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(54) FAN WHEEL OF A DIAGONAL-FLOW FAN

(71) We, KAWASAKI JUKOGYO KABUSHIKI KAISHA, a company organised and existing under the Laws of Japan, of 14, Higashikawasaki-Cho 2-Chome, Ikuta-Ku, Kobe-Shi, Hyogo-Ken, Japan, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to an impeller or fan wheel of a diagonal-flow fan for delivering gases at specific flow rates and pressures, the fan wheel being provided with blades each of the shape of a single-curvature or planar surface which affords high performance of the fan substantially equivalent to that of the fan provided with blades each of an ideal shape of a twisted double-curvature surface.

In the fan wheel of an ordinary centrifugal fan the entrance edges and exit edges of the blades are respectively parallel to the rotational shaft axis. At the same time, when the fan wheel is viewed in its axial direction, each of its blades is arcuately curved or linearly formed as it extends toward the periphery of the fan wheel, and each blade has no twist with respect to the axial direction, and cross sections of the blades taken in parallel planes perpendicular to the axis appear to be superposed on each other. Thus, each blade has a single-curvature or developable curved surface, or a planar surface.

Furthermore, most of the cross sections of these blades with single-curvature surface in an ordinary centrifugal fan have the shape of a single arc, or the shape of two arcs joined together. Accordingly, the fabrication of these blades is relatively simple. However, even in the case of a blade of this kind, a blade cross section shape in which the radius of the arc varies progressively along the chord length is close to the ideal shape from the viewpoint of fluid dynamics, but the fabrication of blades of such a shape is extremely difficult. For this reason, such blades have not as yet been reduced to practice except for centrifugal fans having blades of wing profiles (airfoil profiles) being manufactured in spite of this difficulty in order to utilize the advantages in efficiency and low noise level.

In contrast to a centrifugal fan as described above, a diagonal-flow fan has blades whose entrance edges and exit edges are not parallel to the rotational shaft axis, the radial distance from the shaft axis to each entrance edge varying progressively from one end of the entrance edge to the other, and furthermore, the radial distance from the shaft axis to each exit edge also varying progressively from one end of the exit edge to the other. In addition, each blade must be provided with a complicated double curvature which causes it to have a twist as viewed in the shaft axial direction. These and other features of diagonal-flow fans will be described in detail hereinafter, particularly in comparison with a centrifugal fan.

Theoretically, a diagonal-flow fan should have excellent performance but has not been reduced to practical use because of certain difficulties as will be described hereinafter.

It is an object of this invention to provide a fan wheel of a diagonal-flow fan in which, by utilizing a part of a cylinder (a single-curvature surface or developable surface) or a plane for each blade of the fan wheel, an effect equivalent to that of blades of double-curvature surfaces which are close to the ideal from the viewpoint of fluid dynamics is attained to produce excellent fan performance, and, moreover, the difficulties accompanying the fabrication of diagonal-flow fan blades are overcome thereby to facilitate the production of the fan wheel.

According to one aspect of the invention we provide a fan wheel of a diagonal-flow fan for propelling a flow of a gas, said fan wheel comprising a rotational shaft, a frustoconical main plate coaxially fixed to the shaft, a frustoconical side plate spaced apart from the main plate and forming therebetween a diagonal flow path for the gas, and a plurality of fan blades each fixed at respective opposite side edges to the inner surfaces of the main and side plates and having an inner entrance part and an outer exit part such that innumerable stream surfaces of the gas are formed, in operation of the fan wheel, from said entrance part to said exit part and between said main and side plates, each of said fan blades comprising a plate of a surface shape conforming to a portion of imaginary cylindrical surface with a longitudinal axis, said portion being formed of innumerable elements constituted by mutual intersection lines between said imaginary cylindrical surface and innumerable imaginary coaxial conical surfaces corresponding to said stream surfaces, respectively, said imaginary coaxial conical surfaces having a common axis coinciding with the axis of said rotational shaft and lying in a plane which is in parallel spaced relationship to said longitudinal axis of the cylindrical surface, said common axis being inclined at an angle with respect to said longitudinal axis when viewed in a direction perpendicular to said plane.

According to another aspect of the invention we provide a fan wheel of diagonal-flow fan for propelling a flow of a gas, said fan wheel comprising a rotational shaft, a frustoconical main plate coaxially fixed to the shaft, a frustoconical side plate spaced apart from the main plate and forming therebetween a diagonal flow path for the gas, and a plurality of fan blades each fixed at respective opposite side edges to the inner surfaces of the main and side plates and having an inner entrance part and an outer exit part such that innumerable stream surfaces of the gas are formed, in operation of the fan wheel, from said entrance part to said exit part and between said main and side plates, each of said fan blades comprising a plate of a surface shape conforming to a portion of an imaginary planar surface, said portion being formed of innumerable elements constituted by mutual intersection lines between said imaginary planar surface and innumerable imaginary coaxial conical surfaces corresponding to said stream surfaces, respectively, said imaginary coaxial conical surfaces having a common axis coinciding with the axis of said rotational shaft, said planar surface being in parallel relation to an axis which is at an angle with said common axis.

Other objects and further features of this invention will be apparent from the following detailed description when read in conjunction with the accompanying drawings in which:

Fig. 1 is a partial side view, in section taken along a plane passing through the axis of rotation, of a fan-wheel of an ordinary centrifugal fan;

Fig. 2 is a partial axial view of the same centrifugal fan;

Fig. 3 is a side view similar to Fig. 1 showing an example of a fan wheel of a diagonal-flow fan;

Fig. 4 is a fragmentary perspective view showing an essential part of the fan wheel illustrated in Fig. 3;

Fig. 5 is a planar development of a conical surface formed by a representative streamline shown in Fig. 3;

Fig. 6 is a graphical perspective view for a description of the fabrication of a blade of the fan wheel according to this invention;

Figs. 7A, 7B and 7C are respectively views explanatory of the basic principle of this invention;

Figs. 8A and 8B are respectively vertical and horizontal projections of Fig. 6;

Fig. 9 is a fragmentary perspective view of one part of one example of the fan wheel of a diagonal-flow fan according to this invention;

Figs. 10A, 10B, and 10C are respectively projections for a description of the fabrication of another example of a fan wheel according to the invention;

Fig. 11 is a view similar to Fig. 7C but showing how a so-called "airfoil profile" of the blade can be produced;

Fig. 12 is a partial side view similar to Fig. 3 showing another example of a fan wheel according to the invention;

Fig. 13 is a partial axial view, similar to Fig. 2, but showing another ordinary centrifugal fan with a different shape of blades;

Fig. 14A is a fragmentary axial section of the fan shown in Fig. 13;

Fig. 14B is a section taken along the line XIVB—XIVB in Fig. 14A;

Fig. 15 is a view similar to Fig. 6, but showing how a modified blade of the fan wheel according to this invention is fabricated;

Figs. 16A, 16B and 16C are views similar to Figs. 7A, 7B and 7C, respectively, but explanatory of the basic principle of fabricating the modified blade;

Figs. 17A and 17B are respectively vertical and horizontal projections of Fig. 15; and

Fig. 18 is a view similar to Fig. 7C but explanatory of a blade of a diagonal-flow fan of the straight-line, rearwardly inclined type.

As conducive to a full understanding of this invention, the differences between a centrifugal fan and a diagonal-flow fan and certain problems accompanying diagonal-flow fans, which were briefly mentioned hereinbefore, will first be described more fully.

Referring first to Fig. 1, the fan wheel shown therein of an ordinary centrifugal fan has a number of blades 1, each having an entrance edge 2 and an exit edge 3 both of which are parallel to the rotational shaft axis 4. As viewed in the axial direction (arrow direction P), each blade 1 is arcuately curved as it extends from its entrance edge toward its exit edge or the periphery of the fan wheel as shown in Fig. 2 but has no twist in the direction of the shaft axis 4, and the sections of the blades respectively in spaced apart and parallel planes $a_1, a_2, \ldots\ldots a_n$ intersecting the shaft axis 4 at right angles appear to be superposed on each other. That is, each blade 1 may be considered to be a single-curvature surface or developable surface.

Differing from a centrifugal fan, a diagonal-flow fan has a fan wheel with blades 11, whose entrance edges 12 and exit edges 13 are not parallel to the rotational shaft axis 14 as shown in Fig. 3, and the radial distance from the shaft axis 14 to the entrance edge 12 of each blade progressively varies as $r_{in1}, r_{in2}, \ldots\ldots r_{in_n}$ respectively at positions corresponding to representative streamlines $15_1, 15_2, \ldots . 15_n$ in the gas flow path within the fan wheel. Furthermore, the radial distance from the shaft axis 14 to the exit edge 13 of each blade progressively varies as $r_{out_1}, r_{out_2}, \ldots r_{out_n}$. If these radii vary in this manner, the inflow angles at the entrance edge 12 for minimizing the collision loss for respective streamlines $15_1, 15_2, \ldots 15_n$ and the corresponding outflow angles for evening out the pressure head must be progressively varied as $\beta_{11}, \beta_{12}, \ldots . . \beta_{1n}$ and $\beta_{21}, \beta_{22}, \ldots . . \beta_{2n}$, respectively, as indicated in Fig. 4. It will therefore be understood that in order to obtain an ideal fan performance, the shape of each blade must be made to assume a complicated twisted double-curvature surface as viewed in the direction of the axis 14.

That is, if the blades 11 of the fan wheel of the diagonal-flow fan illustrated in Fig. 3 were to be merely of the shape of a single-curvature surface which has a single arcuate curve or a curve comprising two arcuate curves similar to the blades 1 in the centrifugal fan shown in Fig. 1, the fan performance would drop except in the case of extremely small fans. If, in order to improve the performance, an attempt were to be made to fabricate blades 11 of the shape of a twisted, double-curvature surface, the fabrication would be very difficult.

Similarly as in the case of a centrifugal fan, the use of airfoil profile blades is desirable also in a diagonal-flow fan having double-curvature blades 11 of this character. However, it is impossible productionwise to apply the techniques of fabricating airfoil profile blades, which are difficult to fabricate even in the case of centrifugal fans, to the fabrication of the blades 11 of the shape of a twisted, double-curvature surface of a diagonal-flow fan.

Basically considered, the fan wheels of fans of this character are fabricated, not by casting, but by assembling parts principally of rolled steel plates. Moreover, fans of a wide variety of dimensions, even up to large impellers of diameters of 3 to 4 meters, are produced in a great variety of kinds, each in small quantities. For this reason, it is very difficult to fabricate fan wheels of blades of the shape of a double-curvature surface and airfoil blades at respective costs which are not prohibitive.

Before describing the invention, a centrifugal fans as described have been and are being widely produced, whereas diagonal-flow fans requiring double-curvature blades 11 as shown in Figs. 3 and 4 have not been reduced to practice in spite of the great expections for their high performance.

Before describing the invention, a geometrical analysis of the theoretical shape of the blades of diagonal-flow fans will be made.

As partly described hereinbefore in conjunction with Fig. 3, a plurality of blades 11 are fixed by welding between shroud-like main and side plates 16 and 17, and the main plate 16 at its radially inner part is secured to a hub 18. The representative streamlines $15_1, 15_2, \ldots . . 15_n$ (which are actually "streamsurfaces" but will be herein referred to as "streamlines") respectively are in the shapes of conical surfaces of half vertex angles $\theta_1, \theta_2, \ldots . . \theta_n$. Each blade 11 begins from entrance points (inlets) $M_1, M_2, \ldots\ldots M_n$ on these conical surfaces and ends at exit points (outlets) $N_1, N_2, \ldots . . N_n$. When the conical surface constituted by one (15_1) of the representative streamlines is developed in a planar surface, it appears as in Fig. 5, in which a section of only one blade 11 is shown.

This section of the blade 11 in Fig. 5 has a specific inflow angle β_{11} at the entrance point M_1 and a specific outflow angle β_{21} at the exit point N_1 and, in between, has a shape closely resembling a part of an ellipse and being of gradually varying radius ρ of curvature. The inflow angles and outflow angles of this blade 11 vary as β_{12}, β_{13}, ... β_{1n} and β_{22}, β_{23}, ... β_{2n}, respectively, from their values β_{11} and β_{21} as indicated in Fig. 4 in correspondence with the representative streamlines 15_1, 15_2, ... 15_n shown in Fig. 3. Accordingly, a complicated double-curvature surface is required for each blade 11, as was pointed out hereinbefore.

According to this invention, a shape of the blade close to the above stated ideal shape of the blade is realized by the use of a single-curvature surface without using a complicated double-curvature surface. In order to constitute a single-curvature blade which satisfies the above stated geometrical requirements, this invention makes use of intersections between the above stated conical surfaces constituted by the representative streamlines and an imaginary cylinder.

For simplicity, there are shown, in Figs. 7A to 7C, a single conical surface 15_{11} and an imaginary cylinder 19 intersecting the conical surface to form a line of intersection 15_1. According to this invention, a number of the intersections 15_1, 15_2, ... 15_n are used which are formed by the single cylinder 19 and a number of the conical surfaces 15_{11}, 15_{21}, ... 15_{n1} as shown in Fig. 6.

For the following analysis, three-dimensional rectangular coordinate axes U, V, and W as shown in Figs. 6 and 7A and B are used, the origin of this coordinate system being positioned at the vertex of the conical surface 15_{11}. The W axis is parallel to the centerline O of the cylinder 19, and the V axis passes through the entrance point M_1 mentioned hereinbefore when viewed in the direction of the W axis as in Fig. 7A.

The centerline O of the cylinder 19, which has a radius C, is at a distance U_o from the V axis and at a distance V_o from the U axis. The W axis is inclined by an angle K relative to the centerline axis H of the conical surface 15_{11} of the half vertex angle θ_1. In the above described state, the cylinder 19 intersects the conical surface 15_{11}.

As above stated, the conical surface 15_{11} is the same as the conical surface constituted by the representative streamline 15_1 in Fig. 3. Of the line of intersection between this conical surface 15_{11} and the cylinder 19, the part from the entrance point M_1 to the exit point N_1 is indicated by a thick line on development of the conical surface 15_{11} in Fig. 7C, and this is equivalent to the representation in Fig. 5. That is, in Fig. 5, the blade 11 has a specific inflow angle β_{11} and a specific outflow angle β_{21} on the conical surface of one representative streamline and has a sectional profile in the shape of a smooth curve having a radius of curvature ρ varying progressively along its length. This sectional profile can be obtained geometrically by determining the above described distances U_o and V_o angle K, and radius C by a method described hereinafter.

These relationships will now be geometrically studied. An arbitrary point m on the curve M_1 N_1 constituting one part of the intersection between the conical surface 15_{11} of the representative streamline and the cylinder 19 in Figs. 7A to 7C will be considered. This point m has coordinates (u,v) in Fig. 7A, coordinates (v,w) in Fig. 7B, and coordinates (x,y) in Fig. 7C, the coordinates (x,y) being based on orthogonal coordinate axes X and Y having their origin on the centerline axis H as shown in Fig. 7C. The axis Y is at the angle θ_1 relative to the axis H. In this case, the following relationships were found to exist as a result of our mathematical and geometrical analysis.

$$x=f(\theta_1, u, r) \quad (1)$$
$$y=f(\theta_1, u, r) \quad (2)$$
$$u=f(U_0, V_0, K, \theta_1, C, r) \quad (3)$$
$$\phi=f(\theta_1, u, r) \quad (4)$$

Here, r is the distance of the point m from the centerline axis H as shown in Fig. 7B, and ϕ is the angle between the axis Y and a straight line passing through the point m(x,y) and the origin of the axis Y. Therefore, by substituting the equations (1) to (4) respectively into the relationships

$$\rho=\left[1+\left(\frac{dy^2}{dx}\right)\right]^{3/2}\Big/\frac{d^2y}{dx^2} \quad (5)$$

$$\beta=\tan^{-1}\left(\frac{dy}{dx}\right)+\phi \quad (6)$$

which are derived through differential analysis known in the art, the radius of curvature ρ and the angle β at the point m in Fig. 7C are obtained.

When the point m is at the entrance point M_1, the corresponding angle β coincides with the inflow angle β_{11}. Similarly, when the point m is at the exit point N_1, the corresponding angle β coincides with the outflow angle β_{21}. As the point m is moved from the point M_1 to the point N_1, the radius of curvature ρ varies gradually. For this reason, the curve from the entrance point M_1 to the exit point N_1 is an ideal smooth curve differing from the corresponding curve in the blade of a conventional centrifugal fan wheel which comprises a single arc or at the most two arcs connected together.

Thus, the representative streamline 15_1 shown in Fig. 3 is obtained as indicated in outline form in Fig. 6. In the same manner, the representative streamlines 15_2, 15_3, ... 15_n are obtained respectively from the intersections of the cylinder 19 and the conical surfaces 15_{21}, 15_{31}, ... 15_{n1}.

Fig. 8A shows a projection of this state as viewed in the arrow direction Q (Fig. 6). This projection corresponds to Fig. 7A. Furthermore, Fig. 8B is a projection corresponding to Fig. 7B. These intersection lines can be readily computed by carrying out with respect to the conical surfaces 15_{21}, 15_{31}, ... 15_{n1} operations similar to that with respect to the conical surface 15_{11}.

That is, Figs. 8A and 8B are similar to Figs. 7A and 7B but further have conical surfaces 15_{21}, 15_{31}, ... 15_{n1} having a common centerline axis H with the conical surface 15_{11} and respectively having half vertex angles θ_1, θ_3, ... θ_n. These n conical surfaces 15_{11}, 15_{21}, ... 15_n are arranged in the same manner as the n conical surfaces constituted by the representative steamlines 15_1, 15_2, ... 15_n in Fig. 3, and, according to this invention, the blade 11 shown in Fig. 3 is obtained as a part of the cylinder 19, delimited by the lines of intersections 15_1, 15_2, ... 15_n.

As is apparent from Figs. 6 and 8A, when the group of n conical surfaces inclined as shown is viewed in the axial direction of the cylinder (the arrow direction Q in Fig. 6), the blade 11 coincides with a part of the single-curvature surface of the cylinder 19 of the radius C and has no twist, appearing as a superimposition with the same sectional profile. When the conical surface 15_{11} is developed into a planar surface, it becomes as shown in Fig. 7C as described before, and the other conical surfaces 15_{21}, 15_{31}, ... 15_{n1} also can be similarly developed. The intersections due to these developments are not shown in Fig. 8A, but, as indicated in outline form in Fig. 6, they respectively start at points M_2, M_3, ... M_n and end at points N_2, N_3, ... N_n, having inflow angles and outflow angles β_{12}, β_{22}, ... β_{1n}, β_{2n} respectively differing slightly from the inflow angle β_{11} and outflow angle β_{21} at the streamline 15_1. Between the entrance and exit points, the intersection lines are in the form of smooth curves having a gradually varying radius of curvature ρ.

That the inflow angles β_{11}, β_{12}, ... β_{1n} and the outflow angles β_{21}, β_{22}, ... β_{2n} respectively differ slightly from each other is a natural result of the variations of the radial distance r_{in} at the entrance point and the radial distance r_{out} at the exit point of each of the representative streamlines 15_1, 15_2, ... 15_n as described hereinbefore with respect to Fig. 3.

In designing and producing blades of a diagonal-flow fan according to this invention, the representative streamlines 15_1 to 15_n, to be realized are first determined. From these, the conical surface half vertex angles θ_1 to θ_n are determined. Standard values of the ratio of the inner and outer diameters of each blade have been tentatively determined in accordance with the gas flow rate and the gas delivery pressure, and, therefore, the inflow angles β_{11}, ... β_{1n} at the blade entrance and the outflow angles β_{21}, ... β_{2n} at the blade outlet are determined by the fan wheel rotational speed. If an inner diameter r_o of the fan wheel is taken as 1 (unity), the corresponding outer diameter of the fan wheel will be the ratio of the outer and inner diameters.

If the angle K and the radius C have been determined, the coordinates U_o and V_o are unconditionally determined from the coordinates of the entrance point M_1 and the inflow angle β_{11}. Accordingly, the remaining variables are K and C. These two variables K and C are so adjusted that the outflow angle β_{21} will take a predetermined value. After thus finally determining the angle K and the radius C as well as the coordinates U_o and V_o, it is now possible to plot the entrance and exit points M_1 and N_1 and to draw the curve 15_1 on a blank cylinder 19. This curve 15_1 can be readily determined from the coordinates of the point m, that is, m(u,v,w).

The thus determined positions of the entrance and exit points M_1 and N_1 on the cylinder become basic reference points from which the plotting of the other entrance and exit points M_2, M_3, ... M_n and N_2, N_3, ... N_n starts. The next procedure is to determine the positions of the adjoining entrance and exit points M_2 and N_2 on the line of intersection or curve 15_2. The determination of the positions of these points M_2 and N_2 is made by so adjusting the inner and outer radial distances thereof from the shaft axis with respect to the conical surface 15_{21}, in which the intersection line 15_2 lies, on the basis of the determined values of the angle K, the radius C and the coordinates U_o and V_o as to obtain the predetermined inflow and outflow angles β_{12} and β_{22}. If the thus determined positions of the points do not coincide substantially with expected positions, a different combination of the values of K and C is adopted and the same procedure as above stated is repeated. Thus, it becomes possible to plot the points M_2 and N_2 on the blank cylinder 19. The same procedure is repeated for the other conical streamline surfaces to determine the positions of the other points M_3, M_4, ... M_n and N_3, N_4, ... N_n.

For convenience in design, data may be prepared in advance in the above described manner as design information so that, when the inflow and outflow angles and the ratio of the outer and inner diameters of the fan wheel are given, the essential dimensions can be immediately determined. For example, in the case of an inflow angle β_1, an outer-to-inner diameter ratio λ, and a conical angle θ, a graph with the angle K as the abscissa and the outflow angle β_2 as the ordinate and with the cylinder radius C as a parameter may be prepared beforehand.

Thus, the actual blade 11 is cut out from a blank cylinder 19 or is formed by bending a piece of plate cut out beforehand from a flat plate stock into a curved shape of a radius of curvature of C. By inserting each blade 11 thus formed between the main plate 16 and the side plate 17 as indicated in Fig. 9 to assemble the fan wheel, a fan wheel of a performance equivalent to that of a fan wheel provided with blades of double-curvature surface, which were considered to be requisite for the fan wheel of a diagonal-flow fan, can be fabricated without the use of such double-curvature blades.

In the above description, the line of intersection 15_1 at one end was made a reference curve for a purpose of simplicity. However, in practical design, the reference curve is selected not from the line of intersection at one end but from the line in the middle of the blade. The use of such middle line as a reference curve is advantageous because it represents a mean streamline.

In practice, the plotting of the entrance and exits points as well as the drawing of the contour line of the blade on a blank cylinder can be made manually, but this procedure is most advantageously carried out by a computerized apparatus.

The foregoing description in conjunction with Figs. 7A, B and C and 8A and B relates to a blade of the so-called "turbo type" wherein the shape of the intersection lines, i.e., the blade 11, faces rearward and, moreover, is curved rearward, but, of course, this blade shape is not thus limited. For example, by placing the cylinder 19 in the positional relationship relative to the conical surface 15_{11} as indicated in Figs. 10A, 10B, and 10C, a so-called "radial tip type" blade, in which the outflow angle β_{21} is a large angle such as 90 degrees or an angle close thereto as indicated in Fig. 10C can be obtained.

In addition, blades of wide ranges of values of the inflow angle β_{11} and outflow angle β_{21} can be fabricated. Furthermore, as described in conjunction with Figs 8A and 8B, it is possible to cause the inflow angles β_{12} to β_{1n} and the outflow angles β_{21} to β_{2n} which are necessary for the diagonal-flow fan wheel to respectively vary progressively with respect to the conical surfaces 15_1, 15_2 . . . . . 15_n of the other representative streamlines and, moreover, to realize connection of the entrance and exit points with a smooth curve having gradually varying radii ρ of curvature.

Thus, under various design conditions, the conical surfaces respectively corresponding to the representative streamlines 15_1 to 15_n are caused to be intersected by a common cylinder 19 of a radius C thereby to produce mutual intersection lines $M_1 N_1$, ... $M_n N_n$, and these intersections are caused to substantially coincide respectively with smooth curves of gradually varying radii ρ of curvature between the inflow angles β_{11}, β_{12}, ... β_{1n} and outflow angles β_{21}, β_{22}, ... β_{2n} of each blade which are to vary progressively in correspondence with the positions within the gas flow path of the representative streamlines 15_1 to 15_n on the conical surfaces thereof and between their entrance points M_1 to M_n and exit points N_1 to N_n.

Upon completion of this preparation, one part of the cylindrical surface of the cylinder 19 is substituted for the blade 11 and, between the main plate 16 and the side plate 17, is fixed thereto by welding, riveting, or some other suitable method. Upon completion of this work for all blades, a fan wheel is obtained. Moreover, since the blade 11 is a portion of the cylinder of radius C, it is in the form of a single-curvature or developable surface and can be readily formed.

While the foregoing description relates to only the case where the blade 11 is a thin plate throughout its entire chord length from the entrance points M_1 to M_n to the exit points N_1 to N_n, this invention can be applied also to the fabrication of so-called "airfoil profile" or thick wing profile. A planar development of a conical surface 15_{11} of a representative streamline corresponding to Figs. 5 and 7C or 10C is shown in Fig. 11. In the description up to this point, the intersection line of this conical surface 15_{11} and a single cylinder 19 was used to form a blade of a thin plate with a camber. An airfoil profile can be obtained in the following manner.

A circle of relatively small radius R is drawn at the entrance point M_1. Then, curves 15_{1a} and 15_{1b} will be considered, which are tangent to this circle of the radius R on opposite sides thereof and intersect at a point slightly upstream from the entrance point M_1 to form angles $\Delta\beta_{11}$ and $-\Delta\beta_{11}$ with the inflow angle β_{11}, and which further intersect at the exit point N_1 to form angles $\Delta\beta_{21}$ and $-\Delta\beta_{21}$ with the outflow angle β_{21} and have gradually varying radii ρ of curvature. The distances U_o and V_o, the angle K, and the radius C are so selected that these curves 15_{1a} and 15_{1b} can be obtained as intersections with two different cylinders hereinafter referred to as 19a and 19b but not shown in the drawings.

More specifically, the radii C of the cylinders 19a and 19b and their related relative values are so selected that a curve is obtained as an intersection line for each of the curves 15_{1a} and 15_{1b} as described in connection with Figs 6 and 11. By this procedure, an airfoil cross sectional profile enclosed by the above mentioned circle of the radius R and the curves 15_{1a} and 15_{1b} are obtained. Similar procedures are repeated for the conical surfaces 15_{21} to 15_{n1} of the representative streamlines.

That is, three respectively common cylindrical surfaces R, 19a, and 19b are used in this example, and they are caused to intersect the conical surfaces respectively of the representative streamlines 15_1 to 15_n, and of these, one cylindrical surface R with a small diameter extends along the entrance points M_1 to M_n, (Fig 6) and the remaining two cylindrical surfaces 19a and 19b (not shown) pass tangentially to the cylindrical surface R and respectively through the exit points N_1 to N_n (Fig 6) to form intersection lines of airfoil profile on the conical surfaces 15_{11} to 15_{n1}.

Fig. 12 illustrates one example of construction of a fan wheel wherein an intermediate plate 20 of conical shape is further installed between the main plate 16 and the side plate 17 in the fan wheel shown in Fig. 3, and all blades 11 are divided by this intermediate plate 20 into sections 11_1 and 11_2. Depending on the circumstances, a plurality of intermediate plates can be similarly installed thereby to divide the blades 11 into a greater number of sections.

The reason for such a measure is that, in the case where the requirements for variations of the inflow angles β_{11} to β_{1n} and the outflow angles β_{21} through β_{2n} cannot be satisfied for all of the representative streamlines 15_1 to 15_n related to each blade 11 with only a single cylinder 19, blades produced by intersections with mutually different cylinders are afforded by this measure. Another reason is that, by this construction, the strength of the fan wheel itself is increased by the insertion of the intermediate plate 20. In the case where there is no such requirement, the intermediate plate 20 may be omitted, and, moreover, the plurality of blade sections 11_1 and 11_2 may be fabricated unitarily.

In accordance with the embodiments of the invention, as described above, blades each of a single-curvature (developable) surface, which is a portion of a cylindrical surface, are used instead of blades each of double-curvature (nondevelopable) surface, which was heretofore considered to be indispensable, in the fan wheel of a diagonal-flow fan, whereby a fan performance equivalent to that of a fan provided with ideal double-curvature blades can be attained.

That is, the inflow angles and outflow angles of each blade vary progressively in accordance with the positions taken in the gas flow path by the representative streamlines within the fan wheel. In addition, each curve extending from the corresponding entrance point to the exit point also has a shape which is not a simple arc with a single radius of curvature or, at the most, a curve formed by joining two arcs as in centrifugal fans but is a curve which is close to the ideal according to fluid dynamics and has a radius of curvature varying progressively over the entire chord length. Furthermore, the blade shape according to this invention is applicable to not only a blade of the so-called rearwardly curved turbo type, but also to blades of the radial tip type, to combinations of the turbo type and the radial tip type, and even to airfoil types.

We have succeeded in constructing by the above described method a diagonal flow fan having turbo-type, thin plate blades of an outer diameter of 630 mm., a rotational speed of 3,028 rpm, and a delivery pressure rise of approximately 300 mm. of water without any difficulty from the beginning, which fan produced a good result of a total pressure maximum efficiency of 83 percent.

Thus, diagonal-flow fans, which were heretofore thought to be very difficult to produce because they required double-curvature blades and, as a result, were not reduced to practice as products although there has been high expectation for their realization as fans of high performance intermediate between centrifugal fans and axial-flow fans, can be produced at low cost in accordance with this invention.

This invention can also be embodied in the fan wheel of a diagonal-flow fan of the straight-line, rearwardly inclined (so-called plate-turbo) type which is useful in the handling of gases containing dust, for example.

In the fan wheel of an ordinary centrifugal fan of the straight-line, rearwardly inclined type, the entrance edges 2 and exit edges 3 of the fan blades 1 are respectively parallel to the rotational shaft axis 4 as shown in Fig. 13. At the same time, when the fan wheel is viewed in its axial direction, each blade 1 is inclined rearwardly (rearward facing) in the direction opposite to the direction of rotation S. Each blade, however, has no inclination in the direction of the shaft axis, and its cross sections taken in parallel planes perpendicular to the shaft axis appear to be superposed on each other. Thus, each blade 1 has a planar shape.

Therefore, each blade 1 of a fan wheel of this type can be fabricated in a simple manner by cutting it from a flat plate stock.

A blade 1 of this type, however, is extremely disadvantageous from the viewpoint of fluid dynamics because of its straight-line shape, and a fan provided with blades of this type has a much lower efficiency than a fan of the so-called turbo type in which each blade is curved rearwardly, and its radius of curvature varies progressively along its chord length C. Yet, in spite of this disadvantage, straight-line, rearwardly inclined type centrifugal fans are being used since their straight-line shape facilitates the fabrication of their blades. Another reason for their continued use is that, in the case where the fan is required to propel a dust containing gas, for example, a wear-resistant plate 5 can be readily secured to each blade 1 as shown in Figs. 14A and 14B.

The general structural features of a straight-line, rearwardly inclined type, diagonal-flow fan are similar to those of the diagonal-flow fan described hereinbefore with reference to Figs. 3, 4, and 5 and, therefore, will not be described again.

A blade of a section corresponding to each representative streamline, which blade is inclined in a straight-line in the direction opposite to that of the rotational direction S as in the case of a fan wheel of a straight-line, rearwardly inclined type, centrifugal fan as illustrated in Fig. 13, appears to be simpler to fabricate than a blade of a varying radius of curvature. However, the conical surfaces constituted by the representative streamlines within the fan wheel respectively have different half vertex angles as mentioned hereinbefore. In addition, the inflow and outflow angles at the entrance and exit points corresponding to the representative streamlines respectively require progressively varying values. Therefore, it will be apparent that, on the contrary, a complicated double-curvature surface is required.

According to this invention, the blade of the fan wheel of a diagonal-flow fan of the straight-line, rearwardly inclined type is fabricated by the use of a planar plate. Since a planar plate can be considered to be a cylindrical plate of infinite radius, the principle of how the blade is obtained is basically the same as that described with reference to Figs. 6 to 8B.

Fig. 15 is a perspective view showing intersections between the conical surfaces constituted by the representative streamlines and an imaginary planar surface 29, which can be considered an imaginary cylindrical surface of infinite radius.

Figs. 16A, 16B and 16C show projectionally the intersection between the conical surface 15_{11} constituted by the representative streamline 15_1 and the planar surface 29. The planar surface 29 contains an entrance point M_1 on the conical surface 15_{11} and has an axis intersecting the conical surface 15_{11} with an inclination angle of K relative to the central axis H of the conical surface 15_{11}.

In the figures, U, V, and W are orthogonal coordinate axes with their origin at the vertex O of the conical surface 15_{11}, axis W being parallel to the planar surface 29 containing the entrance point M_1 and, moreover, being inclined by the angle K relative to the central axis H of the conical surface 15_{11}, axis V being superimposed on the point M_1 when viewed in the direction of axis W as in Fig. 16A. From the manner in which the axis W is taken, the angle K is expressed as the angle between the axis W and the axis H. Furthermore, the V coordinate of the point M_1 is L. β_{11a} is the angle between the plane 29 and the U axis.

The conical surface 15_{11} is the same as the conical surface constituted by the representative streamline 15_1. The intersection line between this conical surface 15_{11} and the planar surface 29, that is, that part from the point M_1 to the point N_1, is shown by thick line in the development of the conical surface 15_{11} in Fig. 16C and is equivalent to that shown in Fig. 5. That is, the sectional profile of the blade 11 in the form of a smooth curve having specific inflow and outflow angles β_{11} and β_{21} on the conical surface of one representative streamline as shown in Fig. 5 and having a progressively varying radius of curvature ρ between its entrance and exit points can be obtained geometrically by determining the distance L and the angle K shown in Figs. 16A and 16B by a method described hereinafter.

That the sectional profile of the blade 11 becomes a smooth curve having a progressively varying radius of curvature ρ, in spite of the use of one portion of a planar surface, can be understood from the fact that the conical section produced by diagonally cutting a cone is an ellipse.

These relationships will now be geometrically studied. An arbitrary point m on the curve M_1 N_1 constituting one part of the intersection between the conical surface 15_{11} of the representative streamline 15_1 and the planar surface 29 in Figs. 16A to 16C will be considered. This point m has coordinates (u,v) in Fig. 16A, coordinates (v,w) in Fig. 16B, and coordinates (x,y) in Fig. 16C showing the development of the conical surface 15_{11}, the coordinates being based on the orthogonal coordinate axes X and Y as described hereinbefore.

In this case, the following relationships exist.

$$x=f(\theta_1, u, r) \quad (7)$$
$$y=f(\theta_1, u, r) \quad (8)$$
$$u=f(\theta_1, L, K, r) \quad (9)$$
$$\phi=f(\theta_1, u, r) \quad (10)$$

Here, r and ϕ represent the same variables as before in Eq. (4). By substituting these Eqs. (7) to (10) in the Eqs. (5) and (6) set forth hereinbefore, the radius of curvature ρ and the angle β at the point m in Fig. 16C are obtained. The nature of the angle β and the variation of the radius of curvature ρ depending on the position of the point m are as described hereinbefore. For this reason, the curve from the entrance point M_1 to the exit point N_1 is equivalent to that of a blade in a rearwardly curved type (so-called turbo type) fan wheel, which blade is considered to be ideal from the viewpoint of fluid dynamics. Thus, this blade differs considerably from that in the fan wheel of a conventional straight-line, rearwardly inclined type, centrifugal fan in which the streamline radius ρ is infinity, that is, the blade is straight.

Thus, the representative streamline 15_1 is obtained as indicated in outline form in Fig. 15. In the same manner, the other representative streamlines 15_2, 15_3, ... 15_n are obtained respectively from the intersections of the planar surface 29 and the conical surfaces 15_{21}, 15_{31}, ... 15_{n1}.

Fig. 17A shows a projection of this state as viewed in the arrow direction Q (Fig. 15). This projection corresponds to Fig. 16A. Furthermore, Fig. 17B is a projection corresponding to Fig. 16B. These intersection lines can be readily computed by carrying out with respect to the conical surfaces 15_{21} .... 15_{n1} operations similar to that with respect to the conical surface 15_{11}. That is, Figs. 17A and 17B are respectively Figs. 16A and 16B with the further addition thereto of conical surfaces 15_{21} .... 15_{n1} having a common centerline axis H with the conical surface 15_{11} and respectively having half vertex angles θ_2 .... θ_n. These n conical surfaces 15_{11}, 15_{21}, ... 15_n are arranged in the same manner as the n conical surfaces constituted by the representative streamlines 15_1, 15_2, ... 15_n, and, moreover, the blade 11 is substituted for one part of the planar surface 29 of Fig. 17A.

As is apparent from Figs. 15 and 17A, when the group of n conical surfaces inclined as shown therein is viewed in the direction of the axis W (arrow direction Q in Fig. 15), the blade 11, as one part of the plane of the planar surface 29, has no twist and appears as a superimposition with same sectional profile. When the conical surface 15_{11} is developed into a planar surface, it becomes as shown in Fig. 16C as described before, and the other conical surfaces 15_{21} .... 15_{n1} also can be similarly developed. The intersection lines due to these developments are not shown in Fig. 17A, but, as indicated in outline form in Fig. 15, they respectively start at points M_2, M_3, ... M_n and end at points N_2, N_3, ... N_n, having inflow angles β_{12} .... β_{1n} and outflow angles β_{22} .... β_{2n} respectively differing slightly from the inflow angle β_{11} and the outflow angle β_{21} at the streamline 15_1 (Fig. 4). Between the entrance and exit points, the intersection lines are in the form of smooth curves each having gradually varying radius of curvature ρ.

That the inflow angles β_{11}, β_{12}, ... β_{1n} and the outflow angles β_{21}, β_{22}, ... β_{2n} respectively differ slightly from each other is a natural result of the variations of the radial distance r_{in} at the entrance point and the radial distance r_{out} at the exit point of each of the representative streamlines 15_1, 15_2, ... 15_n as described hereinbefore with reference to Fig. 3.

When all intersection lines, that is, the representative streamlines 15_1 to 15_n have been operationally determined, the part of the planar surface 29 enclosed by the curve M_1 to N_1 at the representative streamline 15_1, the curve M_n to N_n at the representative streamline 15_n, and the curves M_2 to N_2, ... $M_{(n-1)}$ to $N_{(n-1)}$ of the remaining representative streamlines in cut out of the planar surface 29, which is actually a planar plate stock. The outline of this cut out figure can be readily determined from the coordinates of the point m, that is, m(u,v,w) in Figs. 16A and 16B.

Thus, by cutting out each blade 11 from a planar plate stock and securing it by a method such as welding or riveting to and between the main plate 16 and the side plate 17 as indicated in Fig. 9 thereby to assemble the fan wheel, a fan wheel of a performance equivalent to that of a fan wheel provided with blades of double-curvature surface, which were considered to be requisite for the fan wheel of a diagonal-flow fan, can be easily fabricated by the use of planar blades of simple fabrication, to which wear-resistant plates can be readily attached, without the use of such double-curvature blades.

Moreover, the blade 11 is equivalent to a rearwardly curved type (so-called turbo type) blade of progressively varying radius of curvature ρ, which is considered to be ideal from the viewpoint of fluid dynamics.

The above description in conjunction with Figs. 16A to C and 17A and B relates to a blade of the so-called turbo type wherein the shape of the intersection lines, i.e., the blade 11, faces rearward and, moreover, is curved rearward, but, of course, this blade shape is not thus limited.

In the fan wheel of the instant embodiment of this invention, by progressively decreasing the angle K, because of the relationship of the half vertex angle θ, a so-called limit-load blade in which the shape of the blade 11 is rearwardly facing and, at the same time, varies from forward curvature to rearward curvature and, further, a so-called radial tip type blade in which the shape of the blade 11 is rearwardly facing and, at the same time, is forwardly curved can be obtained, although not shown in the drawings. In the blades, similarly as in the aforementioned turbo type, the inflow and outflow angles β_{11} to β_{1n} and β_{21} to β_{2n}, which are necessary for a diagonal-flow fan wheel, are respectively caused to vary progressively, and the entrance and exit points can be joined by smooth curves having gradually varying radii of curvature ρ. In this case also, of course, the blade 11 is still one part of the planar surface 29 or planar plate stock.

In actually designing a fan wheel according to this embodiment of the invention of a straight-line, rearwardly inclined type, diagonal-flow fan, the representative streamlines 15_1 to 15_n are first determined. From these, the conical surface half vertex angles θ_1 to θ_n are determined. Standard values of the ratio of the inner and outer diameters of each blade have been tentatively determined in accordance with the gas flow rate and delivery pressure. Therefore, from the rotational speed of the fan wheel, the distribution of the inflow angle β_1 along the blade entrance edge and the distribution of the outflow angle β_2 along the blade exit edge are determined.

For the determination of the setting position of the planar surface 29, the distance L and the angle β_{11a} shown in Fig. 16A are necessary. When the angle K has been determined, the distance L is determined from the radial distance r_{in1} of the entrance point M_1 and the half vertex angle θ_1 of the conical surface, and the angle β_{11a} is determined from the half vertex angle θ_1 and the inflow angle β_{11}. Therefore, since the angle K is the only unknown variable, its value is so determined that the outflow angle β_{21} at the exit point N_1 will become a specific value.

When the angle K has been determined in this manner, adjustments are made in the inner and outer diameters of the representative streamlines on the basis of these variables L, β_{11a}, and K so that, with respect to the conical surfaces constituted by these representative streamlines, the inflow and outflow angles will become specific respective values.

Up to this point, the entrance point M_1 has been taken as the reference datum point for convenience in description, but the datum point need not be so limited. It is possible to carry forward the operation with any convenient point as the reference datum point.

For convenience in design, data may be prepared in advance in the above described manner as design information, as was previously described with respect to the first embodiment of the invention, so that, when the inflow and outflow angles and the ratio of the outer and inner diameters of the fan wheel are given, the essential dimensions thereof can be immediately determined. For example, in the case of an inflow angle β_1, an outer-to-inner diameter ratio λ, and a conical half vertex angle θ, a graph with the setting angle K as the abscissa and the outflow angle β_2 as the ordinate may be prepared beforehand.

In accordance with the instant embodiment of this invention as described above, blades each constituting one part of a planar surface, which can be easily fabricated and to which wear-resistant materials can be readily affixed, are used instead of blades of double-curvature surfaces, which were heretofore considered to be necessary in the fan wheel of a straight-line, rearwardly inclined type, diagonal-flow fans, to produce a performance equivalent to that of fan wheels with double-curvature blades. Furthermore, in spite of the use of planar blades, the fan wheel of the instant embodiment of this invention exhibits a performance equivalent to that of the so-called turbo type fan wheel of rearwardly curved blade type having double-curvature blades, which are considered to be fluid dynamically ideal but impossible to realize in the fan wheel of a straight-line, rearwardly inclined type centrifugal fan.

In addition, in accordance with the instant embodiment of this invention, the following advantage is afforded. In the fan wheel of a straight-line, rearwardly inclined type, centrifugal fan, when the outer-to-inner diameter ratio λ and the inflow angle β_1 at the entrance point have been determined, the outflow angle β_2 at the exit point is automatically determined from the geometrical relationships indicated in Fig. 18. That is, the following relationship is valid.

$$\beta_2=90°-\cos^{-1}[(Cr^2+\lambda^2-1)/2Cr\lambda], \quad (11)$$

where Cr is the ratio of the chord length C to the inner diameter D_1 of the blade, or $(Cr=C/D_1)$.

$$Cr=\sqrt{\sin^2\beta_1+\lambda^2-1}-\sin\beta_1 \qquad (12)$$

λ is the outer-to-inner diameter ratio.

$$\lambda=D_2/D_1 \qquad (13)$$

Ordinarily, the inflow angle β_1 at the entrance point is selected from experience at a value of 30 to 40 degrees for maximum efficiency. Accordingly, the outflow angle β_2 at the exit point of the blade of a straight-line, rearwardly inclined type, centrifugal fan wheel is determined by only the outer-to-inner diameter ratio λ.

Furthermore, the delivery head H_{ad} is a function of the outflow angle β_2, the outer-to-inner diameter ratio λ, and the circumferential velocity U of the blade exit as indicated by the following equation.

$$H_{ad}=f(\beta_2, \lambda, U_2) \qquad (14)$$

This means that, if the outer-to-inner diameter ratio λ and the inflow angle β_1 are given, the determining parameter for satisfying the required delivery head will be only the circumferential velocity U_2 at the blade exit, and a design matching the given specifications becomes disadvantageously difficult, differing from that of a rearwardly curved type blade of the same centrifugal type.

In contrast, in the case of the fan wheel of this invention of the straight-line, rearwardly inclined type, diagonal-flow fan, as described hereinabove, the outflow angle β_2 can be changed by changing the setting angle of the intersecting planar surface even when, for example, the inflow angle β_1 and the outer-to-inner diameter ratio have been determined. This means that the angle K can be used in addition to the circumferential velocity U_2 of the blade exit as a parameter for satisfying the required delivery head H_{ad}, and, by combining these parameters, a design matching the given specifications can be carried out without difficulty.

Thus, this invention provides a fan wheel of a straight-line, rearwardly inclined type, diagonal-flow fan which fan wheel can be easily fabricated at low cost and, moreover, can be readily provided with wear-resistant plates since planar blades are used. As mentioned hereinbefore, a fan of this character has not heretofore been successfully reduced to a practical product in spite of the great expectations for its high performance intermediate between those of centrifugal fans and axial-flow fans because it was thought to require complicated double-curvature blades, which are difficult to fabricate.

WHAT WE CLAIM IS:—

1. A fan wheel of a diagonal-flow fan for propelling a flow of a gas, said fan wheel comprising a rotational shaft, a frustoconical main plate coaxially fixed to the shaft, a frustoconical side plate spaced apart from the main plate and forming therebetween a diagonal flow path for the gas, and a plurality of fan blades each fixed at respective opposite side edges to the inner surfaces of the main and side plates and having an inner entrance part and an outer exit part such that innumerable stream surfaces of the gas are formed, in operation of the fan wheel, from said entrance part to said exit part and between said main and side plates, each of said fan blades comprising a plate of a surface shape conforming to a portion of an imaginary cylindrical surface with a longitudinal axis, said portion being formed of innumerable elements constituted by mutual intersection lines between said imaginary cylindrical surface and innumerable imaginary coaxial conical surfaces corresponding to said stream surfaces, respectively, said imaginary coaxial conical surfaces having a common axis coinciding with the axis of said rotational shaft and lying in a plane which is in parallel spaced relationship to said longitudinal axis of the cylindrical surface, said common axis being inclined at an angle with respect to said longitudinal axis when viewed in a direction perpendicular to said plane.

2. A fan wheel as claimed in claim 1, wherein the surface shape of each blade is derived from a rectangular coordinate system with two axes lying in a plane perpendicular to the longitudinal axis of said cylindrical surface, said system having its origin at the vertex of one of said conical surfaces, one of said axes lying in a plane which includes a line passing through the vertices of said conical surfaces and which is parallel to said longitudinal axis, and wherein the coordinate of the longitudinal axis with respect to the other of said axes is positive.

3. A fan wheel as claimed in claim 1, wherein the surface shape of each blade is derived from a rectangular coordinate system with two axes lying in a plane perpendicular to the longitudinal axis of said cylindrical surface, said system having its origin at the vertex of one of said conical surfaces, one of said axes lying in a plane which includes a line passing through the vertices of said conical surfaces and which is parallel to said longitudinal axis, and wherein the coordinate of the longitudinal axis with respect to the other of said axes is negative.

4. A fan wheel as claimed in any one of the preceding claims, wherein each of said

blades has a further surface shape on its surface opposite to the surface of said first surface shape, and an entrance surface shape at its inner entrance part, said further surface shape conforming to a portion of a further imaginary cylindrical surface which has been caused to intersect said imaginary coaxial conical surfaces in the same manner as the first mentioned cylindrical surface to form mutual intersection lines, said inner entrance surface shape also conforming to a portion of a still further imaginary cylindrical surface of relatively small diameter which has also been caused to intersect said imaginary conical surfaces to form said mutual intersection lines.

5. A fan wheel of a diagonal-flow fan for propelling a flow of a gas, said fan wheel comprising a rotational shaft, a frustoconical main plate coaxially fixed to the shaft, a frustoconical side plate spaced apart from the main plate and forming therebetween a diagonal flow path for the gas, and a plurality of fan blades each fixed at respective opposite side edges to the inner surfaces of the main and side plates and having an inner entrance part and an outer exit part such that innumerable stream surfaces of the gas are formed, in operation of the fan wheel, from said entrance part to said exit part and between said main and side plates, each of said fan blades comprising a plate of a surface shape conforming to a portion of an imaginary planar surface, said portion being formed of innumerable elements constituted by mutual intersection lines between said imaginary planar surface and innumerable imaginary coaxial conical surfaces corresponding to said stream surfaces, respectively, said imaginary coaxial conical surfaces having a common axis coinciding with the axis of said rotational shaft, said planar surface being in parallel relation to an axis which is at an angle with said common axis.

6. A fan wheel as claimed in any one of claims 1 to 4, wherein each of said blades is divided axially into two blade sections, which have different surface shapes having the same nature as said surface shape and conforming to portions of different imaginary cylindrical surfaces, respectively.

7. A fan wheel of a diagonal-flow form substantially as herein described with reference to the accompanying drawings.

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1595134 COMPLETE SPECIFICATION

11 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 1

FIG. 1

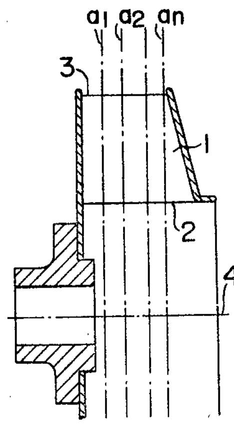


FIG. 3

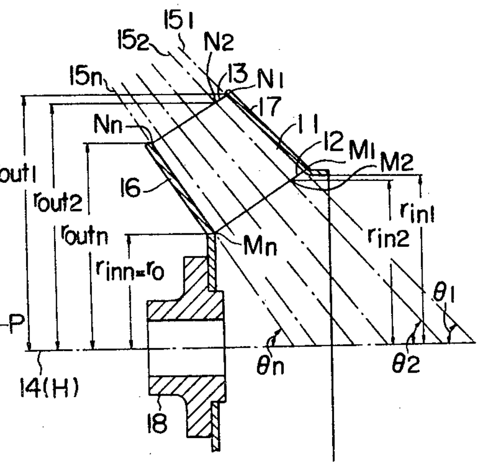
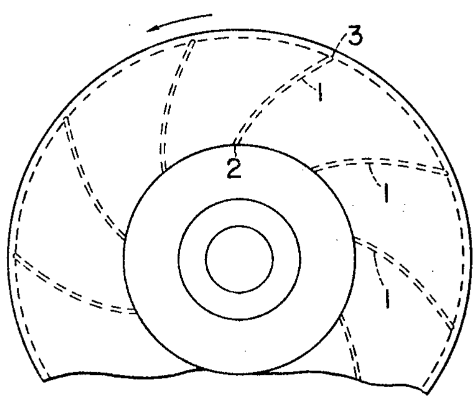


FIG. 2



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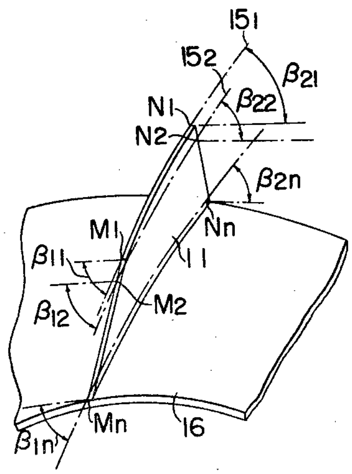
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152
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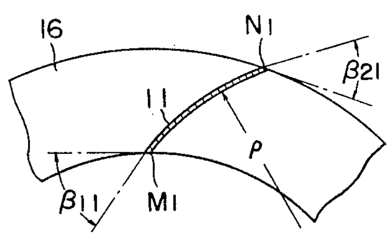
N1
β22
N2
β2n
M1
Nn
β11
11
M2
β12
Mn
16
β1n

F I G. 5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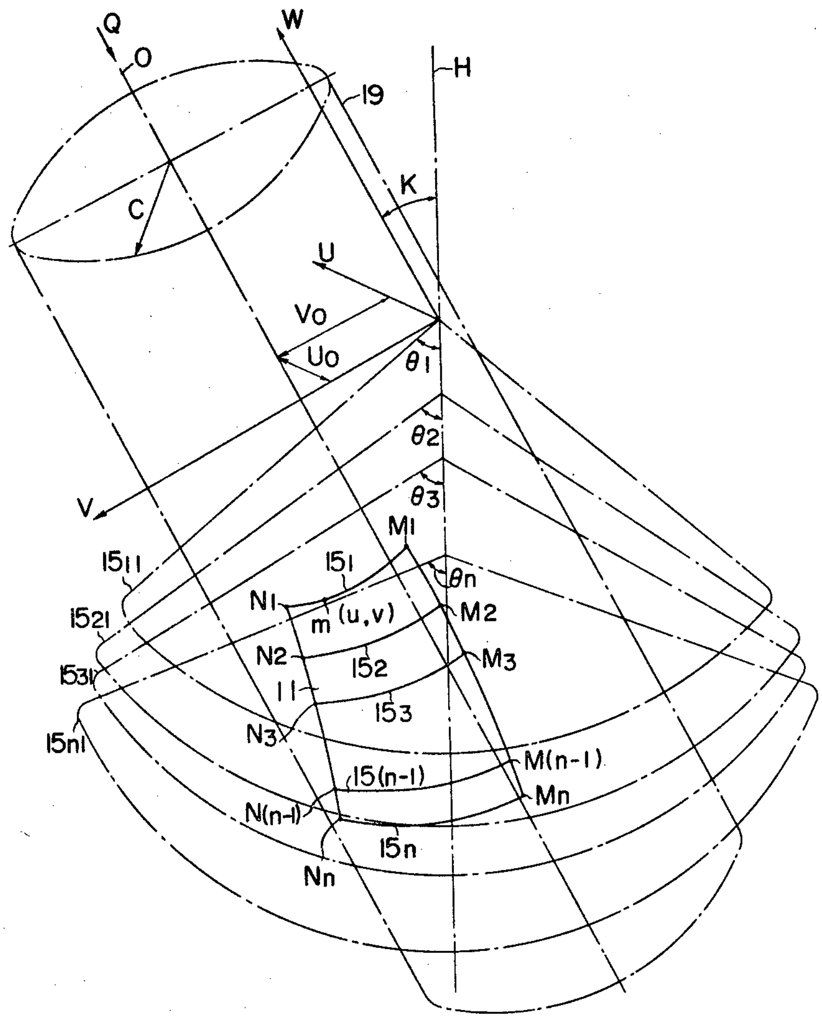
N1
β21
11
ρ
β11
M1

F I G. 6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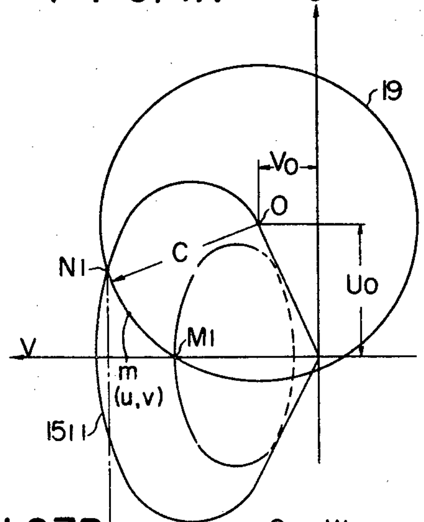
O
W
H
19
K
C
U
Vo
Uo
θ1
θ2
θ3
V
M1
15₁
θn
15₁₁
N1
m (u,v)
M2
15₂₁
N2
15₂
M3
15₃₁
11
15₃
N3
15ₙ₁
M(n-1)
15(n-1)
Mn
N(n-1)
15n
Nn

1595134 COMPLETE SPECIFICATION

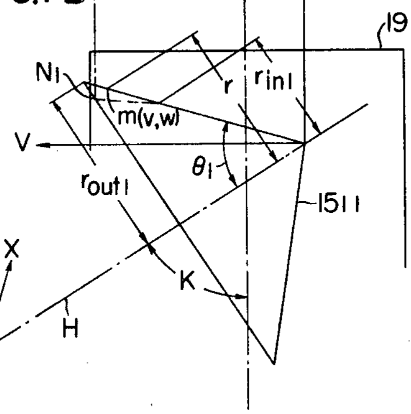
11 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 4

F I G. 7A



F I G.7B



F I G. 7C

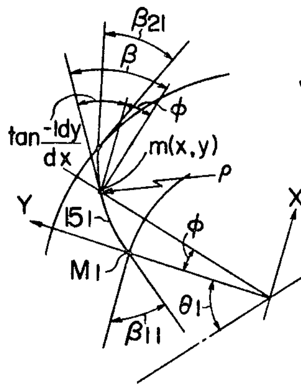
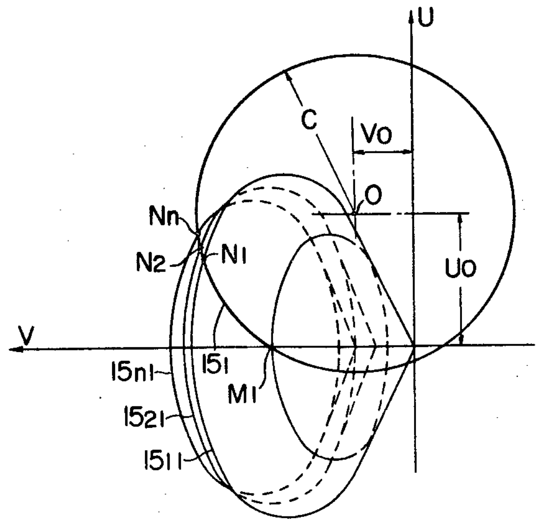


FIG. 8A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C
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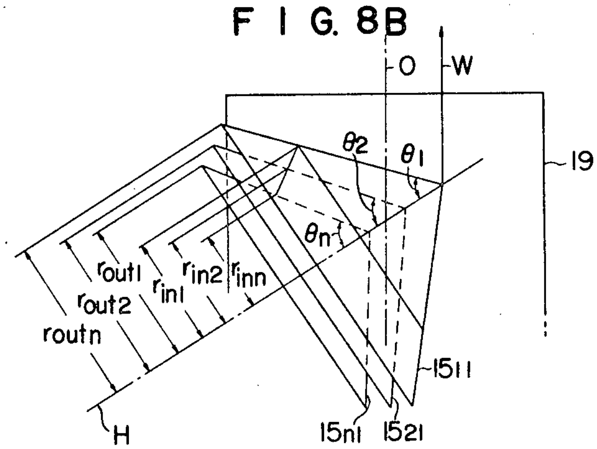
Nn
N2
N1
Uo
V
15n1
151
M1
1521
1511

FIG. 8B


O
W
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θ1
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θn
rout1
rin1
rin2
rinn
rout2
routn
1511
H
15n1
1521

FIG. 9

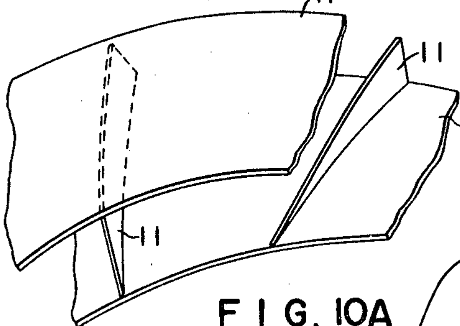


FIG. 10A

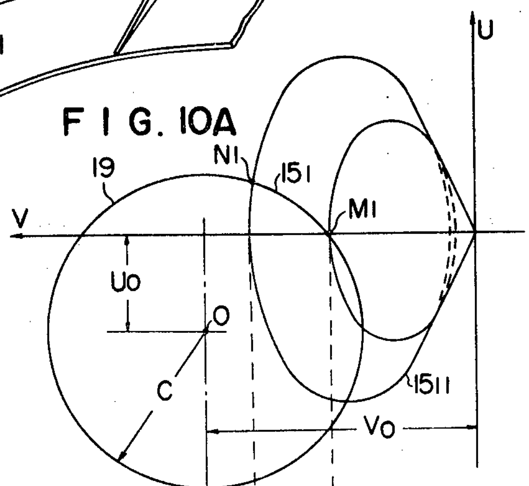


FIG. 10B

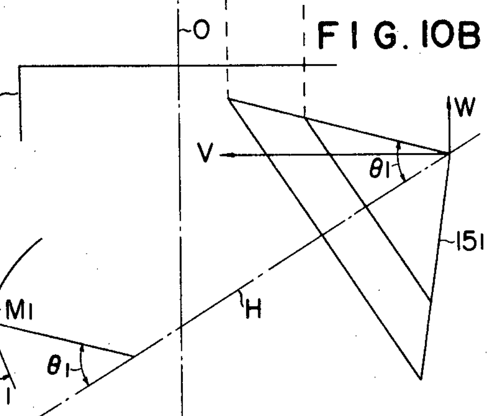


FIG. 10C

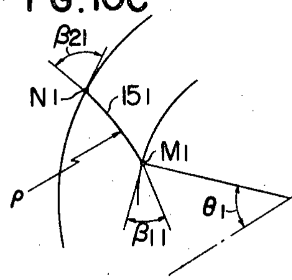
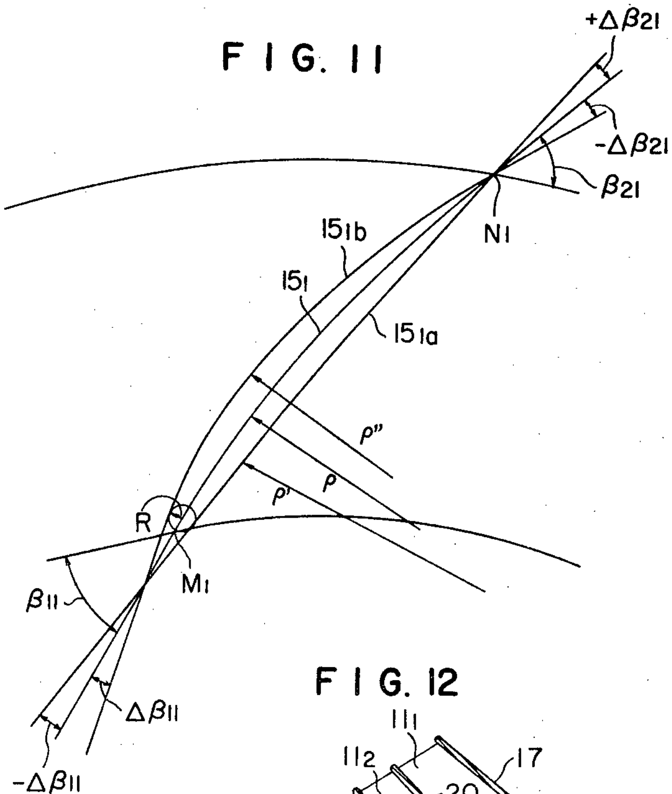


FIG. 11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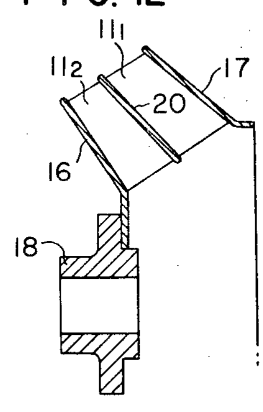
-Δβ21
β21
N1
151b
151
151a
ρ"
ρ
ρ'
R
M1
β11
Δβ11
-Δβ11

FIG. 12


111
112
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20
16
18

FIG. 13 PRIOR ART

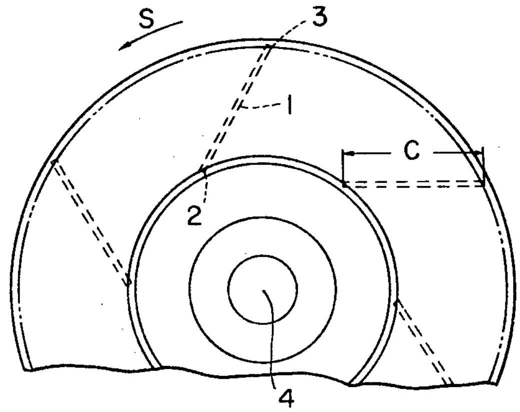


FIG. 14A
PRIOR ART

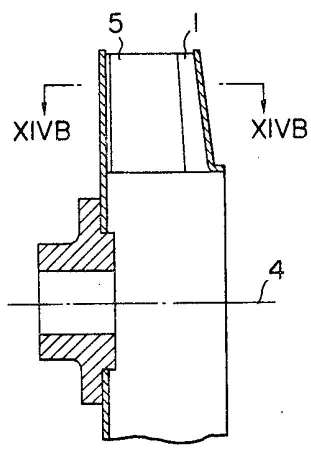


FIG. 14B
PRIOR ART

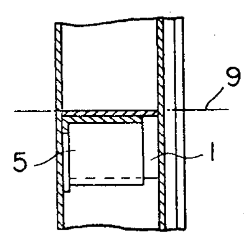


FIG. 15

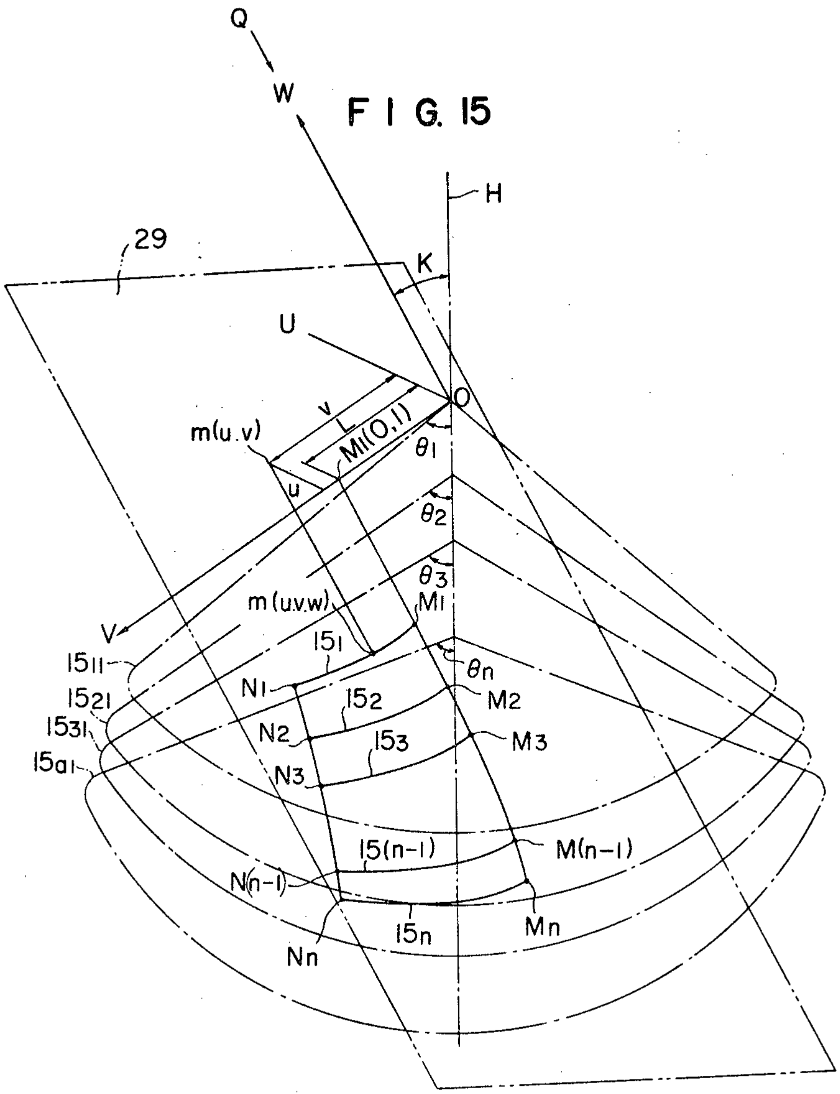

Q
W
H
29
K
U
O
v
L
m(u.v)
MI(O,I)
θ1
u
θ2
θ3
m(u.v.w)
MI
V
151
θn
1511
N1
M2
1521
152
1531
N2
M3
153
15a1
N3
15(n-1)
M(n-1)
N(n-1)
15n
Mn
Nn

FIG. 16A

FIG. 16B

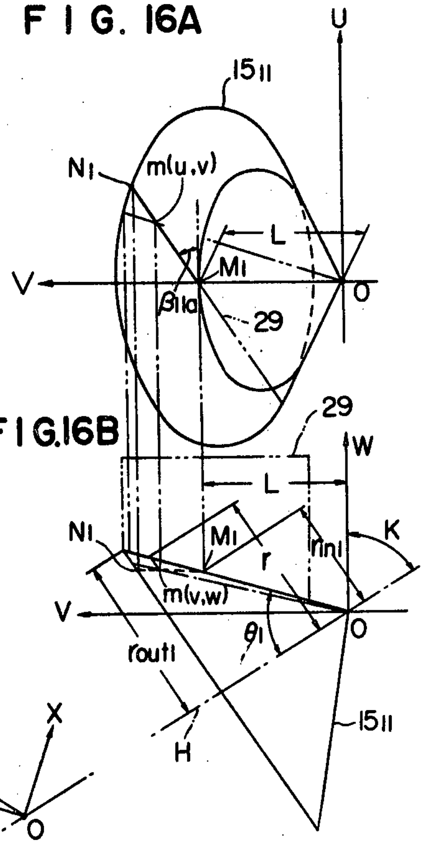
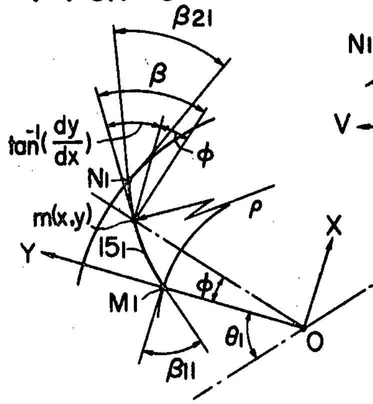
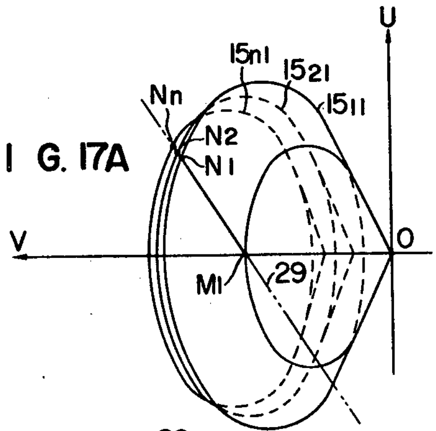


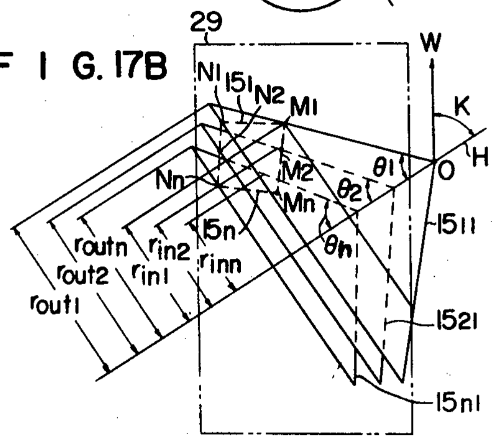
FIG. 16C



F I G. 17A



F I G. 17B



F I G. 18