

July 4, 1933.

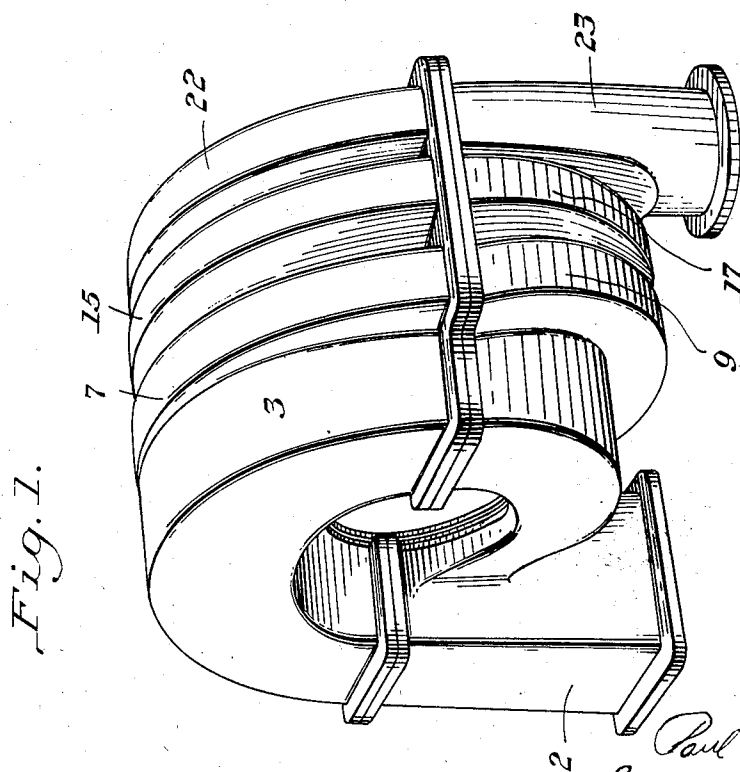
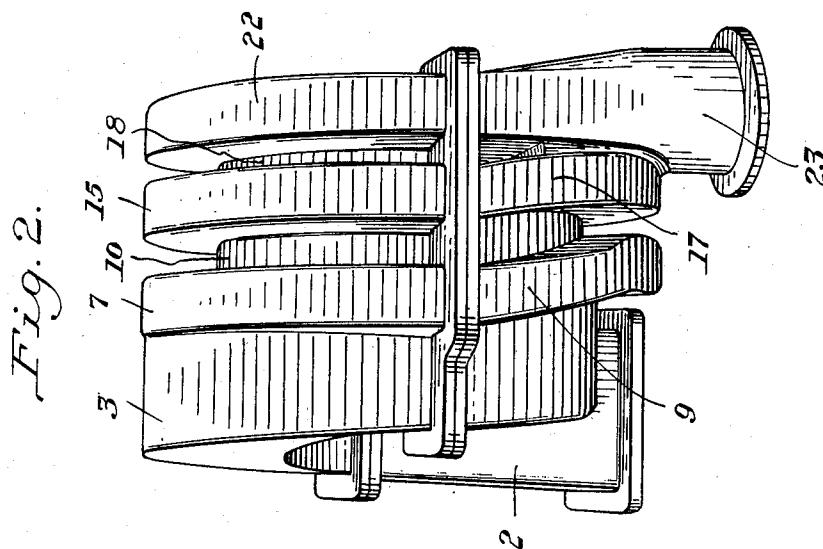
P. E. GOOD

1,917,029

MULTISTAGE ROTARY COMPRESSOR

Filed March 14, 1931

5 Sheets-Sheet 1



INVENTOR
Paul C. Good,
By Lyman S. Bellini, Raymond A. Bellini
Attorneys

July 4, 1933.

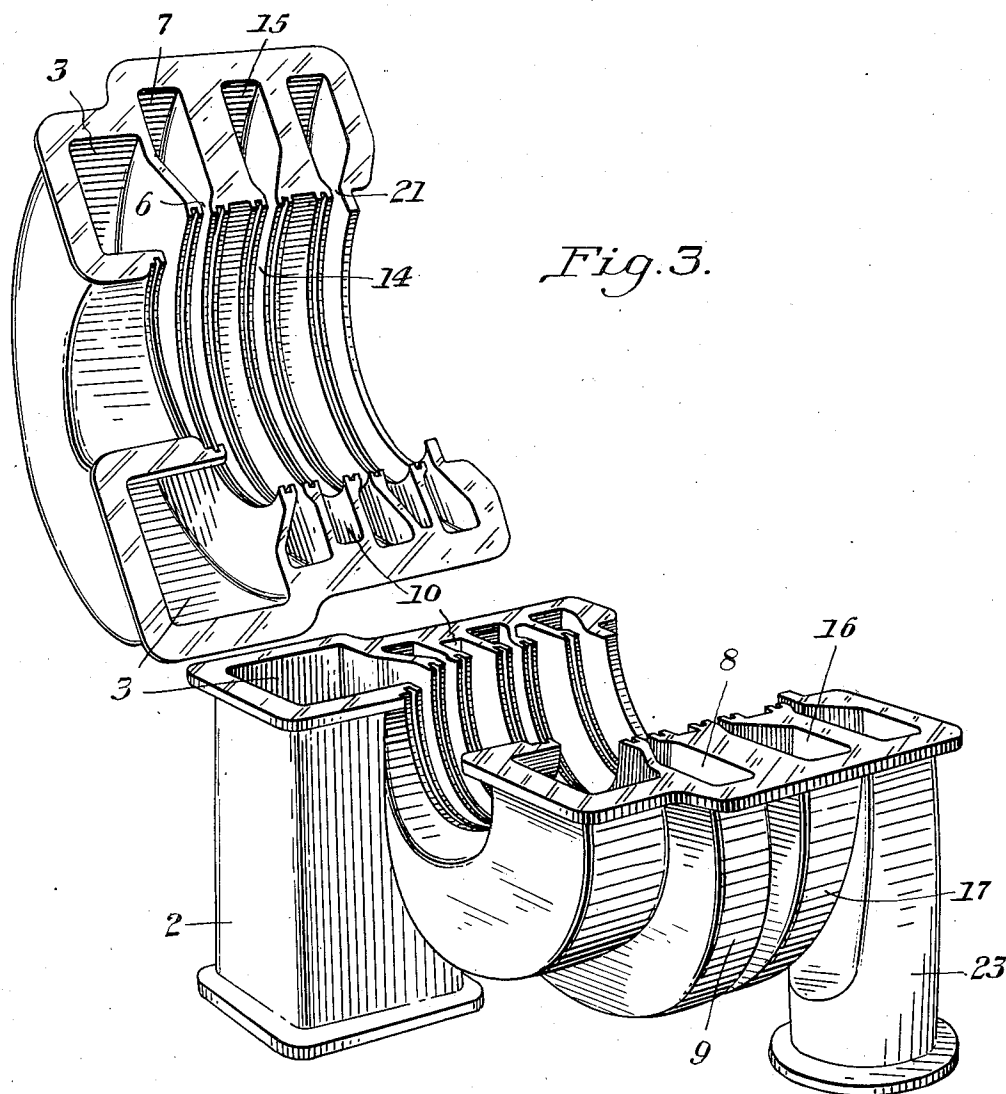
P. E. GOOD

1,917,029

MULTISTAGE ROTARY COMPRESSOR

Filed March 14, 1931

5 Sheets-Sheet 2



INVENTOR
Paul C. Good,
by James Stewart, Carmichael & Blenko
Attorneys

July 4, 1933.

P. E. GOOD

1,917,029

MULTISTAGE ROTARY COMPRESSOR

Filed March 14, 1931

5 Sheets-Sheet 3

Fig. 5.

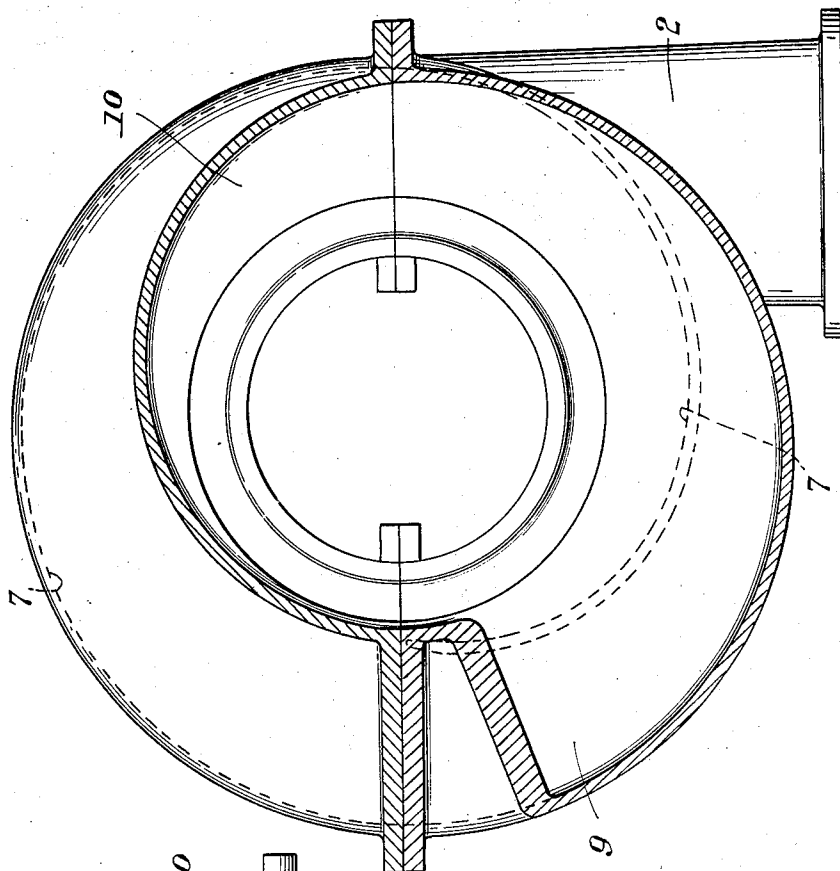
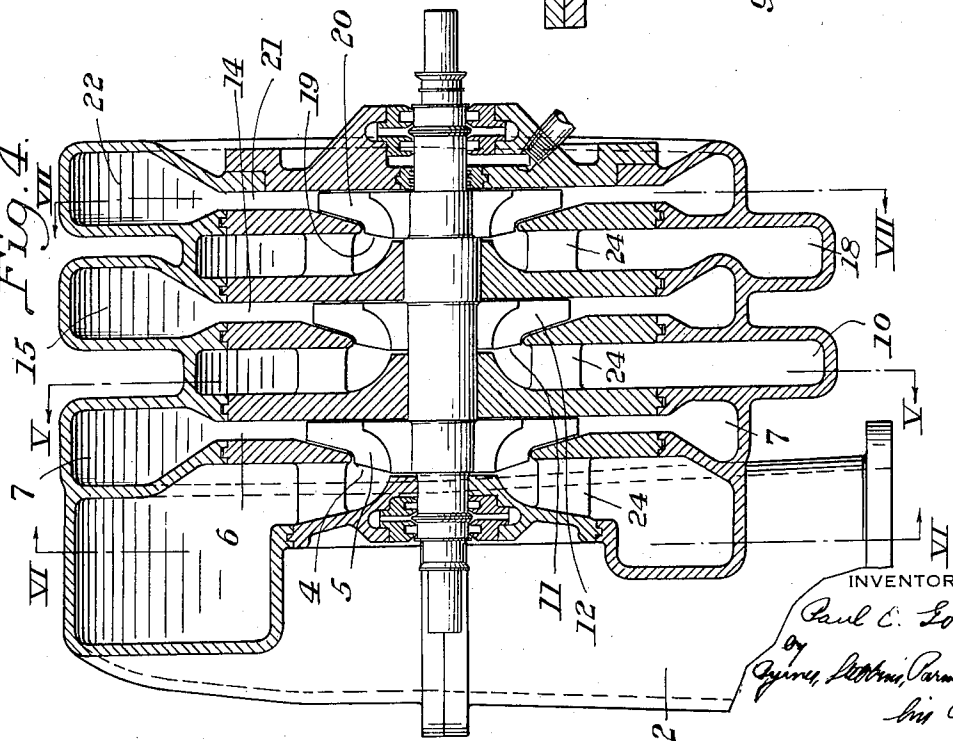


Fig. 4.



INVENTOR

Paul C. Good,
by
James L. Brown, Carmelo R. R. R.
his attys.

July 4, 1933.

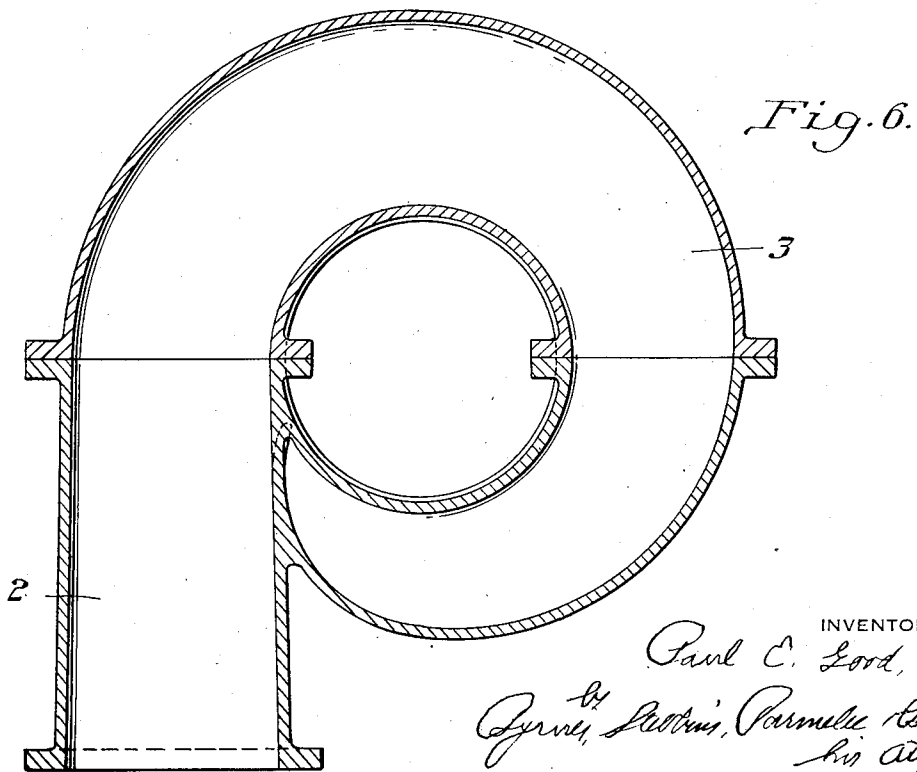
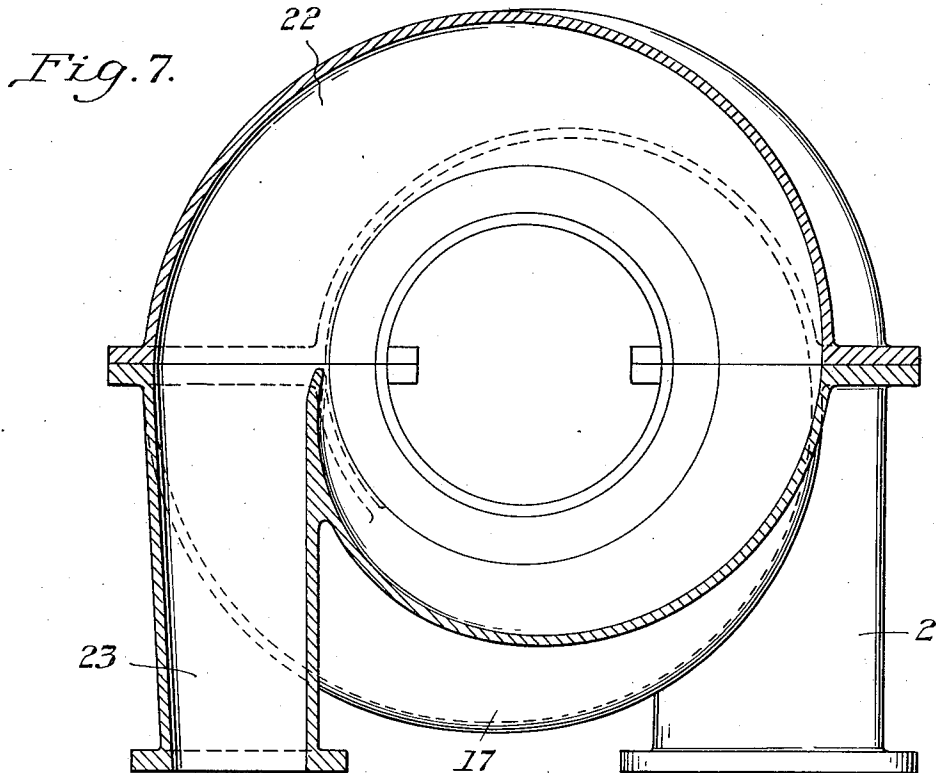
P. E. GOOD

1,917,029

MULTISTAGE ROTARY COMPRESSOR

Filed March 14, 1931.

5 Sheets-Sheet 4



INVENTOR

Paul C. Lord,

by
Lyons, Robbins, Parmelee & Blake,
his attys.

July 4, 1933.

P. E. GOOD

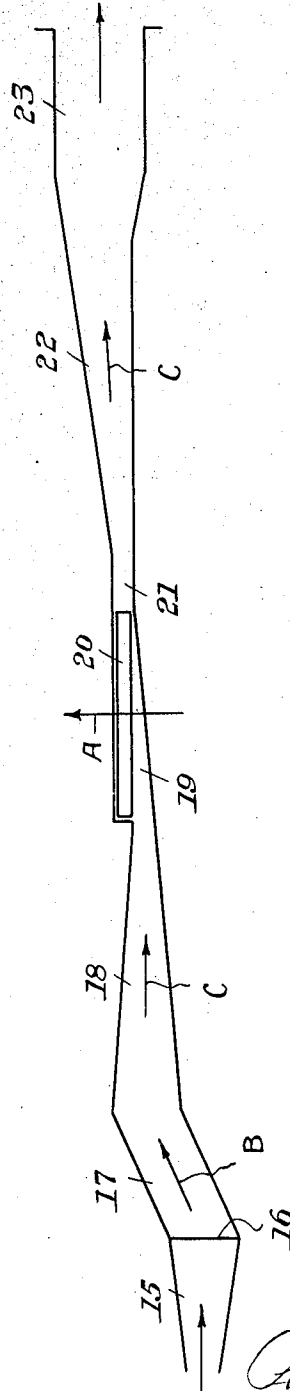
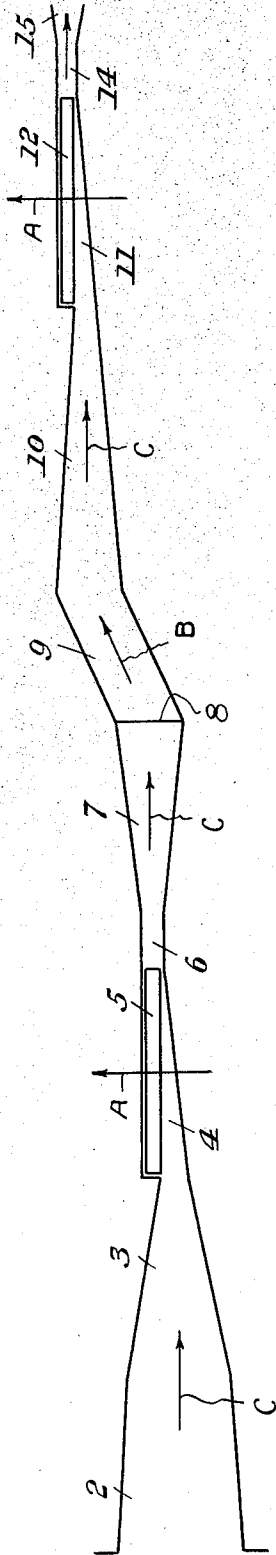
1,917,029

MULTISTAGE ROTARY COMPRESSOR

Filed March 14, 1931

5 Sheets-Sheet 5

Fig. 8.



INVENTOR
Paul E. Good
by James Little Carmichael
his atty

UNITED STATES PATENT OFFICE

PAUL E. GOOD, OF RIVERTON, NEW JERSEY, ASSIGNOR TO ELLIOTT COMPANY, OF
JEANNETTE, PENNSYLVANIA, A CORPORATION OF PENNSYLVANIA

MULTISTAGE ROTARY COMPRESSOR

Application filed March 14, 1931. Serial No. 522,704.

The present invention relates broadly to the art of fluid pressure changing devices, and more particularly to so-called multi-stage devices of the rotating or turbo compressor type.

In many cases, either by reason of high speed driving devices which are readily available, or conservation of space, it is desirable to effect an increase in the pressure of a fluid, such for example as air, by the use of a turbo compressor. Where extremely high pressures are desired, these turbo compressors usually take the form of a series of stages operatively connected one to the other in such manner that fluid having its pressure increased in a preceding stage, is delivered to the inlet of the succeeding stage. Normally the conveying means between the stages is in the form of an annulus which, due to the gradually increasing area available by reason of gradually increasing diameter, is effective for decelerating the velocity of the fluid received and therefore increasing the static pressure. This is desirable, inasmuch as with a multi-stage compressor of the centrifugal type it is desired to effect pressure, and not velocity, conditions.

It is also customary in multi-stage compressors of the character referred to to provide the annular passages intermediate the stages with fluid directing vanes having for their primary purpose to effect a guiding of the fluid and prevent the formation of a high velocity vortex at the inlet of a succeeding stage. Such a vortex would give rise to a centrifugal action opposed to the preceding stage and to a greater or lesser extent nullify the pressure increment which could be realized in the apparatus. Such guide vanes therefore have necessarily been present in one form or another in known multi-stage compressors of the type embodying a series of co-axial impellers in a single housing.

Due to the fact that the fluid leaving a given stage of a centrifugal compressor is rotating at an extremely high velocity, such fluid has a tendency to travel in the path of a spiral in the annular return bend between successive stages. The natural path of a fluid particle in such a return bend is a log-

arithmic spiral. The angular progression of such a spiral in the bend along the axis of the compressor varies in accordance with the conditions under which the compressor is being operated, changing for different speeds, loads and the like. It is therefore apparent that any vanes or guide devices of the character referred to, if correct for one condition of operation are not at the proper angle for another condition of operation. They must therefore be considered as a compromise based on the assumption that a given apparatus will operate a majority of the time under a substantially constant load and at a substantially constant speed.

To those skilled in the art it is well known that such conditions are subject to wide variation, and that the vanes are therefore called upon to effect at different times varying changes in the path which the fluid particles would naturally follow, and to divert such particles into an arbitrary path determined by the vanes.

The fluid stream does not perfectly fill the annular diffuser and there are thus losses due to eddy motion at the boundaries of the fluid stream. In addition to such eddy losses there are surface friction losses which may be considered as arising from a tendency of the fluid particles in immediate contact with the confining surface of the annulus to be at rest relative to that surface, while the fluid particles remote from such surface are traveling at an appreciable velocity. There is thus a relative motion of the molecules in the direction of flow which introduces a resistance to flow or a drag on the moving stream as a whole. It has been determined that under substantially normal conditions of operation with standard types of apparatus the percentage loss due to surface friction may amount to 5.75%, which represents an appreciable reduction in efficiency due to such surface friction.

In addition to losses due to eddy current and surface friction, there are shock losses which, under certain conditions, undoubtedly represent a fairly high proportion of the total losses in the apparatus.

Not only does a multi-stage compressor of

the usual type represent a more or less inefficiently operating structure due to losses of the character referred to and due to a large extent by the guiding vanes necessarily supplied, but it requires accurate machining in order to make proper provision for such vanes and the proper cooperation of the impellers therewith.

It is one of the objects of the present invention to provide for multi-stage pressure increase in a single housing in which such guide vanes are not required and in which the stream of fluid in passing from one stage to the next progresses in a predetermined and controlled angular direction which does not vary for variation in load or speed. By predetermining the direction and controlling the same, as distinguished from the attempt to modify the tendency of a fluid particle to follow a logarithmic spiral, uniform conditions of operation are obtained and maintained.

It is a further object of the present invention to replace the annular diffuser with its metal core across which the fluid particles must pass, with a coreless channel in which there is a solid or undivided stream of fluid. Instead therefore of having a stationary core adjacent which the fluid particles are substantially at rest, there is provided a moving core in which the fluid particles have a maximum velocity. There is thus completely eliminated the surface friction due to such an inner core as necessarily exists in a multi-stage turbo compressor of the conventional type.

It is a further object of the present invention to provide a multi-stage apparatus which avoids entirely sharp bends in the direction of travel of the fluid flow. To attain this object I preferably discharge the fluid from the impeller of any stage into a diffuser which discharges into a volute or snail shell increasing or progressing in cross sectional area in a direction circumferentially of the impeller. Since the volume of fluid is continuously increasing around the periphery of the impeller, starting from any assumed point, the farther one goes from such point in a direction circumferentially of the impeller, the greater is the volume in the direction of motion. The increase in cross sectional area of the discharge volute preferably increases in accordance with a substantially uniform law and in accordance with the increase in the volume of the fluid which it must handle, each portion of the volute handling a proportionate part of the charge as received from the impeller. This discharge volute in turn delivers its fluid volume through definite transfer means into an inlet volute of successively decreasing cross sectional area, which commences to converge after the point of discharge into the inlet of the next succeeding impeller is attained. As the volute progresses circumferentially, the need for additional area disap-

pears because of fluid admission into the impeller, and the volute therefore converges preferably in exactly the proportion that the fluid is delivered into the inlet of the succeeding stage, thereby being effective for proportionately dividing the fluid in accordance with its circumferential progression.

Such a discharge volute and inlet volute are provided for each stage of the machine. Where it is desirable to have such volutes lie in substantially the parallel planes in which the respective impellers rotate, and since the impellers themselves are necessarily axially offset, it is necessary to make provision for transferring the collected fluid from the region of maximum cross sectional area of the discharge volute into the region of maximum cross sectional area of the inlet volute. This transfer in accordance with the present invention, and as before pointed out, is preferably of such characteristics as to afford a solid or undivided stream which is attained by progressively moving all of the fluid toward a common point in the discharge volute, collecting the fluid at such point, and then transferring the collected fluid from such point to the inlet of a succeeding stage by causing it to travel through a passage having only a fluid core and defining a path progressing simultaneously in a predetermined and controlled axial and circumferential direction. In this respect there is a radical distinction from the annular distributed condition of discharge and delivery in a plurality of divided streams such as occurs in the usual type of apparatus. In accordance with the present invention the transfer zone may extend over any desired number of degrees either more or less than a complete circle, but is preferably only of such length as required to effect the desired axial advancement without abrupt changes in the direction of fluid flow, and may be complete in a comparatively few degrees.

In the following detail description the form of the volute disclosed is one in which the polar vector increases, i. e., one in which the increase in area takes place in the direction of the radius of the impeller. It will be understood, however, that it might be one in which the result is accomplished by widening the volute in a direction substantially parallel to the impeller shaft. It will be understood therefore that the term volute as hereinafter used in the specification and claims is used in a generic sense in accordance with its functional characteristics, and not in the limited sense as defining any particular type or configuration.

In the accompanying drawings there is illustrated a single housing for a multi-stage turbo compressor embodying the features of the present invention. In the drawings:

Figure 1 is a perspective view of a housing

embodying the present invention and possessing the characteristics referred to;

Figure 2 is a view similar to Figure 1 showing in greater detail the location and arrangement of the transfer zones;

Figure 3 is an exploded or opened view showing two halves of a single housing;

Figure 4 is a vertical sectional view through a housing at right angles to the plane of division of the sections in Figure 3;

Figure 5 is a transverse sectional view on the line V—V of Figure 4;

Figure 6 is a transverse sectional view on the line VI—VI of Figure 4;

Figure 7 is a transverse sectional view on the line VII—VII of Figure 4; and

Figure 8 is a diagrammatic view indicating the relationship and characteristic configuration of the various volutes and transfer zones as embodied in the preceding figures.

In the drawings I have illustrated a compressor having three stages. It will be understood, however, that the drawings are for purposes of illustration only and that the utility of the invention is not limited to the number of stages provided in a single housing where the housing is of such structure as to give the advantageous features of operation herein set forth.

In Figure 8 it is to be understood that the showing is entirely diagrammatic. In this figure the arrows A represent axis of rotation of the air, it being understood that in the machine hereinafter more particularly described there is a single axis of rotation for all of the impellers. The arrows B represent what has been before referred to as a controlled axial and circumferential progression such as characterizes the flow through the transfer zones. The arrows C represent circumferential progression and indicate the direction of air flow in the respective volutes. Beyond the relationship that may thus be established, the diagrammatic showing does not represent relative relationship of parts in a commercial structure, but merely the sequence of structural features insofar as they are successively effective for producing the results desired. Thus, while in actual practice an inlet volute by means of which air is delivered to an impeller necessarily extends around the axis of rotation of the impeller for progressively delivering air thereto, the relationship is indicated in the diagram as a straight line sequence. The same is true with respect to the discharge volutes which, in actual practice, extend around the impeller axis but are diagrammatically illustrated for purposes of a clearer understanding as actually following an impeller. This explanation is made to prevent misunderstanding in the further consideration of this particular figure.

Having reference first to Figure 8 of the

drawings in which the structure is diagrammatically illustrated, there is shown an inlet connection 2 which communicates with an inlet volute 3 effective for proportionately dividing the fluid flow in accordance with its circumferential progression in such volute. This inlet volute is shown as extending through substantially 360° for delivering fluid into the eye 4 (Figures 3 and 4) of the first stage impeller 5. It is to be observed at this time that the construction of impellers per se constitutes no part of the present invention. They are therefore only diagrammatically illustrated in the drawings.

The first stage impeller 5 in turn delivers its fluid at an increased pressure and high velocity through a diffuser 6 into a discharge volute 7. This discharge volute is effective for progressively collecting and moving all of the fluid from the impeller 5 toward a common point 8 representing the commencement of a transfer zone 9 which has a controlled circumferential and axial progression and delivers the previously collected fluid into the inlet of an inlet volute 10 communicating with the eye 11 of the second stage impeller 12. This impeller, similarly to the first stage impeller 5, discharges its fluid through a diffuser 14 into a discharge volute 15, similar in all respects to the discharge volute 7 for the first stage and effective for collecting and progressively moving the fluid toward a common point 16. This common point may likewise be considered as being the commencement of a second transfer zone 17 having the same circumferential and axial progression as the transfer zone 9, and delivering all of the collected fluid from the first and second stages into an inlet volute 18, likewise similar in all respects to the inlet volute 10 for the second stage.

This inlet volute due to its decreasing cross sectional area circumferentially of the casing, proportionately divides the fluid in accordance with its circumferential progression and delivers it into the eye 19 of the third stage impeller 20. This impeller, similarly to the impellers 5 and 12 discharges the fluid through a diffuser 21 into a discharge volute 22 which is again similar to the discharge volutes 7 and 15 before described, and increases in cross sectional area as the need for additional area, due to increasing volume of fluid discharged, exists. The discharge volute 22 communicates with an outlet connection 23 by means of which the fluid at its then pressure and velocity may be delivered to any desired point of use.

The invention in its simplest form may be defined as an apparatus for increasing the pressure of fluids which comprises a plurality of pressure producing stages in a single housing with an inlet volute for each stage and an outlet volute for each stage in said housing, with the respective outlet volute for

one stage and inlet volute for a succeeding stage connected by a transfer zone. This transfer zone may obviously be of constant cross sectional area throughout its length for maintaining substantially the same velocity as that at which the fluid is received by it, or may be of either decreasing or increasing cross sectional area in the direction of flow for increasing or decreasing the velocity of the fluid as it travels therethrough. Since its mechanical function, however, is purely one of effecting transfer within the confines of a single housing and therefore in the smallest space possible, it may conveniently be of constant cross sectional area as herein illustrated.

As will be apparent more particularly from Figure 2 of the drawings, each such transfer zone extends through a circumferential distance of approximately 45°, the axial progression being as required to connect the outlet of the discharge volute of one stage to the inlet of the inlet volute of the succeeding stage. I have found that a transfer zone of this length may effect the desired transfer of fluid without any abrupt changes in the direction of fluid flow and without completely reversing the direction of flow as is characteristic of the transfer annuli of multi-stage turbo compressors of the usual type in which the flow passage is outwardly from one stage and then at right angles in the direction axially of the housing and then inwardly to the inlet of the succeeding stage. Each transfer zone in accordance with the present invention therefore, may be considered as a continuation of both a discharge volute and an inlet volute which provides a controlled flow path of fixed circumferential and axial progression for a solid or undivided fluid stream, and located within the physical confines of the outside dimensions of the housing itself.

Since the fluid in passing through such a transfer zone is in a solid stream, it is not subjected to the surface friction losses characteristic of a divided stream of the character provided by a series of eddy current producing direction changing and vortex preventing veins. Also, since the solid stream has a moving core as distinguished from a stationary metallic core of the type usually provided in a multi-stage turbo compressor, the surface friction losses are only those occasioned by the outside confining surfaces or envelope. These surfaces are of materially less extent, as will be readily apparent to those skilled in the art, than the corresponding outer surfaces of an annulus as heretofore provided and extending completely around the housing at substantially its point of maximum diameter.

It will also be apparent that the flow through the transfer zones is always in a

path predetermined by the zones themselves and not influenced or changed by variations in the load on the apparatus. The transfer zones always receive fluid from a discharge volute travelling in a circumferential direction and deliver it to an inlet volute in a circumferential direction. Since they always receive fluid travelling in the same direction, they differ from guide vanes which receive fluid tending naturally to travel in a logarithmic spiral varying with the characteristic operation of the machine, and which tend to change this spiral into an arbitrary path determined by the vane structure. The transfer zones thus operate with a minimum eddy motion and with a minimum shock loss and may be designed to most effectively minimize these losses for any condition of operation of the apparatus.

While I have herein shown a structure in which the fluid at increased pressure passes directly from an outlet volute into an inlet volute, it will be apparent that if desired, the housing may be provided with suitable connections to the transfer zones whereby the fluid may be conducted to an extraneous piece of apparatus effective thereon intermediate the stages. In some cases such an operation is desirable, and I wish it to be understood that the present invention lends itself thereto.

For purposes of simplicity, the invention is shown as comprising a housing of non-cooled type. The problems of cooling compressors, however, are well recognized, and to those skilled in the art it will be obvious that the present casing may be provided with cooling means at the will of the designer, such cooling means, however, not constituting any part of the present invention.

I have also defined the construction as being one which may be completely devoid of vanes of any nature whatsoever. It is to be understood, however, that many designers arbitrarily provide short vanes as indicated at 24, Figure 4, for inlet purposes adjacent the eye of an impeller. The present invention, while not requiring such vanes, may be utilized in connection therewith, the vanes always receiving fluid at a predetermined and constant angle so that they may be designed with this thought in mind. Where the vanes are eliminated, the inlet volute wall may be continued inwardly toward the shaft until the surface thus provided by it would stop any vortex action.

The structure described is one in which the respective discharge volutes and inlet volutes are substantially parallel to the plane of the impellers. It has been pointed out, however, that each transfer zone, which effects the axial and circumferential progression of the fluid stream is a continuation of both a discharge volute and an inlet volute. This will make it readily apparent to those skilled in the art that the parallel relationship is not a lim-

itation with respect to the present invention but merely one form which it may assume. To those skilled in the art, it will be apparent that the volutes need only be effective for carrying out their respective functions and to this end may be structurally of a wide variety of different types and arrangements. Thus, instead of having the discharge volutes in the plane of the impellers, they may be constructed to provide throughout their circumference an axial progression of fluid. The same is true of the inlet volutes, thus making it possible for the volutes themselves to constitute not only collecting and distributing means, but also transfer means. Such an arrangement can be afforded by having the volutes themselves extend spirally of the housing whereby the point of termination of a discharge volute would correspond to the point of inlet of an inlet volute, thus obviating the necessity of distinctively different transfer zones having an axial and circumferential progression different from the axial and circumferential progression of the volutes themselves. In such case, however, there would be an effective transfer intermediate the volutes, which transfer can be considered as a transfer zone even though its exact point of commencement and termination is not susceptible of accurate definition.

Reference has hereinbefore been made to the fact that in a multi-stage compressor of the centrifugal type it is desired to effect pressure, and not velocity, conditions. It will also be apparent from the foregoing description that I have provided a structure including discharge volutes and inlet volutes which are effective for handling the fluid as received from an impeller and as delivered to an impeller respectively. In the ordinary rotary impeller operation, energy is communicated to the air by the acceleration thereof. In other words, the air in passing through the impeller is caused to actually rotate therein. This rotation communicates energy in the form of velocity, and if this velocity is subsequently destroyed, in a substantially frictionless process, for example, the energy will re-appear as static pressure. In other words, energy is convertible into pressure and vice versa. It is apparent that a multi-stage apparatus of the character herein provided is designed for the purpose of obtaining a greater total pressure at the outlet than the pressure which could be produced by any individual impeller. This increase in pressure is a function of the design of the volutes which is such that velocity energy may be transformed intermediate the impeller stages into pressure energy, this transformation being obtainable by not only constructing the discharge volutes, for example, so that they are effective for collecting from the flat diffusers 6, 14 and 21 fluid as delivered thereby, but also by making provision for

such additional cross sectional area as to enable any desired energy transformation to occur. In this manner there is built up in the fluid passing through the apparatus a gradually increasing static pressure which is available at the outlet. In any case, such a transformation from velocity into static pressure is necessarily effected by the flat diffusers 6, 14 and 21 due to their increasing diameters.

It has been pointed out that the volutes and the transfer zones may have such attributes, or that they may be constructed for actually maintaining velocity. It will be understood, however, that as a matter of actual practice, since pressure and not velocity is the condition required, the constructional characteristics will be such as to insure an increase in static pressure at the expense of velocity during the travel of the fluid from one impeller to the next.

The advantages of the invention will be apparent from the foregoing specification and statement of objects taken in connection with the drawings forming a part hereof.

While I have illustrated and described a preferred embodiment, it will be understood that the utility of the invention is not limited to the particular configuration or design disclosed and described, since the invention contemplates characteristic differences of operation which are not dependent on specific structural limitations.

I claim:

1. A device for increasing the pressure of fluids comprising initial, intermediate and final stages, each including an impeller chamber having an impeller therein, a discharge volute and an inlet volute for each of said intermediate stages, and a connection between the discharge volute of one of said intermediate stages and the inlet volute of the succeeding stage, successive cross sections taken along said volutes and connections having substantially the same shape, the dimensions thereof changing only slightly from one section to the next, and the center line of the path defined by the volutes and the connection changing its direction only gradually.

2. A device for increasing the pressure of fluids comprising a plurality of stages including at least an initial and a final stage, each having an impeller chamber with an impeller therein, at least one stage having a discharge volute and the succeeding stage having an inlet volute, and a connection between said volutes adjacent their portions of maximum radius, successive cross sections of said volutes and connection having substantially the same shape, the dimensions thereof changing only slightly between sections and the center line thereof changing its direction only gradually, defining a fluid path characterized by substantially similar contour throughout, and by the absence of

sharp turns and abrupt changes of cross sectional area, thus conforming to the line of fluid flow accompanied by minimum loss.

3. A device for increasing the pressure of fluids comprising a plurality of stages, each having an impeller chamber and an impeller therein, inlet and discharge volutes communicating with said impeller chambers, diffusers between the impeller chambers and the discharge volutes, and connections between the discharge volute of one stage and the inlet volute of the succeeding stage, successive cross-sections of said volutes and connections taken along the line of fluid flow having similar shapes, and differing only slightly in dimensions, the center lines of the volutes and connection changing direction only gradually, defining a fluid path characterized by low losses.

4. A device for increasing the pressure of fluids comprising a plurality of impeller chambers each having an impeller therein, a discharge volute communicating with one of said chambers, an inlet volute communicating with the chamber of the succeeding stage, and a connection between said volutes, said volutes and connection being characterized throughout their length by a similar cross-sectional contour and dimensions which change only gradually between successive transverse sections through the fluid path, the center line of the fluid path changing its direction only gradually.

In testimony whereof I have hereunto set my hand.

PAUL E. GOOD.

20	85
25	90
30	95
35	100
40	105
45	110
50	115
55	120
60	125
65	130