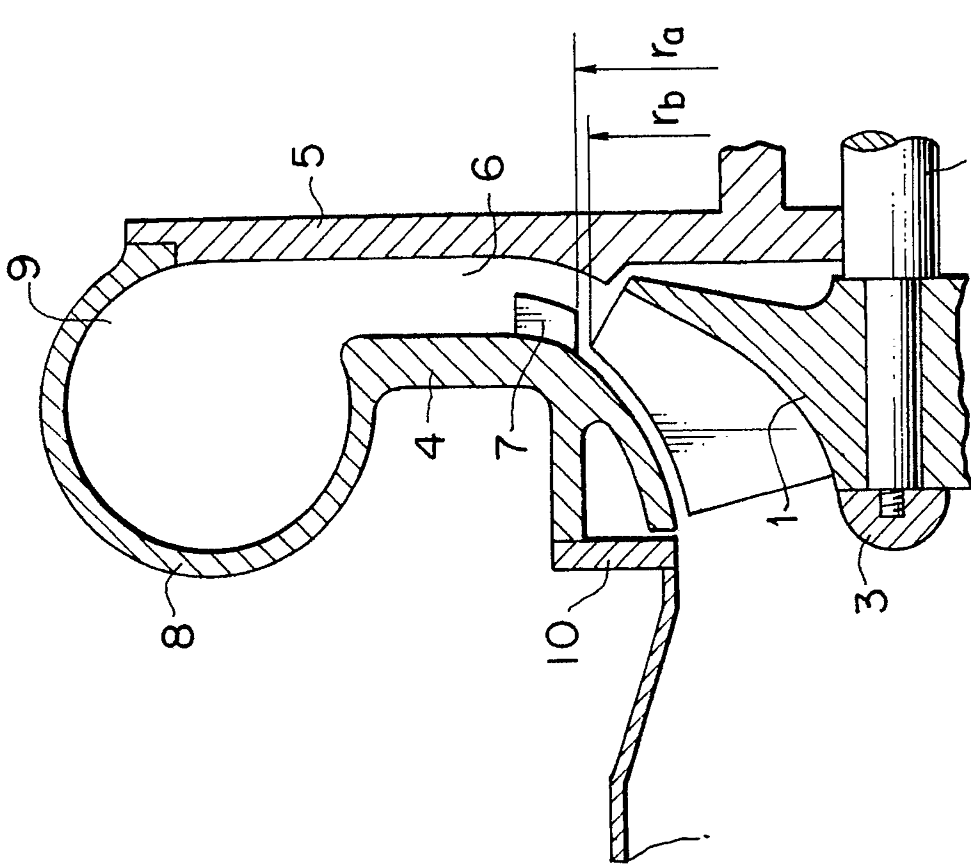


FIG. 8

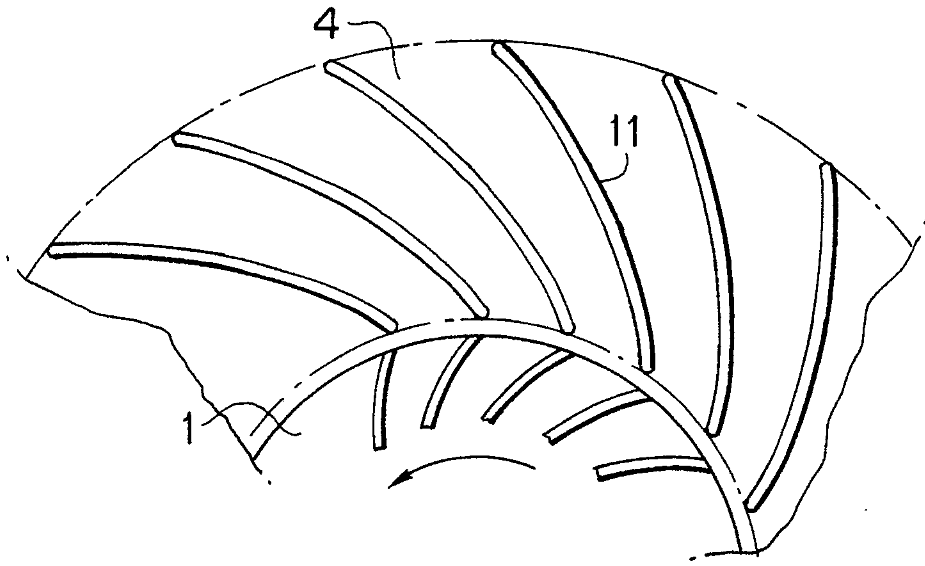
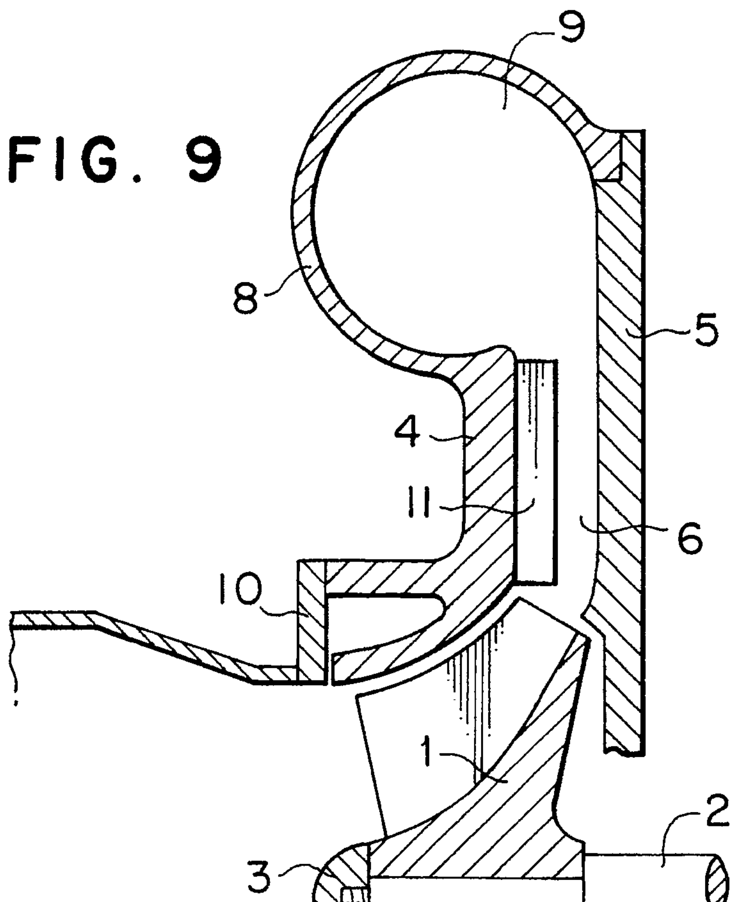


FIG. 9



European Patent Office

EUROPEAN SEARCH REPORT

Application Number

EP 91 10 3850

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
A	US-A-4 850 795 (BANDUKWALLA) * the whole document * – – –	1-4	F 04 D 29/44 F 04 D 17/06 F 04 D 29/62
A	COMPRESSED AIR MAGAZINE,Vol.9,September 1985 Washington,USA. "The X-Flo Compressor-A Machine Whose Time Has Come." Page 30-34.*the whole document – – –	1-3	
A	EP-A-0 201 912 (DRESSSER INDUSTRIES) * page 4, line 23 - page 5, line 29; figure 2 * – – –	1-4	
A	US-A-4 900 225 (WULF) * column 3, lines 20 - 35; figure 2 * – – –	1-3	
A	PATENT ABSTRACTS OF JAPAN vol. 5, no. 80 (M-70)(752) 26 May 1981, & JP-A-56 29099 (HITACHI) 23 March 1981, * the whole document * – – –	4,5	
A	GB-A-6 937 27 (POWER JETS) * page 1, line 75 - page 2, line 57; figure 1 * – – – – –	1-4	
			TECHNICAL FIELDS SEARCHED (Int. Cl.5)
			F 04 D

The present search report has been drawn up for all claims

Place of search	Date of completion of search	Examiner
The Hague	10 June 91	TEERLING J.H.

CATEGORY OF CITED DOCUMENTS

X: particularly relevant if taken alone
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