March 2, 1965 K. D. McMAHAN 3,171,353

CENTRIFUGAL FLUID PUMP

Filed Feb. 27, 1962 7 Sheets-Sheet 1

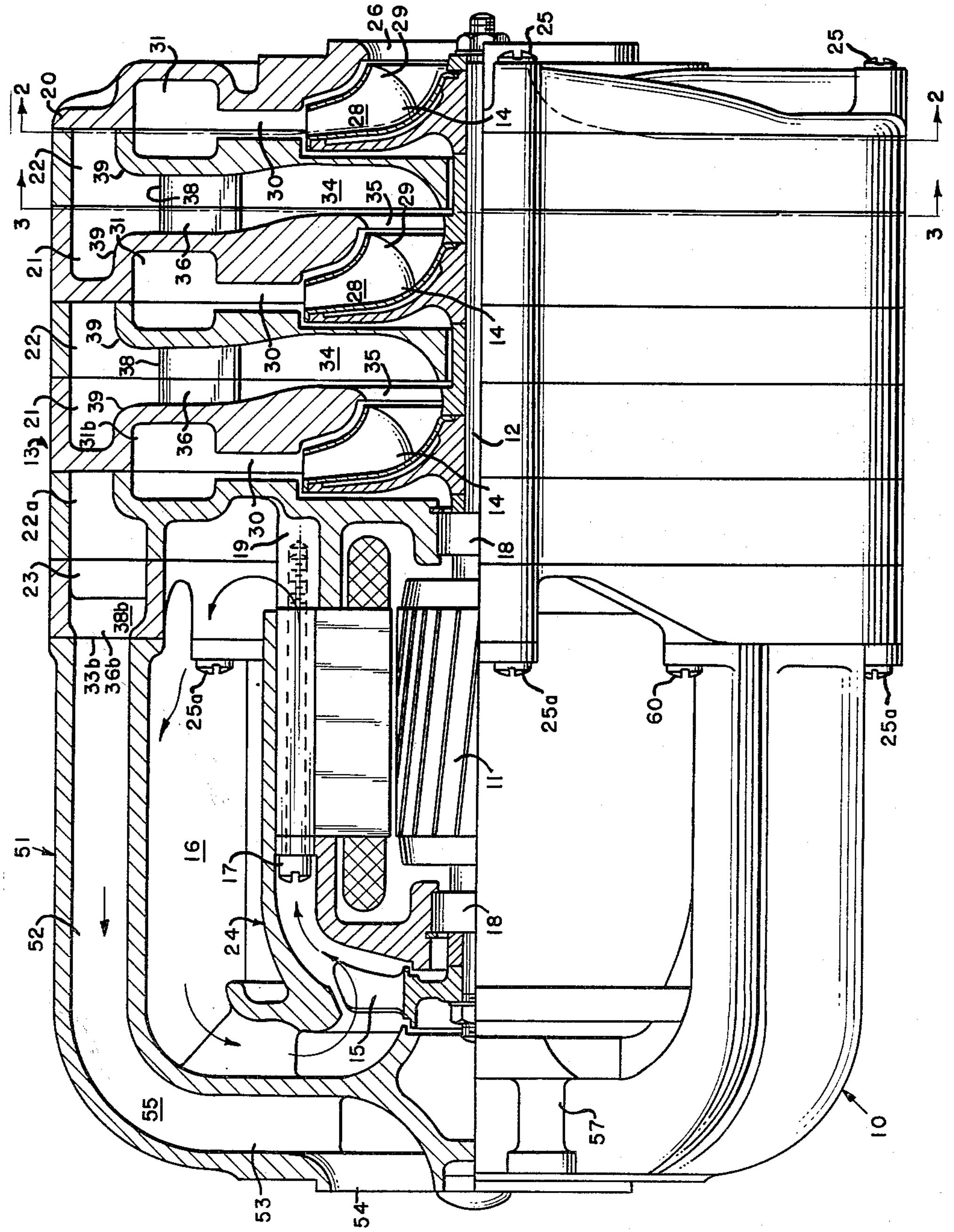

FIG. 1.

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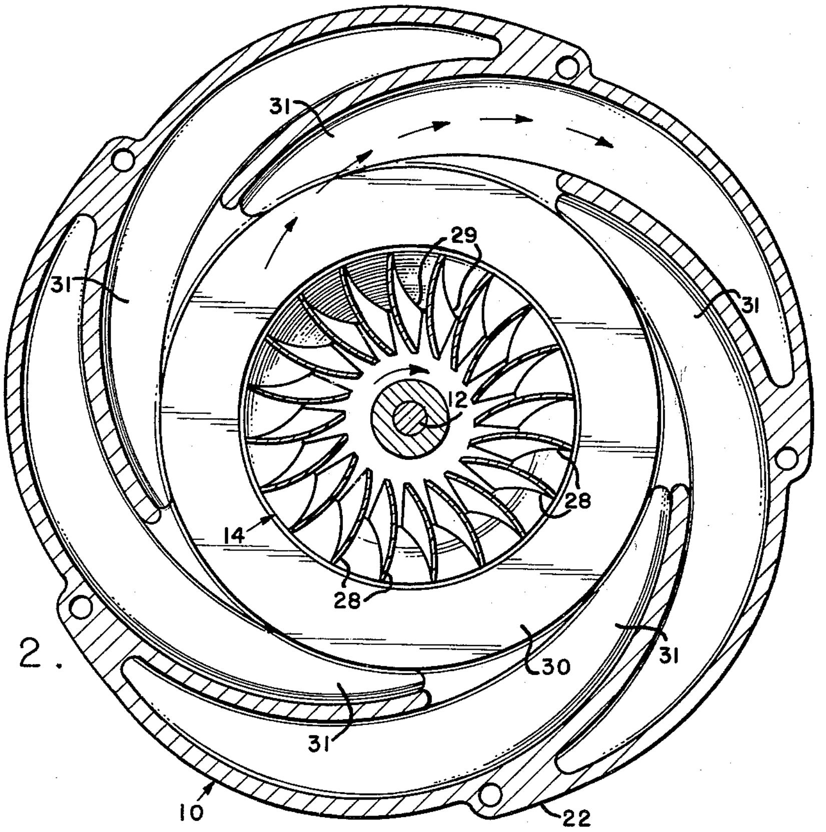

FIG. 2.

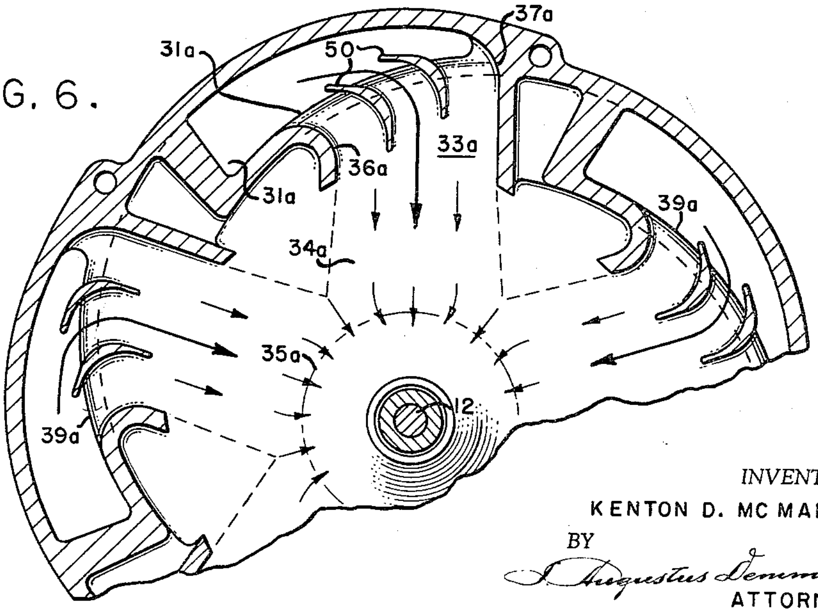

FIG. 6.

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CENTRIFUGAL FLUID PUMP

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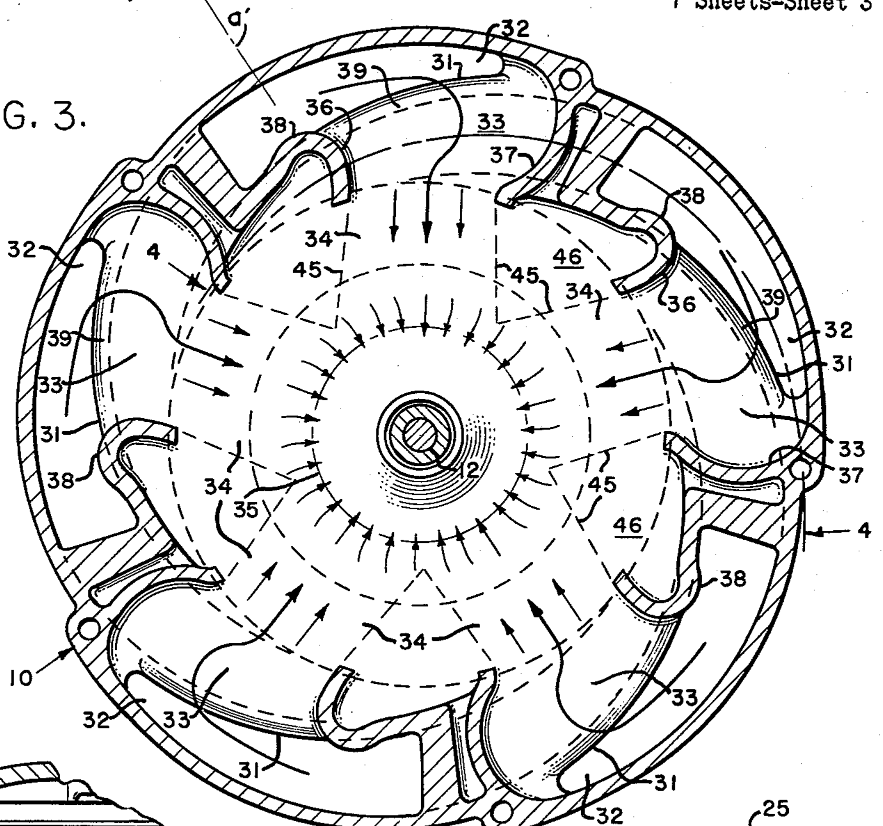
FIG. 3.



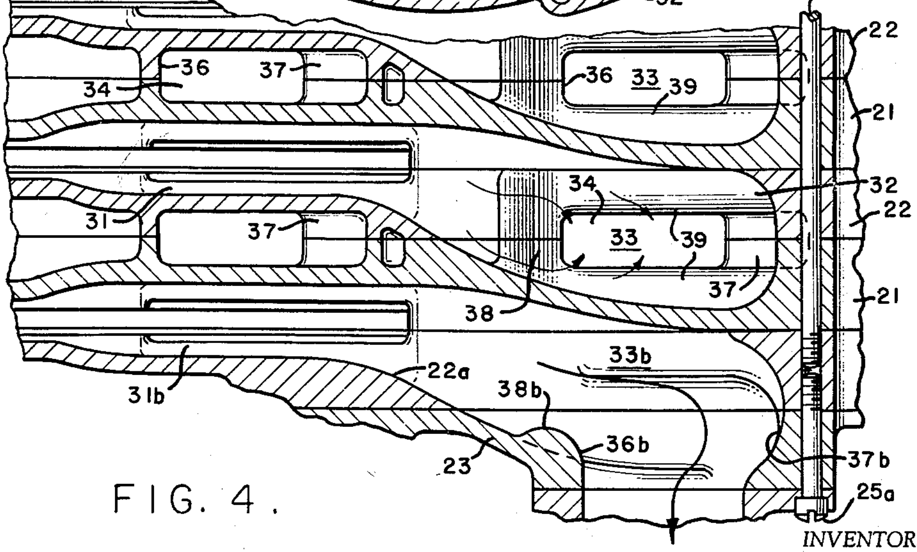


FIG. 4.

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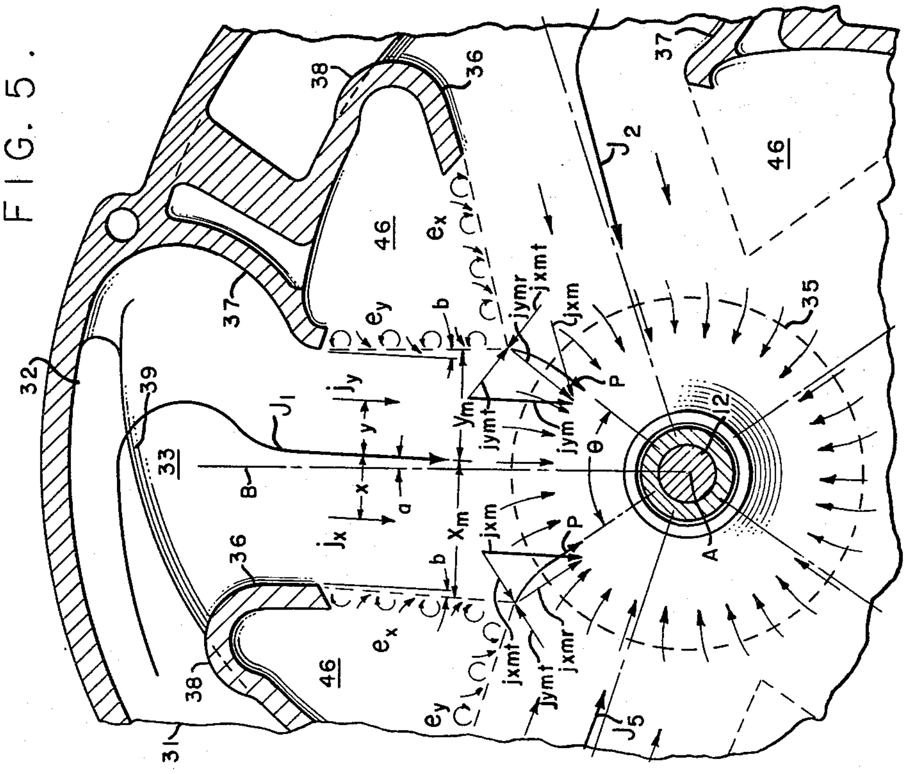

FIG. 5.

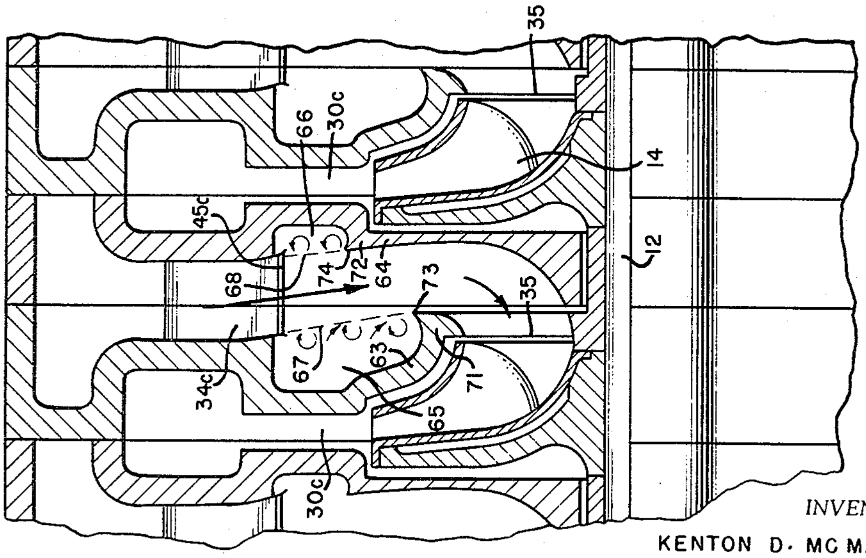

FIG. 9.

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CENTRIFUGAL FLUID PUMP

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FIG. 7.

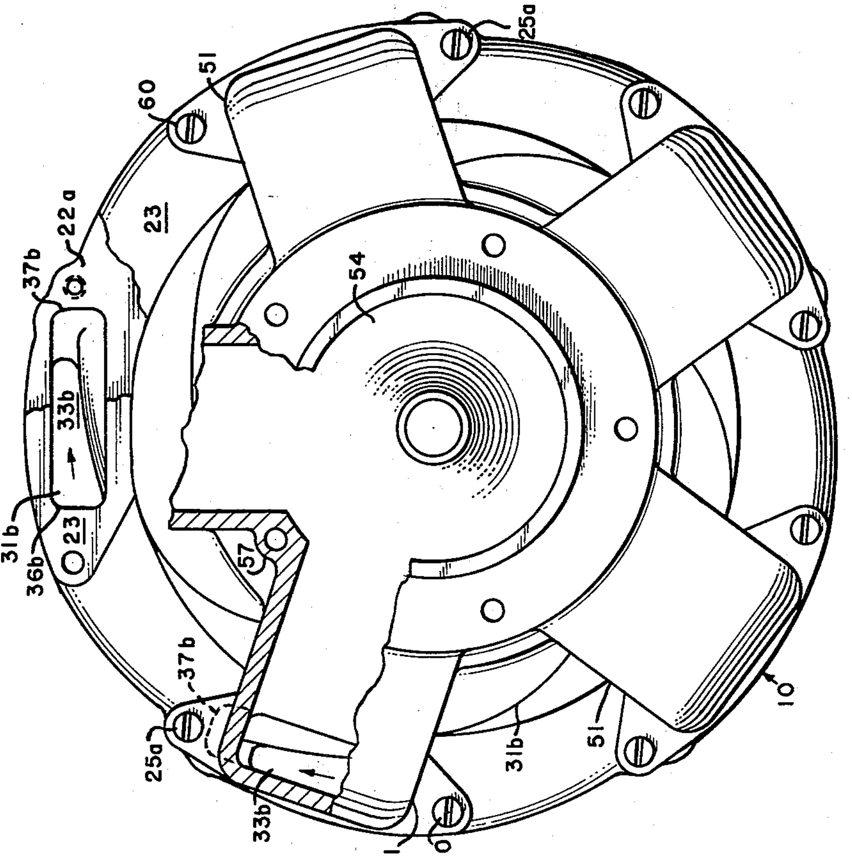
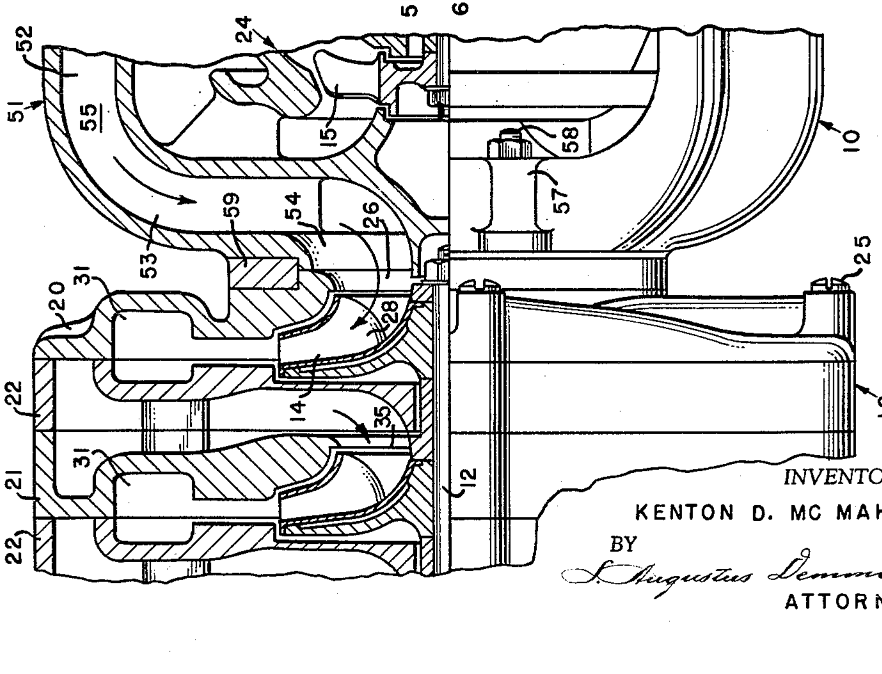


FIG. 8.



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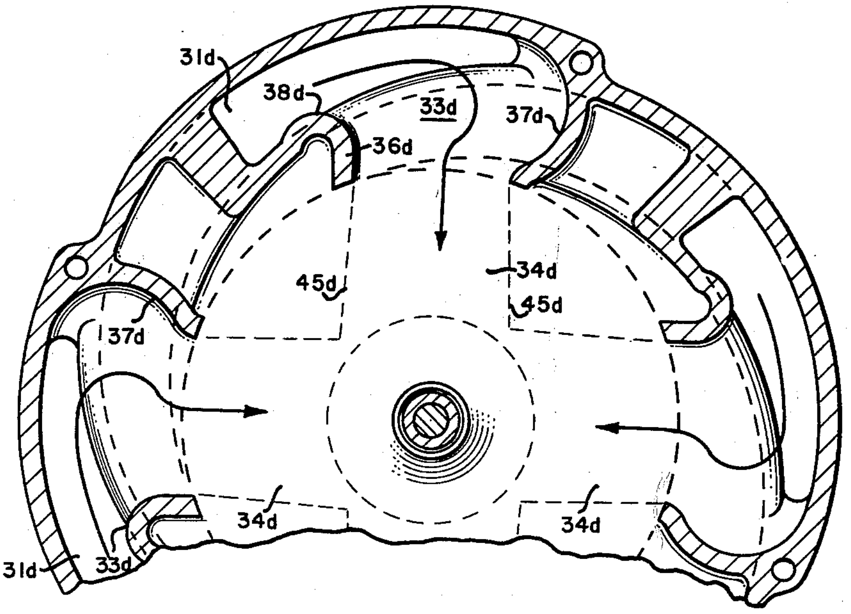

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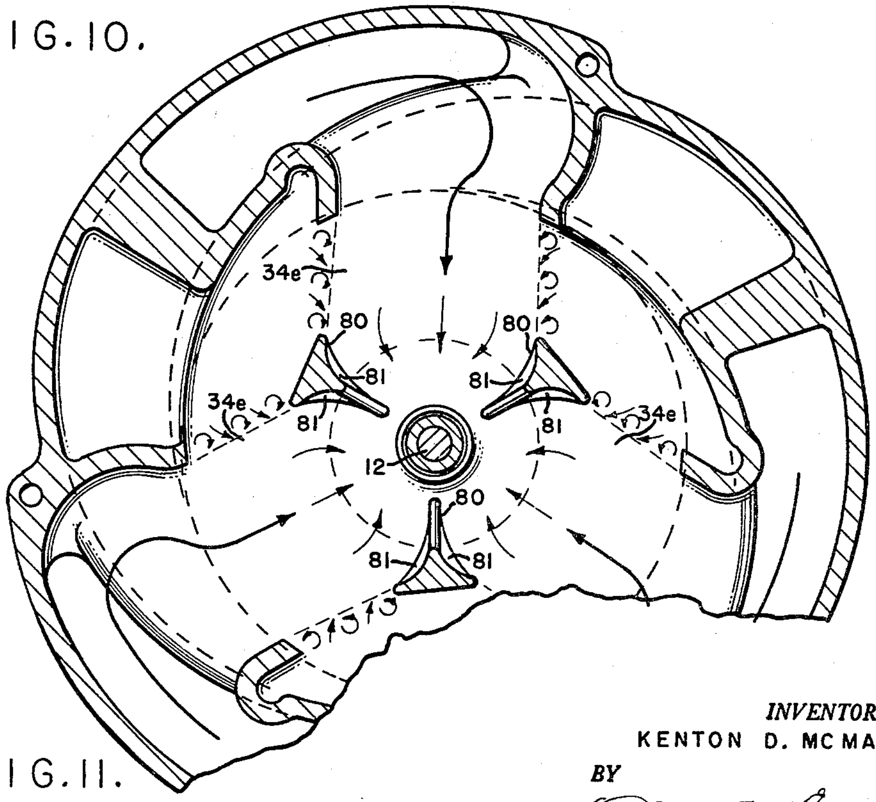

F I G. 11.

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CENTRIFUGAL FLUID PUMP

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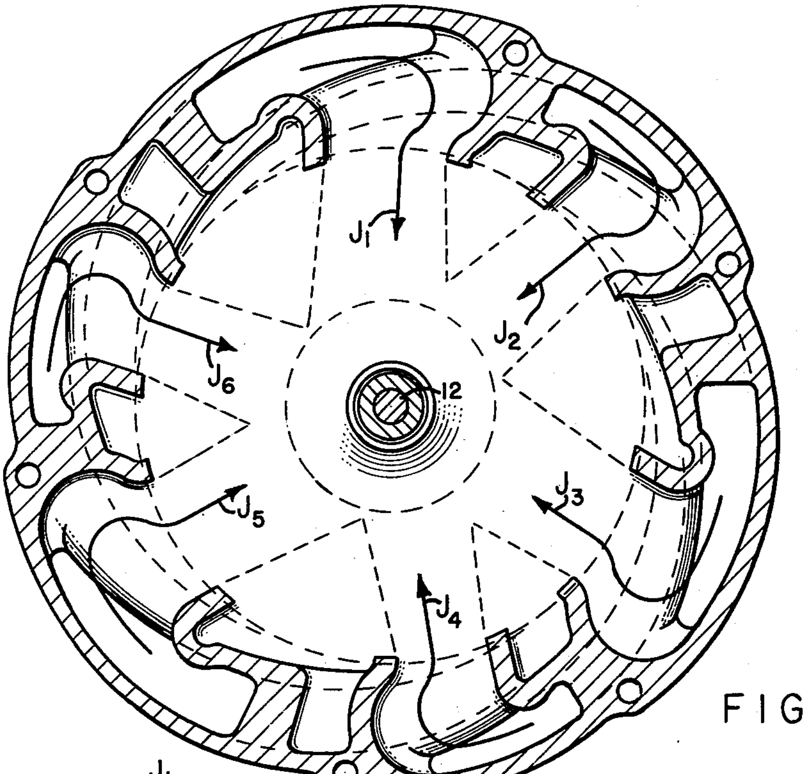

FIG. 12.

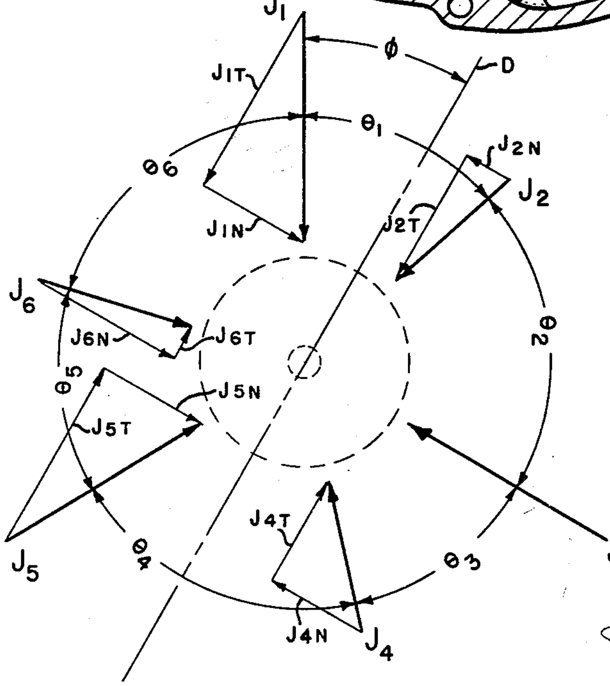

FIG. 13.

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United States Patent Office

3,171,353

Patented Mar. 2, 1965

3,171,353

CENTRIFUGAL FLUID PUMP

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Filed Feb. 27, 1962, Ser. No. 175,940
27 Claims. (Cl. 103—87)

The present invention relates to centrifugal fluid pumps, such as blowers, compressors and the like and is an improvement on the devices shown in United States Patent 2,868,440.

A known type of multi-stage centrifugal fluid pump has a series of successive stage impellers on a common shaft, each stage having an axial suction intake or eye and a volute perimetric discharge imparting rotation to the gases gathered therein and forced therethrough. All of the stages but the last one has passages leading from the outlet of the volute of one stage to the axial suction intake or eye of the succeeding stage.

In Patent 2,868,440, it was disclosed that if two jets of equal magnitude (jet velocity × mass) created from the discharge of an impeller of an earlier stage unit are directed in opposed directions radially inwardly towards the suction eye in alignment along a radial center plane and in centered position over the axis of the eye, substantially balanced impact of the two jets is effected as they meet in the vicinity of said suction eye and substantially smooth axial deflection of said jets into said suction eye is effected as they merge into a single stream. By creating diametrically opposed jets of equal magnitude from each impeller discharge, the rotational velocity components, turbulences, undesired accelerations, eddies and vacuous pockets in the stream flow between the discharge of a volute of one stage and the intake or eye of a succeeding stage, resulting in so-called "interstage" losses, and consequent lowering of overall performance and efficiency of the multi-stage centrifugal machine, are materially reduced.

One object of the present invention is to provide a new and improved multi-stage centrifugal machine for compressing gas or vapors or otherwise pumping fluids designed to further reduce interstage losses and to increase overall performance and efficiency.

In accordance with the present invention, it has been determined that the radial jets from the discharge of the volutes need not be in diametrical opposed relationship to suppress the rotational components, turbulences, undesirable accelerations, eddies and vacuous pockets in said jets, but that these factors disturbing the efficiency of the centrifugal machine can be materially reduced if the magnitude of the radial jets and the spacing therebetween is such, that the resultant of the radial jet momentum (jet velocity × mass) on one side of any selected radial plane passing through the axis of the inlet suction eye is substantially equal to and in substantial radial alignment with the resultant of the radial jet momentum on the other side of the plane. In accordance with this concept, even an odd number of radial jet passages properly spaced will provide the desired jet balance to reduce interstage losses.

In accordance with the present invention, it has been determined that as a jet from a perimetric volute of one stage is turned radially inwardly through a conventional elbow and through a radial passage towards the axis of the eye of the next stage, the jet tends to crowd towards the outer bend of the elbow and away from the inner bend, so that the resultant of the momentum of the jet is offset from the positional or mechanical center line of the radial jet passage toward the outer bend, and furthermore, the direction of the jet stream bends through an angle less than required to bring it parallel with the mechanical centerline, thereby causing the jet to have a rotational component as it enters the eye of this next stage in the same direction as the rotation of the next stage impeller.

Another object of the present invention is to provide a new and improved centrifugal fluid pump designed to compensate for the tendency of the jets to crowd towards the outer bend of the elbow and away from the inner bend as it turns from a perimetric volute of one stage through the elbow radially inwardly towards the axis of the eye of the next stage.

To carry out the last object referred to, the outer bend of the elbow between the outlet of the perimetric volute and the radial jet passage has a bend turning through an angle greater than that necessary to divert the gas from said volute outlet to said radial passage and referred to hereinafter as an "overbend" or an "overextended bend." By means of this elbow overbend, a single radial jet nearly uniform in velocity, mass and direction thereacross and having the resultant of its momentum almost coextensive in position with the radial mechanical centerline of the jet passage will be obtained. As a result, the radial jet in one stage enters the eye of the next stage with little or no rotational components.

It has been found in accordance with the present invention that in a jet passage leading from the outlet of a perimetric volute to a jet passage turned inwardly towards the center of the eye, confining walls in this passage create friction and induce eddies and turbulences resulting in head losses.

A further object of the invention is to provide a new and improved centrifugal fluid pump in which boundary eddies and turbulences in the jets leading from the outlet of the perimetric volute to the eye of the next impeller stage, are materially reduced.

To attain this object of the invention, the circumferential spaced boundaries of the jet passage transverse to the axially facing boundaries are free from confining walls. This feature has the advantages of eliminating wall friction, reducing eddies induced by such walls and reducing the weight and cost of the machine.

In spite of the absence of confining walls in the jet passages of one stage, the jets carry certain eddies and turbulences, but by eliminating confining walls on the circumferentially spaced sides of each jet passage transverse to the axially facing sides of the passage, there is effected wallfree interaction of adjoining jets as they flow into the eye of the next stage, and consequently substantially uniform, substantially eddy-free axial flow of the merged jets through said eye.

Still another object of the invention is to provide new and improved stage units capable of operating over a wide flow range with small variations in pressure ratio and efficiency, permitting an increased number of identical units to be used in series, thereby broadening the field of application, reducing the inventory of sizes and parts, and reducing the cost of tooling and manufacture.

Another object of the present invention is to provide a new and improved centrifugal machine for pumping fluids of the general type described above, designed to permit any number of such machines to be connected in series.

In carrying out the last object referred to, the discharge end of the perimetric volute of the last stage has an overbend leading to a radial jet passage with an axial discharge, so that two or more machines can be connected in series to continue the same pattern of pumping between the machines as is followed through multi-stage operation of a single machine.

Various other objects, features and advantages of the present invention are apparent from the following description and from the accompanying drawings, in which

FIG. 1 is a cut-away side elevation of a form of multistage blower embodying the present invention and shown with five radial jets of equal magnitude for each stage equally spaced and shown provided with overbends in the elbows at the volute discharges of each stage;

FIG. 2 is a transverse section of the blower taken on lines **2—2** of FIG. 1;

FIG. 3 is a transverse section of the blower taken on lines **3—3** of FIG. 1;

FIG. 4 is a circumferential section of the blower taken on lines **4—4** of FIG. 3;

FIG. 5 is an enlargement of part of the section of the blower illustrated in FIG. 3, but shown in connection with vector diagrams;

FIG. 6 is a fragmentary transverse section of a five-jet multi-stage blower but shown with vanes in the elbows at the volute discharges of each stage instead of overbends to equalize the momentum across the elbow for each jet from the inner bend to the outer bend of the elbow;

FIG. 7 is a cut-away end view of the multi-stage blower of FIG. 1, but showing the feature of overbends at the volute discharges of the last stage of the blower and the axial discharge from the blower, to permit two of these blowers to be connected in series;

FIG. 8 is a cut-away side elevation showing the connection between two blowers of the type shown in FIG. 7 connected in series;

FIG 9 is a cut-away side elevation of another form of multi-stage blower embodying the present invention, and shows a construction in which the radial jet passages are wall-free on all sides including its axially facing boundaries;

FIG. 10 is a fragmentary transverse section of a four-jet multi-stage blower embodying the present invention and shown with the overbends at the discharge elbow ends of the perimetric volutes;

FIG. 11 is a fragmentary transverse section of a three-jet multi-stage blower embodying the present invention and shown with overbends at the discharge elbow ends of the perimetric volutes and because of the wide angle between the jets, the blower is shown with vanes near the eye to direct the flow;

FIG. 12 is a transverse section of a multi-stage blower embodying the present invention and shown with overbends at the discharge elbow ends of the perimetric volutes and shown with each stage having six radial jet passages of different cross-sectional areas non-uniformly spaced, these areas and the spacing between jet passages being such, that the resultant of the radial jet momentum on one side of any selected radial plane passing through the axis of the inlet suction eye is substantially equal to and in substantial radial alignment with the resultant of the radial jet momentum on the other side of the plane; and

FIG. 13 is the vector diagram for the construction shown in FIG. 12.

Referring to FIGS. 1–5 of the drawings, there is shown a multi-stage centrifugal fluid pumping machine **10**, which may be used for compressing gas or vapor, and which is shown in the form of a three-stage blower, although the blower may have any number of stages to assure any desired final discharge pressure. The blower **10** is shown driven by a motor **11**, which is secured by screw studs **17**, and which has a shaft **12** mounted on bearings **18**. The blower **10** comprises a casing **13** through which the motor shaft **12** extends axially and three stages of blade impellers **14** in said casing, keyed or otherwise affixed to said shaft. A ventilating fan **15** connected to the motor shaft **12** blows air over the body of the motor **11** and especially through rib passages, not shown, to cool the motor and discharges it into the open space **16** for recirculation back to the inlet side of the fan.

The blower **10** is made up of a plurality of substantially circular disc-like members supported on one such

member and comprising an inlet end impeller member **20** for the first stage, intermediate impeller members **21**, interstage members **22** for conducting the gas from the discharge side of the impeller member of one stage to the axial inlet suction eye of the impeller member of the next stage, an interstage support member **22*a*** similar to member **22** except for the motor end shield flange **19**, tapped to receive screw studs **17**, and minor modifications to the volute discharges to change them from radially inward to axial, and an end volute discharge ring **23** for the last stage. All of the disc-like members **20**, **21**, and **22** are connected face to face in series to member **22*a*** by screw studs **25**. In a similar manner end ring **23** and a combined gas outlet and motor-fan housing member **24** are connected by means of studs **25*a*** to form the multistage centrifugal gas compressor unit **10**.

The first stage impeller member **20** has an axial entrance orifice **26** through which the intake air or gas to be compressed is delivered into the first impeller **14** consisting of a plurality of circumferentially spaced blades **28**. Blades **28** are so shaped that they are concave on their leading faces and are generally farwardly curved at their outer periphery, or discharge ends, as respects their direction of rotation, and have inlet portions **29** inclined outwardly and forwardly to efficently receive the flow from entrance orifice **26** in a shock free manner. Around the impeller **14** is a first stage radial diffuser **30** serving to convert velocity head to pressure head and around this diffuser are a plurality of similar perimetric involute discharge scrolls **31**, five being shown equally spaced, for gathering the air from the diffuser and forcing it therethrough by its rotation for discharge towards the next compressing stage.

The casing **13** is shown substantially circular and the discharge volutes **31** follow somewhat the circular contour of said casing and terminate in outlets **32** equally spaced around the inside of said casing. The discharge volutes **31** will have respective cross-sectional areas expanding towards their respective outlets **32** and will serve thereby not only as discharge conduits but also as diffusers to convert velocity head into pressure head.

At the outlet **32** of each discharge volute **31** of one stage is a turn shown in the form of an elbow **33** for directing the gas from said outlet radially inwardly as a jet through a radial passage **34** towards the suction eye **35** of the next stage.

Although FIGS. 2, 3 and 5 show transverse sections through the first stage of the compressor, it must be understood that all of the other stages of the compressor are similar in construction, except as otherwise noted hereinafter.

It has been determined in accordance with the present invention that momentum impact balance of the radial jets in a stage of a centrifugal gas compressor of the general type described, to reduce interstage losses due to rotational velocity components, turbulences, undesired accelerations, eddies and vacuous pockets in the stream flow between the discharge of a volute of one stage and the intake of a succeeding stage, can be attained without the necessity of locating the radial jets in pairs, with the jets of each pair diametrically opposed, as long as the resultant of the radial jet momentum on one side of any selected radial plane passing through the axis of the inlet suction eye is substantially equal to and in substantial radial alignment with the resultant of the radial jet momentum on the other side of the plane. In accordance with this principle, an odd number of jets for each stage may be employed, so spaced and so related in cross-sectional area as to achieve balanced impact resulting in the reduction of interstage losses. In the specific example shown in FIGS. 1–5, each stage has five radial jet passages **34** equally spaced and of equal cross-sectional areas. The radial jet passages **34** so numbered and so spaced will attain balanced impact on opposite sides of any selected radial plane passing through the axis of the inlet suction eye **35**, and will thereby materially nullify the rotational velocity components of the streams passing into the suction eye, will suppress the formation of eddies and vacuous pockets in said streams, and will create other stabilizing conditions tending to maintain streamline motion or flow affording smooth intake into the axial suction eye and corresponding reduction in interstage head losses.

It has been determined that as a jet from a perimetric volute of one stage is turned radially inwardly through an elbow towards the axis of the eye of the next stage, the jet tends to crowd towards the outer bend of the elbow and away from the inner bend due to centrifugal action, so that the resultant momentum of the jet, i.e. the jet velocity times its mass, is offset from the positional center line of the radial jet passage and from the axis of the eye, thereby causing the jet to have a rotational component as it enters the eye of the next stage. If the resultants of the momentums of all of the jets of each stage are so offset, the merged stream passing into and through the axial eye of the next stage will spin about the axis of the eye under the influence of all the moments engendered by these offset resultants thereby creating interstage losses. In the construction of FIGS. 1–5, this adverse condition is substantially nullified by shaping each elbow **33**, so that the momentum of the elements of each jet are substantially uniform across the elbow from the inner bend to the outer bend, as they turn into the radial passages **34**. For that purpose, the inner bend **36** on the upstream side of the elbow **33** from which the stream tends to break away as it flows through said elbow, turns through an angle only sufficiently to direct the stream from the volute **31** radially inwardly into the radial passage **34**, but the outer bend **37** at the downstream side of the elbow has an overbend, i.e. turns through an angle greater than that sufficient to direct the stream radially inwardly. As an example, although the inner bend **36** on the upstream side of the elbow **33** need be only about 90° to direct the stream radially inwardly, in the specific form of the invention shown, the outer bend **37** extends approximately through an angle of 150°. The effect of this overbend is to compensate for the tendency of the stream to crowd towards the outer bend **37** on the downstream side of the elbow **33** and to cause thereby the resultant momentum of the jet entering the passage **34** to be almost coincident with the center line of the passage, and to pass through the axis of the eye **35**.

It has been found that the exact discharge angle of the inner bend **36** may vary somewhat depending upon the specific design and the amount of reduction in area in the elbow **33**. The design criterion is the maximum bend angle from which the stream will follow or which will yield the most nearly uniform jet stream with the minimum area reduction in the elbow. The angle and the rate of change of direction of the outer bend **37** controls the angle of the resultant momentum of the jet toward the axis. Therefore, as a further aid in reducing the tendency of the stream to crowd toward the outer bend and break away from the inner bend of the elbow, the flow area is significantly reduced from that along a plane *a'* (FIG. 3) normal to the inner periphery of the volute **31** at the entrance to the elbow **33** adjacent to the inner bend **36**, to that at the inlet end of the radial passage **34**. It has been found that this reduction in area for any type of vaneless elbow to effect a uniform velocity therefrom, must be a minimum of 15%. Furthermore, this relatively small decrease in area is possible only in elbows in which the sidewise width of the approach parallel to the impeller axis is substantially greater than the sidewise width of the discharge passage **34**. In the specific form of the invention shown, the reduction in area is approximately 26% and the approach width parallel to the impeller axis is approximately two and a half times that of the discharge passage **34**.

Another aid in preventing the stream from breaking away from the inner bend **36** is a protuberance **38** on the upstream portion of said bend formed by a slight concavity at the inlet end of said bend to deflect the approach stream away from the immediate area of the bend, to crowd said stream around and over such protuberance into the sides of passage **34** over the round-edged side entrances **39**, and thereby increase the actual and effective radius of the inner bend **36**.

In FIG. 5, showing vector diagrams for the jet momentums in each stage of the compressor, the resultants of the momentums of the radial jets in the passages **34** are indicated by the heavy lines $J_1, J_2 \ldots J_5$ respectively. Each radial jet represented by the corresponding resultant line $J_1, J_2 \ldots$ or J_5 has a magnitude which by definition is equal to the momentum (jet velocity times mass) of the entire fluid stream issuing from the corresponding discharge volute **31**. It is seen from the diagrams in FIG. 5 that the path of the resultant J_1 after leaving the elbow is exactly centered over the axis A of the machine, but is displaced slightly by an angle *a*, which is approximately 2° in the specific form shown, from the mechanical radial center line B of the radial passage **34**. As mentioned above, the magnitudes of the jet elements j_x and j_y tend to increase from the downstream side towards the upstream side of the elbow **33**. However, the overbend **37** greatly reduces this effect to an amount such that the moments of each elemental jets j_x and j_y about the main jet axis are in exact balance. This relationship expressed mathematically is as follows:

$$\int_0^{x_m} j_x dx = \int_0^{y_m} j_y dy$$

Where

$$j_x = f(x) \text{ and } j_y = f(y)$$

This mathematical expression states that no rotational components exist in the main jet as it is directed toward the axis A of the machine.

As another feature of the preesnt invention illustrated in FIGS. 1–5, the radial jet passages **34** in each stage are free from confining walls on the circumferentially spaced sides **45** of the jet up to the eye **35** of the next stage. The absence of these confining walls eliminates boundary friction, reduces the formation of eddies usually induced by such walls and reduces the weight and cost of the machine. Also, the absence of any confining walls where adjoining radial jets meet in the vicinity of the eye **35** of the next impeller stage serves to squeeze out any eddies that may be formed and carried on the boundaries of the jets and to cancel out any such eddies and serves to merge adjoining jets in a manner to effect substantially eddy-free axial flow to and through this eye.

FIG. 5 indicates by vector diagrams, the effect of wall-free merging interaction of adjoining radial jets in the vicinity of the eye **35**. It is seen from FIG. 5 that as the stream issues from the elbow **33** as a jet (represented by the resultant J_1 of its momentum), free from confining walls on its circumferentially spaced sides, it diverges slightly by the angle *b* on each side, which in the specific form of the invention illustrated is about 3° and generates boundary eddies and also wall eddies indicated by the circlets e_x and e_y. These eddies are caused by passage of the stream through the discharge volute **31** and the elbow **33**. The jet J_1 also entrains a small amount of fluid from the free and stagnant areas **46** between jets.

Before reaching its segment of the impeller eye **35**, a boundary element of the jet J_1 on one side of said jet shown having a momentum indicated by the vector j_{ym} impinges upon the boundary element of the jet J_2 on the adjoining side of said jet J_2 shown having a momentum indicated by the vector j_{xm}, the angle of interaction between these boundary elements being less than 90°.

Likewise, a boundary element of the jet J_1 on the other side of said jet shown having a momentum indicated by the vector j_{xm} impinges upon the boundary element of the jet J_5 on the adjoining side of said jet J_5 having a vector corresponding to the vector j_{ym}. The elemental jet momentum j_{ym} may be resolved into a radial component j_{ymr} and a tangential component j_{ymt}. The elemental jet momentum j_{xm} may also be resolved into a radial component j_{xmr} and a tangential component j_{xmt}. Since the elemental jet momentum j_{ymt} directly opposes the elemental jet momentum j_{xmt} on one side of the jet J_1 and since the momentum j_{ymt} is of slightly greater value than the momentum j_{xmt}, the jets J_1 and J_2 will combine along the curved path P. A similar condition prevails on the other side of the jet J_1. The interaction of the boundaries of adjoining radial jets free from confining wall, will not only cause the boundary flow to be directed radially inwardly, but through the action of opposing forces at these boundaries, will cause the eddies e_y and the eddies e_x to be squeezed together. Since, the eddies e_y rotate counterclockwise and the eddies e_x rotate clockwise, the pressing of these eddies rotating in opposite directions, will cause these eddies to be suppressed and cancelled out, thereby reducing interstage losses. A further desideratum for the effective suppression of said eddies is a slight further progressive reduction in the flow areas allotted to each of the jets from that at the discharge of the elbow **33** to that just outside of the eye **35** of the next stage along a cylindrical segment subtended by the angle θ (FIG. 5). In addition, for the purpose of further suppressing the eddies, a still further progressive reduction is advantageous between the flow area just outside of the eye of the next stage along a cylindrical segment subtended by the angle θ (FIG. 5) and the total net flow area of the eye **35** in the plane perpendicular to the impeller axis divided by the number of jets. In the specific form of the invention shown, the combined reduction between the flow area at the discharge of the elbow **33** and the corresponding part of the net eye area described is approximately 25%.

The boundary action of the radial jets described causes each jet to fill the eye segment θ, which equals $360°/n$ where n equals the number of radial jets in each stage. Thus in the specific form of the invention shown in FIGS. 1–5, the eye segment θ occupied by each jet is 72°.

In addition to the main features described, the machine shown in FIGS. 1–5 has other auxiliary features which assist in proucing a multi-stage gas compressor of light, inexpensive, compact construction having high specific performance and efficiency. One of these auxiliary features is the progressive increase in the axial width of the discharge volutes **31** from the discharge of the radial diffuser **30** to the start of the overextended outer bends **37**, as shown in FIGS. 1 and 4. Notwithstanding the fact that the axial width of the elbow **33** is progressively decreased from its approach or inlet end to its outlet end at the entrance to the radial passage **34** (about 1 to 2½ in the specific form of the invention illustrated), the axial width of the elbow **33** at its discharge end at the inlet of the passage **34** is considerably greater than the axial width of the radial diffuser **30** (about 2½ to 1 in the specific form of the invention illustrated).

In the specific form of the invention illustrated, this increase in the axial width of the discharge volutes **31** from the discharge of the radial diffuser **30** to the start of the overextended outer bends **37** is about 1 to 6 and provides a wide axial approach width to the elbow **33**, which increases the efficiency and effectiveness of the overextended outer bend **37** in reducing the crowding against said outer bend and permits a more uniform discharge into the passage **34** across its flow area. Also, this axial width increase of the discharge volute **31**, permits the overall diameter of the compressor to be reduced.

Also, it should be noted that the volutes **31** of successive stages are separated by single pressure retaining walls, thereby simplifying the construction and reducing its weight and cost.

An additional feature of construction is the radial diffuser between the impeller discharge and the entrance to the volute **31**.

FIG. 6 shows a construction similar to that of FIGS. 1–5, but it does not have an elbow on the discharge end of the volute or scroll with an overextended bend on the downstream side of the elbow, serving as a means for reducing the crowding of the stream passing through the elbow toward the outer bend on said downstream side of the elbow and thereby as a means for equalizing the momentum of the stream elements across the elbow sufficiently to bring the resultant of the momentum of the radial jet close to coincidence with the mechanical center line of the jet. Instead, the construction of FIG. 6 has vaned means in the elbow to serve a similar purpose, but not as efficiently.

In the construction of FIG. 6, the discharge volute **31*a*** joins an elbow **33*a*** for directing the gas from said volute radially inwardly through a radial passage **34*a*** towards the suction eye **35*a*** of the next stage. The elbow **33*a*** has inner bends **36*a*** and outer bends **37*a*** on the upstream side and downstream side respectively, these being turned only sufficiently to divert the stream from the discharge volute **31*a*** radially inwardly through the radial jet passage **34*a***. However, inside the elbow **33*a*** between the bends **36*a*** and **37*a*** are two vanes, **50**, equally spaced from these bends and from each other and curved to direct the flow smoothly from the discharge volute **31*a*** to the radial jet passage **34*a***. These vanes **50** serve to break up the stream into finite segments across its width and thereby to prevent crowding of the stream for its full width against the outer bend **37*a***. This brings the resultant of the momentum of the radial jet closer to coincidence with the mechanical center of the radial jet passage, so that it reduces the formation of a rotational component in the jet which would tend to spin the jet about the axis of the eye **35*a*** as it enters and passes through said eye.

The vaned construction of FIG. 6 may be advantageously employed but is not as desirable as the overextended bend in the volute discharge elbow of FIGS. 1–5, since this vaned construction is more expensive, especially since the vanes would require special casting methods and/or finish machining, makes the compressor heavier, produces losses due to friction and the formation of eddies and turbulences resulting from the action of the stream as it passes over the vanes **50**, and is not as effective in centralizing the resultant of the momentum of the jet with respect to the radial jet passage.

Except as described, the construction of FIG. 6 is the same as that of FIGS. 1–5.

FIGS. 7 and 8 show a multi-stage compressor unit so constructed at its discharge end as to permit two of such units to be connected end to end in series. The compressor units of FIGS. 7 and 8 are the same as that shown in FIGS. 1–5. FIG. 7 shows an end view of the last stage of the compressor unit of FIG. 1 and FIG. 8 shows two of the units connected together.

In the construction shown in FIGS. 1, 4, 7 and 8, the last stage of the compressor unit has discharge volutes **31*b*** similar to the discharge volutes **31** in the other stages and an elbow **33*b*** at the outlet end of each volute similar to the elbow **33** in the previous stages, except that the elbow **33*b*** is turned to deflect the stream discharged from the volute **31*b*** in a direction substantially parallel to the axis of the compressor unit. For that purpose, each elbow **31*b*** has an inner bend **36*b*** on its upstream side turned only sufficiently to direct the stream in a direction substantially parallel to the axis of the compressor unit **10** and provided with a protuberance **38*b***, FIG. 4, serving a function similar to that of the protuberance **38**, and an outer bend **37*b*** on its downstream side angularly overextended as in the case of the bend **37**, sufficiently to bring the resultant of the momentum of the jet emerging from the elbow substantially coincident with the mechanical center line of the jet passage beyond the elbow. The elbow **33***b* contains a reduction in flow area along its length similar to that of the elbow **33** and the approach width of the volute **31***b* in this direction parallel to the axis of the compressor unit **10** at the inlet of said elbow **33***b* is somewhat greater than the width in a plane at right angles to said axis of a conduit **51** at the outlet of said elbow **33***b*.

On the outlet end of each elbow **33***b* on the last stage of the compressor unit is the conduit **51** of substantially oblong rectangular cross-section internally corresponding substantially to the cross-section of the radial passages **34** in the previous stages and having a section **52** extending substantially parallel to the axis of the compressor unit along the motor-fan housing member **24** and a section **53** extending radially inwardly to an annular axial outlet **54**. Between the conduit **52** and **53** is a comparatively flat, large radius, elbow **55**. It is well known that such an elbow has a minimum of loss and it is apparent that any tendency of the stream to crowd toward the downstream side or outer bend of said elbow cannot disturb the momentum balance of the jets as they merge in outlet **54**. Thus, the jets passing through the conduits **51** merge in the outlet **54** with a minimum of eddies, turbulences and rotational components, so that the loss in efficiency and performance in conducting the compressed gas from the last stage of one compressor unit to the first stage of the other compressor unit is materially reduced.

The motor-fan housing member **24** of one compressor unit has a series of bosses **57** circumferentially spaced and integral with the frame of said member and the inlet end impeller member **20** of the other compressor unit has means (not shown) for removably mounting studs **58** passing through said bosses and adaptor ring **59** for connecting said units together end to end. This fan housing member **24** is connected to the rest of the compressor unit comprising the disc-like members **20**, **21**, **22**, **22***a* and **23** (FIG. 1) by means of the screw studs **25***a*, previously described in connection with the construction of FIGS. 1–5 and also by means of screw studs **60** (FIGS. 1, 7 and 8) connecting the ends of the conduits **51** to the end volute discharge member **23** for the last stage.

When the two compressor units are connected together, as shown in FIG. 8, the compressed gas stream from the outlet **54** of one compressor is admitted directly into the axial entrance orifice **26** of the other compressor unit for successive stage compression through the latter unit in the manner described above.

In the construction of FIGS. 1–8, the radial jet passages **34** are free from confining walls on the circumferentially spaced sides **45** of the passages, as described. In the construction of FIG. 9, not only are the circumferentially spaced sides **45***c* of the radial jet passages **34***c* wall-free, but the axially facing side walls **63** and **64** extending transversely of the axis of the compressor unit and separating the diffusers **30***c* from the radial jet passages **34***c*, have recesses **65** and **66** respectively rendering each passage **34***c* wall-free on its axially facing sides **67** and **68**, and thereby lightening the compressor unit and reducing its cost. The recesses **65** and **66** form lips **71** and **72** at the bottoms thereof, with sharp angled edges **73** and **74** upon which the eddies formed are squeezed, decelerated to average jet velocities and peeled off the jet. Since the recesses **65** and **66** form eddy chambers, the static head in said recesses and connecting stagnant areas automatically build up to that required to accelerate any stagnant fluid up to jet velocity.

FIG. 10 shows a construction similar to that shown in FIGS. 1–5, except that instead of providing five equally spaced radial passages of equal sizes in each stage as in the construction of FIGS. 1–5, the construction of FIG. 10 has four equally spaced radial jet passages **34***d* in each stage, so that the passages are arranged with the jets of each pair in diametrically opposed relationship to attain balance in the resultant momentums on opposite sides of any axial diametrical plane of the compressor unit. In all other respects, the construction of FIG. 10 is similar to that of FIGS. 1–5, with its overextended outer bends **73***d* in the elbows **33***d* at the discharge ends of the volutes **31***d* and the wall-free boundaries on the circumferentially spaced sides **45***d* of the jet passages **34***d*.

The construction of FIGS. 1–5 and that of FIG. 10 indicate that the features of the present invention may be applied to a compressor having any number of jets, odd or even, in each stage within practical limits, determined by the size, characteristics and requirements of the compressor unit.

In the constructions of FIGS. 1–10, there is wall-free interaction of the radial jets in each stage near the region of the eye of the next impeller stage to effect a substantially uniform, substantially eddy-free smooth flow of the merging jets to said eye. To attain smooth interaction of these jets at these regions where the jets begin to meet, it is desirable that the angle between the adjoining boundaries of adjoining jets corresponding to the angle of impingement of the jets be no greater than 90°. Under these conditions, the feature of wall-free interaction of the radial jets near the region of the eye preferably should not be employed for a compressor stage having less than four radial jet passages. Where less than four radial jet passages are employed for a stage, then it is desirable to provide guide vanes at the intersections of adjoining radial passages in said stage to cut down the angle of jet impingement at these intersections.

FIG. 11 shows a compressor unit with three radial jet passages **34***e* of the same size at each stage equally spaced circumferentially. The construction of FIG. 11 is the same as that of FIGS. 1–5, except for the number of radial jet passages, and for the presence of guide vanes **80** at the intersection of the boundaries of the jet passages **34***e* where adjoining jets meet. Each of these guide vanes **80** is located at the intersection of the boundaries of adjoining radial jets or passages **34***e* and has two concave deflecting surfaces **81** converging with streamline progression from alignment with the adjoining boundaries of adjoining jet passages **34***e* respectively toward a radial and axial plane of the eye.

FIG. 12 shows a form of compressor unit which is similar to the compressor unit of FIGS. 1–5, except that FIG. 12 shows a construction with an even number of jet passages **34***f*, six being shown, having different sizes and circumferentially spaced unequally, so that no two jets passing through these passages are diametrically opposed. Notwithstanding this condition, in the construction of FIG. 12, the resultant of the momentums of all of the radial jets in one stage on one side of any selected radial plane passing through the axis of the inlet suction eye is equal to and in substantial radial alignment with the resultant of the momentum of the radial jets in said stage on the other side of the plane. However, in order to attain such balance in jet momentum in a compressor unit with an even number of jets arranged as described, it is necessary that the jets be divided into two sets, the jets in each set maintaining balance in momentum on opposite sides of any plane passing through the axis of the inlet suction eye.

FIG. 13 shows a vector diagram for the jet momentum in the 6-jet construction of FIG. 12. In this diagram of FIG. 13, the resultants of the momentums of the different jets are indicated by radial vectors $J_1, J_2, \ldots J_6$ and in FIG. 12, the jets are indicated by similar indicias on lines representing the center of momentum of the jets. In this construction, a radial plane D has been selected in FIG. 13 at right angles to the vector J_3.

The combined momentum forces about the plane D is the summation of the components of the vectors normal to said plane. For perfect balance of the jets, the summation of all the jet forces normal to plane D must be equal on each side of said plane for any angular position of the plane. Also, the summation of all the tangential forces to plane D must be equal to zero, with due regard for direction, for all angular plane positions. For the plane position shown, the following conditions must prevail:

$$J_{2N}+J_3+J_{4N}=J_{5N}+J_{6N}+J_{1N}$$

and,

$$J_{2T}+0-J_{4T}-J_{5T}-J_{6T}+J_{1T}=0$$

To obtain balance in jet momentum under this formulation, J_1, J_3 and J_5 must be equal in magnitude and must be equally spaced, and J_2, J_4 and J_6 must be equal in magnitude and must be equally spaced. The angle distribution between jets for balance may be as follows:

$\theta_1=48^\circ$ $\theta_4=72^\circ$
$\theta_2=72^\circ$ $\theta_5=48^\circ$
$\theta_3=48^\circ$ $\theta_6=72^\circ$

From the different constructions described, general rules may be formulated for attaining balance in the momentums of the jets in each stage.

(*a*) Jets of equal magnitude must also be equally spaced.

(*b*) Any number of jets (two or more) of equal magnitude may be employed.

(*c*) Jets odd in number must be of equal magnitude and equally spaced.

(*d*) Jets of unequal magnitude must be arranged in sets, each set being made of jets of equal magnitude equally spaced.

In all of the constructions described, the diffuser between the outlet of the impeller and the inlets of the discharge volutes, indicated by the diffuser **30** in FIG. 1, is shown vaneless, but as far as certain aspects of the invention are concerned, the diffuser may be vaned.

Although all the stages of the compressor have been shown alike, and it is one of the objects of the invention to provide an improved stage unit capable of being so operated, it should be understood that the broad concepts of the invention apply equally well to stage units of high capacities and pressure ratio such as used in modern gas turbine engines or to low capacity and high pressure ratio such as required in refrigeration compressors. In the specific form of the invention shown, each stage unit is capable of operating over about a two to one flow range at pressure ratios of the order of 1.1 or 1.2 to one per stage with small variations in pressure and efficiency. By using the high speed compressor such as shown in Patent 2,453,524 or rotor design of Patent 2,392,858 and by making certain adjustments for compressibility, a stage unit of the present invention could be designed to operate equally well at pressure ratios above three to one per stage. However under such conditions, each successive stage necessarily would be of different size and capacity. Likewise, should it be desired to connect two or more of such machines in series, a similar size adjustment would be required. Therefore, as far as certain aspects of the invention are concerned, the compressor unit may be reduced in size from the first to the last stage to compensate for compressibility of gases at increased pressure ratios.

All of the forms of the invention have been described in connection with a multi-stage centrifugal machine. However, it must be understood that as far as certain aspects of the invention are concerned, the invention has utility in connection with a single stage machine, which may be employed as such. Such a single stage machine desirably has means for connection to another similar single stage machine to form a multi-stage compressor therewith or to a multi-stage machine to add to the stages of said multi-stage machine. For example, the two intermediate disc-like impeller members **21** and the two disc-like interstage members **22** in the construction shown in FIG. 1 may be removed and the end impeller member **20** may be connected to the interstage support member **22*a*** in face contact therewith to form a single stage blower unit with a driving motor. Such a unit can be operated as a single stage unit or can be connected to one or more of these single stage units or to a multi-stage unit, as shown in FIG. 8, to make up a multi-stage machine having a greater number of stages than is afforded by any one of said units, or disc-like impeller member or members **21** and disc-like interstage member or members **22** may be added between the members **20** and **22*a***, as shown in FIG. 1, to add to the stages of the unit. It is seen, therefore, that the compressor of the present invention has great adaptability and flexibility permitting a wide range of application.

While the invention has been described with particular reference to specific embodiments, it is to be understood that it is not to be limited thereto but is to be construed broadly and restricted solely by the scope of the appended claims.

What is claimed is:

1. A centrifugal fluid pump, comprising an impeller in a pump stage, said pump having an axial inlet for the impeller and an axial outlet for said pump stage, and means for dividing the discharge of the impeller into an odd number of separate jets of equal magnitude and for directing said jets radially inwardly towards said outlet while maintaining said jets circumferentially spaced equally, said dividing means comprising separate passageways for said jets respectively leading from the discharge of the impeller and having respective circumferentially spaced turns for directing the jets radially inwardly towards said outlet.

2. A centrifugal fluid pump, comprising an impeller in a pump stage, said pump having an axial inlet for the impeller and an axial outlet for said pump stage, and means for dividing the discharge of the impeller into more than two circumferentially spaced jets and for directing said jets radially inwardly towards said outlet and including separate passageways for said jets respectively leading from the discharge of the impeller and having respective circumferentially spaced turns for directing the jets radially inwardly towards said outlet, and means for controlling the distribution of momentum across each jet against the tendency of the jet to crowd towards one side of the corresponding turn as the jet passes through said turn to cause the resultant of the momentum of the jet to pass substantially through the axis of the outlet and to be located near the mechanical radial center line of the jet, at least one of the jets being out of radially opposed alignment with any of the other jets, the magnitudes of the jets and the spacing between the jets being such, that the resultant of the radial jet momentum on one side of any selected radial plane passing through the axis of the outlet is substantially equal to and in substantial radial alignment with the resultant of the radial jet momentum on the other side of said plane.

3. A centrifugal, fluid pump as described in claim 2, wherein each of said passageways comprises a volute, a radial passage, and an elbow joining the outlet end of said volute to the inlet end of said radial passage to form the corresponding turn, each elbow comprising an inner bend and an outer bend, said means for controlling the distribution of momentum across each jet being located in the region of the corresponding elbow and including means for reducing the crowding of the jet against the outer bend and away from the inner bend as said jet passes through the elbow.

4. A centrifugal fluid pump as described in claim 2, wherein each of said passageways comprises a volute, a radial passage, and an elbow joining the outlet end of said volute to the inlet end of said radial passage to form the corresponding turn, each elbow comprising an inner bend and an outer bend, said means for controlling the distribution of momentum across each jet compris-

ing said outer bend on the downstream side of the corresponding elbow angularly overextended beyond what is necessary to direct the jet radially inwardly to reduce the crowding of the jet against the outer bend and away from the inner bend as said jet passes through the elbow.

5. A centrifugal fluid pump as described in claim 2, wherein each of said passageways comprises a volute, a radial passage, and an elbow joining the outlet end of said volute to the inlet end of said radial passage to form the corresponding turn, said means for controlling the distribution of momentum across each jet comprising vane means in the corresponding elbow dividing the jet passing through said elbow into a series of segments side by side across said elbow.

6. A multi-stage centrifugal fluid pump, comprising two successive stage units having two successive coaxial stage impellers respectively, inlet means for the earlier stage unit, an axial inlet suction eye for the later stage unit, outlet means for the discharge from the later stage unit, and means for dividing the discharge of the impeller of the earlier stage unit into more than two circumferentially spaced jets and for directing said jets radially inwardly towards said suction eye and including separate passageways for said jets respectively leading from the discharge of the impeller of the earlier stage unit and having respective turns for directing the jets radially inwardly towards said suction eye and means for controlling the distribution of momentum across each jet against the tendency of the jet to crowd towards one side of the corresponding turn as the jet passes through said turn to cause the resultant of the momentum of the jet to pass substantially through the axis of the impellers and to be located near the mechanical radial center line of the jet, at least one of the jets being out of radially opposed alignment with any of the other jets, the magnitudes of the jets and the spacing between the jets being such, that the resultant of the radial jet momentum on one side of any selected radial plane passing through the axis of the inlet suction eye is substantially equal to and in substantial radial alignment with the resultant of the radial jet momentum on the other side of said plane.

7. A centrifugal fluid pump, comprising an impeller in a pump stage, said pump having an axial inlet for the impeller, and an axial outlet for said pump stage, and means for creating a jet from the discharge of the impeller and for directing said jet radially inwardly towards said outlet and comprising a volute on the outlet side of the impeller, a radial jet passage leading towards said outlet and an elbow between the outlet end of said volute and the inlet end of said radial passage, said elbow having an inner bend and an outer bend, said outer bend being angularly overextended beyond what is necessary to direct the jet radially inwardly from the corresponding volute to reduce the crowding of the jet against the outer bend and away from the inner bend as said jet passes through the elbow, said outer bend being overextended sufficiently to cause the resultant of the momentum of the jet to pass substantially through the axis of the eye and to be located close to the mechanical center line of the radial passage.

8. A centrifugal fluid pump comprising an impeller in a pump stage, said pump having an inlet for the impeller extending along the axis of the pump and an outlet for said pump stage extending along the axis of the pump, and means for dividing the discharge of the impeller into a number of jets and for directing said jets towards said outlet comprising a plurality of volutes on the outlet side of the impeller, elbows at the discharge ends of the volutes respectively and passages between said elbows respectively and said outlet, each of said elbows having an inner bend and an outer bend, the outer bend being angularly overextended beyond what is necessary to direct the jet from the corresponding volute along the corresponding passage to reduce crowding of the jet against the outer bend and away from the inner bend as said jet passes through the elbow and to reduce thereby the rotational component of the jet.

9. A centrifugal fluid pump as described in claim 8, each of said inner bends having a protuberance thereon near the approach end of the inner bend, extending in a direction transverse to the direction of flow through the corresponding elbow.

10. A centrifugal fluid pump as described in claim 8, wherein the flow area of each elbow is reduced from the inlet of said elbow to the outlet of said elbow at the inlet end of the corresponding passage by at least 15%.

11. A multi-stage centrifugal fluid pump, comprising two successive stage units having two successive coaxial stage impellers respectively, inlet means for the earlier stage unit, an axial inlet suction eye for the later stage unit, outlet means for the discharge from the later stage unit, and means for dividing the discharge of the impeller of the earlier stage unit into a number of jets and for directing said jets radially inwardly towards said suction eye, and comprising a plurality of volutes on the outlet side of the impeller of the earlier stage unit, a corresponding plurality of radial jet passages leading towards said eye, and elbows between the outlet ends of said volutes and the inlet ends of said radial passages respectively, each of said elbows having an inner bend and an outer bend, said outer bend being angularly overextended beyond what is necessary to direct the stream radially inwardly from the corresponding volute to reduce the crowding of the jet against the outer bend and away from the inner bend as said jet passes through the elbow.

12. A multi-stage centrifugal fluid pump as described in claim 11, wherein each of said volutes increases in axial width from the inlet of the volute to the inlet of the corresponding elbow, and each of said elbows decreases in axial width from the inlet end of the elbow to the discharge end of the elbow, while the axial width at the outlet of the elbow is greater than the axial width of the volute inlet.

13. A centrifugal fluid pump, comprising an impeller in a pump stage, said pump having an axial inlet for the impeller, and an axial outlet for said pump stage, and means for dividing the discharge of the impeller into a plurality of circumferentially spaced jets and for directing said jets radially inwardly towards said outlet and comprising a plurality of volutes, a plurality of radial passages, and elbows between the outlet ends of said volutes and the inlet ends of said radial passages respectively, each of said elbows having an inner bend and an outer bend, said outer bend being angularly overextended beyond what is necessary to direct the stream radially inwardly from the corresponding volute to reduce the crowding of the jet against the outer bend and away from the inner bend as said jet passes through the elbow, said outer bend being overextended sufficiently to cause the resultant of the momentum of the jet to pass substantially through the axis of the outlet and to be located close to the mechanical center line of the radial passage, the magnitude of the jets and the spacing therebetween being such, that the resultant of the radial jet momentum on one side of any selected radial plane passing through the axis of the outlet is substantially equal to and in substantial radial alignment with the resultant of the radial jet momentum on the other side of said plane.

14. A multi-stage centrifugal fluid pump, comprising two successive stage units having two successive coaxial stage impellers respectively, inlet means for the earlier stage unit, an axial inlet suction eye for the later stage unit, outlet means for the discharge from the later stage unit, and means for dividing the discharge of the impeller of the earlier stage unit into a number of jets and for directing said jets radially inwardly towards said suction eye, said dividing and directing means comprising a plurality of volutes, radial passages corresponding

in number to the number of volutes, and elbows joining the outlet ends of said volutes to the inlet ends of said radial passages respectively, each of said radial passages between said elbow and a region near the eye having circumferentially spaced boundaries which are wall-free.

15. A multi-stage centrifugal fluid pump as described in claim 14, wherein said boundaries are wall-free up to the points where the adjoining boundaries of adjoining radial jets meet, whereby the interaction of adjoining jets at said points are free from wall interference.

16. A multi-stage centrifugal fluid pump as described in claim 14, wherein the angles between the adjoining boundaries of adjoining jets do not exceed 90°, and wherein said boundaries are wall-free up to the points where the adjoining boundaries of adjoining radial jets meet, whereby the interaction of adjoining jets at said points are free from wall interference.

17. A multi-stage centrifugal fluid pump as described in claim 14, wherein the angles between the adjoining boundaries of adjoining jets exceed 90°, and wherein vane means are provided in the regions near the eye where the adjoining boundaries of adjoining radial jets meet to guide the jets smoothly toward said eye.

18. A multi-stage centrifugal fluid pump as described in claim 14, wherein vane means are provided in the regions near the eye where the adjoining boundaries of adjoining radial jets meet to guide the jets smoothly towards said eye.

19. A multi-stage centrifugal fluid pump, comprising two successive stage units having two successive coaxial stage impellers respectively, inlet means for the earlier stage unit, an axial inlet suction eye for the later stage unit, outlet means for the discharge from the later stage unit, and means for dividing the discharge of the impeller of the earlier stage unit into a number of jets and for directing said jets radially towards said suction eye, said dividing and directing means comprising a plurality of volutes, radial passages corresponding in number to the number of volutes, and elbows joining the outlet ends of said volutes to the inlet ends of said radial passages respectively, said radial passages having axially facing boundaries which are wall-free between said elbow and a region near the eye.

20. A multi-stage centrifugal fluid pump, comprising two successive stage units having two successive coaxial stage impellers respectively, inlet means for the earlier stage unit, an axial inlet suction eye for the later stage unit, outlet means for the discharge from the later stage unit, and means for dividing the discharge of the impeller of the earlier stage unit into a number of circumferentially spaced jets and for directing said jets radially towards said suction eye, said dividing and directing means comprising a plurality of volutes, radial passages corresponding in number to the number of volutes, and elbows joining the outlet ends of said volutes to the inlet ends of said radial passages respectively, said passage having all of its peripheral boundaries wall free between said elbow and a region near the eye.

21. A multi-stage centrifugal fluid pump comprising two successive stage units having two successive coaxial stage impellers respectively, inlet means for the earlier stage unit, an axial inlet suction eye for the later stage unit, outlet means for the discharge from the later stage unit, and means for dividing the discharge of the impeller of the earlier stage unit into a plurality of circumferentially spaced jets and for directing said jets radially inwardly towards said eye and including a plurality of volutes and elbows joining the outlet ends of said volutes to the inlet ends of said radial passages respectively, the flow areas allotted to each of said jets progressively decreasing from that at the discharge end of the corresponding elbow to that at the end of the jet just outside of said eye, whereby eddies created in said jets are suppressed.

22. A multi-stage centrifugal fluid pump as described in claim 21, wherein there is a further reduction in flow area from that at the combined ends of the jets just outside of said eye to that of the eye at right angles to the axis of the impellers.

23. A multi-stage centrifugal fluid pump comprising two successive stage units having two successive coaxial stage impellers respectively, inlet means for the earlier stage unit, an axial inlet suction eye for the later stage unit, outlet means for the discharge from the later stage unit, and passage means for dividing the discharge of the impeller of the earlier stage unit into a plurality of circumferentially spaced jets and for directing said jets towards said eye in directions, each having a radially inward component and including a plurality of volutes and elbows joining the outlet ends of said volutes to the inlet end of said passage means respectively, the volutes between stages being separated by single pressure retaining walls.

24. A centrifugal fluid pump comprising an impeller having an axial inlet and constituting a plurality of blades concave on their leading faces and generally forwardly curved at their discharge ends as respect their direction of rotation, said blades having inlet portions inclined outwardly and forwardly to receive the flow into the field of action of said impeller in a shock free manner, a radial diffuser around said impeller to convert velocity head into pressure head, a plurality of similar perimetric involute discharge scrolls distributed around said diffuser, axial outlet means beyond said scrolls, and means for directing the discharge from said scrolls as separate jets towards said outlet means in a radially inward direction.

25. A centrifugal fluid pump comprising an impeller for a pump stage, said pump having an inlet for the impeller extending along the axis of the pump and an outlet for said pump stage extending along the axis of the pump, and means for dividing the discharge of the impeller into a number of jets and for directing said jets towards said outlet comprising a plurality of volutes on the outlet side of the impeller, elbows at the discharge ends of the volutes respectively and passages between said elbows respectively and said outlet, each of said elbows having an inner bend and an outerbend, each of said inner bends having a protuberance thereon near the approach end of the inner bend, extending in a direction transverse to the direction of flow through the corresponding elbow for reducing the tendency of the jet as it passes through said elbow to break away from said inner bend.

26. A multi-stage centrifugal fluid pump, comprising two successive stage units having two successive coaxial stage impellers respectively, inlet means for the earlier stage unit, an axial inlet suction eye for the later stage unit, outlet means for the discharge from the later stage unit, and means for dividing the discharge of the impeller of the earlier stage unit into a number of jets and for directing said jets towards said suction eye in directions, each having a radially inward component, said dividing and directing means comprising a plurality of volutes, passages corresponding in number to the number of volutes extending in said directions respectively, and elbows joining the outlet ends of said volutes to the inlet ends of said passages respectively, each of said passages between said elbow and a region near the eye having circumferentially spaced boundaries which are wall-free.

27. A centrifugal fluid pump comprising an impeller having an axial inlet eye, an axial inlet for the pump, an axial outlet for the pump having a conformation which can mate with the conformation of said axial pump inlet, a motor for driving said impeller, means for dividing the discharge of the impeller into a plurality of circumferentially spaced jets and for directing said jets radially inwardly towards said outlet and including separate passageways for said jets respectively leading from the discharge of the impeller and having respective turns for directing the jets radially inwardly towards said out-

let, the magnitudes of the jets and the spacing between the jets being such, that the resultant of the radial jet momentum on one side of any selected radial plane passing through the axis of the outlet is substantially equal to and in substantial radial alignment with the resultant of the radial jet momentum on the other side of said plane, and means for removably connecting said pump to a similar centrifugal fluid pump with the outlet of said first mentioned pump discharging into the axial inlet of said similar pump to produce with said similar pump a multi-stage pump unit comprising two pumps connected in series in multi-stage relationship and having respective motors.

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