

[54] **DIFFUSER FOR A CENTRIFUGAL COMPRESSOR**

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[73] Assignee: **General Motors Corporation**, Detroit, Mich.

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[21] Appl. No.: **394,356**

[52] U.S. Cl. **415/211**

[51] Int. Cl. **F01d 1/02, F01d 1/06, F01d 9/04**

[58] Field of Search 415/210, 211, 219 A, 207; 137/15.1, 15.2; 138/39, DIG. 11

[56] **References Cited**

UNITED STATES PATENTS

2,042,550	6/1936	Puffer	415/211
2,596,646	5/1952	Buchi	415/211
2,609,141	9/1952	Ave	415/210
2,708,883	5/1955	Keller et al.	415/207

FOREIGN PATENTS OR APPLICATIONS

309,294	8/1955	Switzerland	415/211
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170,815 10/1921 Great Britain 415/211

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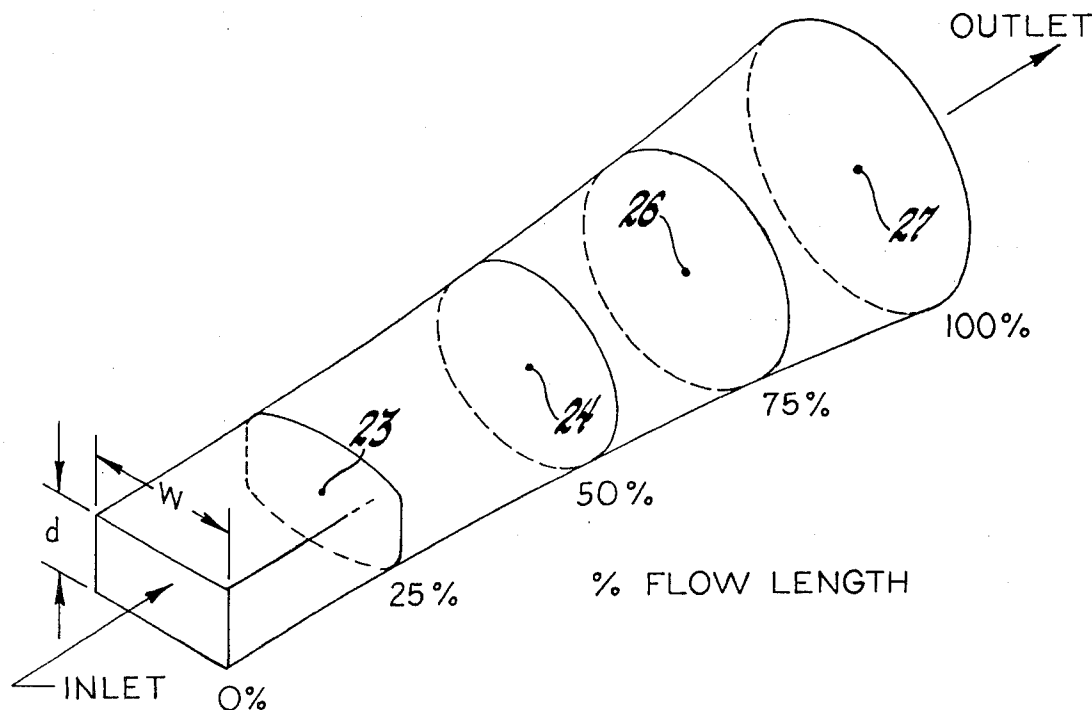
[57] **ABSTRACT**

A diffuser for a centrifugal compressor has a body defining diffusing passages extending tangentially and radially from an annular space around the circumference of the compressor impeller. These passages diverge in the direction of flow and trend smoothly in cross-section from rectangular at the inlet to circular at the outlet in the preferred case. The cross-section of the passage follows the relation

$$|x/a|^s + |y/b|^s = 1,$$

where x and y are coordinates, a and b are width and depth parameters, and s is a shape factor which varies progressively along the diffusing passage from near infinity at the inlet to preferably 2 at the outlet.

4 Claims, 8 Drawing Figures



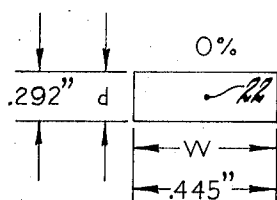


Fig. 3

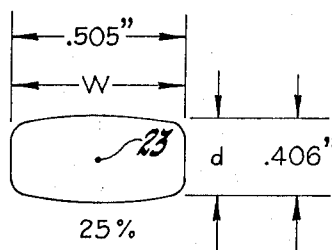


Fig. 4

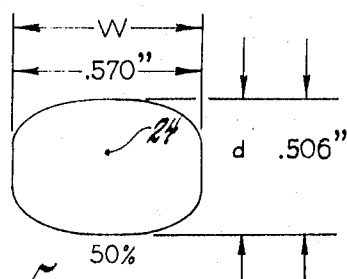


Fig. 5

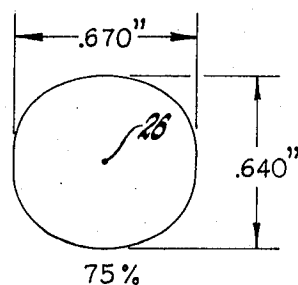


Fig. 6

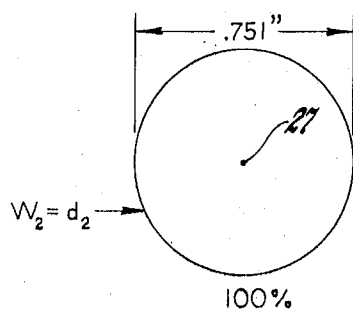


Fig. 7

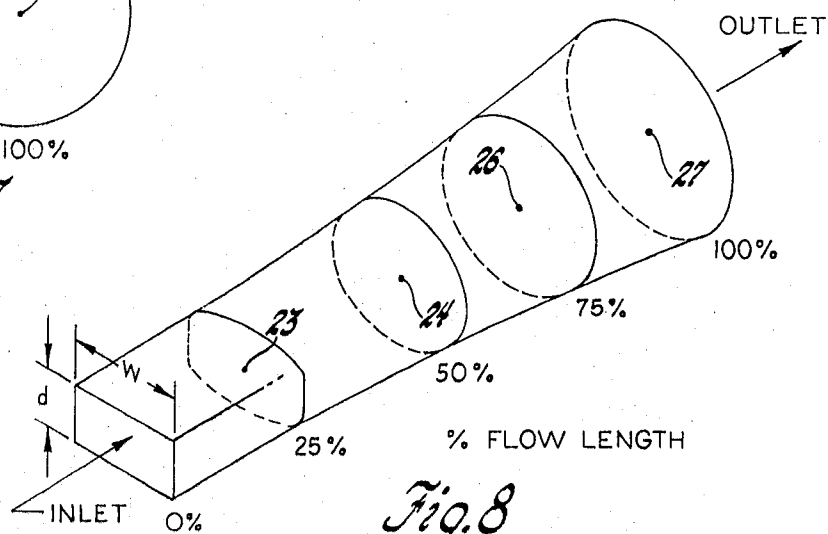


Fig. 8

DIFFUSER FOR A CENTRIFUGAL COMPRESSOR

My invention is directed to improvements in diffusers for centrifugal compressors and the like, and particularly to a diffuser having some of the advantages of both a two-dimensional or three-dimensional rectangular passage diffuser with flattened wedge-type vanes between the diffusing passages and of a three-dimensional diffuser with passages of more or less circular cross-section, which may intersect to provide more or less elliptical edges at the intersections of the passages. Particularly, my invention is directed to a diffuser in which the diffusing passages have rectangular inlets and have a gradual transition to an elliptical (including circular) outlet.

An object of the invention is to improve the efficiency (pressure recovery) and flow range of a diffuser for a centrifugal compressor. A further object is to provide a diffuser having smooth flow characteristics with transition from rectangular to elliptical cross-section in the diffuser passages. A further object is to provide a diffuser having the flow range advantages of the rectangular inlet with a conformation providing a relatively large hydraulic radius downstream from the inlet for a given flow area, with smooth transition from a rectangular form to elliptical. A still further object is to provide greater freedom and certainty in the design of diffusers.

The nature of my invention and its advantages will be clear to those skilled in the art from the succeeding detailed description of the preferred embodiment of the invention and the accompanying drawings.

FIG. 1 is a generally radial partial sectional view of a centrifugal compressor, taken on a surface indicated by the line 1—1 in FIG. 2.

FIG. 2 is a partial transverse sectional view of the compressor stator taken on a surface indicated by the line 2—2 in FIG. 1.

FIGS. 3, 4, 5, 6, and 7 are diagrammatic illustrations of successive cross-sections of a typical diffuser passage.

FIG. 8 is an axonometric illustration of the change in contour of a diffuser passage in accordance with FIGS. 3 through 7.

Referring first to FIGS. 1 and 2, a typical centrifugal compressor 2 includes a rotor or impeller 3 including a hub or disk 4 rotatable about an axis contained in the plane of the figure. An annular array of impeller blades 6 extending from the hub receive air entering generally axially of the compressor through an inlet 7 and discharge it into a vaneless space 8. The impeller is mounted in a stator 9 comprising a rear plate 10 and a front plate 11. The rear plate mounts a bearing 12 for a shaft 14 by which the impeller 3 is driven. The rear plate extends close to the rear face of the impeller 4 and the front plate bears forwardly adjacent the tips of the blades 6 to define the annular air inlet 7 between the front plate and hub.

The portion of the stator 9 radially outward of the vaneless space 8 is a diffuser 15 which defines generally tangentially and radially extending diffusing passages 16 which terminate in an annular outer space 18 between the front and rear plates.

The manner in which the diffusing passages are manufactured is immaterial to the invention; they may be machined or may be cast, for instance. A numerically-controlled machine may be programmed to generate the passages or to generate a master form having the

shape of the passage. Preferably, each passage is formed half in the rear surface of the front plate and half in the front surface of the rear plate, these plates meeting along a joining plane 19. As so far described, the compressor may be regarded as of known type, an example of such compressors being described in Atkinson U.S. Pat. No. 2,819,012 issued Jan. 7, 1958. My invention is specifically directed to the conformation of the diffusing passages 16.

In operation of such a compressor, the impeller 3 is rotated at high speed to pump a gas, which may be air and which will be so termed. The air is delivered from the impeller at high speed with a considerable radial component of velocity and a greater tangential component. The air then flows generally spirally through the vaneless space 8, which may be of a relatively small radial dimension, into the diffusing passages 16 which gradually increase in area from the inlet 20 to the outlet 21 of each passage. The divergence of the passages must be gradual to provide for smooth reduction in velocity and consequent conversion of velocity head into static head as the air flows through the diffuser. The air flows from the diffusing passages at relatively low velocity. In an efficient diffuser, most of the velocity head is converted to static head. The air discharged into the outer space 18 may then be collected in a scroll or any other suitable structure for delivery to a point of use.

The width dimension of the diffuser is indicated in FIG. 2 by the arrow and legend w , and the depth dimension by the arrow and legend d in FIG. 1.

In general, prior art diffusers have been characterized by diffusing passages of rectangular or approximately circular cross-section. In typical rectangular diffusers, the diffusing passages may have the same depth (dimension parallel to the axis of rotation of the compressor) through the entire length, but increasing width (dimension in the radial direction) from inlet to outlet. They may, however, diverge instead in width. These are called two-dimensional diffusers. Some rectangular diffusers are three-dimensional; that is, the passages increase in both width and depth in the downstream direction. With diffusing passages of generally circular or elliptical section, the passages ordinarily diverge both radially and axially. Circular cross-section passages for diffusers intersecting to define generally elliptical leading edges at the entrance to the passages have been proposed. For such a diffuser with an initial circular section, there is no problem of transition to a circular cross-section downstream in the diffusing passages. However, with the rectangular inlet which I consider desirable, the solutions to transition into a circular cross-section have not been ideal.

It is understood by those skilled in the art that efficiency in a diffusing passage is promoted by cross-sections approaching the circular, and in any event with rounded corners, for the reason that the wetted perimeter and thus friction are less than for a rectangular passage of the same area. Otherwise stated, the hydraulic radius is greater for a given area. Abrupt changes in the cross-sectional shape of the passages are undesirable, as are abrupt changes in dimensions.

In the ensuing discussion it will be understood that the term "rectangle" embraces the square which is a special case of a rectangle, and the term "ellipse" embraces the circle which is a special case of an ellipse.

There have been proposals of diffusers for centrifugal or mixed-flow compressors in which the initial portion

of the passage is analogous to a rectangle, or approximately circular without merging of the passages, and in which the outlet is circular. The most pertinent of these of which I am aware are in patents to Buchi U.S. Pat. No. 2,596,646, May 13, 1952; Aue U.S. Pat. No. 2,609,141, Sept. 2, 1952; and Leduc U.S. Pat. No. 2,658,338, Nov. 10, 1953. It will be apparent from the succeeding description of the geometry of my diffusing passages that they are different from those referred to.

Proceeding now to this detailed description, FIGS. 3 through 7 show respectively the cross-sections of a representative diffusing passage at 0, 25, 50, 75 and 100 percent of its length, corresponding to the points 22, 23, 24, 26, and 27 marked off on one of the diffusing passages 16 in FIG. 2. At point 22 at 0 percent of the length of the passage (FIG. 3), the width is 0.445 inch and the depth 0.292 inch; the boundaries are rectilinear and the passage is rectangular. At the outlet point 27 shown in FIG. 7, the outline of the passage as extended to this point is circular, with a diameter of 0.751 inch. The cross-section of the passage at both ends and along its length between the ends may be represented by the equation

$$|x/a|^s + |y/b|^s = 1,$$

where x and y are the axial and radial coordinates of the boundary of the cross-section of the passage, a is half the width w of the passage radially of the diffuser, b is half the depth d of the passage axially of the diffuser, and the exponent s is a shape factor varying progressively from a very large value at the inlet to or near two at the outlet. With the exponent equal to two, the curve defined by this relation is an ellipse, and if a and b are equal, it is a circle. As the exponent increases, the cross-section deviates progressively from the elliptical shape and approaches the rectangle as a limiting case, the relation giving a true rectangle when the exponent s reaches infinity. When the value of s is greater than a hundred, the outline is substantially rectangular. Incidentally, this curve has been termed a "superellipse."

The initial value of passage depth d is primarily a matter of the axial dimension of the outlet of the impeller. The value of the width dimension w depends primarily upon the number of diffusing passages considered desirable for a particular compressor and is also affected by the angle between the passage centerline and the radial direction. This is true for rectangular inlet diffusers in general. As will be seen in FIG. 2, the diffusing passages 16 are separated by a knife edge or wedge 28 at the leading edge of the vane or separating structure 30 between the passages 16. The inner surface of the vane up to the point 22 abreast of the next downstream vane is preferably a surface generated by a line parallel to the axis of the rotation of the compressor so that the inner surface of the vane between point 28 and point 32 shown in FIG. 2 is a type of cylindrical surface, preferably something on the order of a spiral cylinder. This accords with the outwardly spiralling flow of air from the periphery of the impeller.

Thus, at point 22 the outer and inner boundaries of the diffusing passage are defined by straight lines and the forward and rear boundaries are defined by straight lines, as illustrated in FIG. 3. The rectangle may be considered to be generated by substituting the values $w/2$ and $d/2$ and an exponent greater than 1,000 in the equation stated above. Now, if the exponent s is allowed to decrease, the cross-section of the passage begins its transition into an ellipse. As shown in FIG. 4,

at the 25 percent point indicated at 23 in FIG. 2, the exponent s is decreased to 100 and the width and depth increase to 0.505 and 0.406 inches respectively. At the 50 percent point 24 the exponent may be 8 with 0.570 inch width and 0.506 inch depth. At the 75 percent point 26, the exponent has decreased to 2.05, the width is 0.670 and depth 0.640, and the passage is closely approaching a circle. Finally, at the 100 percent point for outlet 27 the exponent is diminished to 2, width and depth are equal, and the curve is a circle of diameter 0.751 inch.

It is to be understood that the specific dimensions recited are those of a particular diffuser designed for a particular compressor having particular dimensions, flow rates, and pressure rise. Values for different compressors will vary. However, the values stated are considered to be informative and illustrative of the nature of the diffusing passages developed by the application of the principles of the invention.

In designing the diffuser, the inlet dimensions are determined by the dimensions of the outer boundary of the vaneless space around the impeller, the number of passages, and the relation between radial and tangential velocity of the discharged air. This is well understood and is a dimension problem common to all diffusers with rectangular inlets to diffuser passages.

The amount of diffusion required will determine the desired ratio of the outlet area of the diffusing passage to its inlet area. The angle of divergence may follow the usual practice, ordinarily not exceeding about 6°. The length of the diffusing passages is largely determined by the area ratio taken in connection, of course, with the maximum desired angle of divergence.

It is apparent that the area should increase progressively and at a relatively constant rate. The factors which determine the area at any cross-section of the area are the width and depth and the exponent s . The designer thus has three factors with which to work in securing the desired divergence of the passage. It is highly desirable that both width and depth increase along the passage from inlet to outlet and that the shape of the passage trend smoothly from the rectangle into the ultimate ellipse. Thus, the parameters a and b in the cross-section equation increase along the centerline of the passage and the exponent s decreases. The nature of such variation in a typical case is illustrated by the specific example described above. In connection with this example, it is noted that the ratio of w to d decreases from inlet to outlet but this results from the fact that w is initially greater than d . It may also be desirable to mention the areas of the cross-sections of FIGS. 3 to 7 which are, respectively, in square inches, 0.130, 0.205, 0.281, 0.364, and 0.442. It will be seen that these increase approximately linearly with distance.

As indicated above, in designing a specific diffuser, the parameters a , b , and s are under control of the designer, who thus has three factors entering into the area of any cross-section of the passage.

The area of the superellipse

$$|x/a|^s + |y/b|^s = 1$$

may be expressed as $A = kab$, where k is a constant determined by the exponent s . In the range of values of s from 2 to infinity, k ranges from π to 4. Intermediate values may be determined by integration and expressed in a curve or table.

The function is a smooth one passing through the following points:

s	2	3	4	6	10	16	30	100
k	3.14	3.53	3.71	3.86	3.95	3.98	3.99	4.00

The mean line of the passage which passes through the points 22, 23, 24, 26, and 27 at the center of the cross-sections may be a straight line or a curved line as desired. In the particular case of the diffuser illustrated, it is a straight line from point 22 to point 27. Because of the incurving toward the rotor of the portion of the outer boundary between the leading edge 28 and point 32, the initial portion of the mean line may be considered to have a slight curvature toward the center of rotation of the rotor.

The diffusing passages so far described diverge from the inlet 22 to the outlet. In this case, the throat of the diffuser is at the inlet, that is at point 22. In some cases with supersonic inlet flow, a diffuser may converge initially to a throat and then diverge. In such case, the diffuser may have decreasing values of the exponent s from the inlet to the outlet as previously described, but differ from that previously non-flesh in that the area of the passage decreases from the inlet to the throat and then increases from the throat to the outlet.

It should be apparent to those skilled in the art from the foregoing discussion that the principles of my invention provide for a diffuser having a highly desirable balance of the properties of rectangular passage diffusers and of the so-called pipe diffusers in which the passages are approximately circular from end to end. The principles of the invention provide for smooth transition under easily determined mathematical conditions from rectangular to elliptical through the diffusing passage.

The detailed description of the preferred embodiment of the invention for the purpose of explaining the principles thereof is not to be considered as limiting or restricting the invention, since many modifications may be made by the exercise of skill in the art.

I claim:

1. A diffuser for a centrifugal compressor comprising a body defining a central space of circular cross-section to receive a centrifugal impeller and defining an annular array of diffusing passages extending generally radially and tangentially from the periphery of the central space, the passages being substantially rectangular at the inlets and substantially elliptical at the outlets and having cross-sections trending consistently from the inlet to the outlet according to the relation that the absolute value of the quantity x/a raised to power s plus the absolute value of the quantity y/b raised to power s equals unity, where x and y are the coordinates of the boundary of a cross-section of the passage, a is half the width of the passage radially of the diffuser and b is half the depth of the passage axially of the diffuser at the cross-section, and the exponent s is a shape factor varying progressively in value from a large value at the inlet to substantially two at the outlet, and the ratio of a to b converging toward unity toward the outlet.

2. A diffuser for a centrifugal compressor comprising a body defining a central space of circular cross-section to receive a centrifugal impeller and defining an annular array of diffusing passages extending generally radially and tangentially from the periphery of the central space, the passages being rectangular at the inlets and

substantially elliptical at the outlets and having cross-sections trending consistently from the inlet to the outlet according to the relation that the absolute value of the quantity x/a raised to power s plus the absolute value of the quantity y/b raised to power s equals unity, where x and y are the coordinates of the boundary of a cross-section of the passage, a is half the width of the passage radially of the diffuser and b is half the depth of the passage axially of the diffuser at the cross-section, and the exponent s is a shape factor varying progressively in value from a large value at the inlet to near two at the outlet, the values of a and b varying smoothly from the inlet to the outlet, the values of a , b , and s varying so that the passages vary smoothly in area from the inlet to the outlet, and the ratio of a to b being near unity at the outlet.

3. A diffuser for a centrifugal compressor comprising a body defining a central space of circular cross-section to receive a centrifugal impeller and defining an annular array of diffusing passages extending generally radially and tangentially from the periphery of the central space, the passages being rectangular at the inlets and substantially elliptical at the outlets and having cross-sections trending consistently from the inlet to the outlet according to the relation that the absolute value of the quantity x/a raised to power s plus the absolute value of the quantity y/b raised to power s equals unity, where x and y are the coordinates of the boundary of a cross-section of the passage, a is half the width of the passage radially of the diffuser and b is half the depth of the passage axially of the diffuser at the cross-section, and the exponent s is a shape factor varying progressively in value from a large value at the inlet to near two at the outlet, the values of a and b increasing smoothly from a throat to the outlet, the values of a , b , and s varying so that the passages increase progressively in area from the throat to the outlet, and the ratio of aa to b being near unity at the outlet.

4. A diffuser for a centrifugal compressor comprising a body defining a central space of circular cross-section to receive a centrifugal impeller and defining an annular array of diffusing passages extending generally radially and tangentially from the periphery of the central space, the passages being rectangular at the inlets and substantially elliptical at the outlets and having cross-sections trending consistently from the inlet to the outlet according to the relation that the absolute value of the quantity x/a raised to power s plus the absolute value of the quantity y/b raised to power s equals unity, where x and y are the coordinates of the boundary of a cross-section of the passage, a is half the width of the passage radially of the diffuser and b is half the depth of the passage axially of the diffuser at the cross-section, and the exponent s is a shape factor varying progressively in value from a large value at the inlet to near two at the outlet, the values of a and b increasing smoothly from the inlet to the outlet, the values of a , b , and s varying so that the passages increase progressively in area from the inlet to the outlet, and the ratio of a to b being near unity at the outlet.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 3,860,360
DATED : January 14, 1975
INVENTOR(S) : Mason K. Yu

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 5, line 21, "non-flesh" should read -- described --.

Column 6, line 42, "aa" should read -- a --.

Signed and sealed this 27th day of May 1975.

(SEAL)

Attest:

RUTH C. MASON
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents
and Trademarks