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[56]

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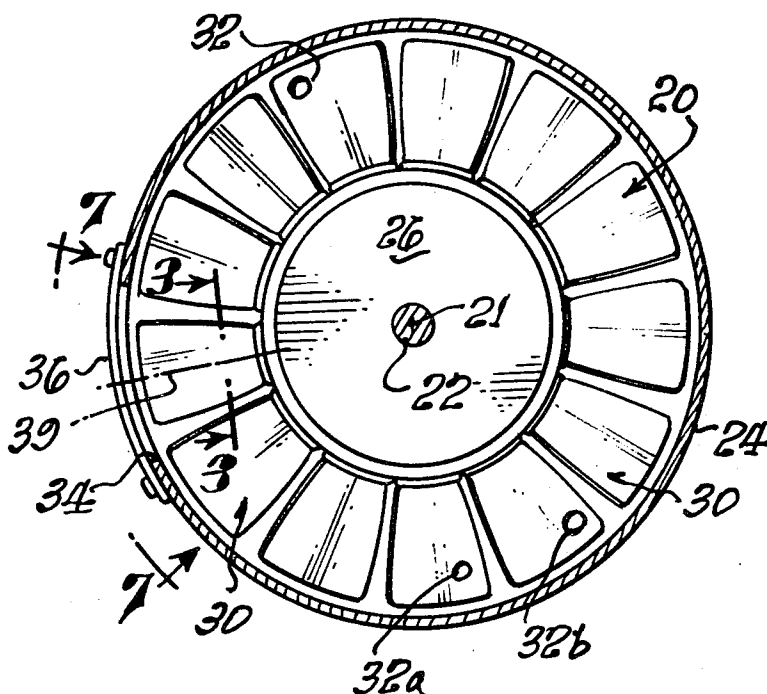
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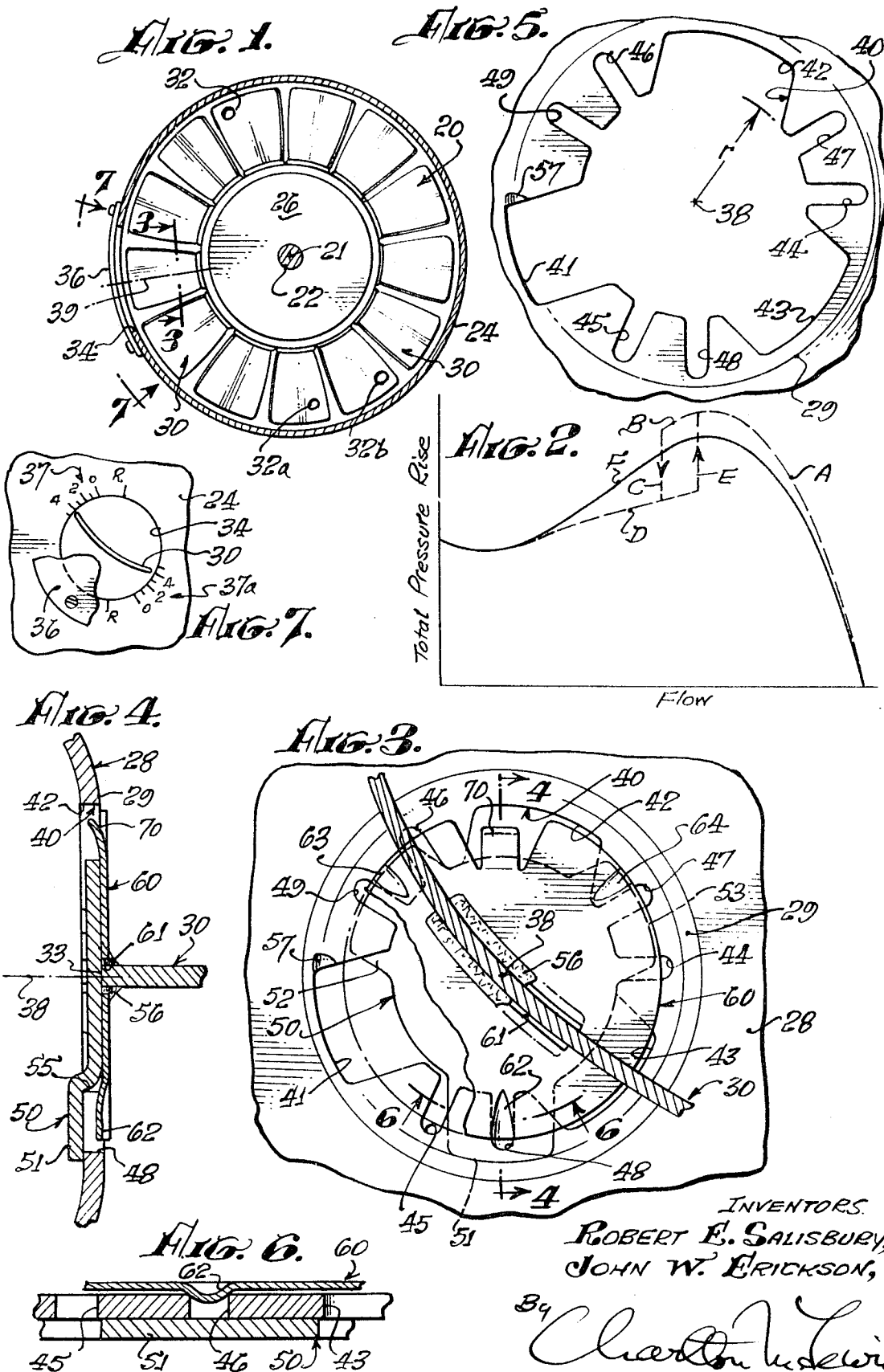
[54] **BLADE MOUNT AND STALL CONTROL FOR**
VANE AXIAL COMPRESSORS
6 Claims, 10 Drawing Figs.

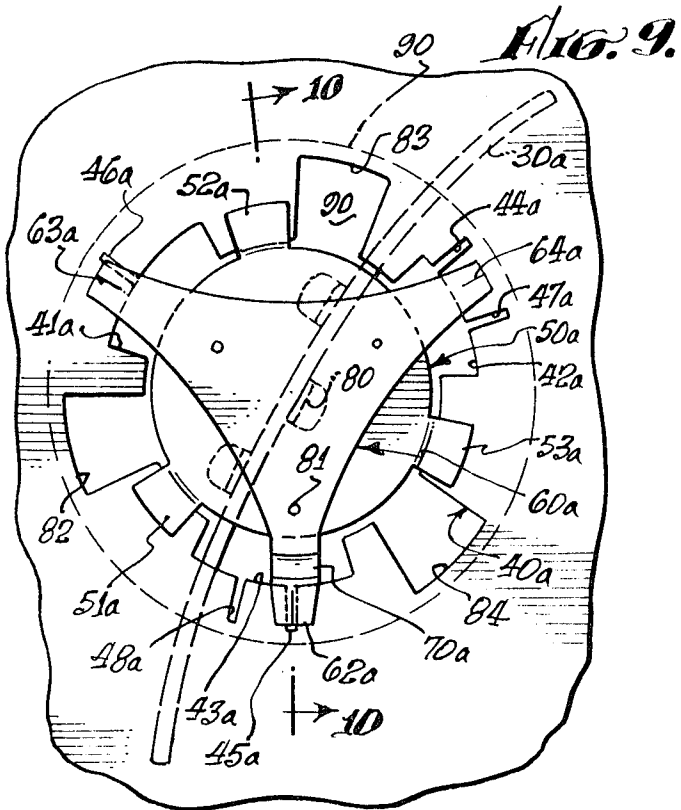
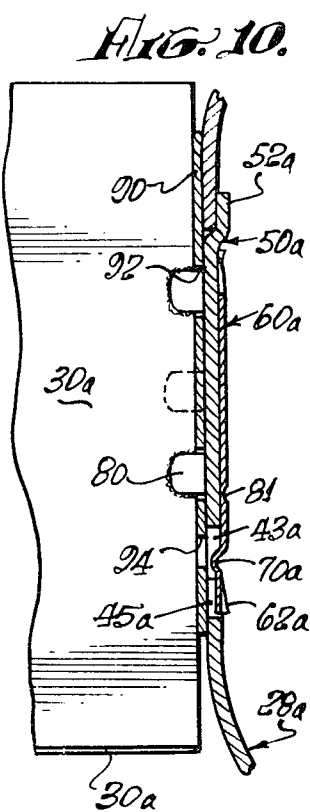
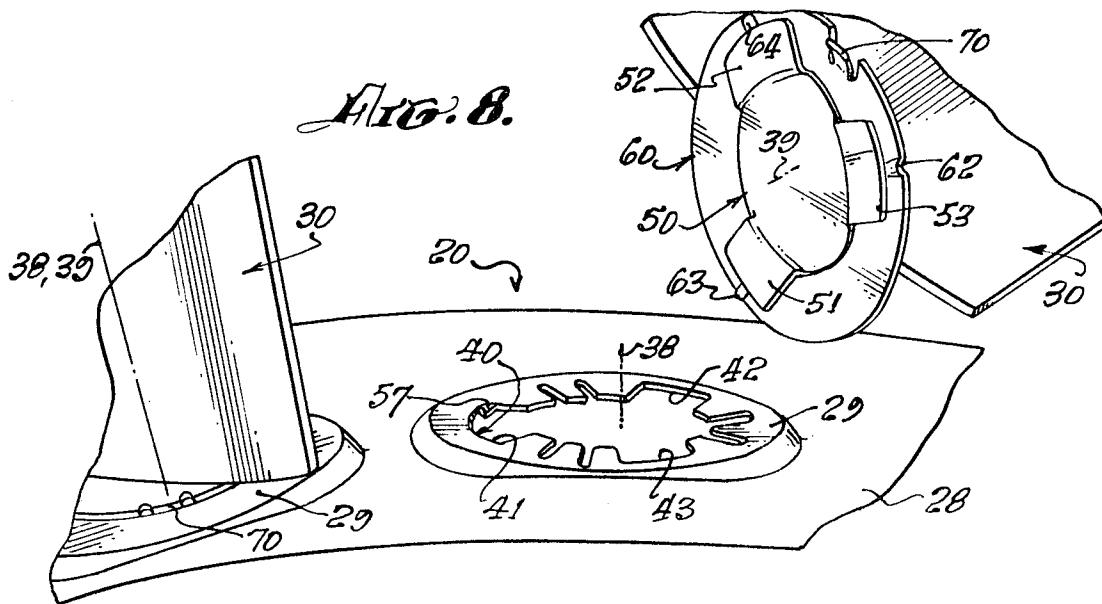
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ABSTRACT: Radial compressor blades are adjustably and releasably mounted on the impeller hub. A set of rigid bayonet formations defines the blade axial position positively at all pitch angles. A set of flexible detent formations defines the pitch angle effectively positively during operation, but yieldably for manual adjustment between discrete values. A positive lock must be released for blade removal.

Especially at low pitch angles, the compressor is stabilized against stall by aperturing one or more blades.







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BLADE MOUNT AND STALL CONTROL FOR VANE AXIAL COMPRESSORS

This invention relates generally to axial flow fans, blowers and gas compressors, which will be referred to collectively as compressors. The invention provides improved structure for mounting the impeller blades on the fan hub, and also provides improved stability with respect to aerodynamic stalling.

One important object of the invention is to provide structure by which the pitch angle of the mounted impeller blades can be adjusted conveniently, while insuring reliable locking of the blades in adjusted position. The invention further permits convenient and rapid disassembly of one or more blades individually, as for inspection or replacement.

A further object of the invention is to provide mounting structure for impeller blades that is more economical to manufacture than previously known structures, while insuring accurate and reproducible positioning of each blade with respect to the fan hub.

The invention has the particular advantage that each blade is shiftable only among a finite number of discrete pitch angles, each of which is positively and precisely defined by the mechanical mounting structure, with clear indication by reference marks of improved type. All of the blades can therefore be shifted from one position to another without requiring any precision tools, yet with full confidence that the adjusted angles of all blades are accurately equal.

Another aspect of the invention improves fan operation throughout a wide range of blade adjustment by reducing the tendency to abrupt aerodynamic stalling. It is well known that axial compressors are subject to instability as the airflow is throttled, typically shifting abruptly to a stalled condition with a significant drop in output pressure. That tendency varies in severity as the blade pitch angle is changed, ordinarily becoming more serious as the openings between blades are closed down.

The present invention increases the range of stable operation by providing one or more paths for backward gas flow between the pressure side and the suction side of individual blades. Such paths are typically provided via apertures in the blades, a single aperture near the blade tip being normally sufficient. One or more blades may be so apertured. When a plurality of blades are apertured, they are preferably selected symmetrically with respect to the blower axis. Provision of a small number of such paths for backflow, typically from one to six, reduces the total pressure produced by the fan only slightly, and typically has no measurable effect on the normal flow. The resulting increase in the range of stable operation, although advantageous in any compressor, is especially valuable in combination with an impeller having adjustable blades.

The prior art includes many suggested structures for adjustably mounting impeller blades on a hub. Many of those structures require accurate and even elaborate machining of parts, and are therefore expensive to construct. Others require manipulation of locknuts within the impeller hub, or of set-screws, before the blades can be adjusted, followed by tightening of those elements after adjustment. With such structures, quite aside from the labor and time required to set and lock the blades, it is extremely difficult to position all blades at accurately identical pitch angles. Still other proposed structures provide convenient adjustment of blade pitch between only two or three alternative values, or hold the blades so loosely that they tend to vibrate during operation. Other previously suggested structures permit individual adjustment of the blades, but not their removal.

Those and other disadvantages of the prior art are overcome by structure that includes mutually complementary formations of bayonet type mounted essentially rigidly on the blade and on the fan hub, the axis of the mount structure being typically perpendicular to the compressor axis and essentially coinciding with the longitudinal axis of the blade. That rigid bayonet structure positively restrains the assembled blade against radially outward movement from the hub, rigidly

defining the direction of the longitudinal blade axis relative to the hub, while leaving the blade essentially free to rotate within a limited range of rotary adjustment about the mount axis. When the blade is rotated to the limit of that range of adjustment in one direction the rigid bayonet structure releases the blade and it may be freely removed from the hub in a radial direction.

The invention further provides locking means for retaining the blade in any selected one of a plurality of distinct, angularly spaced, rotary positions. Such locking means preferably comprise resilient detent structure for positively and accurately defining each discrete position, while permitting the blade to be shifted from one position to another merely by manual application of a suitable torque.

In preferred form, the invention further provides structure for locking the blade essentially positively to prevent its rotation from the angular range of its selectively adjustable positions to the release position of the bayonet formations. That locking structure typically comprises a latch member that engages a positive stop to prevent such release of the blade, but is resiliently deflectable out of the path of that stop, as by application of a suitable tool, when it is desired to remove a blade from the fan hub.

A full understanding of the invention, and of its further objects and advantages, will be had from the following description of certain illustrative manners of carrying it out, which description is to be read with relation to the accompanying drawings, in which

FIG. 1 is a transverse section of an illustrative compressor impeller embodying the invention, as seen from the pressure side;

FIG. 2 is a schematic graph illustrating the effect of one aspect of the invention on the stall characteristic of a typical compressor;

FIG. 3 is a fragmentary section of line 3-3 of FIG. 1 at enlarged scale, representing one embodiment of another aspect of the invention;

FIG. 4 is a section on line 4-4 of FIG. 3;

FIG. 5 is an elevation of the hub with blade removed, in the same aspect as FIG. 3;

FIG. 6 is a section on line 6-6 at further enlarged scale;

FIG. 7 is a fragmentary elevation in the aspect indicated by line 7-7 of FIG. 1;

FIG. 8 is a schematic perspective, showing a mounted blade and an unmounted blade;

FIG. 9 is a section corresponding to FIG. 3 but looking radially outward from inside the hub and representing a modification; and

FIG. 10 is a section on line 10-10 of FIG. 9.

In FIG. 1 an axial flow compressor is shown in transverse section, as seen from the pressure side, with impeller 20 mounted on the shaft 22 and enclosed in the cylindrical housing 24. Shaft 22 is journaled on the axis 21 and is driven in conventional manner, not explicitly shown. Impeller 20 comprises the hub 26 on which the blades 30 are mounted by mechanism to be more particularly described. The removable plate 36 provides access to the blades one at a time through the aperture 34 in housing 24.

In accordance with one aspect of the invention, one or more selected blades are apertured, the apertures being most effective when near the blade tip and closer to the leading edge than to the trailing edge of the blade, as illustratively shown at 32, 32a and 32b. When the compressor is operated under design conditions, the apertures or ports 32 are found to have only negligible effect on the total pressure that is produced, typically lowering that pressure by 1 or 2 percent. There is ordinarily no measurable effect upon the total flow. However, as the flow is reduced by throttling of the output, the abrupt aerodynamic stalling that is characteristic of axial compressors under such conditions is greatly reduced or entirely eliminated.

In FIG. 2 the dashed lines are a schematic plot of total pressure rise as a function of flow for constant speed operation of a

typical conventional single-stage compressor. As the weight flow is reduced by throttling from the normal operating region A to the critical region B below the peak pressure, the total pressure tends to decrease abruptly, as at C, to a lowered value, shown by the curve D. If the flow is then again increased, the compressor recovers abruptly, but on the line E, which corresponds to a higher flow rate than that at which the decrease C occurred. Hence there is a hysteresis region of unstable operation, represented in the present illustrative diagram by the area enclosed by lines B, C, D and E. As is well known, such instability can lead to serious difficulties and even dangers, depending upon the function of the particular compressor.

In contrast, an impeller provided with antistall ports in accordance with the present invention typically produces the stable operation represented by the solid line F in FIG. 2. The total pressure rise produced in the normal operating region A is only slightly reduced. That reduction increases gradually as the flow is throttled, but typically merges smoothly and without any sharp break into curve D, the normal operating characteristic for low flow. As the flow is increased, the pressure recovers along the same line F, without hysteresis.

The phenomenon of abrupt stall is not well understood, and no successful analytical treatment has been proposed. Therefore no detailed analysis can be given of the described action of the antistall ports 32 of the present invention. However, that action is believed to be due, at least in part, to the production of a local stall condition adjacent each port early in the throttling phase. Such local stall regions may then spread gradually to affect the entire fan, eliminating the instability and accompanying hysteresis that are normally encountered.

A remarkable feature of the described antistall apertures is that only one such aperture is sufficient to extend the region of stable operation very significantly, and may produce complete stability as shown in FIG. 2. When several apertures are used, they have been found most effective when located in blades that are angularly spaced in a symmetrical pattern. Such arrangement probably tends to stimulate the normal stall patterns in the blading, which usually occur symmetrically with respect to the axis. The number of blades per row is usually selected as a prime number, which is necessarily odd. FIG. 1 illustrates an impeller with 13 blades of which three are apertured, forming two blade groups that are arranged symmetrically. Although apertures 32 are shown typically as holes within the blade boundaries, the term "aperture" is intended to include openings that intersect the blade edge.

A preferred structure for adjustably mounting each of the impeller blades 30 is shown somewhat schematically in FIGS. 3 to 8. A section of the cylindrical hub shell 28 is flattened at each blade, and the flat area 29 is punched to form an aperture 40 of a pattern typically as shown in FIG. 5. Aperture 40 is generally circular with primary radius r , and has three angularly spaced bays 41, 42 and 43 and six slots 44 to 49, which extend radially outward from the circular aperture edges. Bay 41 is somewhat narrower and radially deeper than bays 42 and 43. Two of the slots 44 to 49 are positioned between each pair of adjacent bays 41 to 43. As will become apparent, those slots may be replaced, if desired, by channels or recesses of any desired form, and may be provided in any desired number.

Blade 30 carries at its base end 33 the rigid disk like bayonet element 50, and the slightly flexible detent element 60 of resilient sheet material. Elements 50 and 60 are typically welded to the blade end, as indicated at 56, in parallel adjacent relation, perpendicular to the longitudinal blade axis, indicated at 39. Element 60 may be slotted at 61 to insure firm bonding of both elements. The shape of bayonet element 50 is generally complementary to aperture 40 of FIG. 5, being generally circular with radially projecting wings 51, 52 and 53 which are adapted to enter freely through the respective bays of aperture 40. Bayonet wing 51 is longer than the others and can only enter bay 41, whereas wings 52 and 53 are too wide to enter bay 41, thus insuring unique indexing of the blade as it is assembled.

Each of the bayonet wings 51 to 53 is offset as shown best in FIG. 3, just sufficiently to engage the inner face of hub shell 28 when rotated after full insertion through aperture 40. The wings preferably lie flatly in a common plane and do not bias rotation of the bayonet member preferentially in either direction. The wing offset is relatively sharp, and is dimensioned to provide a free fit within radius r of hub aperture 40, as indicated at 55 in FIG. 4, accurately guiding blade rotation. The magnitude of the offset is so related to the thickness of the hub sleeve that the latter fits closely between the offset wings and the butt end 33 of the blade where it overlies the hub, positively maintaining coaxial relation of the bayonet fittings on the common axis 38, but permitting free blade rotation. As a further indexing device, a positive stop is provided to prevent the inserted bayonet element 60 from being rotated clockwise as seen in FIG. 3. Such a stop is shown at 57, comprising an inwardly bent ear on the edge of bay 41.

Detent element 60 is generally circular and directly overlies the outer face of hub sleeve 28. Element 60 carries three angularly spaced detent formations 62, 63 and 64, which comprise radial ridges on the inner face of the element. Those ridges are of such dimensions as to enter the radial channels 44 to 49 of aperture 40, engaging the edges of those channels obliquely and camming the entire assembly to a definite rotary position (FIG. 6). Each of the detent formations 62 to 64 cooperates with one pair of the radial channels 44 to 49, and is thus capable of defining two distinct rotary positions of the assembly. However, channels 44 to 49 are angularly staggered in such a way that only one detent formation engages a channel in any one assembly position. Thus the detent mechanism is capable of defining six closely adjacent rotary positions, even though each of the detent formations occupies a relatively large sector and can therefore be made rugged in structure and both positive and accurate in its action. Those detent formations 62 to 64 which are not engaged in a slot are supported in slightly deflected position on the outer hub surface. Thus all three detent formations exert resilient force on the hub, urging the blade outward and maintaining firm contact of bayonet wings 51 to 53 against the inner hub face.

In operation of the blower, centrifugal force urges each blade strongly away from axis of rotation 21. That force is taken by bayonet element 50, being transferred through its rigid and sturdy wings 51 to 53 to the inner hub face. In practice it has been found that at normal operating speed the blade is maintained with its longitudinal axis in proper position relative to the hub entirely by that action of bayonet element 50 and does not depend upon the resilient action of detent element 60. The resilient stiffness of the latter is therefore required primarily to provide reliable definition of the pitch angle of the blade. For a blade that is properly balanced with respect to mounting axis 38, such definition requires relatively little torque.

As a convenience during blade adjustment, and as assurance against loss of a blade in case the described detent system should fail for any reason, it is desirable to provide a protective latch mechanism for preventing rotation of bayonet element 50 to blade-releasing position. In the present embodiment such a latch comprises the radial arm 70 which is formed on detent element 60 in the space between the adjacent two detent formations 63 and 64. Arm 70 is bent toward the hub and enters bay 42 of hub aperture 40, as shown best in FIG. 4. During assembly of a blade, arm 70 strikes the outer hub face in the vicinity of detent slots 44 and 47 and can slide freely over that face and over the detent slots until it reaches bay 42. The arm then resiliently springs into that bay, positively limiting rotation of the assembly to the angular range defined by the dimensions of the bay and arm. In order to disassemble the blade, a suitable tool is inserted through access aperture 34 and hooked under arm 70, and the arm is lifted sufficiently to swing over the outer face of the hub. The assembly may then be rotated freely to releasing position.

The access aperture 34 in housing 24 is covered by the removable cover plate 36, providing convenient access for as-

sembly, adjustment, or removal of blades 30, the shaft being rotated to bring the blades successively into alignment with the aperture. Scale marks are preferably provided on housing 24 at the periphery of aperture 34 for reading directly the pitch adjustment of each blade in turn. Correct centering of the blade in aperture 34 is insured by providing a scale for each blade edge, as shown in FIG. 7 at 37 and 37a, and setting the impeller angle so that both scales read the same. Scale indications, designated R in FIG. 7, preferably show the release position of the blade.

FIGS. 9 and 10 represent a modified structure in accordance with the invention, in which generally corresponding parts are designated with the same numerals with addition of a letter *a*. FIG. 9 corresponds generally to FIG. 3 of the first-described embodiment, but in opposite aspect, showing the structure as seen from within the hub. In FIGS. 9 and 10 the resilient detent element 60a is mounted on the opposite face of rigid bayonet element 50a from blade 30a. The ears 80 are punched out of element 50a and are welded to the blade, while element 60a may be spotwelded to element 50a as indicated at 81.

Bayonet element 50a carries the wings 51a, 52a and 53a which engage the inner face of hub shell 28a as shown in the drawings, and which can pass through the respective bays 41a, 42a and 43a of hub aperture 40a when the blade is rotated to bayonet-releasing position.

Detent element 60a carries three resilient arms with the cam formations 61a, 62a and 63a at their ends. Those cam formations cooperate with the radial detent channels 44a through 48a, which are formed in the present embodiment in the periphery of the aperture bays, rather than in the inner periphery of the mounting aperture, as in the previous embodiment. Only five detent channels are shown, providing five different angles of blade pitch, but any desired number may be provided. During insertion and removal of the blade, the wings of detent element 60a pass through the special bays 82, 83 and 84 of mounting aperture 40a.

Air leakage through the portions of mounting aperture 40 that are not covered by the bayonet formations is preferably prevented by providing a cover plate 90, which is typically circular and may be mounted between the blade end and bayonet element 50a. Apertures 92 in the cover plate accommodate the mounting ears 80 and locate the plate. A gasket may be provided near the periphery of the cover plate if desired, but is not ordinarily required. A similar cover plate may be used with the previously described embodiment.

In the present embodiment the mounted blade is locked against rotation to blade-releasing position by the corrugation 70a formed in one of the arms of detent element 60a in position to project into the bay 43a of the mounting aperture, as shown best in FIG. 10. To release the blade, that detent arm is deflected toward the impeller axis, as by inserting a tool through housing aperture 34, through the small hole 94 in cover plate 90 and through bay 43a.

A particular advantage of the illustrated structures is that the mounting apertures in the hub shell, though of special shape, can be formed by a simple punching operation. The resilient detent element, being carried by the blade, is readily replaceable with the blade. On the other hand, it will be evident that many variations may be made in the illustrative structures that have been described without departing from the proper scope of the invention. For example, the detent channels 44a to 48a of FIGS. 9 and 10 can, by simple transposition of parts, be formed in the periphery of bayonet element 50a, and can then be engaged by cam formations carried by flexible detent arms mounted on the hub shell at each mounting aperture and projecting radially inward with respect to that aperture. As a further example, although the described camwise engagement of the resilient detent formations for defining the blade pitch angle has the advantage of facilitating blade adjustment, those formations can readily be modified to provide positive engagement with the fixed channels or their equivalent. Such positive engagement can be released to per-

mit blade adjustment by insertion of a suitable tool through housing access aperture 34, in the manner already described for releasing locking formation 70.

We claim:

1. In an axial flow compressor having a hub and a plurality of blades that are releasably mountable on the hub with each blade extending generally radially from the hub, structure for mounting each blade on the hub and comprising in combination
 - complementary bayonet formations mounted on the blade and on the hub on respective mounting axes that are longitudinal of the blade and generally radial with respect to the hub, said formations being engageable in coaxial relation of the mounting axes to define an assembled position of the blade relative to the hub along the length of the mounting axis and to positively prevent blade movement outward from the hub along the mounting axis away from that assembled position while permitting essentially free blade rotation with respect to the mounting axis throughout a limited angular range, said formations being releasable in response to blade rotation beyond said range in one direction to permit removal of the blade, and retaining means acting between the blade and the hub for defining a plurality of mutually spaced angular operating positions of the blade within said limited range and for releasably retaining the blade in a selected one of said operating positions.
2. Blade-mounting structure as defined in claim 1, and in which
 - said retaining means are resiliently releasable in response to application to the blade of rotational torque with respect to said mounting axis, such torque exceeding the maximum torque acting on the blade during normal operation of the fan.
3. Blade-mounting structure as defined in claim 1, and in which said retaining means comprise
 - a plurality of first detent formations mounted on one of said blade and hub and forming at least two groups of formations that are angularly spaced by more than said angular range, the formations of each group being angularly spaced by less than said angular range and by more than the spacing of adjacent operating positions of the blade, and a plurality of second detent formations mounted on the other of said blade and hub and angularly spaced in general correspondence to respective groups of said first detent formations, the first and second detent formations being adapted for selective mutual engagement to define said plurality of distinct angular operating positions of the blade, the mutual angular spacing of said formations being such that adjacent operating positions of the blade correspond to engagement of different second detent formations with first detent formations of their respective groups.
4. Blade-mounting structure as defined in claim 1, and including also
 - locking structure normally acting to positively prevent blade rotation from said limited angular range to said blade-releasing position, said locking structure being resiliently deflectable to release the blade for such rotation.
5. Blade-mounting structure as defined in claim 4, said retaining means and said locking structure comprising
 - a common element mounted on one of the blade and hub and including first and second resiliently deflectable portions,
 - a detent formation mounted on the other of the blade and hub and engageable camwise by said first portion to retain the blade yieldably in an operating position, and a stop formation mounted on said other of the blade and hub and normally engageable by said second portion to positively prevent blade rotation from said limited angular range to said blade-releasing position, said second portion being manually deflectable to release said stop formation.

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6. A rotary, axial flow gas compressor having its blades mounted by the blade-mounting structure defined in claim 1 for releasably retaining the blades in a selected operating position, and in which

at least one blade is apertured to form a path for gas flow between the pressure side and the suction side of the blade.

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