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(54) Turbocharger wheel and associated method of design

(57) A turbocharger turbine wheel (10; 20; 30; 40) includes a hub (13; 23; 33; 43)and a plurality of blades (12; 22; 32; 42). Both the center of mass of the hub and the center of mass of the plurality of blades are on an axis of rotation. The blades are circumferentially spaced such that they are rotationally asymmetric. Each consecutive pair of blades is characterized by a spacing angle (301). A line that intersects with and is normal to the axis of rotation defines a plane of symmetry, and the spacing angles are symmetric across the plane of symmetry.

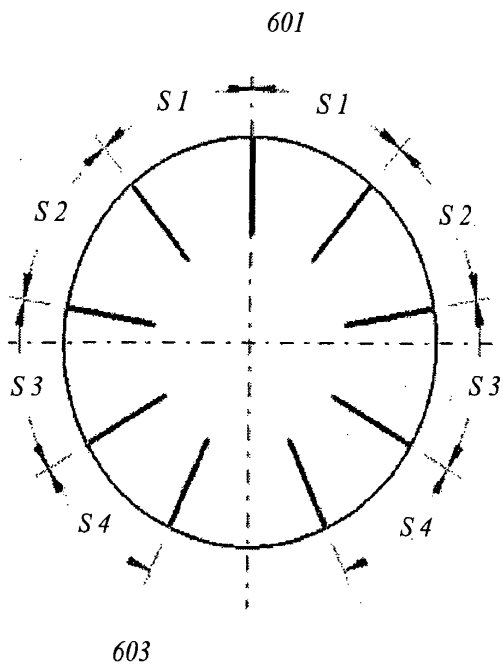

FIG. 6

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Description

[0001] The present invention relates to a wheel for a turbocharger, and more particularly, to an automotive turbocharger wheel having blades spaced at angles that limit the generation of noise in the audible range.

BACKGROUND OF THE INVENTION

[0002] Radial automotive turbines are generally configured with an inlet volute in which a stream of exhaust gas spirals in to drive the blades of a turbine wheel. At the location around the volute where the exhaust stream first opens up to the turbine wheel, there is a structural feature where the blades pass from being in close proximity to the surrounding volute wall to being distant from the volute wall. Because of the appearance of this feature in cross section, it is sometimes referred to as the tongue.

[0003] Automotive turbochargers often have on the order of seven to eighteen turbine blades. Within the lower range of numbers of blades, and at typical turbine rotational rates, the blades may pass the tongue at a frequency that is within the human audible range. This creates a humming noise that is not desirable.

[0004] One solution to this problem is to increase the number of blades, such as from eleven to thirteen blades for a smaller automotive turbocharger. This causes the blades to pass the tongue at a frequency that is above the human audible range at typical operating speeds. Unfortunately, the increase in the number of blades can lead to several undesirable consequences. For example, the increase in blades can lead to a wheel that is more expensive to make (both because of an increase in materials and because of an increase in tooling costs). Also, because there is less room for fillets at the base of each blade, the blade support is weakened, leading to a less durable turbine wheel. Moreover, because the wheel will likely have a greater rotational inertia, it will be less responsive to changes in the exhaust pressure, such as during engine transient operating conditions.

[0005] There exists a need for durable and cost-efficient turbine wheels that minimize undesirable noise. Preferred embodiments of the present invention satisfy these and other needs, and provide further related advantages.

SUMMARY OF THE INVENTION

[0006] In various embodiments, the present invention solves some or all of the needs mentioned above, providing a durable and cost-efficient turbine wheel that minimizes undesirable noise.

[0007] The turbocharger wheel, e.g., a turbine wheel, which is for use as part of a rotor group, includes a hub and a plurality of blades. The turbine wheel is characterized by a line defining an axis of rotation. Both the center of mass ("CM") of the hub and the CM of the plurality of blades are on the axis of rotation. The plurality of blades is circumferentially spaced around the hub such that the blades are rotationally asymmetric around the axis of rotation. Advantageously, this asymmetry spreads the acoustic energy generated by the blades passing the volute tongue over a range of different frequencies, thereby reducing the acoustic energy at any one frequency. This, in turn, provides for automotive turbine wheels to be made with fewer blades than might otherwise be desirable for rotationally symmetric blades that concentrate acoustic energy in frequencies that are audible to humans.

[0008] Each consecutive pair of blades is characterized by a spacing angle between the consecutive pair of blades. A set of spacing angles that meet all the requirements can be iteratively calculated. In a further feature, the turbocharger wheel, e.g., a turbine wheel is characterized by a second line that intersects with and is normal to the line defining the axis of rotation. The line defining the axis of rotation and the second line define a plane of symmetry by extending along and being contained within the plane, and the spacing angles of the plurality of blades are symmetric across the plane of symmetry. Advantageously, this planar symmetry provides for the angles to be iteratively calculated using a significantly reduced number of variables, and therefore a reduced number of calculations.

[0009] Other features and advantages of the invention will become apparent from the following detailed description of the preferred embodiments, taken with the accompanying drawings, which illustrate, by way of example, the principles of the invention. The detailed description of particular preferred embodiments, as set out below to enable one to build and use an embodiment of the invention, are not intended to limit the enumerated claims, but rather, they are intended to serve as particular examples of the claimed invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010]

FIG. 1 is a system view of an embodiment of a turbocharged internal combustion engine under the invention.

FIG. 2 is a cross sectional view of a turbine used in the turbocharged internal combustion engine depicted in FIG. 1.

FIG 3 is a depiction of a set of blade spacing angles having a plane of symmetry.

FIG 4 is an embodiment of a method of designing and creating turbocharger wheel tooling for creating a turbocharger wheel.

FIG. 5 is a depiction of an offset between a center of rotation and a CM of a set of blades.

FIG. 6 is a depiction of a set of blade spacing angles having a plane of symmetry and having an odd number of blades.

FIG. 7 is a depiction of a set of blade spacing angles having a plane of symmetry and having an even number of blades.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0011] The invention summarized above and defined by the enumerated claims may be better understood by referring to the following detailed description, which should be read with the accompanying drawings. This detailed description of particular preferred embodiments of the invention, set out below to enable one to build and use particular implementations of the invention, is not intended to limit the enumerated claims, but rather, it is intended to provide particular examples of them.

[0012] Typical embodiments of the present invention reside in a motor vehicle equipped with an internal combustion engine ("ICE") and a turbocharger. The turbocharger is equipped with a turbine wheel characterized by a unique blade configuration that provides for durability, a low rotational moment of inertia, and quiet operation within the human range of hearing.

[0013] With reference to FIG. 1, a typical embodiment of a turbocharger 101 having a radial turbine and a radial compressor includes a turbocharger housing and a rotor group configured to rotate within the turbocharger housing around an axis of rotation 103 during turbocharger operation on thrust bearings and two sets of journal bearings (one for each respective rotor wheel), or alternatively, other similarly supportive bearings. The turbocharger housing includes a turbine housing 105, a compressor housing 107, and a bearing housing 109 (i.e., a center housing that contains the bearings) that connects the turbine housing to the compressor housing. The rotor group includes a radial turbine wheel 111 located substantially within the turbine housing, a radial compressor wheel 113 located substantially within the compressor housing, and a shaft 115 extending along the axis of rotation, through the bearing housing, to connect the turbine wheel to the compressor wheel.

[0014] The turbine housing 105 and turbine wheel 111 form a turbine configured to circumferentially receive a high-pressure and high-temperature exhaust gas stream 121 from an engine, e.g., from an exhaust manifold 123 of an internal combustion engine 125. The turbine wheel (and thus the rotor group) is driven in rotation around the axis of rotation 103 by the high-pressure and high-temperature exhaust gas stream, which becomes a lower-pressure and lower-temperature exhaust gas stream 127 and is axially released into an exhaust system (not shown).

[0015] The compressor housing 107 and compressor wheel 113 form a compressor stage. The compressor wheel, being driven in rotation by the exhaust-gas driven turbine wheel 111, is configured to compress axially received input air (e.g., ambient air 131, or already-pressurized air from a previous-stage in a multi-stage compressor) into a pressurized air stream 133 that is ejected circumferentially from the compressor. Due to the compression process, the pressurized air stream is characterized by an increased temperature over that of the input air.

[0016] Optionally, the pressurized air stream may be channeled through a convectively cooled charge air cooler 135 configured to dissipate heat from the pressurized air stream, increasing its density. The resulting cooled and pressurized output air stream 137 is channeled into an intake manifold 139 on the internal combustion engine, or alternatively, into a subsequent-stage, in-series compressor. The operation of the system is controlled by an ECU 151 (engine control unit) that connects to the remainder of the system via communication connections.

TURBINE

[0017] With reference to FIGS. 1 and 2, the turbine housing 105 forms an exhaust gas entrance passageway 217 leading into a primary-scroll passageway 219 configured to receive the exhaust gas stream from the engine in a direction normal to and radially offset from the rotor group axis of rotation 103. The primary-scroll passageway substantially forms a convergent passageway that spirals inward enough and converges enough to accelerate the exhaust gas 223, funneling it to impinge on the axially upstream end 275 of turbocharger turbine blades 231, and then passing through gaps between the blades.

[0018] At the location where the exhaust gas entrance passageway 217 leads into the primary-scroll passageway 219, there is a structure that is characterized by a tongue-like shape when viewed in the cross-section of FIG. 2 (i.e., taken normal to the rotor group axis of rotation 103). More particularly, the structure of a tongue 235 appears as a protrusion having a tip.

[0019] It is desirable for typical automotive turbochargers to have on the order of eleven turbine blades 231, and often have a radius between 12mm and 75 mm. Within the typical eleven-blade automotive turbine, and at typical automotive turbine rotational rates, the blades pass the tongue 235 at a frequency that is within the human audible range. This creates a humming noise that is not desirable.

[0020] Under a first embodiment of the invention, the turbine wheel 111, which is part of the rotor group, is characterized by a line defining the axis of rotation 103 (i.e., the axis is collinear with the line). The turbine wheel may include a rotationally symmetric hub 241 (possibly being characterized by spherical symmetry around the axis of rotor rotation). The turbine hub supports the plurality of blades. The center of mass ("CM") of the hub is on the axis of rotation, and the CM of the plurality of blades is also on the axis of rotation.

[0021] Unlike prior art turbine wheels, the plurality of blades 231 are circumferentially spaced around the hub at varying angles such that the blades are rotationally asymmetric around the axis of rotation 103. For the purposes of this application, it should be understood that the term rotationally asymmetric is defined to mean that the wheel cannot be rotated around the axis of rotation (by any amount other than an integer multiple of 360 degrees) to a position in which the structure is substantially identical (i.e., identical to within a functionally reasonable measurement tolerance level).

[0022] In this particular embodiment, the turbine wheel 111 consists only of the hub 241 and the plurality of blades 231, and the hub is rotationally symmetric around the rotor group axis of rotation. It should be understood that the blades include a fillet that distributes blade root stresses to the hub.

[0023] With reference to FIGS. 1 to 3, to make the blades 231 rotationally asymmetric, each consecutive pair of blades is characterized by a spacing angle 301 S_n between the consecutive pair of blades. The spacing angle may be measured from any reference point (i.e., any axial, radial and circumferential position) on the consecutive blades so long as it is consistently done from the same reference point on each blade. For example, it could be measured from the leading edge of the blade where the leading edge connects to the hub on each blade. Alternatively, it could be measured from the CM of each blade, which might simplify calculation of the CM of the complete set of blades. The spacing angles S_n do not vary periodically in a pattern that would create rotational symmetry.

[0024] The calculation of the set of spacing angles 301 that avoids rotational symmetry of the wheel 111 (and more particularly of the blades 231), and yet that has the CM on the rotor group axis of rotation 103, is a complex mathematical problem. The problem can be substantially simplified by allowing for the spacing of the blades to have a plane of symmetry. More particularly, the turbine wheel (and more particularly the plurality of turbine blades) is characterized by a second line 303 that is normal to and intersecting with the line defining the axis of rotor rotation 103. The axis of rotation and the second line define a plane of symmetry by extending along and being contained within the plane, and the spacing angles of the plurality of blades are symmetric across the plane of symmetry (i.e., they are mirrored, as indicated in FIG. 3). In the case where a spacing angle extends across the plane of symmetry, it is bisected by the plane so that half of the spacing angle is on each side of the plane.

[0025] As was previously noted, a prior art solution to this problem was to increase the number of blades to a point at which the hum frequency is out of the human range of hearing (e.g., greater than 20,000 Hz). One of the downsides of this solution is that the blade crowding limited the size of the fillets, and therefore limited the spreading of blade root stresses. Therefore, the blade spacing angles 301 S_n are preferably limited to at least the minimum size of the blade spacing between evenly spaced blades for the fewest number of blades necessary to take the hum out of the range of human hearing (e.g., 13), and possibly larger number (e.g., 18) as long as the blade root stresses are within acceptable level. As was hinted at above, the problem of finding good series of blade spacing angles 301 is a difficult optimization problem. This problem may be solved by using an iterative computerized software system. The system will be programmed to implement a method of designing and creating turbine wheel tooling for creating a turbine wheel having n asymmetrically spaced blades and an axis of rotation.

[0026] With reference to FIGS. 3 to 5, steps are identified to provide a method of designing and creating turbocharger wheel tooling for creating a turbocharger wheel having n blades asymmetrically spaced and an axis of rotation. A number of blades and an initial spacing angle S_{IN} for each consecutive pair of blades must first be established 401. The number of blades will typically be selected by a design team based on the desired parameters of the turbine, such as the anticipated operating speeds of the turbine and aerodynamic considerations. The initial spacing angles can be set in a variety of ways. For example, the average spacing angle could be randomly varied, or the design team could arbitrarily select numbers. Typically, it would be desirable to use initial spacing angle 301 values that vary significantly from one blade spacing angle to the next. An exception to this would be for wheels with an odd number of blades and a plane of symmetry on the line between two consecutive spacing angles, wherein the spacing angles on immediate opposite sides of the plane will inherently be the same.

[0027] Next, an iterative optimization computer program is run 403 on a computer. The program is configured to solve a constrained optimization problem using the steps of (1) calculating 405 a CM 501 of either the complete set of blades 231 or of the entire wheel 111 (i.e., a CM indicative of the CM of the blades with respect to the axis of rotor rotation); (2) iteratively adjusting 407 the spacing angles such that the distance between the calculated center of mass and the wheel axis of rotation is decreased and the spacing angles vary according to a set of one or more constraints and an objective variable in order to limit the acoustic energy generated at any one frequency audible to humans; and (3) continuing the iterations 409 until the calculated CM is effectively on the axis of rotation and the variation of consecutive spacing angles is optimized to establish a set of final spacing angles S_F in consecutive order. Greater detail of the optimization computer program is not necessary, as the field of programming computers to iteratively optimize variables is known.

[0028] The distance between the calculated center of mass and the wheel axis of rotation is a relatively straight forward calculation. Nevertheless, a variety of different constraints and/or objective variables might be used to limit the acoustic energy generated at any one frequency. Each set of one or more constraints and an objective variable will have strengths and weaknesses, such as required computation time and/or accuracy in representing an optimal acoustic solution. Such constraints and objective variables might include comparisons of consecutive blade angles, and comparisons of all blade angles to one another, among other options.

[0029] As an example of the first type of constraint and objective variable described above, an objective variable that might be used is to maximize the variation of each consecutive blade angle, while the blade angles are constrained to be within a minimum and a maximum angle. As an example of the second type of constraint and objective variable described above, the standard deviation of the set of all blade angles could be maximized, while the blade angles are constrained between a minimum and a maximum angle.

[0030] For the purposes of this application, the variation of consecutive spacing angles is considered to be optimized when the optimization computer program iteratively reaches an optimum level on the objective variable (e.g., the variation of each consecutive pair of blade angles is maximized). It should be noted that optimized spacing angles may be different when different constraints and/or objective angles are used. Other objective variables that might be used include: target standard deviation level (rather than maximum), target angle variation (rather than maximum), angle variations within a certain range, and the like.

[0031] The step of iteratively adjusting 407 the spacing angles is preferably done by increasing the variation of consecutive spacing angles. It should be noted that a variety of techniques may be used to establish a level of the variation of consecutive spacing angles. For example, the sum of the absolute value of the difference between each consecutive pair of spacing angles may be calculated. The larger this number is, the greater variation there is considered to be between all such consecutive spacing angles.

[0032] It should be noted that during the iterations of the solution, the CM will not be restricted to the plane of symmetry unless the spacing angle is considered to be the spacing between the CM of each blade.

[0033] Once the optimization program has established a set of final spacing angles S_F in consecutive order, tooling is formed 411. The tooling is configured to create a void usable for creating turbine wheels characterized by having the set of final spacing angles S_F angles in consecutive order.

[0034] As was discussed above, the optimization problem is simplified when the blade spacing angles are symmetric across a plane of symmetry. To implement that, in the step of establishing 401 initial spacing angles, the initial spacing angles S_{IN} are selected to be symmetric 421 across a plane of symmetry that contains and is defined in part the line defining the axis of rotation. Additionally, in the step of running 403 an iterative optimization computer program, the iterative adjustment of the spacing angles maintains 423 the symmetry of the spacing angles across the plane of symmetry. Advantageously, this reduces the number of variables.

[0035] As was previously discussed, it is preferable to set a minimum spacing angle that allows for good mechanical and aerodynamic characteristics. Thus, in the step of iteratively adjusting the spacing angles, each spacing angle is constrained to be greater than a minimum spacing angle S_{MIN}, such as 20.0 or 27.7 degrees (corresponding to the spacing of 18 or 13 blade evenly spaced blades).

[0036] With reference to FIGS. 6 and 7, it should be noted that the calculation-simplifying procedure of using a plane of symmetry can be implemented for either an even number of blades or an odd number of blades. To provide for an odd number of blades, the reference point of a first blade 601 is considered to be on the plane of symmetry 303, and an opposing spacing angle 603 on the opposite side of the wheel is bisected by the plane of symmetry, as is shown in FIG. 6. One side effect of this is to have two adjoining blade spacing angles that are the same (on either side of the first blade). To provide for an even number of blades, no blade reference points are considered to be on the plane of symmetry, and two opposing spacing angles 701 on opposite sides of the wheel are each bisected by the plane of symmetry, as are shown in FIG. 7. In either case, it is not required to use one of the bisected angles for the purposes of CM calculation, though it is preferable to use it for spacing angle variation calculations.

[0037] It is to be understood that the invention comprises apparatus and methods for designing and for producing a turbine blade, as well as the apparatus of the turbine blade itself. Alternate variations of these embodiments could comprise other types of blade configurations. Moreover, while this invention is described for a turbine wheel, compressor wheels may also be within the scope of the invention, although there might be greater risk of flow instability issues. In short, the above disclosed features can be combined in a wide variety of configurations within the anticipated scope of the invention.

[0038] While particular forms of the invention have been illustrated and described, it will be apparent that various modifications can be made without departing from the spirit and scope of the invention. Thus, although the invention has been described in detail with reference only to the preferred embodiments, those having ordinary skill in the art will appreciate that various modifications can be made without departing from the scope of the invention. Accordingly, the invention is not intended to be limited by the above discussion, and is defined with reference to the following claims.

Claims

1. A turbocharger wheel for use with a rotor group, comprising:

   a hub; and
   a plurality of blades;
   wherein the turbocharger wheel is **characterized by** an axis of rotation;
   wherein the center of mass of the hub is on the axis of rotation;
   wherein the center of mass of the plurality of blades is on the axis of rotation; and
   wherein the plurality of blades is circumferentially spaced around the hub such that the plurality of blades are rotationally asymmetric around the axis of rotation.

2. The turbocharger wheel of claim 1, wherein the wheel consists only of the hub and the plurality of blades, and wherein the hub is rotationally symmetric.

3. The turbocharger wheel of claim 1, wherein:

   each consecutive pair of blades of the plurality of blades is **characterized by** a spacing angle between the consecutive pair of blades;
   a plane of symmetry is defined in part by the axis of rotation, which extends along the plane of symmetry; and
   the spacing angles of the plurality of blades are symmetric across the plane of symmetry.

4. The turbocharger wheel of claim 1, wherein the wheel has a radius between 12mm and 75 mm.

5. The turbocharger wheel of claim 4, wherein:

   each consecutive pair of blades is **characterized by** a spacing angle between the consecutive pair of blades; and
   each spacing angle is greater than 20.0 degrees.

6. The turbocharger wheel of claim 1, wherein:

   each consecutive pair of blades is **characterized by** a spacing angle between the consecutive pair of blades; and
   each spacing angle is greater than 20.0 degrees.

7. A method of designing and creating turbocharger wheel tooling for creating a turbocharger wheel having n blades and an axis of rotation, comprising:

   establishing an initial spacing angle S_{IN} for each consecutive pair of blades;
   running an iterative optimization computer program on a computer, the program being configured to solve an optimization problem using the steps of
   calculating a center of mass indicative of the center of mass of the plurality of blades with respect to the axis of rotation,
   iteratively adjusting the spacing angles such that the distance between the calculated center of mass and the wheel axis of rotor rotation is decreased and the spacing angles vary enough to limit the acoustic energy generated at any one frequency audible to humans, and
   continuing the iterations until the calculated center of mass is effectively on the axis of rotation and the variation of spacing angles is optimized to establish a set of final spacing angles S_F in consecutive order; and
   once the optimization program has established a set of final spacing angles S_F, forming tooling that is configured to create a void usable for creating turbocharger wheels **characterized by** having the set of final spacing angles S_F in consecutive order.

8. The method of claim 7, wherein, in the step of continuing the iterations, the spacing angles are iteratively adjusted such that the variation of consecutive spacing angles is optimized.

9. The method of claim 7, wherein:

   in the step of establishing, the initial spacing angles S_{IN} are selected to be symmetric across a plane of symmetry that is defined in part by the axis of rotation, which extends along the plane of symmetry; and
   in the step of running an iterative optimization computer program, the iterative adjustment of the spacing angles maintains the symmetry of the spacing angles across the plane of symmetry.

10. The method of claim 9, wherein, in the step of continuing the iterations, the spacing angles are iteratively adjusted such that the variation of consecutive spacing angles is optimized.

11. The method of claim 7, wherein each spacing angle is constrained to be greater than a minimum spacing angle S_{MIN}.

12. The method of claim 11, wherein the minimum spacing angle S_{MIN}. is 20.0 degrees.

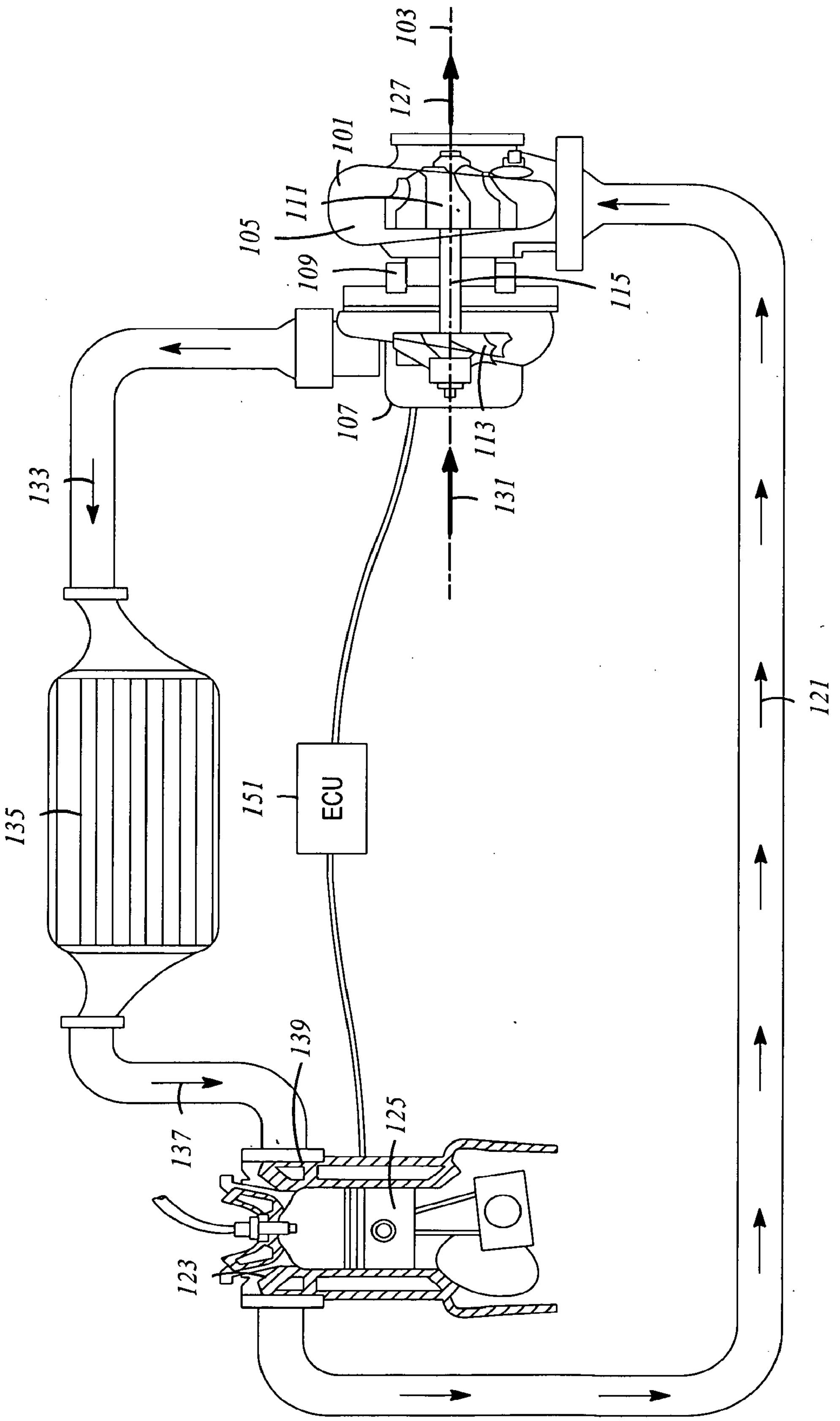
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FIG. 1

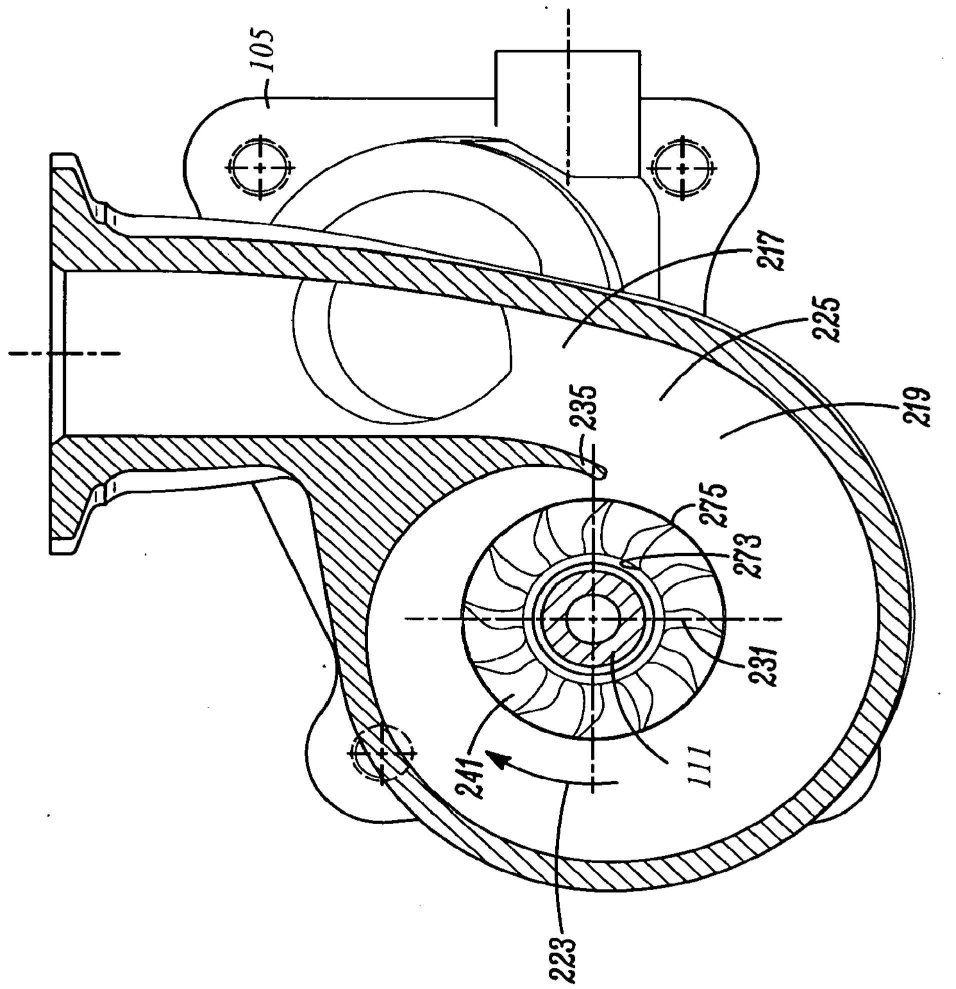
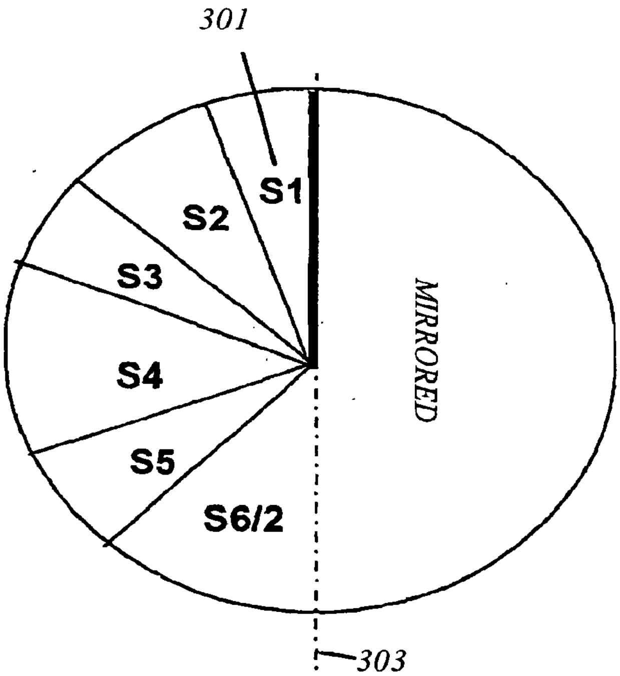


FIG. 2

FIG. 3



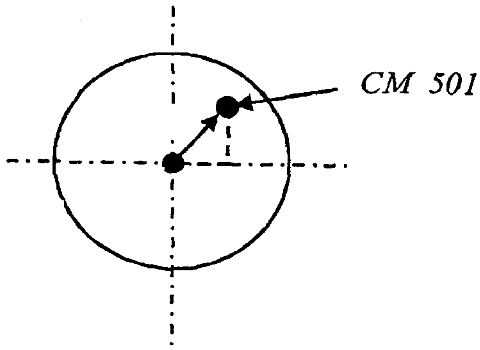


FIG. 5

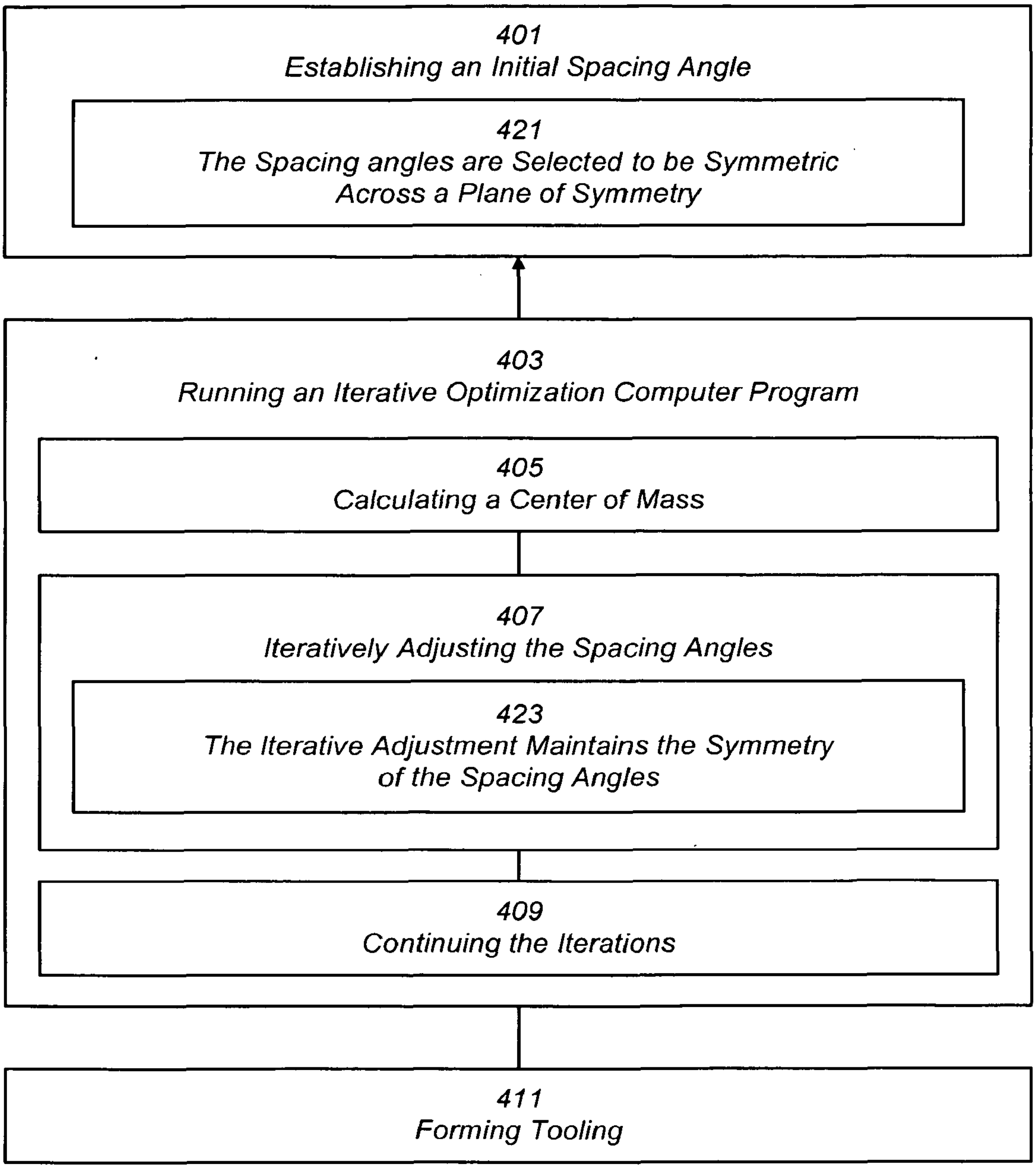
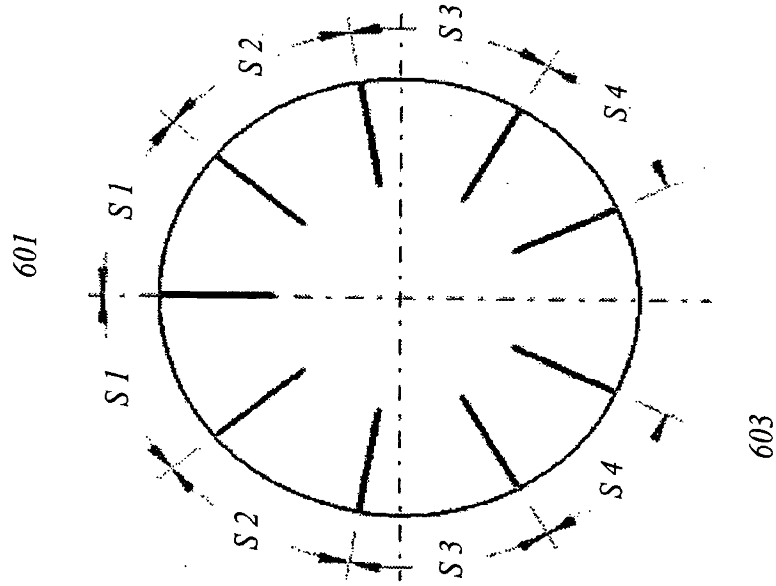
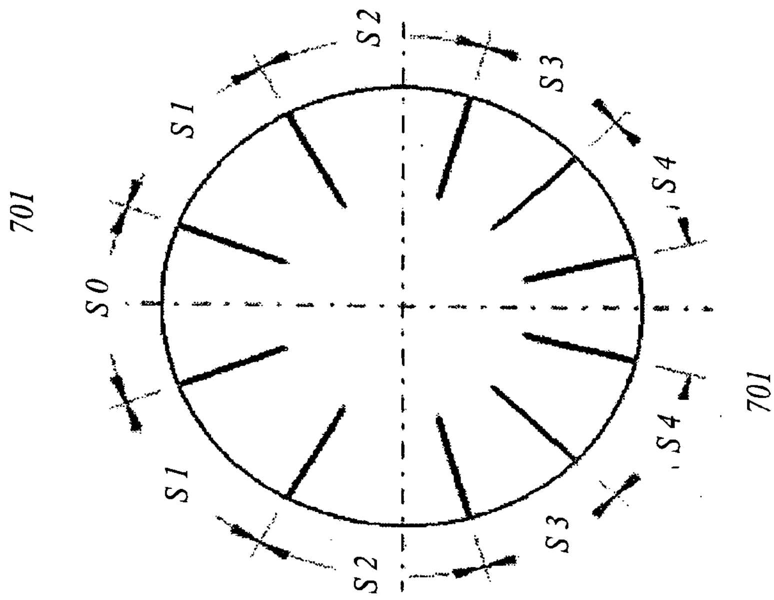

401
Establishing an Initial Spacing Angle
421
The Spacing angles are Selected to be Symmetric Across a Plane of Symmetry
403
Running an Iterative Optimization Computer Program
405
Calculating a Center of Mass
407
Iteratively Adjusting the Spacing Angles
423
The Iterative Adjustment Maintains the Symmetry of the Spacing Angles
409
Continuing the Iterations
411
Forming Tooling

FIG. 4



ODD NUMBER OF BLADES

FIG. 6



EVEN NUMBER OF BLADES

FIG. 7

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EUROPEAN SEARCH REPORT

Application Number
EP 14 15 3874

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	US 4 253 800 A (SEGAWA YORIHIDE ET AL) 3 March 1981 (1981-03-03) * column 2, line 41 - line 55 * * column 4, line 35 * * figures 1,3,5,7 * -----	1-6	INV. F01D5/04 F02C6/12 F04D29/28 F04D29/66

TECHNICAL FIELDS SEARCHED (IPC)
F01D
F02C
F04D

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	15 April 2014	Rolé, Florian

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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A : technological background
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T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons
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ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 14 15 3874

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
The members are as contained in the European Patent Office EDP file on
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15-04-2014

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 4253800 A	03-03-1981	JP S5525555 A	23-02-1980
		US 4253800 A	03-03-1981

EPO FORM P0459

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82