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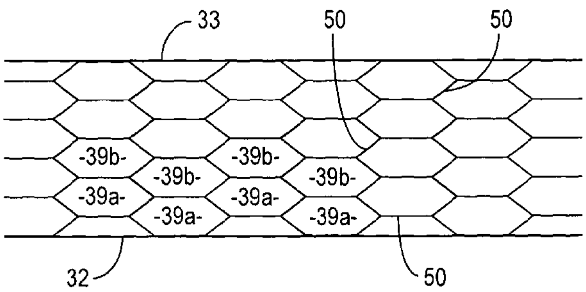


*Fig. 13*

(57) **Abstract**: A variable geometry turbine comprises a turbine wheel mounted for rotation about a turbine axis within a housing, the housing defining an annular inlet surrounding the turbine wheel and defined between first and second inlet sidewalls; and a cylindrical sleeve axially movable across the annular inlet to vary the size of a gas flow path through the inlet; wherein the annular inlet is divided into at least two axially offset inlet passages which axially overlap.

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# Turbomachine

The present invention relates to a variable geometry turbine. The variable geometry turbine may, for example, form a part of a turbocharger.

Turbochargers are well known devices for supplying air to an intake of an internal combustion engine at pressures above atmospheric pressure (boost pressures). A conventional turbocharger essentially comprises an exhaust gas driven turbine wheel mounted on a rotatable shaft within a turbine housing connected downstream of an engine outlet manifold. Rotation of the turbine wheel rotates a compressor wheel mounted on the other end of the shaft within a compressor housing. The compressor wheel delivers compressed air to an engine intake manifold. The turbocharger shaft is conventionally supported by journal and thrust bearings, including appropriate lubricating systems, located within a central bearing housing connected between the turbine and compressor wheel housings.

The turbine stage of a typical turbocharger comprises: a turbine chamber within which the turbine wheel is mounted; an annular inlet defined between facing radial walls arranged around the turbine chamber; an inlet volute arranged around the annular inlet; and an outlet passageway extending from the turbine chamber. The passageways and chamber communicate such that pressurised exhaust gas admitted to the inlet volute flows through the inlet to the outlet passageway via the turbine and rotates the turbine wheel. It is also known to improve turbine performance by providing vanes, referred to as nozzle vanes, in the inlet so as to deflect gas flowing through the inlet. That is, gas flowing through the annular inlet flows through inlet passages (defined between adjacent vanes) which induce swirl in the gas flow, turning the flow direction towards the direction of rotation of the turbine wheel.

Turbines may be of a fixed or variable geometry type. Variable geometry turbines differ from fixed geometry turbines in that the size of the inlet can be varied to optimise gas flow velocities over a range of mass flow rates so that the power output of the turbine can be varied to suit varying engine demands. For instance, when the volume of exhaust gas being delivered to the turbine is relatively low, the velocity of the gas reaching the turbine wheel is maintained at a level which ensures efficient turbine operation by reducing the size of the inlet using a variable geometry mechanism. Turbochargers provided with a variable geometry turbine are referred to as variable geometry turbochargers.

Nozzle vane arrangements in variable geometry turbochargers can take different forms. In one type, known as a "sliding nozzle ring", the vanes are fixed to an axially movable wall that slides across the inlet passageway. The axially movable wall moves towards a facing shroud plate in order to close down the inlet passageway and in so doing the vanes pass through apertures in the shroud plate. Alternatively, the nozzle ring is fixed to a wall of the turbine and a shroud plate is moved over the vanes to vary the size of the inlet passageway.

The moving component of the variable geometry mechanism, whether it is the nozzle ring or the shroud plate, is supported for axial movement in a cavity in a part of the turbocharger housing (usually either the turbine housing or the turbocharger bearing housing). It may be sealed with respect to the cavity walls to reduce or prevent leakage flow around the back of the nozzle ring.

The moveable wall of the variable geometry mechanism is axially displaced by a suitable actuator assembly comprising an actuator and a linkage. An example of such a known actuator assembly is for instance disclosed in US 5,868,552. The linkage comprises a yoke pivotally supported within the bearing housing and having two arms, each of which extends into engagement with an end of a respective push rod on which the moving component (in this instance the nozzle ring) is mounted. The yoke is mounted on a shaft journaled in the bearing housing and supporting a crank external to the bearing housing which may be connected to the actuator in any appropriate manner. The actuator which moves the yoke can take a variety of forms, including pneumatic, hydraulic and electric forms, and can be linked to the yoke in a variety of ways. The actuator will generally adjust the position of the moving wall under the control of an engine control unit (ECU) in order to modify the airflow through the turbine to meet performance requirements.

In use, axial forces are imported on the moveable wall by the air flow through the inlet, which must be accommodated by the actuator assembly. In addition, a torque is imparted to the nozzle ring as a result of gas flow vane passages being deflected towards the direction of rotation of the turbine wheel. If the nozzle ring is the moving wall of the variable geometry mechanism this torque also has to be reacted or otherwise accommodated by the actuator assembly such as by parts of the linkage.

It is one object of the present invention to obviate or mitigate the aforesaid disadvantages. It is also an object of the present invention to provide an improved or alternative variable geometry mechanism and turbine

According to an aspect of the present invention there is provided a variable geometry turbine comprising a turbine wheel mounted for rotation about a turbine axis within a housing, the housing defining an annular inlet surrounding the turbine wheel and defined between first and second inlet sidewalls; and a cylindrical sleeve axially movable across the annular inlet to vary the size of a gas flow path through the inlet; wherein the annular inlet is divided into at least two axially offset inlet passages which axially overlap.

It will be appreciated that axially offset inlet passages include inlet passages with different axial positions and/or inlet passages with different axial extents. Axially offset inlet passages may be spaced apart, adjacent or axially overlapping.

The annular inlet may be divided into an annular array of substantially tubular inlet passages extending generally towards the turbine wheel, wherein the annular array of inlet passages comprises at least three axially offset inlet passages which axially overlap.

At least two of said axially offset inlet passages which axially overlap may circumferentially overlap.

The substantially tubular inlet passages may have a generally diamond or generally hexagonal cross-section.

The inlet may be divided into said inlet passages by inlet passage walls defined by a plurality of generally annular non-planar baffles.

The baffles may be generally annular rings which are circumferentially corrugated.

The baffles may have a generally hyperbolic paraboloidal surface.

The annular array of inlet passages may be constructed from a plurality of discrete circumferentially adjacent segments.

A variable geometry turbine may comprise an annular inlet surrounding a turbine wheel mounted for rotation about a turbine axis within a turbine chamber defined by a housing, the chamber having an annular inlet defined between inboard and outboard inlet side walls and surrounding the turbine wheel, the annular inlet including:

a first pair of first and second circumferentially spaced inlet passages; and

a second pair of third and fourth circumferentially spaced inlet passages;

wherein the second pair of inlet passages is axially displaced from the first pair of inlet passages; and

wherein a cylindrical sleeve is supported within the housing for reciprocal motion in an axial direction to vary the size of the annular inlet; and

wherein the sleeve is movable between at least a first position in which each of the first pair of inlet passages is at least partially open to gas flow, and the second pair of inlet passages are fully open to gas flow, and a second position in which the first pair of inlet passages are fully blocked to the gas flow and each of the second pair or inlet passages is at least partially blocked to gas flow.

Typically, exhaust gas may flow to the annular inlet via a surrounding volute. In some embodiments of the invention the volute may be axially or circumferentially divided, the annular inlet being defined downstream of the volute or any divided portion of the volute. In such divided volute turbines the adjacent volute portions generally do not communicate with each other, other than at their downstream ends where they terminate at the inlet.

The inboard and outboard inlet sidewalls may for instance be continuations of walls which define the volute.

Typically, the maximum width of the inlet will correspond to the area swept out by rotation of the tips of the turbine wheel blades.

When the sleeve is in the second position each of the second pair of inlet passages may be fully blocked to gas flow.

Some variable geometry turbochargers may include a third pair of fourth and fifth circumferentially spaced inlet passages which are axially displaced from both the first and second pairs of inlet passages. Such embodiments may comprise four or more axially displaced pairs of circumferentially spaced inlet passages. When the sleeve is in the second position, all but one of said axially spaced pairs of circumferentially spaced inlet passages may be fully blocked to gas flow, the remaining pair of circumferentially spaced inlet passages being at least partially blocked to gas flow.

Each of the pairs of inlet passages may be a part of a respective annular array of circumferentially spaced inlet passages surrounding the turbine wheel.

Each pair or annular array of inlet passages may comprise passages which are substantially axially coincident.

At least one inlet passage of at least one pair or annular array of inlet passages may axially overlap at least one of the inlet passages of an adjacent pair or annular array of inlet passages.

The first position of the sleeve may be an open position in which each of said pairs or annular arrays of circumferentially spaced inlet passages are open to gas flow.

The second position of the sleeve may be a closed position in which a free end of the sleeve projects across the annular inlet and abuts either the inboard or outboard side wall.

The sleeve may be controllably positioned between said first and second positions.

In some embodiments the number of inlet passages comprising each annular array of circumferentially spaced inlet passages may be the same.

In other embodiments the number of inlet passages comprising one annular array of circumferentially spaced inlet passages may differ from the number of inlet passages comprising at least one other annular array of circumferentially spaced inlet passages.

A variable geometry turbine may comprise a turbine wheel mounted for rotation about a turbine axis within a housing, the housing defining a annular inlet surrounding the turbine wheel and defined between inboard and outboard inlet side walls, wherein a cylindrical sleeve is mounted within the housing for axial slideable movement across at least a portion of the annular inlet to vary the size of the annular inlet, further comprising:

at least one annular baffle axially spaced from the inboard and outboard side walls of the annular inlet to divide the annular inlet into axially adjacent annular portions, and wherein inlet vanes extend axially across at least two of said annular portions defined by the or each baffle.

Again, gas may flow to the annular inlet via an annular volute or similar chamber surrounding the annular inlet. In some embodiments the volute may be a divided volute, for instance split into separate axial or circumferential portions which may for instance receive gas from different sources (e.g. different banks of cylinders in a multi-cylinder combustion engine). In embodiments of the present invention the inlet and baffle will be downstream of the volute, or any volute portions in a divided volute.

A variable geometry turbine may comprise a turbine wheel mounted for rotation about a turbine axis within a housing, the housing having an annular inlet surrounding the turbine wheel and defined between inboard and outboard inlet side walls, wherein the annular inlet is axially divided into adjacent annular regions by two or more annular inlet baffles, and wherein a cylindrical sleeve is mounted within the housing for axial slideable movement across at least a portion of the annular inlet to vary the size of the annular inlet.

As with other variable geometry turbines, the annular inlet may be defined downstream of a surrounding volute (which may be a divided volute) or similar gas chamber.

Some variable geometry turbines may comprise at least two of said annular baffles which divide the annular inlet into at least three axially adjacent annular portions.

Movement of the sleeve between positions defining the maximum and minimum width of the inlet is confined to discreet positions corresponding to the axial location of the or each annular baffle.

Accordingly, in some variable geometry turbines the sleeve may be controlled to move in a step-wise fashion between discreet positions which may correspond to open and closed positions as well as intermediate positions, wherein each of the intermediate positions corresponds to the position of an annular baffle. In such intermediate positions the free end of the sleeve may axially align with the leading edge of a baffle.

Some variable geometry turbines may comprise at least two of said annular baffles dividing the annular inlet into at least three axially adjacent annular portions, wherein at least one of said annular portions does not include any inlet vanes.

A variable geometry turbine may comprise a turbine wheel mounted for rotation about a turbine axis within a housing, the housing including an annular inlet surrounding the turbine wheel and defined between inboard and outboard inlet side walls, wherein the annular inlet includes a nozzle structure comprising an annular array of substantially tubular inlet passages extending generally towards the turbine wheel, wherein the annular array of inlet passages comprises at least three axially displaced inlet passages.

The nozzle structure may be disposed downstream of an annular volute (which may be axially or circumferentially divided) which surrounds the annular inlet passage to deliver gas flow to the annular inlet passage.

The inlet passages may have a generally diamond, pentagonal, hexagonal or other polygonal cross section along at least a portion of their length.

In some variable geometry turbines the geometry of any given inlet passage may vary along its length. For instance, the cross-sectional area of the inlet passage may decrease to a minimum and then increase again. Similarly, the cross-sectional area may change shape at different positions along its length. For example, the inlet passage may have one cross section at its inlet (upstream) end and another cross section at its outlet (downstream) end. The cross section may change gradually along its length from inlet to outlet. Inlet passages may be substantially straight, or may be curved. In either case they may be swept forwards or backwards relative to the direction of rotation of the turbine wheel.

There may be two or more adjacent annular arrays of inlet passages. Adjacent annular arrays may comprise inlet passages of a different number and/or size and/or geometry or configuration. For instance the passages of one annular array may define a different swirl angle to the passages of another annular array.

The inlet passages may be defined by two or more annular inlet baffles positioned within the annular inlet, wherein adjacent inlet baffles contact one another or are otherwise joined to one another at circumferentially spaced locations to define inlet passages between the areas of contact. The annular inlet baffles may be circumferentially corrugated, so that the areas of contact between adjacent baffles extend across substantially the full radial width of each annular baffle.

The cylindrical sleeve of any aspect of the invention may be mounted within a housing cavity separated from the inlet passage by said inboard side wall, wherein a free end of the cylindrical sleeve extends from said cavity into the annular inlet to define the width of the annular inlet.

Gas flow through the annular inlet may therefore be confined between the free end of the sleeve and the outboard side wall.

In some variable geometry turbines the housing comprises a bearing or centre housing portion, and a turbine housing portion, wherein the turbine wheel rotates in a chamber defined between the bearing/central housing and the turbine housing portions, and wherein the cylindrical sleeve is mounted with a housing cavity defined within the bearing/central housing.

The cylindrical sleeve of any of the aspects of the invention may alternatively be mounted within a housing cavity separated from the inlet passage by said outboard side wall, wherein a free end of the cylindrical sleeve extends from said cavity into the annular inlet to define the width of the annular inlet.

Gas flow through the annular inlet may therefore be confined between the free end of the sleeve and the inboard side wall.

In some variable geometry turbines the housing comprises a bearing or centre housing portion, and a turbine housing portion, wherein the turbine wheel rotates in a chamber defined between the bearing/central housing and the turbine housing portions, and wherein the cylindrical sleeve is mounted with a housing cavity defined within the turbine housing.

The cylindrical sleeve is preferably movable across an outside diameter of the annular inlet to selectively block upstream ends of respective inlet passages or portions relative to gas flow through the turbine.

However in other variable geometry turbines the cylindrical sleeve is movable across an inside diameter of the annular inlet to selectively block downstream ends of respective inlet passages or portions relative to gas flow through the turbine.

A variable geometry turbine may comprise a turbine wheel mounted for rotation about a turbine axis within a housing, the housing defining an annular inlet surrounding the turbine wheel and defined between inboard and outboard inlet sidewalls, and further comprising at least one annular baffle axially spaced from the inboard and outboard sidewalls of the annular inlet to divide the annular inlet into axially adjacent annular portions, and a cylindrical sleeve axially movable within the annular inlet around the outside diameter of the annular inlet portions and said at least one annular baffle to vary the size of the annular inlet defined between a free end of the sleeve and either the inboard or outboard sidewall.

Once again, the annular inlet may be defined downstream of a surrounding volute (including a divided volute or similar chamber for delivering gas flow to the annular inlet). The effective axial width of the inlet is defined between the free end of the sleeve and either the inboard or outboard sidewalls (depending on which side of the housing the sleeve is mounted).

In some variable geometry turbines the cylindrical sleeve is mounted for movement in a step-wise manner between an open position, a closed position, and one or more positions corresponding to the position of the or each annular baffle.

The sleeve is therefore constrained to move between discreet predetermined positions, some of which correspond to the location of inlet baffles. In some embodiments the sleeve may be prevented from being positioned such that its free end lies between adjacent baffles.

One or more vanes may extend across at least one of the annular inlet portions.

Accordingly, there may be provided a method of controlling or operating a turbine according to the present invention, in which the sleeve is moved in discreet axial steps between positions corresponding to a closed position, an open position and intermediate positions in which the free end of the sleeve is aligned with an annular inlet baffle.

Specific embodiments of the present invention will now be described, with reference to the accompanying drawings.

Fig. 1 is an axial cross-section through a known turbocharger including a variable geometry turbine.

Fig. 2 is a schematic representation of a radial view around a portion of the circumference of the annular inlet of the turbine illustrated in Figure 1.

Fig. 3 is an axial cross-section through part of a turbocharger including a variable geometry turbine in accordance with an embodiment of the present invention.

Figs. 4a and 4b illustrate detail of the nozzle assembly of the turbine of Fig. 3.

Fig. 5 is a schematic representation of a radial view around a portion of the circumference of the annular inlet of the nozzle assembly of Figures 4a and 4b.

Fig. 6 shows the schematic illustration of Fig. 5 modified to show a sleeve forming part of the nozzle assembly of Figs. 4a and 4b.

Figs. 7a to 7d are axial cross-sections through part of a variable geometry turbine in accordance with alternative embodiments of the present invention.

Figs. 8a to 8f, 9a to 9d, 10, 11a to 11d, and 12 to 17 are each schematic illustrations of a radial view around a portion of the circumference of a respective inlet structure in accordance with various embodiments of the present invention.

Figs. 18 to 19 are axial cross-sections schematically illustrating embodiments of the present invention.

Fig. 21 is a schematic illustration of a radial view around a portion of the circumference of an annular inlet structure in accordance with a embodiment of the present invention.

Figs. 22a to 22b illustrate portions of a turbine and nozzle assembly in accordance with an embodiment of the present invention.

Figs. 23 and 24 are each schematic illustrations of a radial view around a portion of the circumference of an annular inlet structure in accordance with respective embodiments of the present invention.

Figs. 25a and 25b illustrate a modification of an embodiment of the present invention.

Figs. 27a to 27b are axial cross-sections through part of a turbine in accordance with another embodiment of the present invention.

Figs. 28a to 28b are axial cross-sections through part of a turbine in accordance with another embodiment of the present invention.

Figs. 29a to 29c illustration a detail of a inlet sleeve in accordance with embodiments of the present invention.

Figs. 30a and 30b schematically illustrate a detail of possible modifications to embodiments of the present invention.

Fig. 31 schematically illustrates a turbine incorporating an axially sliding sleeve and a baffle/vane arrangement in accordance with a preferred embodiment of the present invention.

Figs. 32a and 32b are perspective and side-on schematic illustrations of a further alternative embodiment of a baffle/vanes structure according to the present invention.

Fig. 33 is a perspective schematic illustration of still another embodiment of a baffle/vane structure according to the present invention.

Fig. 34 is a perspective schematic illustration of still another embodiment of a baffle/vane structure according to the present invention.

Referring to Figure 1, this illustrates a known turbocharger comprising a variable geometry turbine housing 1 and a compressor housing 2 interconnected by a central bearing housing 3. A turbocharger shaft 4 extends from the turbine housing 1 to the compressor housing 2 through the bearing housing 3. A turbine wheel 5 is mounted on one end of the shaft 4 for rotation within the turbine housing 1, and a compressor wheel 6 is mounted on the other end of the shaft 4 for rotation within the compressor housing 2. The shaft 4 rotates about turbocharger axis 4a on bearing assemblies located in the bearing housing.

The turbine housing 1 defines a volute 7 to which gas from an internal combustion engine (not shown) is delivered. The exhaust gas flows from the volute 7 to an axial outlet passageway 8 via an annular inlet 9 and turbine wheel 5. The inlet 9 is defined between sides walls, one side wall being surface 10 of a radial wall of a movable annular nozzle ring wall member 11 and on the opposite side wall being an annular shroud plate 12. The shroud 12 covers the opening of an annular recess 13 in the turbine housing 1.

The nozzle ring 11 supports an array of circumferentially and equally spaced nozzle vanes 14 each of which extends across the full axial width of the inlet 9. The nozzle vanes 14 are orientated to deflect gas flowing through the inlet 9 towards the direction of rotation of the turbine wheel 5. When the nozzle ring 11 is proximate to the annular shroud 12, the vanes 14 project through suitably configured slots in the shroud 12, into the recess 13.

An actuator (not shown) is operable to control the position of the nozzle ring 11 via an actuator output shaft (not shown), which is linked to a stirrup member 15. The stirrup member 15 in turn engages axially extending guide rods 16 that support the nozzle ring 11. Accordingly, by appropriate control of the actuator (which may for instance be pneumatic or electric or any other suitable type), the axial position of the guide rods 16 and thus of the nozzle ring 11 can be controlled. It will be appreciated that details of the nozzle ring mounting and guide arrangements may differ from those illustrated.

The nozzle ring 11 has axially extending radially inner and outer annular flanges 17 and 18 that extend into an annular cavity 19 provided in the turbine housing 1. Inner and outer sealing rings 20 and 21 are provided to seal the nozzle ring 11 with respect to inner and outer annular surfaces of the annular cavity 19 respectively, whilst allowing the nozzle ring 11 to slide within the annular cavity 19. The inner sealing ring 20 is supported within an annular groove formed in the radially inner annular surface of the cavity 19 and bears against the inner annular flange 17 of the nozzle ring 11. The outer sealing ring 20 is supported within an annular groove formed in the radially outer annular surface of the cavity 19 and bears against the outer annular flange 18 of the nozzle ring 11.

Gas flowing from the inlet volute 7 to the outlet passageway 8 passes over the turbine wheel 5 and as a result torque is applied to the shaft 4 to drive the compressor wheel 6. Rotation of the compressor wheel 6 within the compressor housing 2 pressurises ambient air present in an air inlet 22 and delivers the pressurised air to an air outlet volute 23 from which it is fed to an internal combustion engine (not shown). The speed of the turbine wheel 5 is dependent upon the velocity of the gas passing through the annular inlet 9. For a fixed rate of mass of gas flowing into the inlet 9, the gas velocity is a function of the width of the inlet 9, the width being adjustable by controlling the axial position of the nozzle ring 11. (As the width of the inlet 9 is reduced, the velocity of the gas passing through it increases.) Figure 1 shows the annular inlet 9 fully open. The inlet passageway 9 may be closed to a minimum by moving the nozzle ring 11 towards the shroud 12.

Referring to Fig 2, this is a schematic representation of a radial view around a portion of the circumference of the annular inlet 9 of the turbine of Fig 1, un-rolled and laid flat in the plane of the paper. In this representation the nozzle ring 11 is in a fully open position such that parallel lines 11 and 12 represent the nozzle ring 11 and shroud plate 12 respectively, and parallel lines 14 represent the leading edges of the nozzle vanes 14 which extend across the inlet 9. The dimension c is a portion of the circumference of the inlet 9, and the dimension w is the maximum width of the annular inlet 9. From Fig 2 it can be seen that the vanes 14 divide the annular inlet 9 into an annular array of circumferentially adjacent inlet passages 14a. Each inlet passage 14a extends generally radially, but with a forward sweep (with decreasing radius) resulting from the configuration of the vanes 14 which as mentioned above is designed to deflect the gas flow passing through the inlet 9 towards the direction of rotation of the turbine wheel. The geometry of each of the inlet passages 14a, which extend across the full width w of the inlet 9, is defined by the configuration and spacing of the vanes 14, but as shown have a generally rectangular cross-section.

Fig 3 is a cross-section through part of a turbocharger including a variable geometry turbine in accordance with an embodiment of the present invention. Where appropriate corresponding features of the turbochargers of Fig 1 and Fig 3 are identified with the same reference numbers. References to "axial" and "axially" are to be understood as referring to the axis of rotation of the turbine wheel. Fig 3 shows the bearing housing 3 and turbine housing 4 of the turbocharger, with the compressor (not shown) removed. As with the known turbocharger of Fig 1, a turbocharger shaft 4 extends through the bearing housing 3 to the turbine housing 1 and a turbine wheel 5 is mounted on one end of the shaft 4 within the turbine housing 1. The turbine housing 1 defines a volute 7 from which exhaust gas flow is delivered to an annular inlet 9 which surrounds the turbine wheel 5.

In accordance with the present invention, the size of the inlet 9 is variable by controlling the position of an axially sliding cylindrical sleeve 30 which is supported on guide rods 31 which are slidably mounted within a cavity 19 defined by the bearing housing 3. The guide rods 31 may have a configuration substantially the same as that of the guide rods 16 illustrated in Fig 1, and be actuated in the same way via a yoke (not shown) linked to inboard ends 31a of the guide rods 31. Outboard ends 31a of the guide rods 31 are connected to radially extended flanges 30a of the sleeve 30. Respective separate flanges 30a maybe provided for connection to the guide rods 31 as illustrated, or the sleeve 30 may comprise a single annular radially extending flange which is connected to the guide rods 31. The sleeve 30 has a free end which projects into the inlet 9 so that the width of the inlet can be varied in a controlled manner by appropriate movement and positioning of the sleeve 30 via the guide rods 31.

Also in accordance with the present invention the inlet 9 is, at least in part, defined between facing side walls of the turbine housing which in this embodiment comprise nozzle rings 32 and 33 of a nozzle assembly 34. The nozzle assembly 34 is shown in greater detail in Figs 4a and 4b (together with a section of the sleeve 31, and a guide rod 31). The first nozzle ring 32 of the nozzle assembly 34 extends radially across the opening of the cavity 19 of the turbine housing to the sleeve 30. Seal ring 35 seals the nozzle ring 32 with respect to the sleeve 30 to prevent gas leakage between the inlet 9 and the cavity 19. Similarly, a seal ring 36 seals the nozzle ring 32 with respect to the turbine housing adjacent a radial inner periphery of the nozzle ring 32. The second nozzle ring 33 of the nozzle ring assembly 34 is fixed to a radial wall of the turbine housing, within a shallow annual recess defined by the turbine housing and is sealed with respect thereto by seal ring 36 to prevent gas leakage between the nozzle ring 33 and the turbine housing.

An annular array of circumferentially equispaced nozzle vanes 37 extend between the first and second nozzle rings 32 and 33. The nozzle vanes 37 divide the annular inlet into circumferentially spaced inlet portions. Radially extending annular inlet baffles 38a, 38b and 38c are axially equispaced between the nozzle rings 32 and 33 and further divide the annular inlet 9 into axially spaced inlet portions. The baffles 38 are relatively thin rings coaxial with the turbine axis and orientated parallel to the nozzle rings 32 and 33 so that they have radially extending faces. Accordingly, the vanes 37 together with the inlet baffles 38a-38c divide the annular inlet 9 into a plurality of discreet inlet passages 39 (not all of which are individually referenced in the drawings) which is best illustrated in Fig 5 which is a schematic representation of a radial view of an un-rolled portion of the circumference of the nozzle assembly 34 corresponding to the representation of the known inlet structure shown in Fig 2. Again the dimension w is the full width of the inlet 9 and the dimension c is a portion of the circumference of the inlet.

Referring to Fig 5, the vanes 37, and inlet baffles 38a-38c, divide the inlet 9 into four axially spaced annular arrays of circumferentially spaced inlet passages 39a, 39b, 39c and 39d respectively. In contrast, the known arrangement of Fig 2 has a single annular array of circumferentially spaced inlet passages, each of which extends across the full width of the inlet 9. The exact configuration of the inlet passages 39a to 39d is defined by the configuration of the vanes 37 and baffles 38a to 38c, but as illustrated it can be seen that the passages have a generally rectangular (in this case nearly square) cross section. Each of the inlet passages 39a – 39d directs gas flow to the turbine wheel, and due to the sweep of the vanes 37 turns the gas flow in a direction towards to the direction of the rotation of the turbine wheel 5. In this embodiment the inlet passages 39 in each annular array are circumferentially adjacent and each annular array 39a to 39d is axially adjacent to the next.

As described above, the size of the inlet 9 is controlled by adjustment of the axial position of the sleeve 30 which slides over the outside diameter of the vanes and baffles. Depending upon the positioning of the sleeve 30, one or more of the axially spaced annular arrays of inlet passages 39a-39d may therefore be blocked or partially blocked to gas flow through the inlet 9. For instance, Fig 4a illustrates the sleeve 30 in an almost fully open position in which the first annular array of gas flow passages 39a is partially blocked to gas flow, and the second to fourth annular arrays of inlet passages 39b-39d are fully open to gas flow. Fig 4b (and Fig 3), show the sleeve 30 in a fully closed position in which the end of the sleeve 30 bears against the nozzle ring 33 and all four of the axially adjacent annular arrays of inlet passages 39a-39d are closed (subject to the potential for a minimum amount of leakage into the inlet passages 39d between the sleeve 30 and the nozzle ring 33).

By controlling the position of the sleeve 30 between the open and closed positions, a selected number of the axially adjacent annular arrays of inlet passages 39a-39d may be opened or blocked, or partially opened/blocked. For instance, by positioning the sleeve 30 so that the free end of the sleeve is axially aligned with the first inlet baffle 38a, the first annular array of inlet passages 39a is closed and the second to fourth annular arrays of inlet passages 39b-39d are fully opened to gas flow. Similarly, by positioning the free end of the sleeve 30 part way between inlet baffles 38b and 38c the first and second annular arrays of inlet passages 39a and 39b will be fully closed, the fourth annular array of inlet passage 39d will be fully open and the third annular array of inlet passages 39c will be partially open. This is schematically illustrated in Fig 6 which superimposes the sleeve 30 on the view shown in Fig 5.

In the embodiments of the invention described above (and below) the sleeve 30 can fully close the inlet, i.e. block the inlet 9 completely. In other embodiments the sleeve need not necessarily be capable of closing the inlet fully, but might have a "closed" position in which the final array of passages 39 is at least partially open. For instance, the free end of the sleeve could be provided with axially extending lands which provide a hard stop for the closed position of the sleeve, with flow gaps defined between lands around the circumference of the sleeve.

In this embodiment of the invention, the increased acceleration of the gas flow is achieved by reducing the size of the inlet 9 occurs upstream of the inlet passages 39. In the absence of inlet baffles 38, gas accelerating past the end of the sleeve 30 will expand axially across the full width of the inlet 9 before it reaches the turbine wheel 5. This would result in substantial loss of energy in the gas flow as it passes through the inlet which may largely negate the desired effect of constricting the inlet. Accordingly, such a variable geometry turbine could be expect to be very inefficient and thus impractical for many applications, such as for instance for use in a turbocharger turbine. With the present invention, as the sleeve 30 moves beyond the first and subsequent inlet baffles, the volume of the inlet 9 within which the gas can expand is reduced which similarly reduces the potential for loss in energy by expansion of the gas flow within the inlet 9 upstream of the turbine wheel. This in turn significantly improves the efficiency of the inlet. As the free end of the sleeve aligns with a given inlet baffle it is effectively equivalent to a moving radial wall member. Between these locations it is possible there may be a drop off in efficiency but this will not be to the same extent as would be experienced in the absence of any inlet baffles. Surprisingly, simulations suggest that the inlet structure of the present invention has even better efficiency than some known moving wall inlet structures, particularly at smaller inlet widths.

The embodiment of the invention illustrated in Figs 3 to 6 has three inlet baffles 38, but more or less than three baffles could be incorporated in alternative embodiments. For instance, provision of only a single inlet baffle, for example midway between the nozzle rings 32 and 33, may improve efficiency above that attainable in the absence of any inlet baffle to a sufficient extent to provide an effective variable geometry turbine structure for use in a turbocharger and other applications.

Efficiency of the turbine inlet can be expected to vary in a somewhat step-wise function of inlet size corresponding to the location of the or each inlet baffle. This effect can however be smoothed by increasing the number of baffles. Although increasing the number of baffles (which have an axial thickness) may increase aerodynamic drag and reduce the maximum cross-sectional flow area available to gas flow for any given inlet width w, this may, if necessary, be compensated by constructing the annular inlet 9 to have a larger maximum axial width and than would be the case in the absence of baffles.

The turbine according to the present invention also has a number of other advantages over the known moving nozzle ring turbine shown in Fig 1. With the present invention there are considerably reduced pressure and aerodynamic forces on the sleeve compared to those acting on a radial wall. For instance, the axial force imposed on the sleeve 30 by air flow through the inlet is much less than that imposed on a moveable radial wall. This allows the use of a smaller, less robust actuator, and also a less robust linkage between the actuator and the sleeve, as the axial force required to move the sleeve and hold it in position is much less than that required to control the position of a radial wall. The reduction in axial forces on the sleeve compared to those experienced by a radial wall also simplifies accurate control of the size of the inlet.

Employing a cylindrical sleeve as the moving component for varying the inlet size, instead of a moving radial wall, also avoids the need to provide slots to receive the vanes as the inlet width is reduced, which is a requirement of known inlet structures comprising a moving nozzle ring (as illustrated for instance in Fig 1) and also of alternative known structures in which the vanes are fixed and a slotted shroud is moved axially over the vanes to vary the inlet width. The present invention thus eliminates many of the interface requirements between the moving component and the vane array which in turn increases manufacturing tolerances. Absence of such slots also reduces the possibility of gas leakage around the vane array and simplifies sealing requirements.

Preferentially, the sleeve surrounds the inlet portions, which has been found to give an improved aerodynamic performance. In other words, the inner diameter of the sleeve is greater than an outer diameter (or outer radial extent) of the inlet portion or portions. In another embodiment, the sleeve may be surrounded by the inlet portions. In other words, the outer diameter of the sleeve may be less than inner diameter of the inlet portion or portions. In another embodiment, the sleeve may be moveable through the inlet portion or portions. In other words, the diameter (e.g. inner or outer, or average diameter) of the sleeve may be less than an outer diameter of the inlet portion or portions, and greater than an inner diameter of the inlet portion or portions.

Known devices comprising a moveable nozzle ring in which the moving wall member includes the vanes, for instance as shown in Fig 1, also experience significant torque as the gas flow is deflected by the vanes. With the present invention there is no such torque on the moving component which further reduces the force on the actuator and actuator linkages.

With the embodiment of the invention illustrated in Figs 3 and 4, the inlet passages 39 are defined by a nozzle assembly 34 comprising the nozzle rings 32 and 33 which support the inlet vanes 37 and baffles 38. The nozzle rings 32 and 33 thus define the sidewalls of the annular inlet 9 of the turbine. This structure may have advantages such as allowing differently configured nozzle assemblies to be fitted to a common turbine housing so that the inlet structure (i.e. configuration of inlet passages 39) may be varied between turbines which are otherwise substantially identical. This (modular) construction may have manufacturing benefits. However, it will be appreciated that the vanes 37 and baffles 38 which define the passages 39 (or any other structure which may define the inlet passages 39 as described below), need not be formed in a separable modular nozzle assembly, but could be cast or machined integrally with the turbocharger housing (e.g. the bearing housing and/or turbine housing in a typical turbine structure). In such embodiments, sidewalls of the inlet 9 need not be formed by discreet nozzle rings as with the embodiments of Figs. 3 and 5. Accordingly, although in the description below reference numerals 32 and 33 are conveniently used to identify sidewalls of a turbine inlet 9, these are not to be considered limited to the nozzle rings 32 and 33.

In the embodiment of the invention illustrated in Figs 3-6, the turbine nozzle comprises three inlet baffles 38, but as mentioned above there may be more or less inlet baffles in alternative embodiments of the invention. For instance, embodiments with only one or two inlet baffles are effective in significantly increasing the efficiency of a turbine inlet in which the moving component used to vary the inlet size is a cylindrical sleeve surrounding the vane array. Similarly, embodiments with more than three baffles may be advantageous in some embodiments. In some applications, such as for instance turbocharger applications, it is expected that 3 to 6 baffles would be appropriate.

The baffles need not be axially equi-spaced across the width of the inlet 9, and in the case of a single baffle this need not be located mid-way between side walls of the inlet 9. For instance, the axial spacing between any two adjacent baffles, or between a baffle and an adjacent side wall of the inlet may increase or decrease from one axial side of the inlet to the other, or may first increase and then decrease, or vice versa. For instance, where there is more than one inlet baffle, the axial space between the adjacent baffles and between any baffle and a side wall of the inlet may reduce/increase across the inlet 9 so that as the inlet is progressively closed by the cylindrical sleeve, the axial width of any exposed inlet passages 39 reduces/increases.

In the embodiment of the invention illustrated in Figs 3-6, each of the inlet baffles comprises a radially extending wall of constant thickness so that opposing surfaces of each baffle lie in a radial plane. In addition, facing surfaces of each baffle are parallel both to one another and to the facing surfaces of the nozzle rings 32 and 33 which defined the side walls of the annular inlet 9. In alternative embodiments of the invention the opposing surfaces of any given baffle need not be parallel to one another and/or need not lie in a radial plane, and/or need not be parallel to the facing surface of an adjacent baffle or inlet side wall.

For example, one or both of the opposing surfaces of a single inlet baffle may lie on a frusto-conical surface of revolution about the turbine axis. Such surfaces may be parallel with one another, or may angle in opposing directions. In embodiments comprising a plurality of frustoconical baffles, adjacent baffles may have facing surfaces which are parallel to one another or which lie at an angle to one another. Similarly, the inlet side walls, (e.g. nozzle rings 32 and 33) may have surfaces which may be parallel or angled to the facing surfaces of adjacent inlet baffles.

An inlet baffle may have a uniform axial thickness, or may have a thickness which varies across its radius. For instance, a baffle may have a narrowing axial thickness with decreasing radius. For instance, an inlet baffle may taper or may have a radial cross section which is has an aerofoil shape similar to that of a conventional inlet vane.

Examples of some of the possible alternatives described above are shown in Figs 7a to 7d. These Figures are a simplified radial cross-sections through a turbine inlet 9 comprising sidewalls 11 and 12, and baffles 38. Details of inlet vanes 37 are omitted from some of the figures for simplicity.

Fig 7a illustrates an embodiment comprising an annular inlet 9 defined between side walls 32 and 33 and comprising a nozzle having three baffles 38a-38c. In this particular case baffle 38c is much closer to side wall 33 than to the neighbouring baffle 38b. Similarly the spacing of baffles 38a and 38b, and the spacing of side wall 32 and baffle 38a is greater than the spacing between baffle 38c and side wall 33. In this particular embodiment the baffles are radial and parallel to one another as well as to the side walls 32 and 33.

Fig 7b is a modification of the structure shown in Fig 7a, in which the side wall 33 of the turbine housing 1 lies of a frusto-conical surface so is angled with respect to the baffle 38c. In alternative embodiments the side wall 32 could be angled in a similar way, and in some embodiments both side walls 32 and 33 may be angled so that both sides of the annular inlet 9 taper inwardly.

Fig 7c illustrates an embodiment including three inlet baffles 38a-38c which have progressively increased spacing across the inlet 9, so that as the sleeve 30 is moved to close the inlet the axial width of the inlet passages 39 increases.

The embodiment of Fig 7d, the inlet nozzle comprises 5 baffles 38a-38e. As can be seen, in cross-section the baffles have a "fan" arrangement. That is, the central baffle 38c, which is mid way between inlet side walls 32 and 33, lies in a radial plane, but nozzle rings 38a, 38b, and baffles 38d and 38e are inclined so that they each lie on a frusto-conical surface with the effect that the inlet passages 39 tend to converge towards the central inlet baffle 38c. In addition, the effect is to define a tapering nozzle which has a maximum width defined between the nozzle ring 38a and the nozzle ring 38e, and which narrows with decreasing radius. In other words, the nozzle tapers inwardly. A similar effect could be achieved by dispensing with nozzle rings 38a and 38e and inclining the side walls 32 and 33 instead.

The inlet vanes may have any suitable configuration, and may for instance have substantially the same aerofoil configuration of conventional inlet vanes or any alternative configuration selected to define a particular arrangement and configuration of inlet passages 39. That is, since the vanes and inlet baffles together define the configuration and orientation of the inlet passages 39, a wide variety of different inlet passage configurations can be achieved by appropriate design of the configuration and orientation of the individual nozzle vanes or inlet baffles, and moreover the designs can be such that there may be a variety of differently configured inlet passages within a single nozzle assembly.

As mentioned above, the efficiency of the turbine inlet may vary as the sleeve moves to different positions, and in particular may be greater at positions in which the free end of the sleeve is aligned with one of the baffles than when it is positioned between baffles. Accordingly, in some embodiments of the invention the actuator and/or control system for the sleeve may be configured so that the sleeve only moves in a step-wise manner between fully open and closed (including any "over-open" or "over-closed") positions and positions corresponding to the location of some or all of the baffles, and does not move to locations between adjacent baffles. The effect of this is to provide an inlet with a plurality of discreet sizes between a maximum and minimum. This may provide efficiency advantages, and may allow a lower cost actuator to be used.

Similarly, in some embodiments of the invention it may be desirable to locate baffles at particular axial positions corresponding to sleeve positions (i.e. inlet sizes) which are optimum for certain pre-determined operating conditions of the turbine. For instance, such positions for a turbocharger turbine might correspond to preferred inlet widths for operation at peak engine torque, rated engine speed and freeway cruise point. In some applications, for instance in turbocharged power generators, the power generating engine may be operated at fixed loads and/or speeds with no need to allow for continuous adjustment of the turbine inlet width. In such embodiments baffles can be placed at positions corresponding to the optimum inlet widths for the particular operating conditions required, and the sleeve operated to move only between positions corresponding to the positions of the or each baffle.

In the embodiments of the invention described above, each inlet vane may be viewed as comprising axially adjacent inlet vane portions separated by the inlet baffles. Thus, in the illustrated embodiment each vane 37 may be considered to comprise portions which are axially aligned so that they are equivalent to a single vane extending across the full width of the inlet 9. However, in alternative embodiments it may for instance be desirable to circumferentially stagger inlet vane portions between adjacent pairs of inlet baffles, and in some embodiments it may no longer be possible to identify the equivalent of a single vane extending across the full width of the inlet 9.

In an embodiment in which the sleeve 30 is actuated from the turbine housing side of the inlet, so that its free end moves towards the bearing housing side of the inlet 9 as the inlet is closed (this possibility is discussed in more detail further below) the arrays of inlet channels 39c and 39d are less able to stimulate vibration and fatigue in the turbine blades because the hub end of the turbine leading edge is more rigidly connected to the turbine hub (by virtue of it being closer to the turbine wheel back face). In some applications of the invention it may be desirable to maximise turbine efficiency at smaller inlet openings and thus the vane arrays 39c and 39d may have a reduced clearance with respect of the turbine wheel (as illustrated) to boost efficiency given that this may not result in any significant vibration/fatigue problem as the turbine blades are more rigidly supported in this region. In addition, increasing the swirl angle of the vanes in the array 39d can offer a slight efficiency increase when the sleeve is at nearly closed positions (in which the leading edge of the sleeve 30 extends beyond the location of the inlet baffle 38c). This would have the additional effect of reducing the rate that the cross-sectional flow area changes as a function of sleeve motion, when the sleeve is nearly closed, which allows the actuator to control the cross-sectional flow area more precisely.

For certain engine applications (such as for EGR) it may be desirable to reduce the turbine efficiency in one or more of the arrays of inlet channels. For instance, it may be desirable to reduce efficiency at relatively open inlet widths in some applications. Such reduced efficiency could for instance be achieved by reducing the radial extent of the vanes (as illustrated) and/or by increasing the circumferential width or otherwise configured of the vanes to reduce the effective inlet area. The inlet area could be reduced further by providing other obstacles to flow, for instance posts extending axially into the channel. The axial width of the array can be reduced to increase effective friction losses, and the swirl angle of the vanes could be configured to provide mixed swirl. Other examples (not illustrated) could include a ring of similar and evenly spaced posts, two or more concentric rings of posts, a ring of unevenly and randomly distributed posts, or even a ring of vanes arranged to reverse the swirl angle of the gas (i.e. to rotate gas in the opposite direction to the turbine).

In the embodiments of the invention described above, each inlet baffle is annular and as such extends around the full circumference of the inlet 9. Each inlet baffle may however be considered to comprise an annular array of adjacent baffle portions defined between adjacent inlet vanes (or vane portions). In the illustrated embodiment of Figs 3-6, the baffle "portions" of each baffle 38 are aligned to define the respective annular baffle. However, in alternative embodiments it may for instance be desirable to effectively omit some baffle portions, and in some embodiments it may no longer be possible to identify the equivalent of a single inlet baffle extending annularly around the full circumference of in the inlet 9.

Non limiting examples of various alternative embodiments are illustrated in Figs 8a to 8f and 9a to 9d. These Figures are schematic radial views of un-rolled portions of the circumference of the respective embodiments corresponding to the views shown in Figs 2 and 5 for example.

Figure 8a illustrates an embodiment in which inlet vane portions 37a-37d extend between adjacent inlet baffles 38 and between in the baffles 38 and side walls 32 and 33. No single inlet vane 37 is continuous across a baffle 38, with the effect that individual inlet passages 39 are arranged in circumferentially staggered annular arrays 39a-39b (there is circumferential overlap between axially adjacent passages 39).

Figure 8b is a modification of the embodiment shown in Figure 8a, in which some vanes 37 do extend across the full width of the inlet 9, whereas other vane portions extend only between neighbouring baffles 38 or between a baffle 38 and enabling inlet wall 32/33. There are again four annular arrays of circumferentially adjacent inlet passages 39a-39d, but in this case each annular array includes inlet passages 39 of different sizes, in this case some have a rectangular cross-section whereas others have a square cross-section.

Fig 8c illustrates an embodiment of the invention in which inlet vanes 37 extend from the side walls 32 and 33 respectively, but in which no single inlet vane 37 extends the full width of the inlet 9. The effect in this case is to create four annular arrays of circumferentially adjacent in the passages 39a-39b, wherein the passages adjacent each side wall 32 and 33 have a rectangular cross-section and the passages 39b and 39c define between the baffles 38 have a generally square cross-section.

Fig 8d illustrates an embodiment in which inlet vanes 37 extend only half way across the full width of the inlet 9, in this case extending from side wall 32 to a central inlet baffle 38b. In this case there only two annular arrays of inlet passages 39a and 39b whereas the "arrays" of 39c and 39d are each replaced by a single annular passage way 39c and 39d respectively.

Although a single 'vaneless' space 39d may be provided without any vanes or other structures crossing it, if two vaneless spaces are provided (as shown in figure 8d) then the baffle separating them will require support. This could for instance be in the form of at least three small axially extending struts spaced around the turbine inlet between that central baffle and a neighbouring baffle or a side wall.

A single vaneless space 19c between one of the side walls 32 or 33 and the annular arrays of passages (i.e. at one axial end of the turbine inlet) may be very beneficial. By including a vaneless space to be exposed when the sleeve is fully open, the flow range of the variable geometry turbine can be considerably increased. Optionally the radially outboard inlet of the vaneless space may be axially wider than the radially inboard outlet (not illustrated).

The embodiments of Figures 8e and 8f also comprise at least one annular inlet passage absent any vanes. In the embodiment of Fig 8e, there is a single inlet baffle 38 and vanes 37 extend from side wall 32 to the inlet baffle 38, but do not extend from the inlet baffle 38 to the side wall 33. This creates a first annular array of adjacent inlet passages 39a and a single annular inlet passage 39b. Figure 8f is an extreme example of the embodiments shown in Fig 8e, in which there is only a single vane 37 shown which extends from side wall 32 to the single inlet baffle 38. Where the Figure shows only a single vane 37 it is to be understood that there is a diametrically opposed vane 37 so that there are two adjacent semi-circular inlet portions 39a in a first annular array, and a axially adjacent single annular inlet passageway 39b. In practice, there are unlikely to be any applications to the present invention which will require only a single pair of diametrically opposed vanes 37.

In some embodiments there may be at least 6 vanes to help ensure the ends of the vanes are close enough together without being impractically long and inducing excessive gas friction. This may also help the gas to swirl in relatively homogenously (e.g. constant swirl angle around the circumference) which may be difficult to achieve with fewer than 6 vanes. In some embodiments there may be at least 9 vanes, preferably at least 12 and normally at least 14. For instance, such a turbine inlet could have 9-18 vanes, with very small turbocharger turbines suiting perhaps 13-16 vanes and very large automotive ones suiting perhaps 15-18 vanes.

In some embodiments of the invention the skin friction induced by the baffles may be reduced by reducing the radial extent of the baffles and vanes, and hence reducing the vane length. If necessary or desired the number of vanes can be increased to increase the "vane solidity".

With the materials available at present, and the gas pulsations and temperature variations expected, as many as 30 circumferentially distributed gas passages may for instance be appropriate for some applications of the invention, such as for instance heavy duty engine turbocharger applications. In other embodiments as many as 40 circumferentially distributed gas passages perhaps be appropriate, for instance for light duty engine turbocharger applications. For fuel cell turbocharger applications 75 or more circumferentially distributed gas passages may be desirable (due to the lower exhaust temperatures and absence of gas pulsations). For very large turbines operated at low temperatures, low turbine pressure differentials, low gas speeds, and in the absence of gas pulsations and temperature variations, 100 circumferentially distributed gas passages may appropriate.

Therefore the number of circumferentially distributed gas passages (which may all be at least partially axially overlapping) may generally be between 8 and 100. In other embodiments there may be between 12 and 100, or between 18 and 100 (perhaps 23 and 100, possibly 26 and 100 or conceivably 30 to 100). According to one embodiment of the invention, there may be provided two axially divided annular arrays of gas passages, each annular array having between 12 and 100 circumferentially distributed gas passages.

Such structures with large numbers of circumferentially distributed gas passages are not shown for simplicity, but it should be understood that the structures described herein are examples and the principles described may be implemented with large numbers of circumferentially distributed gas passages.optionally between 18 and 100.

It will thus be appreciated that the number of vanes can vary from those illustrated in Figs. 8a-8f.

Figures 9a to 9d show embodiments in which vanes 37 extend across the full width of the inlet 9, but at least one or more inlet baffles extend only a part way around the circumference of the inlet.

Fig 9a illustrates an embodiment of the invention comprising a single inlet baffle 38 which extends around the full circumference of the inlet 9 (in this case midway between the side walls 32 and 33), and inlet baffle portions 38a and 38c which extend between other pairs of vanes 37 (which extend across the full width of the inlet 9).

The embodiment of Fig 9b differs from the embodiment of Fig 9a in that there are two baffles 38a and 38d which extend around the full circumference of the inlet 9, but where baffle 38c is split into discontinuous baffle portions extending between every other pair of vanes 37.

Figure 9c is an embodiment in which there is no single inlet baffle extending the full circumference of the annular inlet 9, rather inlet baffles 38a-38c comprise baffle portions extending between respective pairs of inlet vanes 37. In the particular embodiment illustrated, the inlet baffle portions 38b are circumferentially staggered relative to the inlet baffle portions 38a and 38c. The individual inlet passages 39 are axially staggered, in that there is axial overlap between circumferentially adjacent passages 39.

The embodiment of Fig 9d shows another example of a nozzle which has no single inlet baffle extending the full circumference of the annular inlet 9. Moreover, this embodiment shows how the spacing between inlet baffle portions extending between one pair of vanes may differ to that between the baffle portions extending between an adjacent pair of vanes.

The embodiments of Figs 8 and 9 have generally regular arrays of inlet passages 39. However, this need not necessarily be the case. For example, Fig 10 schematically illustrates an embodiment in which there is no single inlet baffle extending around the full circumference of the inlet, and no single inlet vane extending across the full width of the inlet. In this case the passage array is very irregular. In practice this specific pattern may not be particularly desirable, but it is included to illustrate the extent of variation that can be achieved (subject to manufacturing suitability) with some embodiments of the present invention.

It will be appreciated that the vanes or vane portions of the various embodiments of the invention described above may have any suitable cross-sections or configurations. For instance, the vanes may have a relatively conventional airfoil configuration. In general, it may be advantageous to ensure that the leading edge of each vane has an increased thickness compared with the trailing edge of each vane. Increasing the thickness of the leading edge of the vanes offers higher tolerance to any variations in the incident angle of gas flow impinging on the vanes. That is, depending on the flow/pressure in the turbine volute the direction that gas will impinge on the vanes can vary. If gas hits a simple sheet structure at an angle it may cause the gas flow on the lee-side to separate off from the sheet leaving a vortex/turbulent area which greatly reduces efficiency.

In addition, it will be appreciated that the configuration and/or arrangement of the vanes may vary in order to produce inlet flow passages 39 of a desired configuration. For example, it is generally beneficial for the passages 39 to curve rather than follow a substantially straight path.

In view of the wide variety of possible alternative structures according to the present invention, it may not therefore always be possible to view the inlet nozzle structures as comprising discernable inlet vanes in the conventional sense or even vane portions. Similarly, it may not be possible to identify individual inlet baffles or baffle portions as such. Rather, in more general terms it may be more appropriate to consider the invention as relating to an inlet nozzle structure which defines a plurality of discrete inlet passages which may take a variety of configurations and be arranged in a variety of different ways. Common to all of the embodiments of the invention illustrated in Figures 3 to 10, the turbine nozzle comprises at least two axial spaced annular arrays of inlet passages. In some embodiments a single axial "array" may in fact comprise only one circumferential inlet passage. However, in most embodiments it is envisaged that each annular array will comprise many inlet passages circumferentially spaced (e.g. adjacent) around the annular inlet.

In any given embodiment of the invention it may be possible to identify annular arrays of circumferentially spaced inlet passages 39 in different ways. For instance, Figs 11a to 11d show the embodiment of Fig 9d, but with axially spaced annular arrays of circumferentially spaced in the passages 39 identified in different ways. For instance, referring first to Fig 11a, four annular arrays of inlet passages 39a-39d are identified. In this case, the inlet passages of the first array 39a have differing axial widths, but are adjacent one another. The inlet passages 39b of a second array each have the same axial width but are staggered relative to one another, and are not always adjacent one another. A third annular array of circumferentially spaced inlet passages 39c is identified which have the same axial width and position, but are not adjacent one another. Finally, a fourth annual array of circumferentially spaced inlet passages 39d corresponds to the first array 39a.

For any particular embodiment of the present invention it may not be necessary to identify more than two distinct axially spaced annular arrays of inlet passages, even when more than two such arrays may exist. For instance, Fig 11b identifies only two annular arrays of spaced inlet passages 39a and 39b. In this case, the inlet passages in each annular array are neither circumferentially nor axially adjacent one another. In Fig 11c two different annular arrays of circumferentially spaced inlet passages 39a and 39b are identified. In this case the inlet passages 39a of the first array are actually circumferentially adjacent inlet passages 39b of the second array, the axial spacing being achieved by an overlap in the axial dimension of the passages of each array. That is to say, the inlet passages 39b have a greater axial width than the inlet passages 39a so that at least a portion of each inlet passages 39b is axially spaced from the inlet passages 39a. Finally, Fig 11d shows another approach to identifying two axially spaced annular arrays of inlet passages 39a and 39b. In this case the passages 39a and 39b are axially adjacent one another, but the passages 39 of each array are not circumferentially adjacent.

It will be understood that further possible distinct annular arrays of inlet passages according to the present invention can be identified with the embodiment of the invention illustrated in Fig 11a-11d, and that similarly in other embodiments of the invention it will be possible to define distinct axially spaced annular arrays of inlet passages in different ways.

With all embodiments of the invention illustrated in Figs 3 to 11, each inlet passage 39 has a generally rectilinear cross section. However, alternative cross sections are possible, such as for instance diamond shaped or hexagonal cross-sections as shown in Figs 12 and 13 defined by inlet walls 50. These are examples of embodiments wherein it is not necessarily appropriate to consider any single inlet wall 50 as constituting either a vane in the conventional sense or an inlet baffle distinct from inlet vanes. However, in each case the nozzle structure clearly comprises a plurality of inlet passages 39. In Figs 12 or 13 one approach to identifying two distinct axially spaced annular arrays of circumferentially spaced passages, 39a and 39b is shown. In each of these embodiments the inlet passages in each annular array identified are circumferentially adjacent one another. Another feature of these embodiments is that adjacent annular arrays which are spaced axially across the inlet overlap one another to a degree. That is, a portion of each individual inlet passage 39b of the second annular array axially overlaps a portion of each inlet passage 39a of the first annular arrays. It is believed that such nozzle structures will further smooth any tendency for the turbine efficiency to have a "stepped" characteristic with varying inlet size.

The adjacent annular arrays which are spaced axially across the inlet overlap one another in a further manner. That is, a portion of each individual inlet passage 39b of the second annular array circumferentially overlaps a portion of each inlet passage 39a of the first annular arrays. It is believed that such nozzle structures will further smooth any tendency for the turbine efficiency to have a "stepped" characteristic with varying inlet size.

Figs 14 and 15 show the same embodiments as Figs 12 and 13 but illustrate a different approach to identifying axially spaced annular arrays of inlet passages 39a and 39b. In this case, in each embodiment two annular arrays of inlet passages which are axially spaced but which do not axially overlap are identified.

It will once again be appreciated that the precise configuration of the inlet passages is governed by the configuration of the walls defining them, and that the nozzle structure may be designed such that there are individual inlet passages within the nozzle structure with a different configuration to that of other inlet passages within the same nozzle. A variation of the "honeycomb" embodiment of Figs 12 and 13 is for instance illustrated in Fig 16. With this embodiment inlet walls 50 again define generally hexagonal inlet passages 39 but in this case the array is somewhat irregular. One particular approach to identifying examples of two axially spaced annular arrays of inlet passages 30a and 39b is illustrated. It will be appreciated that alternative spaced annular arrays of inlet passages may be identified by taking a similar approach to that described above in relation to Figs 11a to 11d for example.

In all of the embodiments of the invention illustrated in Figures 3 to 16, and described above, the inlet nozzle structure comprises a plurality of inlet passages including at least one inlet passage spaced circumferentially and axially respectively from two other inlet passages, or indeed spaced both circumferentially and axially from each of the other two inlet passages. The spacing may be such that at least some of the passages are adjacent one another, and there may be axial and/or circumferential overlap between at least some of the passages. One other way to express this relationship is that in each of the embodiments of the invention illustrated it is possible to identify a first pair of inlet passages that are circumferentially spaced – and possibly adjacent and/or circumferentially overlapping (or staggered), and a second pair of inlet passages which are axially spaced – and possibly adjacent and/or overlapping (or staggered). Depending on how the pairs are identified, in some cases only three passages may be required to define the two pairs, with one inlet passage common to both the first and second pairs.

For example, Fig 17 shows the embodiment of Figs. 13 and 15 described above. Referring to Fig 12, a first inlet passage 60 is circumferentially spaced from a second inlet passage 61 and is axially spaced from a third inlet passage 62. In this case the passages are adjacent to one another. Similarly, a single inlet passage 63 is circumferentially spaced from an inlet passage 64 and axially spaced from an inlet passage 65. Here the passages are not adjacent. Inlet passages 60 and 61 can for instance be considered to comprise a first pair of circumferentially spaced inlet passages (as well as axially spaced by virtue of their axial overlap), and inlet passages 60 and 62 can be considered to comprise a second pair of inlet passages that are axially spaced, with the single inlet passage 60 common to both pairs. Likewise, inlet passage 63 and 64 can be considered to comprise a first pair of inlet passages which are circumferentially spaced but not adjacent and inlet passages 63 and 65 can be considered to comprise a second pair of inlet passages which are axially spaced (and in this case also circumferentially spaced), in this case a single inlet passage 63 being common to both pairs. Alternatively, inlet passages 60 and 63 can for instance be considered to comprise a first pair of circumferentially spaced inlet passages, and inlet passages 64 and 65 can be considered to comprise a second pair of axially spaced inlet passages.

Referring to figures 18 to 20, these illustrate embodiments of the invention in views comprising an array of "diamond shaped" inlet passages 39 in axial-cross section corresponding generally to figures 7a, 7b and 7d respectively. This illustrates that the nozzle may taper inwardly, comprising individual inlet passages 39 which narrow with decreasing radius. It will be appreciated that the same approach could be taken with the hexagonal inlet passage array as illustrated in Figs 13 and 15 for example.

More generally it will be appreciated that the configuration of inlet passages 39 may vary considerably between embodiments of the invention. For instance, inlet passages 39 may have a greater or lesser forward sweep relative to the direction of rotation of the turbine blade 5 to induce more or less swirl in the inlet gas flow. The degree of sweep (or swirl angle) may vary along the length of the inlet passages. Different inlet passages may have different swirl angles. For instance, one annular array of inlet passages may all have the same swirl angle but this may differ from the swirl angle of another (e.g. adjacent) annular array of inlet passages.

Also, individual inlet passages 39 may have a cross sectional area which is constant along its length, or which tapers, or which for instance narrows and then widens again between its upstream to downstream ends. For example the cross-sectional area may change from one size and/or shape at the inlet of the passage to another size and/or shape at its outlet. For instance the cross-sectional shape may be diamond shaped or hexagonal at the inlet and change gradually to a more rectangular or square shape at its outlet.

In some embodiments of the invention it may be appropriate to have inlet passages 39 that are restricted to the radial plane, broadly equivalent for instance to known turbocharger nozzle designs comprising straight vanes, i.e. vanes which lie in a plane containing the axis of the turbocharger.

Referring to Figure 18, for example, as previously discussed, the size of the inlet 9 is varied by the axial movement of the sleeve 30. The inlet passages 39 of the nozzle are such that there are two substantially radial gas passages (which direct gas, in use, substantially radially inward to wards the turbine wheel). These two substantially radial gas passages 39 are spaced circumferentially from one another and are arranged such that each gas passage 39 has an opening which is configured such that a single substantially cylindrical axially sliding sleeve may move axially past the gas passage and may selectively close at least part of the opening. The sliding sleeve may also substantially close each of the openings of the two gas passages 39. Each opening of the gas passages 39 overlaps in the axial direction. When the sleeve is in a first position the sleeve can close at least part of a first of the two openings, whilst a second of the two openings is substantially unobstructed by the sleeve. For example, the sleeve may leave the second of the two openings totally exposed to the inlet volute. In a second position of the sleeve, the sleeve at lest partially closes both the first and second openings.

Although in one sense the "diamond" and "honeycomb" structures shown in Figs 12 and 13 for example can not necessarily be considered to comprise vanes in the conventional sense, or clearly discernable baffles, it is in fact possible to construct such nozzle structures from discrete inlet baffles of an appropriate configuration. For example, Fig 21 shows how the structure shown schematically in Fig 13 can be constructed by pressing together axially adjacent baffles, four of which 78a-78d are identified in the figure. Each of these baffles is an annular ring but is circumferentially corrugated along the lines of a "wavy washer" and are aligned "out of phase" (circumferentially staggered) so that hexagonal inlet passages 39 are defined between adjacent baffles.

If the corrugations of each baffle extend strictly radially, each of the inlet passages 39 will extend along a radius. However, by sweeping the corrugations forward relative to the circumferential direction of each baffle, inlet passages 39 which similarly sweep forwards can be defined. This is illustrated in Figs 22a to 22d. Fig 22a shows seven baffles in the baffles 80 provided with spiral corrugations prior to assembly into a nozzle structure. To complete the nozzle the baffles 80 are pressed together and joined by any suitable means. Fig 22b is a cross section through a part of a turbocharger with the resultant nozzle structure in situ. Fig 22c is an end view of the nozzle structure surrounding the turbine wheel 5, looking along the axis of the turbocharger shaft 4m, and Fig 22d is an axial cross section corresponding for instance to Fig 18.

It will be appreciated that various modifications can be made to the embodiment of the invention illustrated in Figs 21 and 22a to 22d. For example, the corrugations or waves could take a variety of forms including for instance sinusoidal and diagonal or "V" shapes, or any other shape appropriate to define the required configuration of inlet passages 39. Furthermore, whereas with the illustrated embodiment each of the baffles 80 is corrugated, in other embodiments it may be desirable to place non-corrugated (e.g. strictly radial) baffles between one or more pairs of corrugated baffles to modify the configuration of the inlet passages 39 and certain axial locations across the inlet. Similarly, individual corrugated baffles 80 need not have the same depth of corrugation. Moreover, in some embodiments the baffles 80 can be pressed together in such a way as to have greater or smaller areas of contact between baffles 80 to that illustrated in figures 16 to 17 to again vary the configuration of the inlet passages. Indeed, the contact area may vary across the radius of the nozzle structure to define individual inlet passages 39 which have a corresponding varying cross sectional area.

Various possibilities exist for joining the baffles together. For instance the baffles may be brazed together (for example using silver brazing or other brazing appropriate for the high temperatures encountered in a turbine inlet) or adjacent baffles may be provided with mating formations, such as complimentary projections and indentations. Alternatively, baffles may be spot welded together. Other appropriate manufacturing methods will be apparent to the appropriately skilled person.

With the embodiment of the invention illustrated in Figs 21 and 22a to 22d, adjacent baffles are aligned in anti-phase so that every other baffle 70 is directly aligned. This creates a honeycomb like structure in which axially adjacent inlet passages 39 are precisely aligned along the axis of the turbocharger. However, by introducing a slight circumferential offset into each successive baffle as shown in Fig 23 it is possible to circumferentially stagger axially adjacent inlet passages 39 as illustrated by the lines 90 shown skewed at an angle to the dotted line 91 which is parallel to the turbocharger axis. This could for instance be used to partially alleviate high cycle fatigue in turbine blades when the sleeve is at the open position.

In some embodiments the baffles may be generally annular and have a generally hyperbolic paraboloidal surface (i.e. have a surface which is generally defined in part by the surface of a hyperbolic paraboloid). A hyperbolic paraboloid may be commonly referred to as having a saddle shape. One type of hyperbolic paraboloid may be defined in Cartesian geometry by the equation

$$z = \frac{x^2}{a^2} - \frac{y^2}{b^2}.$$

where x, y and z are Cartesian co-ordinates in three dimensions and a and b are constants. In some cases a and b may have substantially the same value. The hyperbolic paraboloidal or 'saddle' shaped baffle may include any number of corners, edges or vertices which are located above or below the major plane of the baffle. While such a baffle may conveniently incorporate four such corners, edges or vertices, it may incoporate any other number as desired, such as six, eight or more.

Figure 24 illustrates an alternative approach to producing a honeycomb structure substantially the same as that shown in 21 but formed from a single helical baffle structure 100 rather than individual annular baffles as illustrated for instance in Fig 21.

A structure such as that shown for instance in Fig 16 could also be fabricated from corrugated baffles, but with the corrugations defined in order to produce the more "irregular" honeycomb array illustrated. In this case, and referring back to Fig 16, the walls 50 could for instance be provided by pressing or otherwise joining together annular baffles of three different configurations (two of which are mirror images of each other) as illustrated in bold line, which shown three baffle plates pressed adjacent one another and a fourth baffle plate adjacent the wall 33 of the inlet 9.

As illustrated in Figs. 25a and 25b, some of the flow channels may be blocked to tailor efficiency in regions corresponding to certain inlet widths. For instance in Figs. 25a and 25b part-hexagonal channels at the axial ends of the nozzle are shown blocked out. In the case of Fig. 25b, the axial width of the channels in these regions is reduced which may be beneficial in reducing vibration on the blade when these channels are exposed to the inlet flow.

Whatever the configuration, or method of construction, of the nozzle assembly (e.g. assemblies comprising vanes/baffles or "honeycomb" structures), surfaces defining the inlet passages may be coated with a suitable catalyst for oxidising soot at the high operating temperatures of the turbine in order to help prevent deposition and accumulation of soot on surfaces of the nozzle.

It will be appreciated by the skilled person that there are a variety of different ways in which the nozzle assembly and other details of the inlet structures in accordance with the present invention can be constructed. For example, in the case of the honeycomb structures, the nozzle assembly may be constructed from discrete segments. The segments may define one or more inlet passageways. These segments may be of the same shape or may have different shapes. The segments may in some embodiments be arranged circumferentially in an end-to-end manner to form the honeycomb structure. Alternatively the segments may be interdigitated or they may tessellate to form an annular portion of the nozzle assembly.

Embodiments of the invention illustrated for example in Figs 3, 4a-4b, 7a-7d, 18-20 and 22a-22d each show an turbine inlet structure in which the sleeve 30 slides around the outside diameter of the nozzle structure, so that the sleeve acts to block/unblock inlet passages 39 at their upstream ends. However, in alternative embodiments of the invention the cylindrical sleeve may be located on the inside diameter of the nozzle so that it opens and closes inlet passages 39 at their downstream ends adjacent the turbine wheel. For example, Figs 26a to 26c show a modification of the embodiment of the invention illustrated in Figs 3 and 4a-4b, wherein a modified sleeve 130 slides across the inlet passage 9 downstream of inlet passages 39 so that it slides between the nozzle and turbine wheel. Other details of this embodiment of the invention are substantially the same as those shown and described in relation to Figs 3 and 4a-4b and like reference numerals are used where appropriate. The only significant differences are those necessary to accommodate the reduced diameter sleeve 130, namely repositioning of one of the two nozzle rings, identified as nozzle ring 132, and flanges 130a to which support rods 31 are connected. In particular, it will be appreciated that each of the various nozzle structures illustrated and described above, and all variations as described above, can be included in embodiments of the invention in which the sleeve 130 is positioned around the turbine wheel at the internal diameter of the inlet nozzle.

In some embodiments of the invention it may be advantageous to provide two axially slideable sleeves, comprising a first sleeve located around the outside diameter of the inlet passages and a second cylindrical sleeve located at the inside diameter of the inlet passages. In such cases the first and second sleeves may have the same axial extent across the width of the inlet 9, or one of the two sleeves may extend further than the other at least some positions, so that in such positions the overall axial width of the annular inlets differs from its upstream to its downstream openings. The two sleeves could be coupled together (or integral) for actuation as a unit, or may be independently arranged and actuated.

Embodiments of the invention described above show the sleeve 30 and 130 extending across the annular inlet 9 from the bearing housing side of the turbine wheel. In alternative embodiments of the invention the sleeve may extend across the annular inlet 9 from the turbine housing side of the wheel. In other words, the sleeve and actuating mechanism can be housed in the turbine housing rather than in the bearing housing. Examples of such embodiments of the invention are shown in Figs 27a and 27b, and 28a and 28b.

Actuating the sleeve from the turbine side can be beneficial for mitigating high cycle fatigue of the turbine blades, because when the sleeve is nearly closed, exposing just one ring of inlet passages. When the sleeve is closed from the turbine side, then ordinarily it closes towards the bearing housing side, and towards the rear of the turbine wheel – which is where the blade is most robustly supported by the turbine back face.

It should also be noted however that it is possible to provide the actuator on one side, arranged to pull the sleeve from the other side via one or more struts (generally at least two and usually three will be necessary). Therefore the actuator could be in the bearing housing, and connected by some "pull-rods" (not shown) to a sleeve in the turbine housing. The "pull-rods" pull the sleeve towards the bearing housing to block the gas inlets. Alternatively the actuator could be in the turbine housing connected by "pull-rods" to a sleeve that is pulled from the bearing housing towards the turbine housing so as to block the gas inlets. These embodiments are not illustrated, partly for brevity and partly because it will typically be preferable to provide the actuator and the sleeve on the same side of the annular turbine inlet.

If pull rods are desired, it may be desirable to align them circumferentially with vanes, for example along the edges (e.g. the radially outer edges) of some of the vanes (e.g. of three sets of axially divided vanes), which may be circumferentially aligned (i.e. non-staggered) vanes.

One possible advantage of the pull rod system (not shown) is that it might assist with aligning the sleeve around the nozzle (due to the extra axial length of the sleeve system) and thus preventing it from tilting and jamming. Another reason to implement a pull rod system would be to gain the benefits of bearing housing actuation while also the mitigation of turbine blade high cycle fatigue that can result from sliding the sleeve from the turbine side.

Referring first to Figs 27a and 27b, a nozzle assembly is indicated generally by reference 34 and may take any of the variety of forms described above and alternatives thereto. The significant difference between the embodiment of Figs 27a and 27b and for instance the embodiment of Fig 3 for example, is that a cylindrical sleeve 230 is mounted within a cavity 240 defined in a turbine housing 1 rather than in the bearing housing 3. Notwithstanding this different location of the sleeve 230, so that it slides across the inlet 9 from the turbine side to the bearing housing side, the manner of mounting and actuating the sleeve is very similar to that illustrated in Fig 3. That is, sleeve 230 is mounted on guide rods 241 which are linked to an actuator yoke 243, which may be in turn actuated by a variety of different forms of actuator including pneumatic, hydraulic and electric. In the illustrated example the guide rods 241 are slidably supported within bushes 244. The nozzle assembly 34 comprises a first nozzle ring 232 which defines a first side wall of the inlet 9, and a second nozzle ring 233 which closes the annular recess 240 to the inlet 9, and as such defines a second side wall of the inlet 9. An annular seal ring 107 is provided to seal the sleeve 230 with respect to the nozzle ring 233. It will be appreciated that other aspects of operation in this embodiment of the invention will be substantially the same as those of the embodiments in the invention described above in which the sleeve 30 is actuated from the bearing housing side. In particular, the inlet passages 39 will function in substantially the same way.

Referring to Figures 28a and 28b, these show modification of the embodiment shown in Figs 27a and 27b in which the sleeve 330 is positioned on the inside diameter of the nozzle assembly 34 rather than on the outside diameter. In this particular embodiment, the nozzle assembly 34 is located between a side wall 332 of the housing 1, and a facing side wall 332 on the opposite side of annular inlet 9 and which closes annular cavity 240 within which guide rods 241 are slidingly supported. Here again, sleeves 330 may be actuated by any suitable actuator linked to the sleeves by a yoke 243. In this embodiment the cavity 240 is sealed with respect to the inlet 9 by a seal ring 334 supported on the inside diameter of an annular member 335.

As mentioned above, alternative embodiments of the invention may comprise two parallel sleeves, one on the inside diameter and one on the outside diameter, which may be arranged and controlled to move together or independently of one another, and may have different lengths.

Various modifications may be made to the structure of the sleeve. For instance, Figures 29a and 29c show three different possibilities for the profiling of the free end of the sleeve 30. Whereas the sleeve 30 of Fig. 29a has a squared-off end, the free end of the sleeve 30 could be curved or otherwise streamlines as shown in Figs. 29b and 29c. This may improve aerodynamic efficiency as gas flows past the sleeve through the open portion of the inlet 9.

Figs. 30a and 30b show two possible arrangements for a sleeve 30 including a piston ring seal 100 adjacent the free end of the sleeve 30 to prevent gas flow between the sleeve 30 and a nozzle array in the accordance with the invention, indicated generally by reference 101. It will be appreciated that the nozzle assembly 101 may have any of the possible configurations according to the present invention described above. It will also be appreciated that the free end of the sleeve 30 could be profiled as for instance shown in Figs. 29b and 29c (and if at the nozzle inner diameter, could be oppositely profiled i.e. on its outer diameter). This, and other shapes, such as a radial ridge (not shown) may be implemented to modify the aerodynamic efficiency of the turbine or to modify the axial or radial aerodynamic forces experienced by the sleeve.

Referring now to Fig. 31, there is shown a cross-sectional view of a turbine incorporating an axially sliding sleeve 401 and a baffle/vane arrangement in accordance with a preferred embodiment of the present invention in which the vanes 402 are configured so that their radially inner edges 403, i.e. the vane surfaces defining the gas outlets of the baffle/vane structure, have less (or minimal) axial overlap than their radially outer edges 404, i.e. the vane surfaces defining the inlets to the baffle/vane structure.

Figs. 32a and 32b are perspective and side-on views of a further alternative embodiment of a baffle/vanes structure according to the present invention which, when mounted within the annular inlet to the turbine, divides the inlet into at least two axially offset inlet passages which axially overlap.

Figs. 33 and 34 are perspective views of still further embodiments of baffle/vane structures according to the present invention which, when mounted within the annular inlet to the turbine, divides the inlet into at least two axially offset inlet passages which axially overlap.

It is also possible to profile or chamfer the opposite side of the sleeve (i.e. the edge that contacts the nozzle) to facilitate smooth running and mitigate the possibility of the sleeve jamming for example against a baffle.

Furthermore, it will be appreciated that these possibilities, including those shown in Figs. 29a – 29c, 25a and 25b are applicable to the sleeve regardless of whether it is mounted on the bearing housing or turbine housing side of the nozzle, and regardless of whether it is mounted on the inner or outer diameter of the nozzle or both.

Nozzle structures in accordance with the present invention may be configured to provide varying efficiency for different inlet widths (i.e. corresponding to different positions of the sleeve or sleeves). For instance, it is mentioned above in relation to the embodiment of Figs. 3 to 6 that baffles may be unequally spaced across the axial width of the inlet. Where the sleeve is capable of moving to positions between the location of baffles, there may be greater inefficiency at such an intermediate position between two relatively widely spaced baffles than between two relatively closely spaced baffles. The ability to tailor the efficiency of the nozzle in this way may have a number of applications.

For instance, turbocharged engines may have an exhaust flow path for returning exhaust gas into the engine inlet. Such systems are generally referred to as "exhaust gas re-circulation" systems, or EGR systems. EGR systems are designed to reduce particulate emissions from the engine by re-circulating a portion of exhaust gas for re-combustion which may often be necessary to meet increasingly stringent emissions legislation. Introduction of re-circulating exhaust gas into the boosted inlet air flow can require a raised exhaust manifold pressure in "short route" EGR systems in which the re-circulating exhaust gas passes from the exhaust to the engine inlet without reaching the turbocharger turbine.

Variable geometry turbochargers can be used to assist in raising the exhaust gas to the required pressure for re-circulation to increase the "back pressure" in the exhaust gas flow upstream of the turbine. When using a variable geometry turbocharger in such a way it has been found that it can be advantageous to reduce the operating efficiency of the turbine at certain inlet widths. In accordance with the present invention this can be achieved by constructing the nozzle e.g. spacing of the inlet baffles, so that the inlet passages 39 are particularly wide (axially) in the region of the mid-stroke position of the sleeve. For instance, between two suitably widely positioned baffles, there will be a range of relatively inefficient positions for the sleeve, typically corresponding to the pair of baffles being a third to a two-thirds open, and the baffle positions may be chosen to provide inefficient operation when the whole inlet is more than half open. Such deliberately produced inefficiency may not have any significant effect on the efficiency of the nozzle when the sleeve is fully open, or indeed fully or nearly fully closed.

It would be possible to achieve a similar effect from "honeycomb" type nozzle structures in accordance with the invention, by ensuring that the inlet passages 39 have a greater maximum axial width around the mid-point of the nozzle assembly or any other axial location of the nozzle corresponding to inlet widths at which reduced efficiency is desired.

In some embodiments of the invention it might be advantageous to decrease the baffle spacing (or otherwise increase the axial size of the inlet passages 39) in regions of the inlet corresponding to closed or relatively closed positions of the sleeve. That is, using a given number of baffles there may be advantages in arranging the baffles closer together near to the fully closed position. For any given number of baffles, this may increase efficiency in relatively closed positions of the sleeve.

Various other modifications may be made to certain embodiments of the invention. For instance, the sleeve could be provided with one or more bypass apertures which are only exposed to gas flow through the inlet when the sleeve is in a closed or "over-closed" position. An "over-closed" position may be regarded as a position in which the sleeve moves axially beyond a position necessary to fully block the inlet. A bypass aperture could for instance allow exhaust gas to bleed through the sleeve towards the turbine inlet, towards the turbine downstream of it's inlet (e.g. via the turbine shroud) or even downstream of the turbine to bypass it entirely in order to increase the temperature of exhaust gas downstream of the turbine which might be useful in order to oxidise soot collected in a downstream particulate filter, in order to re-generate the filter. In other applications there may be other advantageous aerodynamic effects to be achieved by allowing the sleeve to move into an "over-closed" position, and thereby open an alternative gas flow path.

Similarly, in some embodiments of the invention it may be advantageous for the sleeve to be movable to an "over-open" position to expose a bypass gas passage which is not normally open as the sleeve moves through its normal operating range to control the size of the inlet. Such a bypass passage could for instance provide wastegate functionality which may extend the effective flow range of the turbine. The bypass passage could for instance comprise one or more bypass apertures formed in a cylindrical surface extending inboard of the sliding sleeve (e.g. as an extension to the sleeve). This arrangement may be particularly suitable for a turbine-side mounted sleeve. In an alternative arrangement movement of the sleeve into an "over-open" position may expose apertures provided in the turbine housing thereby opening a bypass flow path. This arrangement may be particularly suitable for a sleeve mounted on the bearing housing side of the inlet. Bypass arrangements such as that disclosed in US 7,207,176 could for instance be adapted for application to embodiments of the present invention.

It will be understood that whereas embodiments of the present invention have been described in relation to the turbine of a turbocharger, the invention is not limited in application to turbochargers but could be incorporated in turbines of other apparatus. Non-limiting examples of such alternatives include power turbines, steam turbines and gas turbines. In embodiments in which the turbine is part of a turbocharger, the turbocharger might be part of a turbocharged combustion engine, such as a compression ignition (diesel) engine, or a gasoline direction injection (GDi) engine for example. Such applications could include more than one turbocharger including a turbine according to the present invention. Other possible applications include fuel cell turbochargers or turbines.

Turbines in accordance with the present invention may include a wastegate, which may be a controllable independently of the sleeve (or sleeves). Wastegates of conventional design might be used.

The present invention may be used in one or more turbines of a multi-stage turbine arrangement. For instance, a radial inflow turbine according to the present invention may be combined with a second turbine stage which could be radial or axial. The multi-stage turbines may be mounted to a common turbine shaft. Turbines according to the present invention may similarly be included in turbochargers of a multi-turbocharger system. For instance, turbochargers in a series or parallel arrangement may include turbines according to the present invention.

Turbines according to the present invention may also be used for generating electrical energy (for instance in an automotive system) or in waste heat recovery systems (again particularly for automotive applications, e.g. where a secondary fluid such as water or a refrigerant fluid is boiled by low grade engine/exhaust heat, and expands to drive the turbine). The secondary fluid could even be compressed air as described by the Brayton cycle.

The turbine inlet volute may be a divided volute. For instance, it is known to provide a turbocharger turbine with a volute divided into more than one chamber, each volute chamber being connected to a different set of engine cylinders. In this case, the division is usually an annular wall within the volute separating the volute into axially adjacent portions. It may also be possible to divide the volute circumferentially so that different arcuate portions of the volute deliver gas to different arcuate portions of the turbine inlet.

The turbine of the present invention has been illustrated in the figures using a single flow volute, however it is applicable to housings that are split axially, whereby gas from one or more of the cylinders of an engine are directed to one of the divided volutes, and gas from one or more of the other cylinders is directed to a different volute of the turbine housing. It is also possible to split a turbine housing circumferentially to provide multiple circumferentially divided volutes, or even to split the turbine housing both circumferentially and axially.

However an axially or circumferentially split volute can for instance be distinguished from the axially and circumferentially spaced gas inlet passages of the present invention. For example, the latter relate to a nozzle structure arranged to accelerate exhaust gas from the volute towards the turbine, and also possibly to adjust or control the swirl angle of the gas as it accelerates. Although straight inlet gas passages are in principle possible, generally they are curved so as to control the gas swirl angle efficiently. The gas inlet passages may also distinguished from divided volutes in that the former receive gas from the volute (or divided volute), and split the gas into an array of paths. By contrast divided volutes receive gas from the exhaust manifold, and generally from differing cylinders of an engine so as to retain the gas velocity in gas pulses resulting from individual engine cylinder opening events. As such, a divided volute transmits the gas to the annular inlet, while the gas inlet passages of the present invention accept gas from the volute.

It would be possible to provide the present invention in conjunction with an axially divided volute. In such embodiments the baffle(s) axially dividing the gas inlet passages would generally be distinct from the wall(s) axially dividing the volutes.

It would also be possible to provide the present invention in conjunction with a circumferentially divided volute. A wall dividing two circumferentially spaced volutes could extend radially inwards to further serve as one of the vanes (again provided that the sliding sleeve operates at the inner diameter of the gas inlet passages). Alternatively such a volute dividing wall could extend radially inward and adjacent to the sliding sleeve, so the sleeve is radially inboard of the volute dividing wall, but outboard of the gas inlet passages. Such an arrangement could beneficially mitigate the loss of gas velocity in gas pulses experienced in a single volute turbine, and might also assist in guiding the sliding sleeve to mitigate the possibility of it becoming misaligned and consequently jamming.

The present invention has been described generally in relation to radial inflow turbines. However it is not necessary for the flow to be fully restricted to the radial plane, and a moderately conical inlet may be implemented instead. Furthermore the invention may be applied to "mixed-flow" turbines, whereby the conical inlet has a cone angle in the region of up to 45 degrees or where the turbine housing is axially split into more than one volute, each having a different degree of mixed flow direction. For example one volute might have an inlet substantially in the radial plane while a second volute might have an inlet extending backward in the region of 45 degrees. The present invention could be applied to either one or both of the volutes in such an embodiment.

The invention described in the present could be applied in the case of an axially divided turbine housing, where one volute directs gas axially to the turbine, and another volute directs gas radially or at an intermediate angle to the turbine.

The invention is also applicable to dual (or multi) stage turbines. Therefore it might be applied to the first stage of a multi-stage turbine where the first stage is a radial-inflow turbine stage (or mixed flow turbine stage) and there are one or more additional stages such as axial turbines stage and/or a radial-outlet turbine stage.

As indicated above, the present invention may be implemented to vary the geometry of only one or some of the volutes of an axially divided volute turbine. Indeed it would be possible to provide two variable geometry mechanisms as described herein, utilising two sliding sleeves so as to vary the flow of two axially divided volutes independently.

The present invention could be implemented in conjunction with a sliding variable geometry turbine mechanism of the prior art such as described in US4557665, US5868552, or US6931849. For example the cylindrical sliding wall may additionally be provided with a radial sliding wall. The cylindrical sliding wall acts to vary the number of gas inlet passages exposed, while the sliding radial wall acts to vary the width of a second set of gas inlet passages which are at a different radial extent to the others. Another way to combine the present invention with a sliding variable geometry turbine mechanism of the prior art would be to implement the two types of variable geometry mechanism in two different volutes of an axially divided volute turbine. A third way to implement these mechanisms in conjunction would be to provide them on different turbines of a multiple turbine system, such as a two stage turbocharger.

The present invention could be implemented in conjunction with a swing vane variable geometry mechanism such as described in US6779971 or US2008118349. One possible way to achieve this would be to provide an array of swing vanes each having local baffles (e.g. circular), which are arranged flush with annular baffles. The annular baffles have enough clearance to allow the vanes to rotate between predefined angles. The sliding sleeve as described herein could be permitted to slide inboard or outboard of the annular baffles. This design presents some technical challenges so it might be preferred to implement an array of swing vanes radially inboard or radially outboard of the axially divided array of gas inlet passages as described herein, however the advantage of doing so may be small compared to the cost of doing so. A third, and perhaps better way to combine the present invention with a swing vane system would be to provide a twin inlet (axially divided volute) turbine with an array of swing vanes in one volute, and the sliding sleeve and axially divided baffles described herein in the second volute. A fourth and more yet better way to combine the present invention with a swing vane system would be to provide two turbines (or two turbochargers) in one system (for example in a twin turbo engine system), one of them being a swing vane turbine, and the other being a turbine according to the present invention.

The axially divided gas passages and sliding sleeve described herein might also be implemented in conjunction with a "variable flow turbine" design as described in

JP10008977 In these designs a "variable flow turbine" has an inner main volute and an outer (or in rare cases an axially adjacent) "flow extension" volute the entry of which is controlled by a valve similar in shape to conventional flap valves or wastegate valves, the present invention might be implemented to vary the cross sectional area of the flow path back from the outer volute to the inner volute. This might alleviate the need for the outer volute to have such a gat at it's inlet. Alternatively/additionally the present invention might be implemented to vary the flow cross sectional area of the inner volute to the turbine. Additionally/alternatively the present invention might be implemented in a multi-turbine (or multi turbocharger) system, one exhibiting the present invention, and the other exhibiting a "variable flow turbine" such as described in JP10008977.

Whereas examples of mechanisms for actuating the inlet sleeves are discussed above, it will be appreciated that other mechanisms may be employed as appropriate to different embodiments and applications of the invention.

A turbine nozzle according to the present invention could be implemented in conjunction with the circumferentially sliding volute tongue extender described in DE102007058246.

A turbine nozzle according to the present invention could be implemented with a multiple volute turbine housing being an asymmetric housing, where one volute is larger than another. The dividing wall between the volutes may or may not extend in to the annular nozzle.

A turbine nozzle according to the present invention could be enabled to also actuate a second device, for example a variable geometry mechanism of a different turbine, a boost relief valve, or a variable geometry compressor mechanism.

A turbine nozzle according to the present invention may be implemented in conjunction with a shaft operating on fluid film bearings (i.e. oil fed) and could be implemented with a shaft operating on rolling element bearings (i.e. ball bearings), however other bearings such as aerostatic, aerodynamic and magnetic are possible.

A turbine nozzle according to the present invention may be implemented to drive an electric machine. For example it could drive a shaft supporting the turbine, a compressor and a generator. The generator might be between the compressor and the turbine, or it might be axially outboard, in particular beyond the compressor.

A turbine nozzle according to the present invention may be implemented in conjunction with a dual walled or otherwise thermally insulating turbine housing. Alternatively or additionally the turbine housing could be cooled for example with water cooling. Alternatively or additionally the turbine housing could be provided with a non metallic layer, for example ceramic for insulation or aramid fibre or substitute fibres for burst containment.

Furthermore the material of a turbine nozzle according to the invention (or indeed the sliding sleeve) could be ceramic, cermet, instead of metal. Of if of metal could be any steel, or a nickel based alloy such as inconel. It could be provided with a coating, for example on the sliding interface of the nozzle and the sleeve there could be a coating of diamond-like-carbon, anodisation, or tribaloy or a substitute wear resistant coating. On the aerodynamic surfaces there could be a coating to promote smoothness or resist corrosion. Such coatings on the turbine components could include non-deposited coatings such as plasma-electrolytic-oxide coating or substitute coatings. Optionally the nozzle or the sleeve could be provided with a sensor that could be an integrated sensor (such as a pressure, temperature, vibration or speed sensor). Such sensors would need to be insulated electrically from other metallic components.

A turbine nozzle according to the present invention could be implemented in conjunction with noise reduction means such as absorption or reflection silencers, including quarter wave or Helmholtz resonators. These could in principle be provided in any of the aerodynamic surfaces.

A turbine nozzle according to the present invention could be implemented in conjunction with oil sealing means on the shaft of the turbine, which could include blown double seals such as piston rings. A range of oil slingers and other oil seals as known in the prior art could be provided.

A turbine nozzle according to the present invention could be implemented in conjunction with a low-restriction pipe bend, for example at the turbine outlet, the bend having a widened portion at the bend.

The turbine inlet could have a valve arranged to control the ratio of inlet flow between two or more volutes, or control the ratio of flow (or back pressure) between various gas sources such as engine cylinders.

The turbine inlet may be formed as a contiguous element with an exhaust manifold.

A wide range of control strategies may be implemented to control the sliding sleeve described herein. The range of possible control strategies includes all those already described in the literature with respect to controlling conventional variable geometry mechanisms, especially sliding vane mechanisms used on automotive turbochargers.

Among the various possible actuation methods possible, is the axially arranged tripod which permits on-axis actuation for example using a pneumatic actuator can. The sliding sleeve may be actuated from a chamber situated axially away from the turbine, which may contain a soot collection or oxidation element, such as the wire mesh or catalyst coated wire mesh as described in WO2010012992.

A turbine nozzle according to the invention may be used in conjunction with a splitted turbine wheel, having some blades that extend the full axial width of the turbine inlet, and some vanes which extend only part way from the turbine back face axially across the inlet. For example the shorter vanes may extend up to but not beyond a particular axial nozzle division, such as a baffle. The short and long vanes may alternate, or alternatively there could be several short vanes between each long vane.

Another option is to have more than two types of vane. There might also or alternatively be variation in the number of blades along the turbine. For example some blades may extend all the way from the turbine inlet to the turbine outlet while other vanes (e.g. alternating) might extend only from the inlet partway to the outlet, or from the outlet only partway to the inlet.

The turbine might be provided with an integral rotating wall which may be adjacent to the turbine shroud formed by the turbine housing. This forms a front face for the passages between the turbine blades. Alternatively or additionally the turbine might be provided with one or more rotating walls partway between the hub/backface of the turbine and the frontface of the turbine. Such one or more rotating walls might be aligned axially with one or more respective axial dividers of the axially divided nozzle described herein. This would prevent the gas expanding away from the turbine hub and backface when the sliding sleeve is only partly open, and would contribute to turbine efficiency.

Other possible modifications and alternatives to the embodiments illustrated and describe above will be readily apparent to the appropriately skilled person.

# CLAIMS

1. A variable geometry turbine comprising

a turbine wheel mounted for rotation about a turbine axis within a housing, the housing defining an annular inlet surrounding the turbine wheel and defined between first and second inlet sidewalls; and

a cylindrical sleeve axially movable across the annular inlet to vary the size of a gas flow path through the inlet;

wherein the annular inlet is divided into at least two axially offset inlet passages which axially overlap.

2. A variable geometry turbine according to claim 1, wherein the annular inlet is divided into an annular array of substantially tubular inlet passages extending generally towards the turbine wheel, wherein the annular array of inlet passages comprises at least three axially offset inlet passages which axially overlap.

3. A variable geometry turbine according to either claim 1 or claim 2, wherein at least two of said axially offset inlet passages which axially overlap circumferentially overlap.

3. A variable geometry turbine according to claim 2, wherein the substantially tubular inlet passages have a generally diamond or generally hexagonal cross-section.

4. A variable geometry turbine according to any preceding claim, wherein the inlet is divided into said inlet passages by inlet passage walls defined by a plurality of generally annular non-planar baffles.

5. A variable geometry turbine according to claim 4, wherein the baffles are generally annular rings which are circumferentially corrugated.

6. A variable geometry turbine according to claim 4, wherein the baffles have a generally hyperbolic paraboloidal surface.

7. A variable geometry turbine according to either claim 2 or claim 3, wherein the annular array of inlet passages is constructed from a plurality of discrete circumferentially adjacent segments.

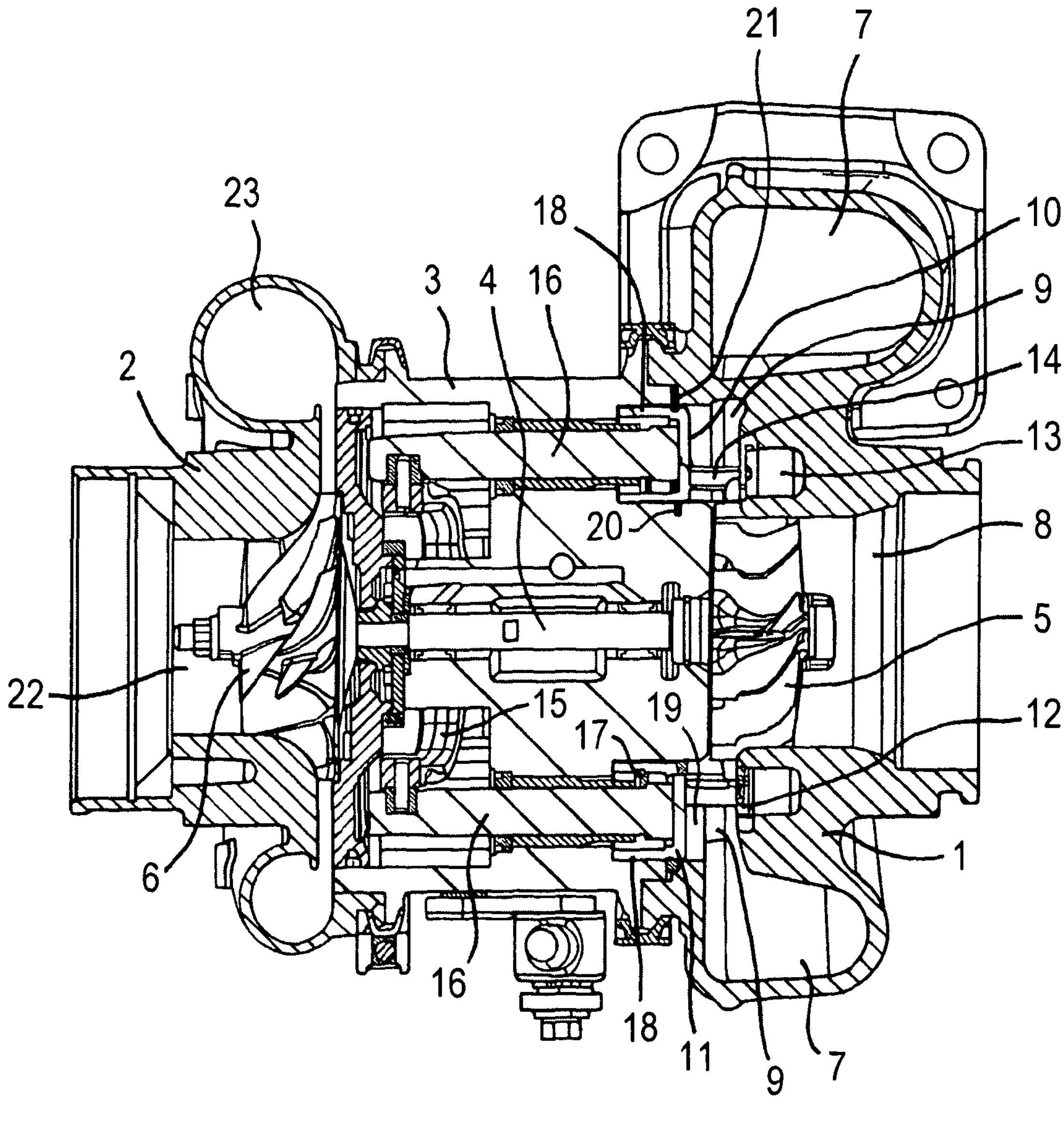


Fig. 1

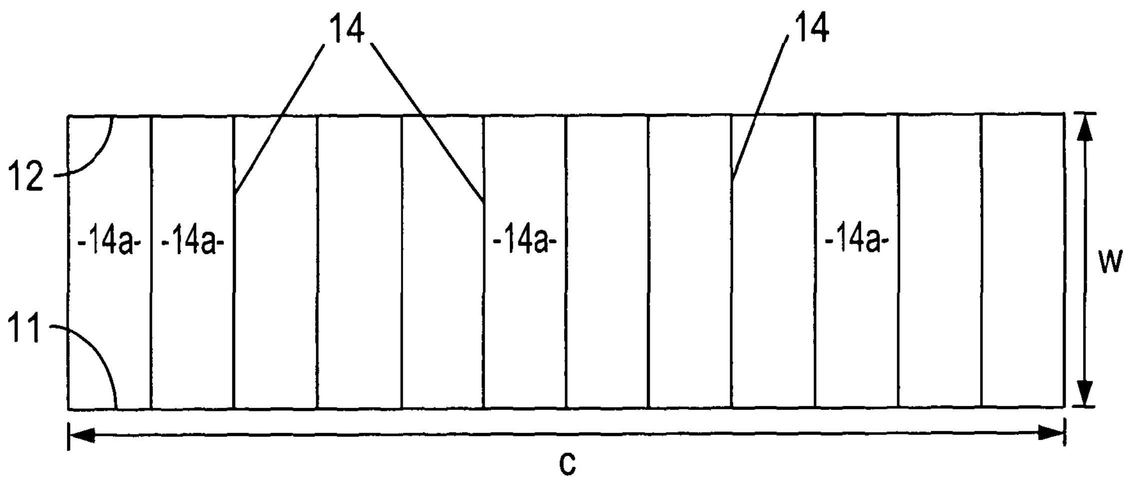


*Fig. 2*

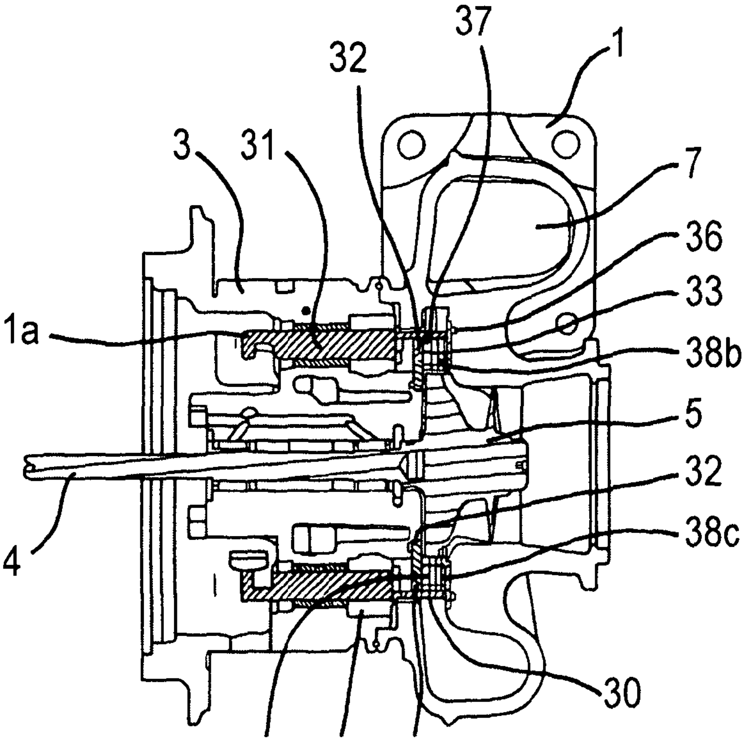


Fig. 3

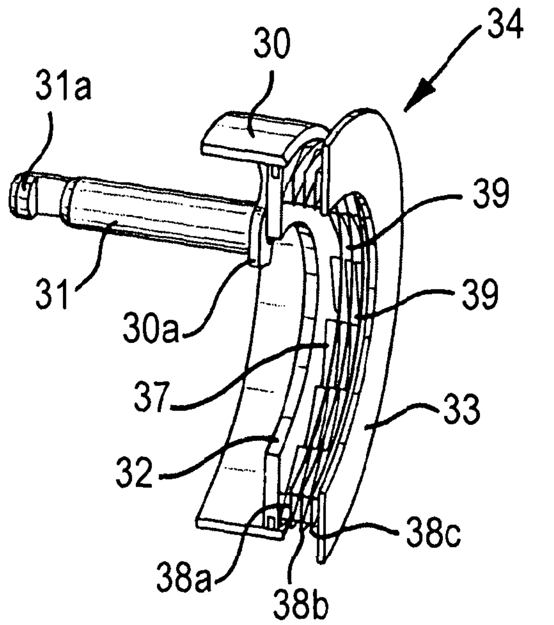


Fig. 4a

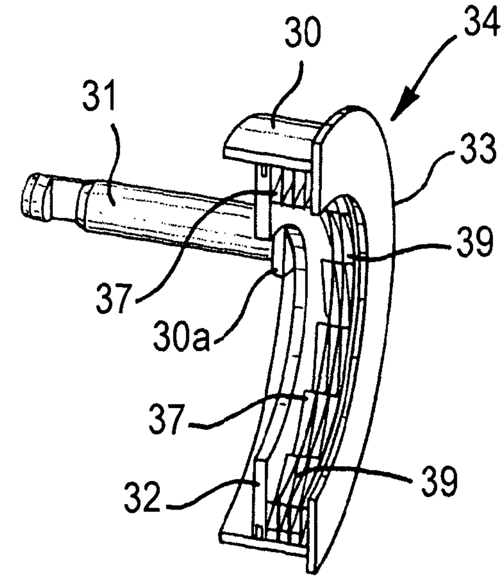


Fig. 4b

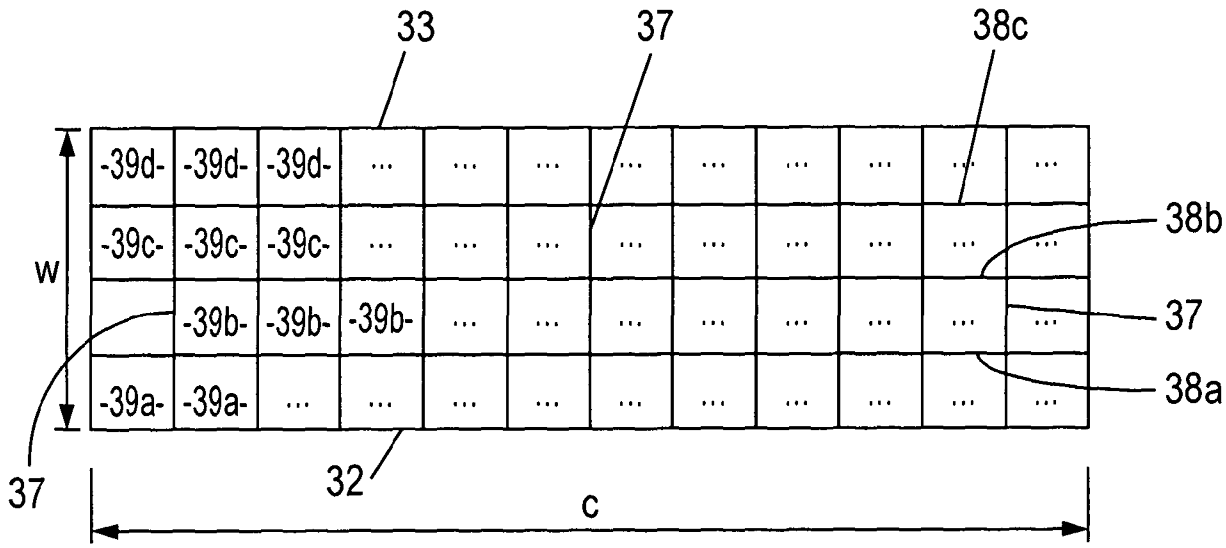

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Fig. 5

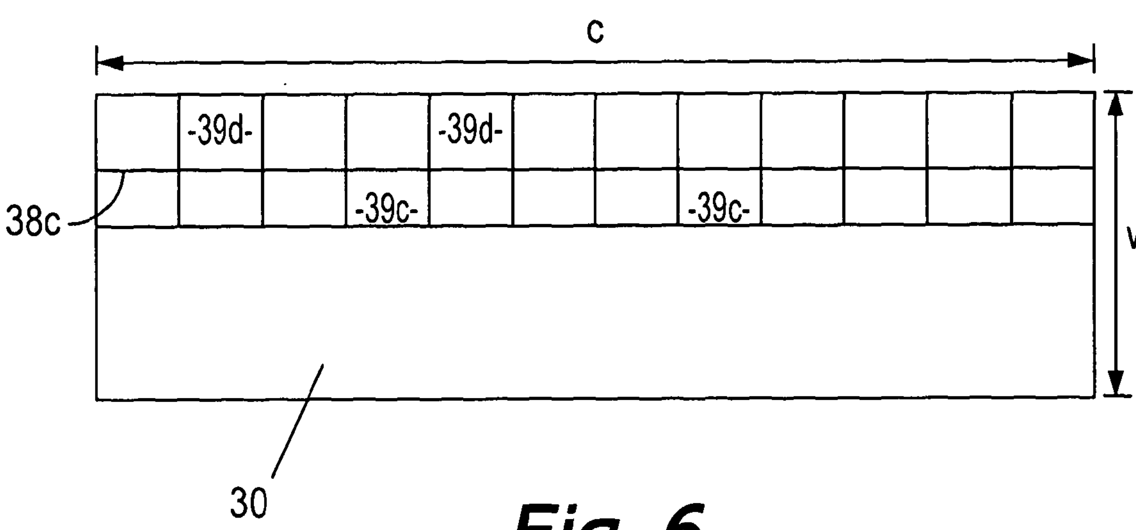

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Fig. 6

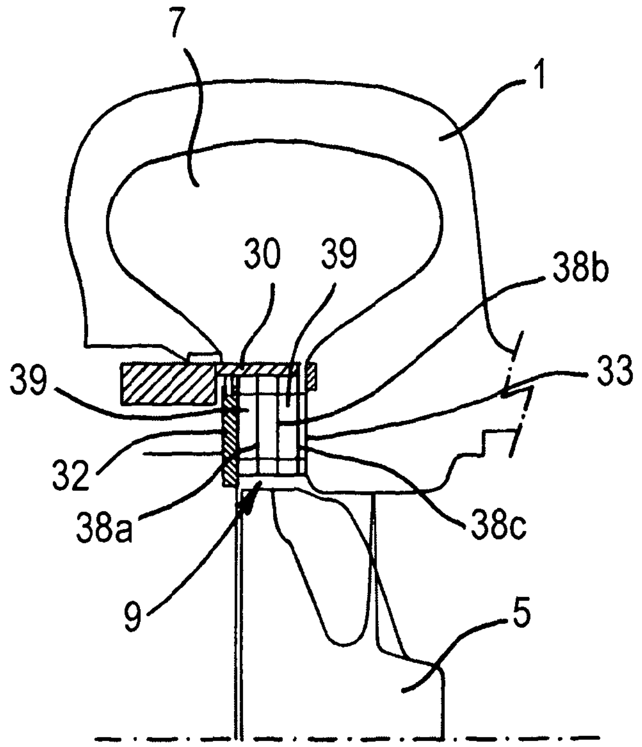


Fig. 7a

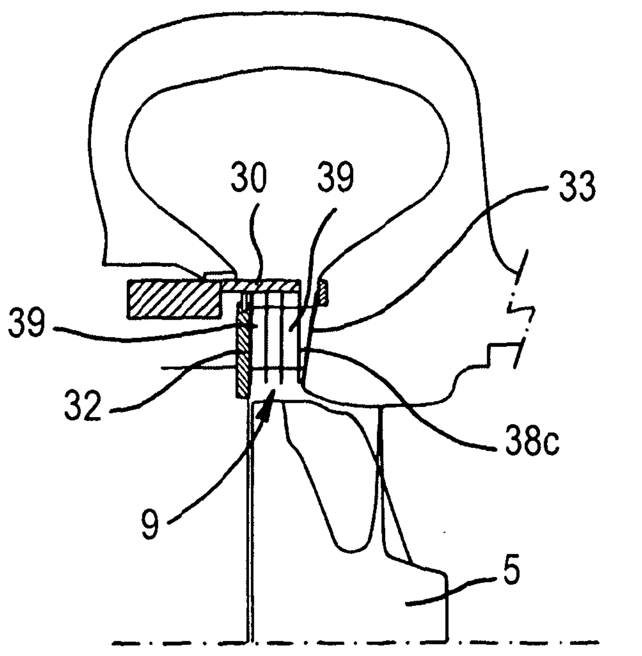


Fig. 7b

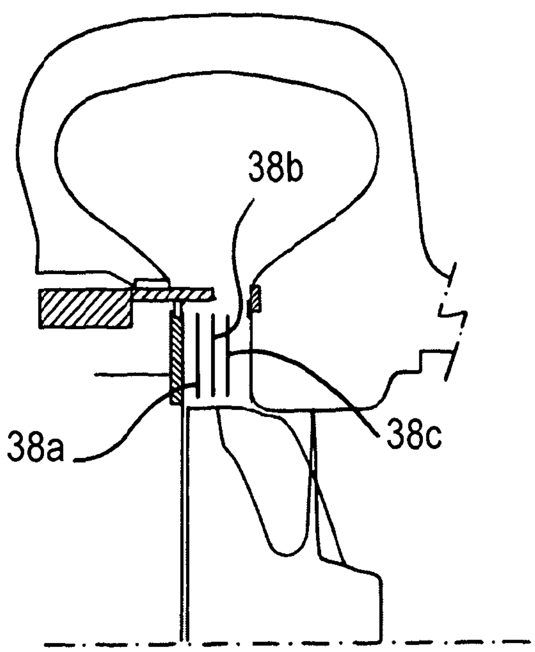


Fig. 7c

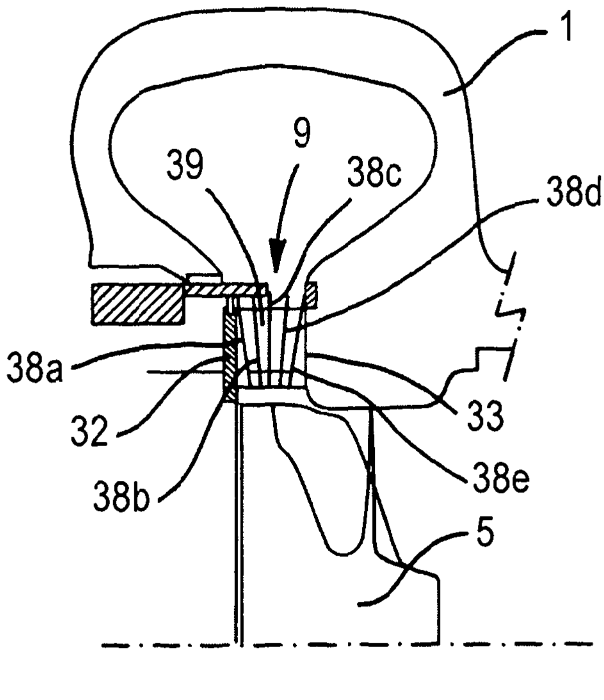


Fig. 7d

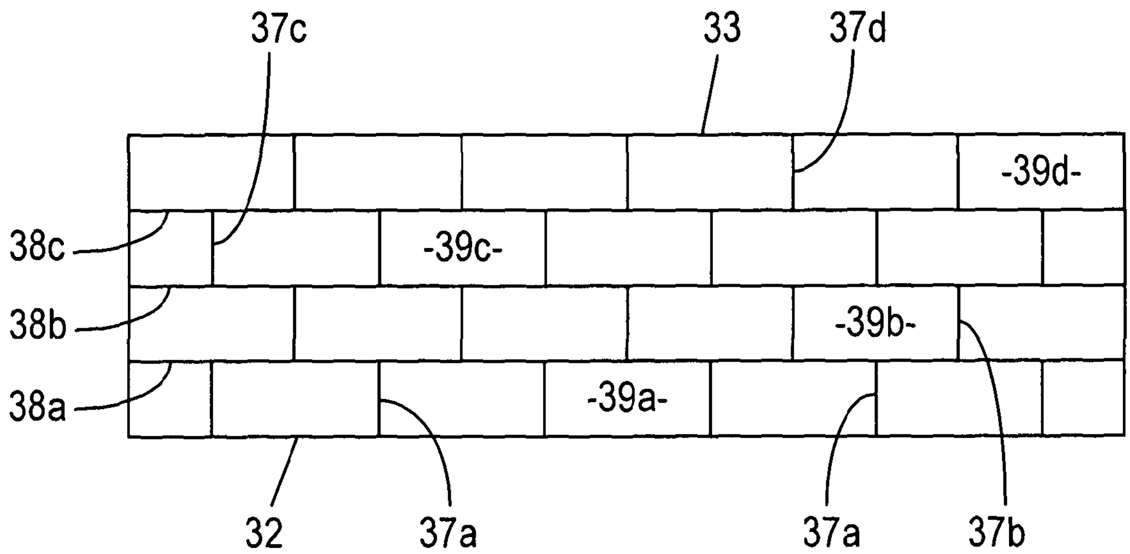
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Fig. 8a

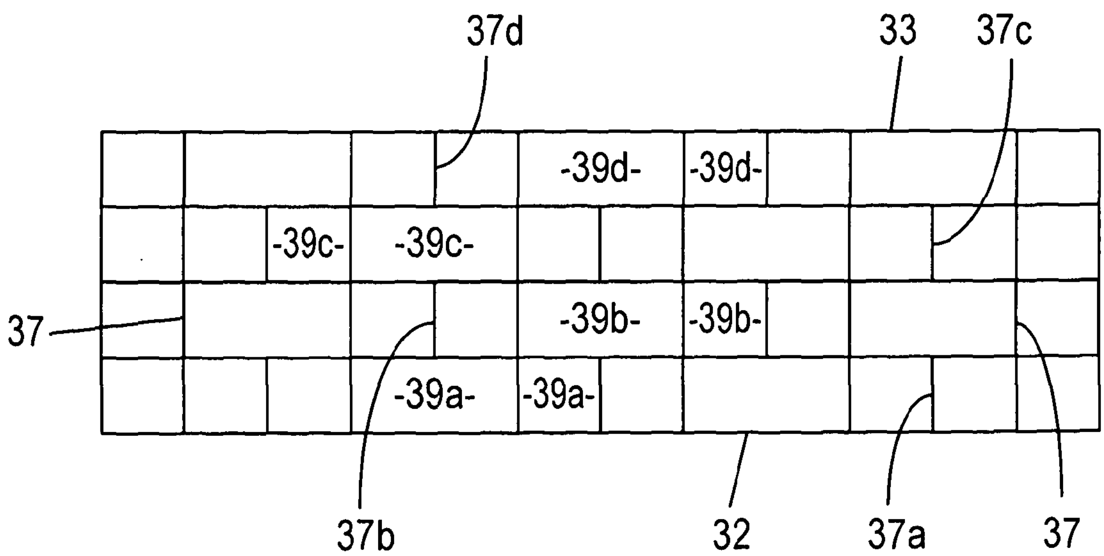
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Fig. 8b

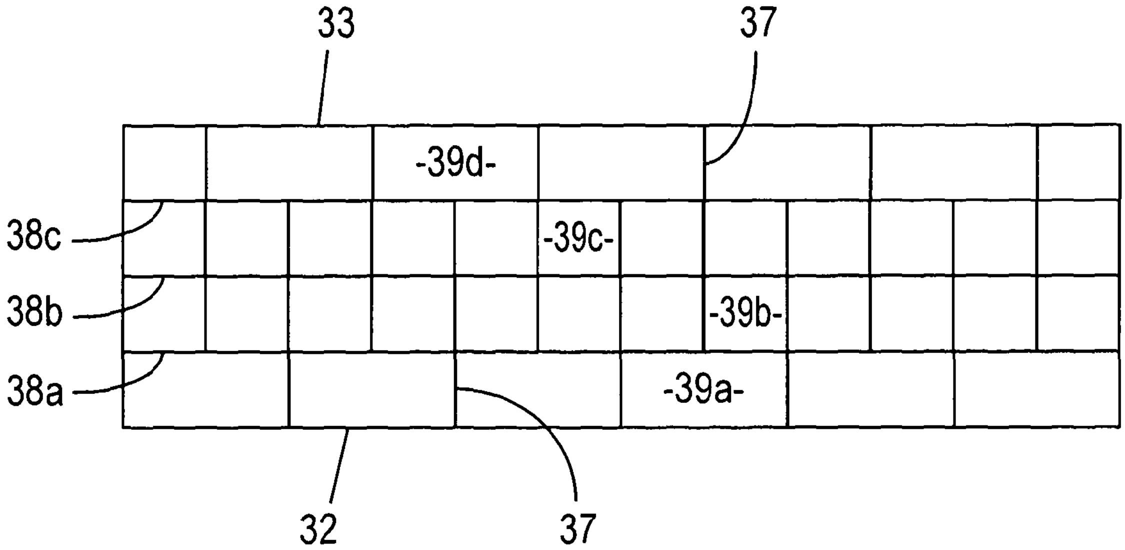
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Fig. 8c

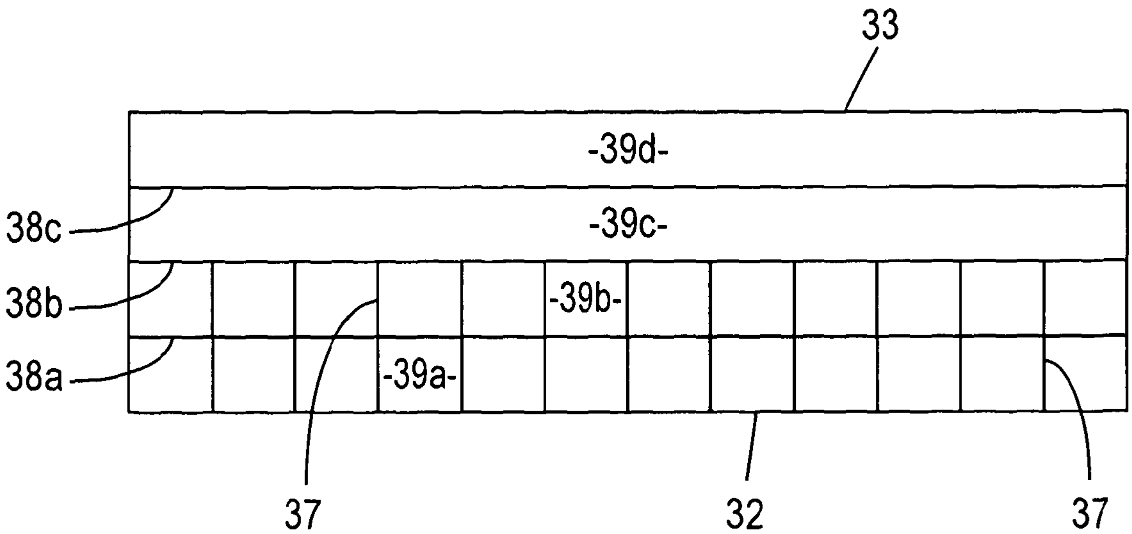
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Fig. 8d

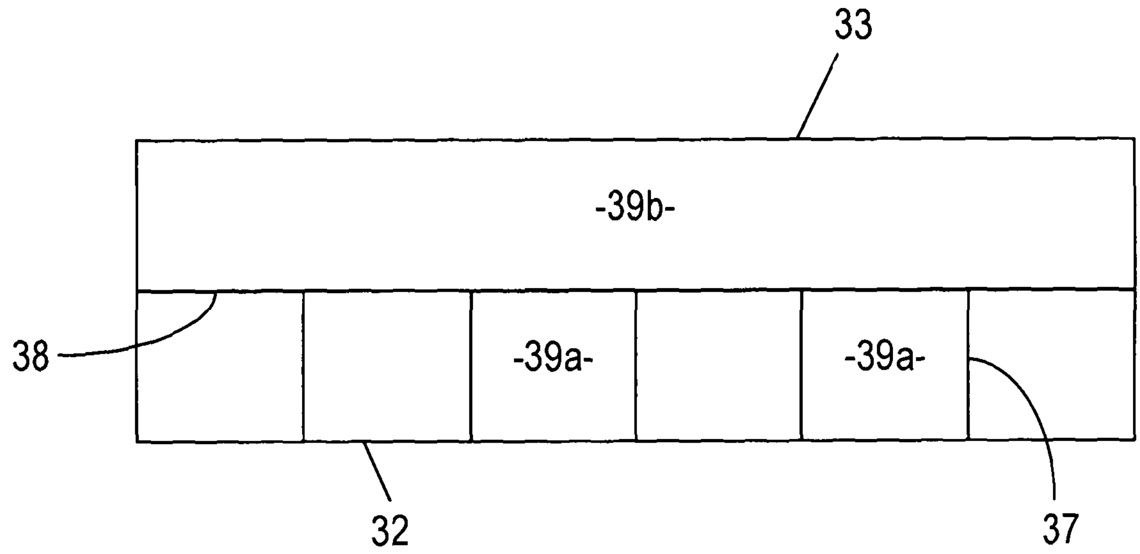


*Fig. 8e*

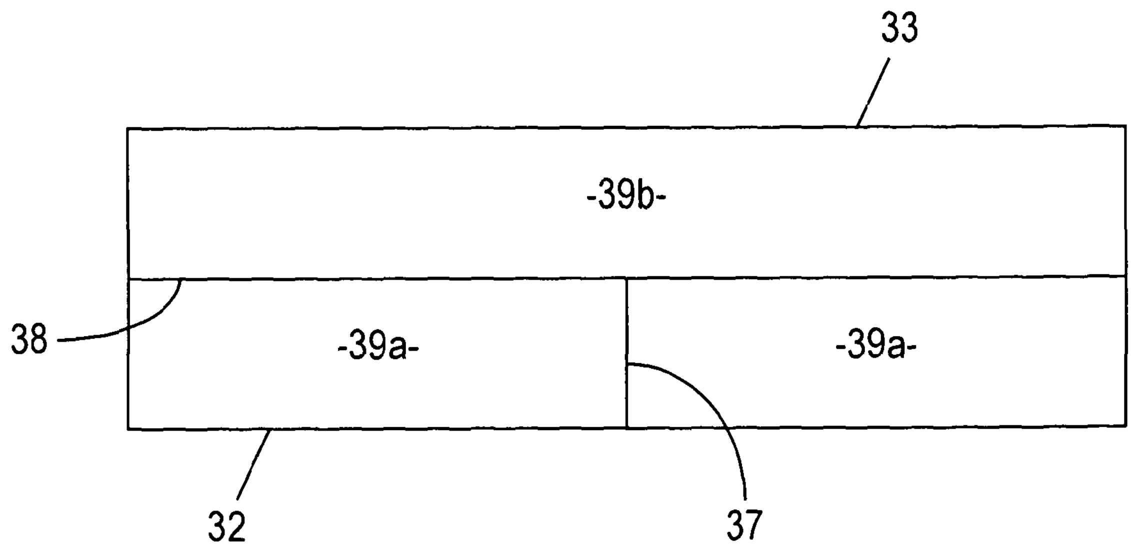


*Fig. 8f*

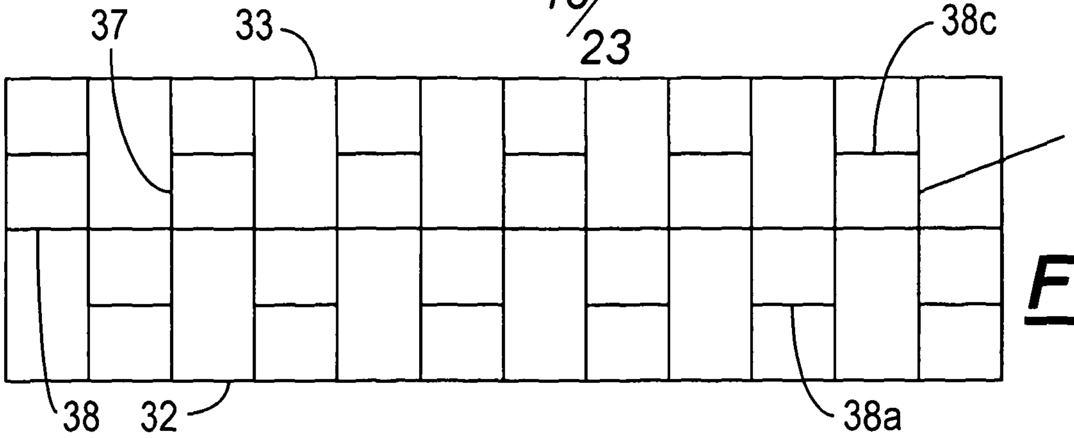


Fig. 9a

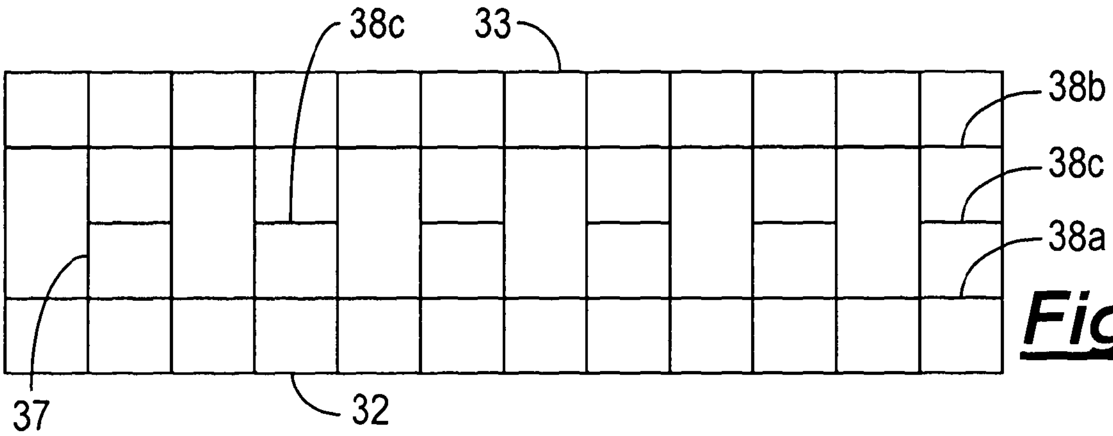


Fig. 9b

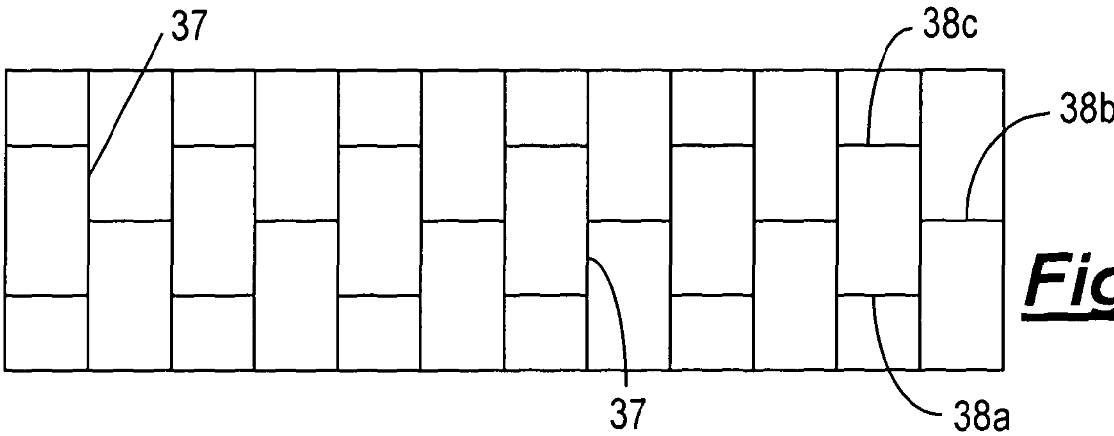


Fig. 9c

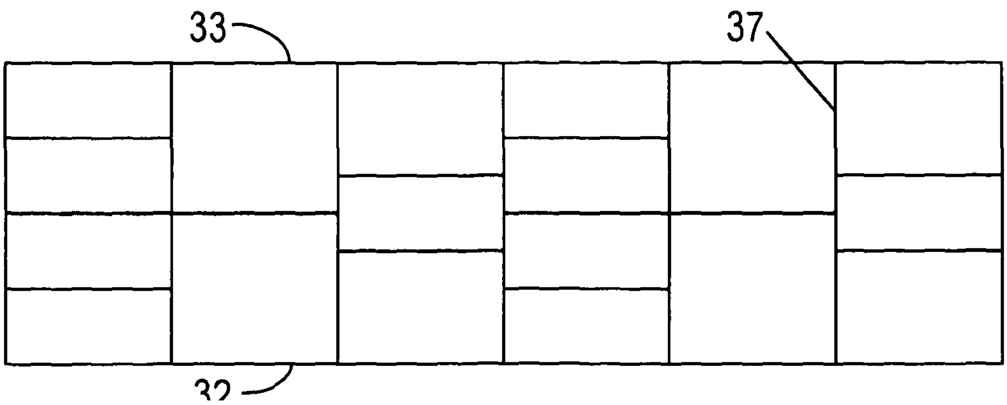


Fig. 9d

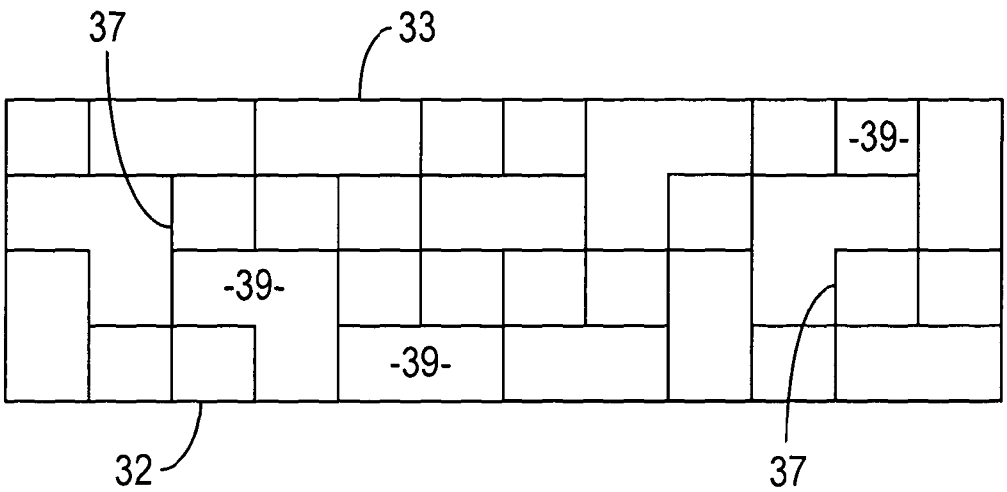


Fig. 10

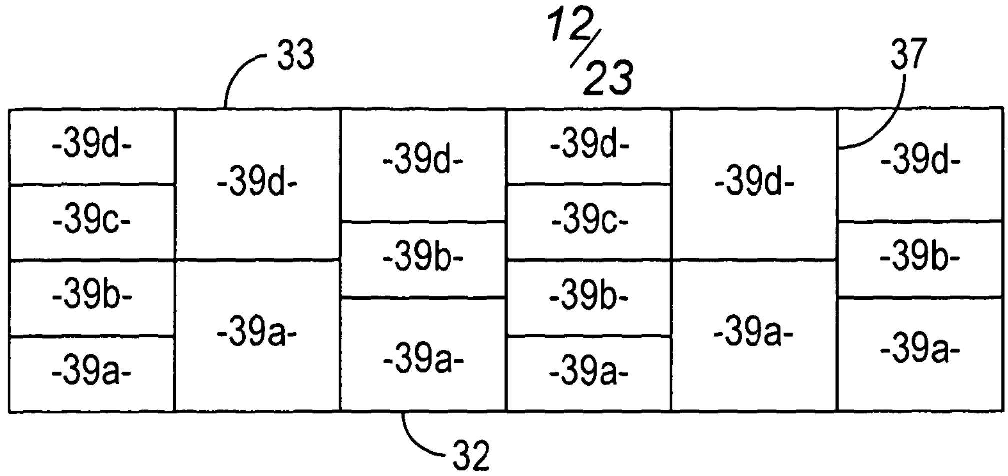


Fig.11a

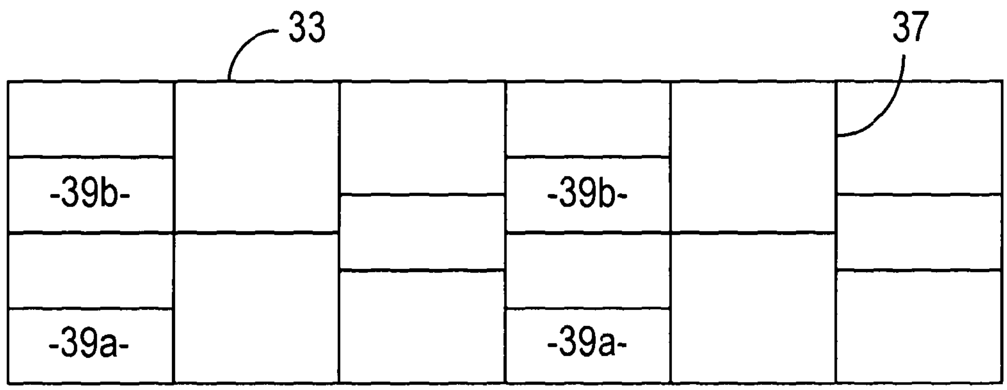


Fig.11b

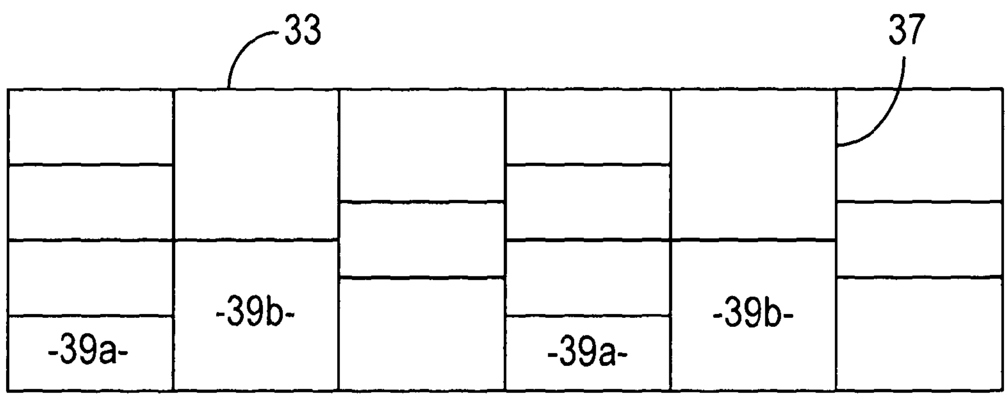


Fig.11c

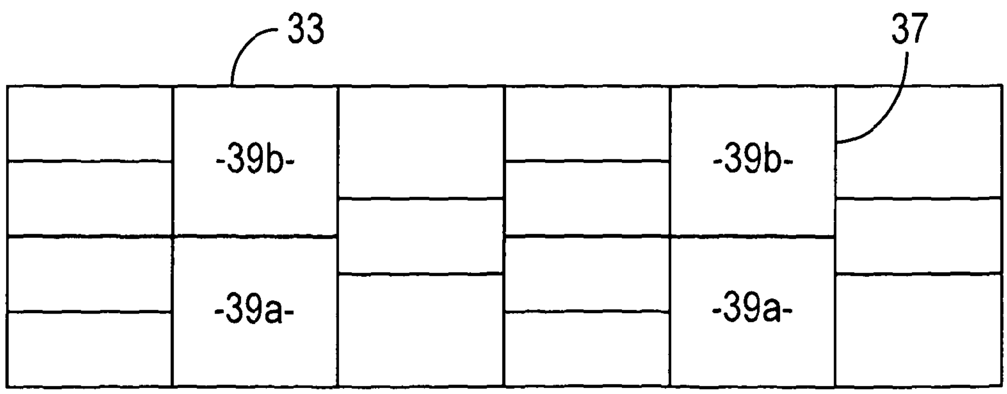


Fig.11d

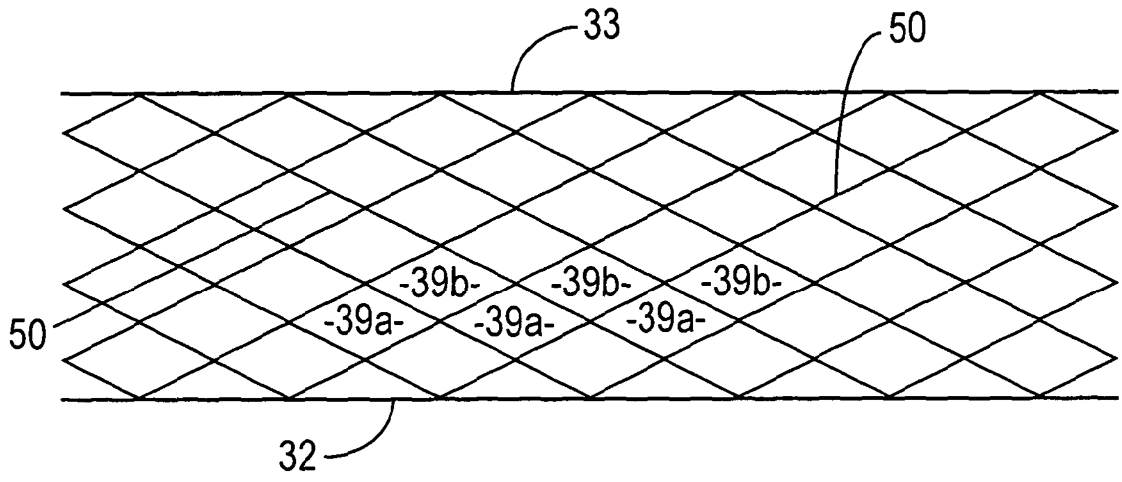
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Fig. 12

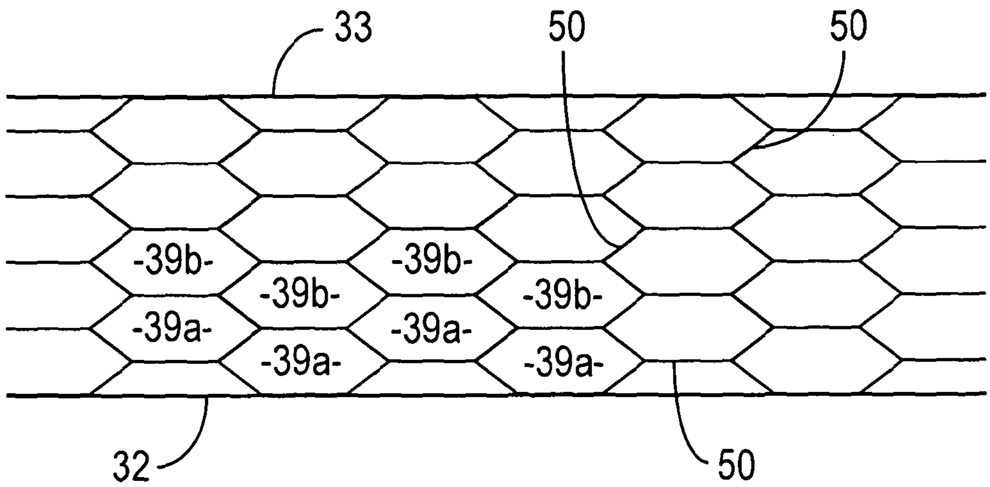
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Fig. 13

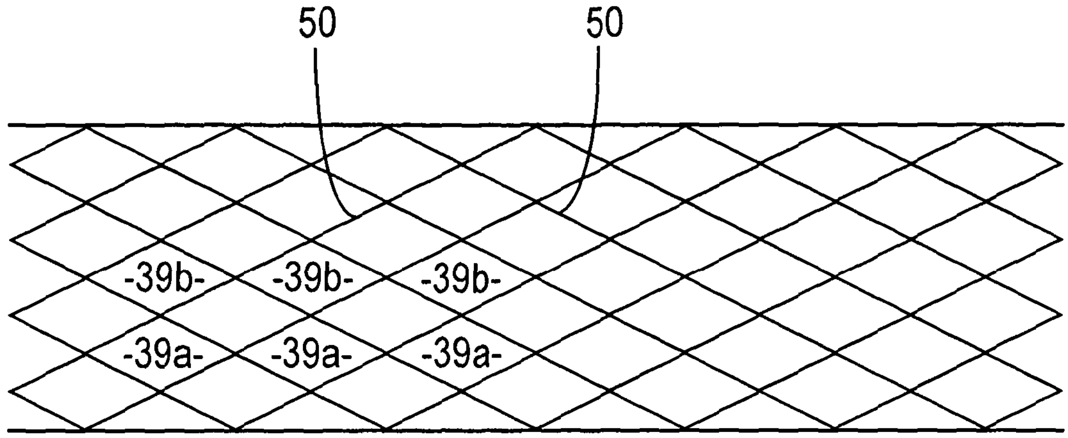
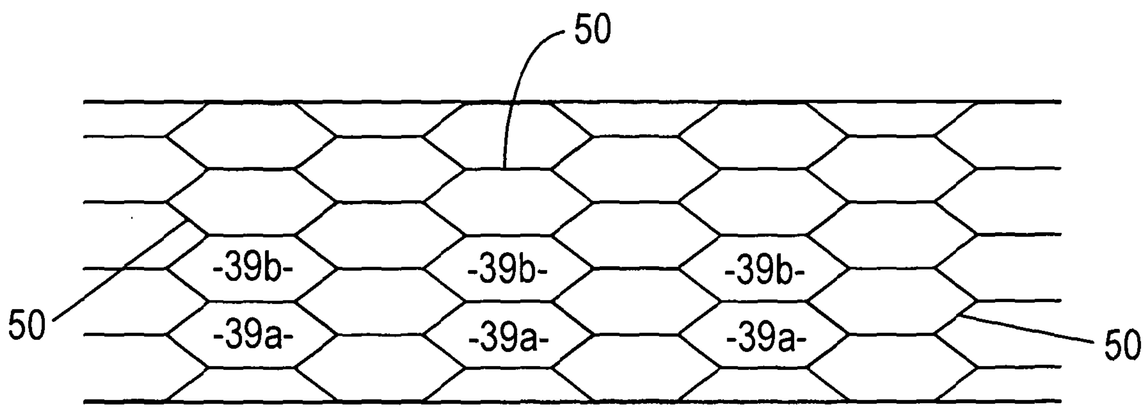



Fig. 14

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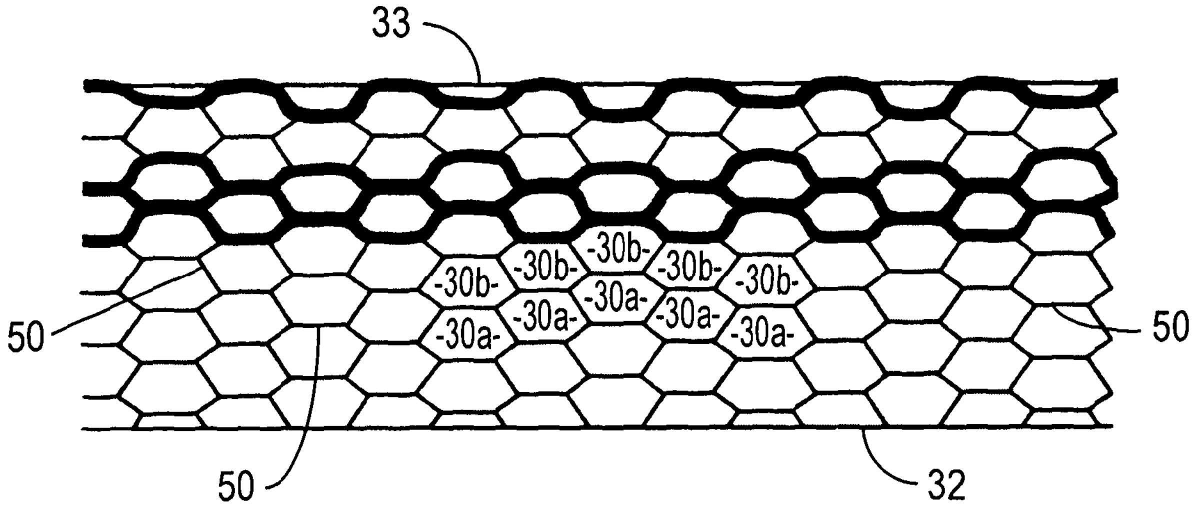
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Fig. 16

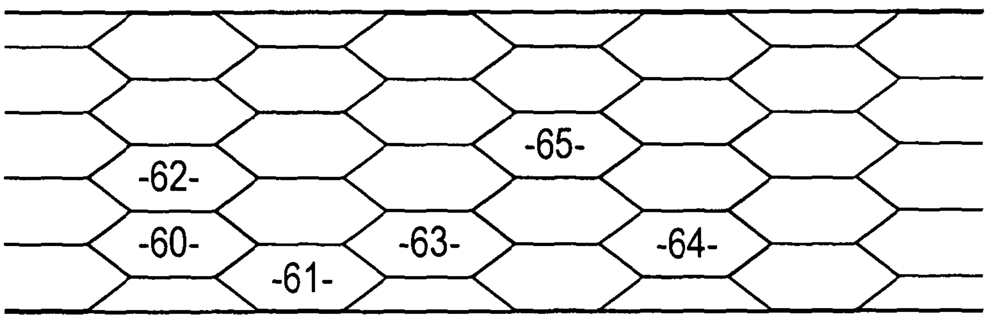
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Fig. 17

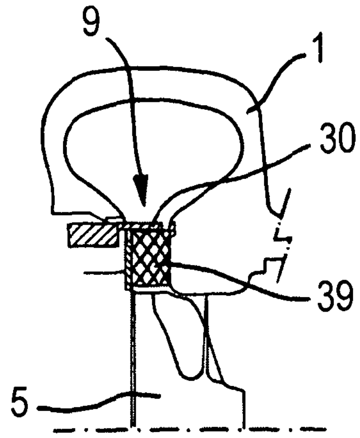


Fig. 18

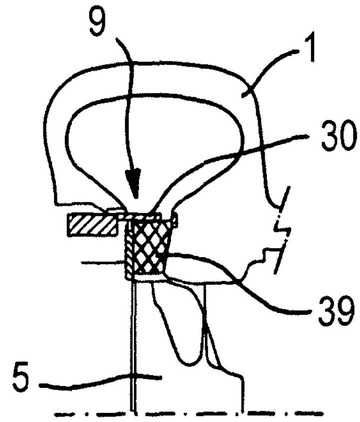


Fig. 19

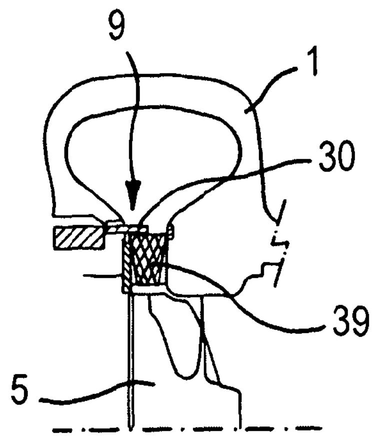


Fig. 20

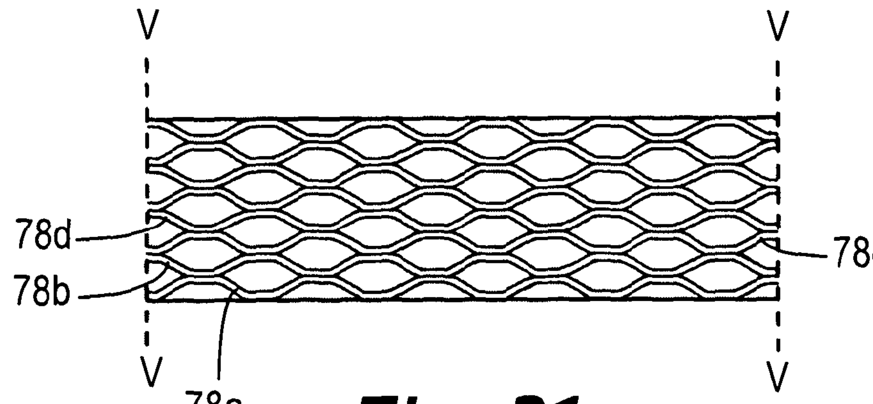


Fig. 21

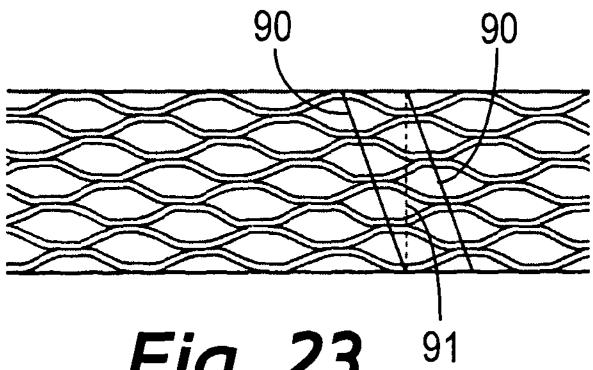


Fig. 23

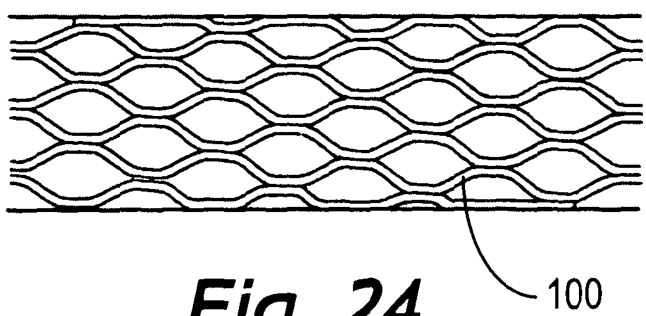


Fig. 24

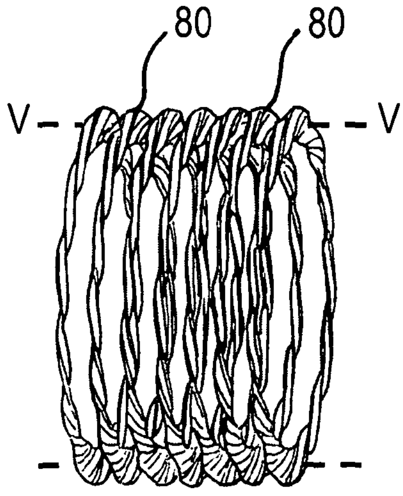


Fig. 22a

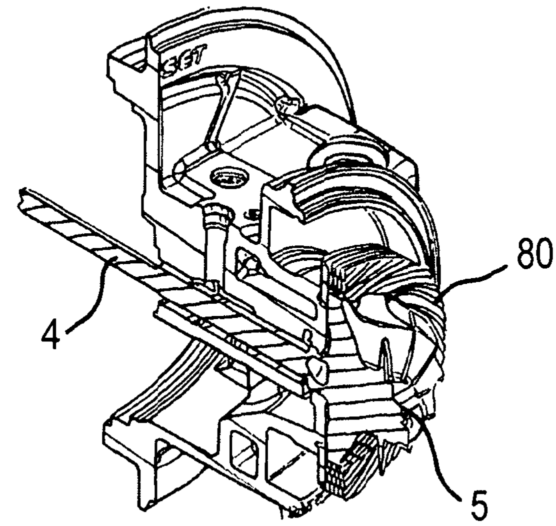


Fig. 22b

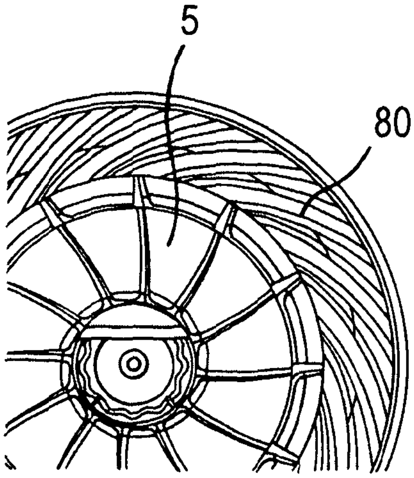


Fig. 22c

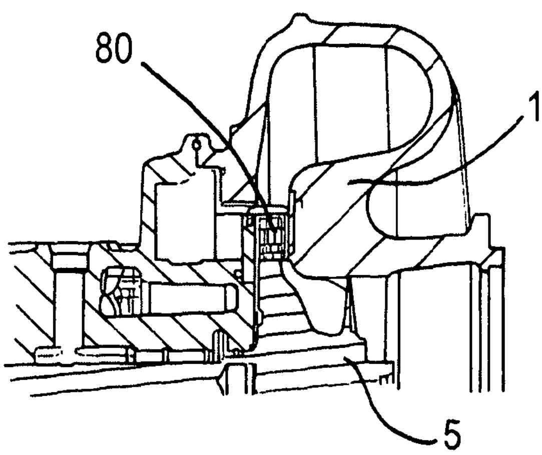


Fig. 22d

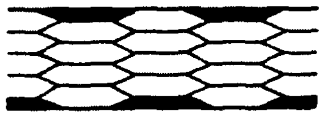

Fig. 25a

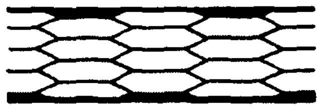

Fig. 25b

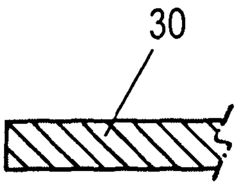


Fig. 29a

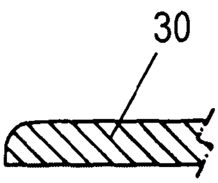


Fig. 29b

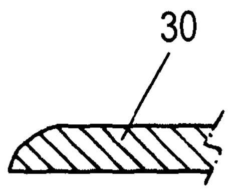


Fig. 29c

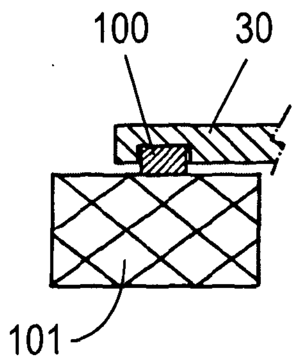


Fig. 30a

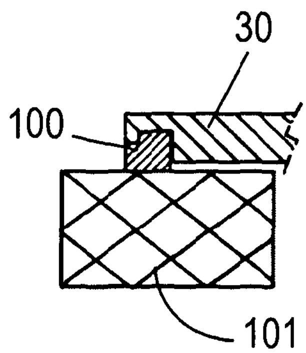


Fig. 30b

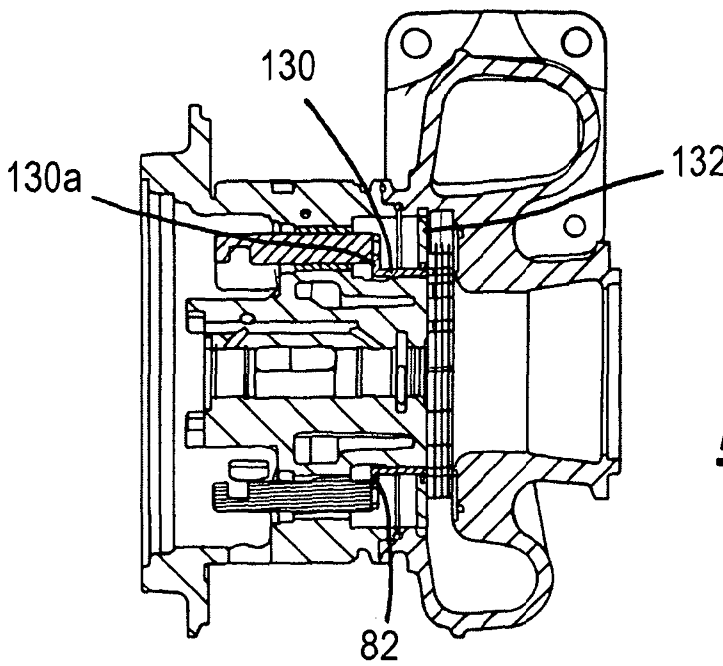


Fig. 26a

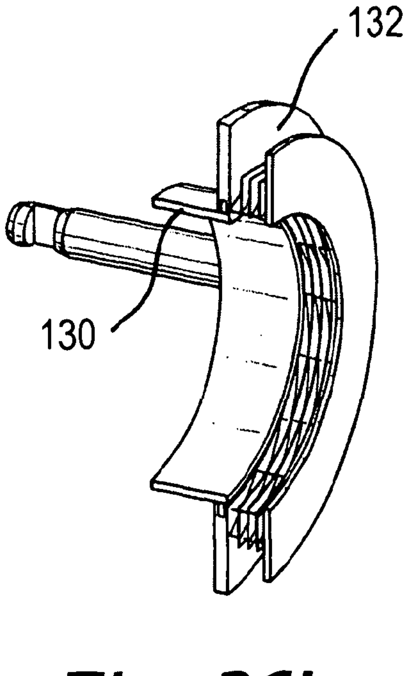


Fig. 26b

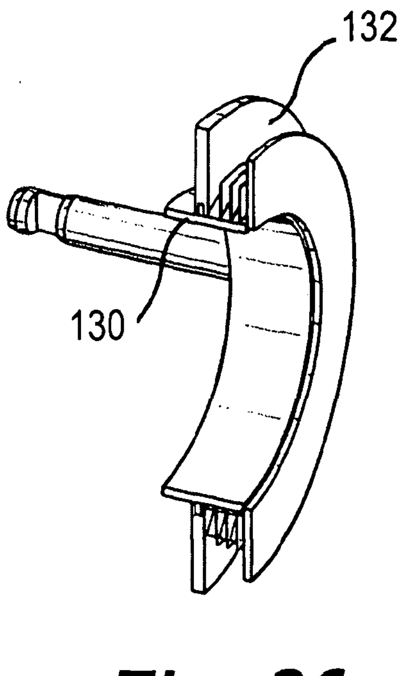


Fig. 26c

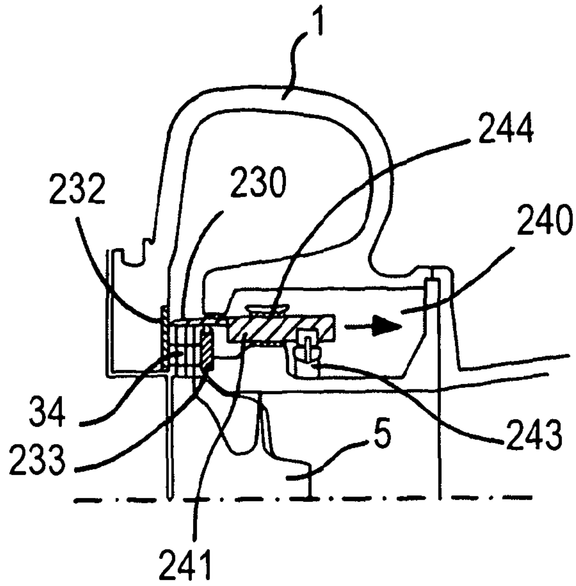


Fig. 27a

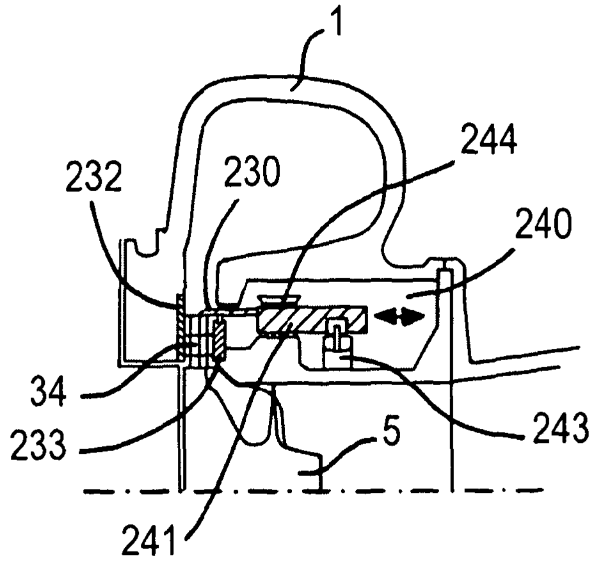


Fig. 27b

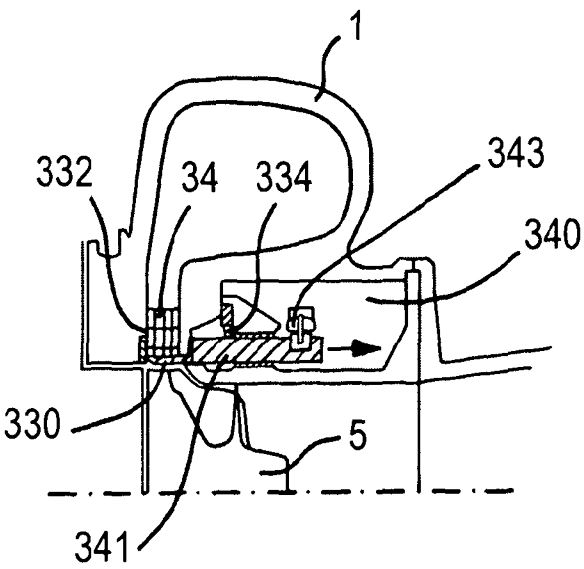


Fig. 28a

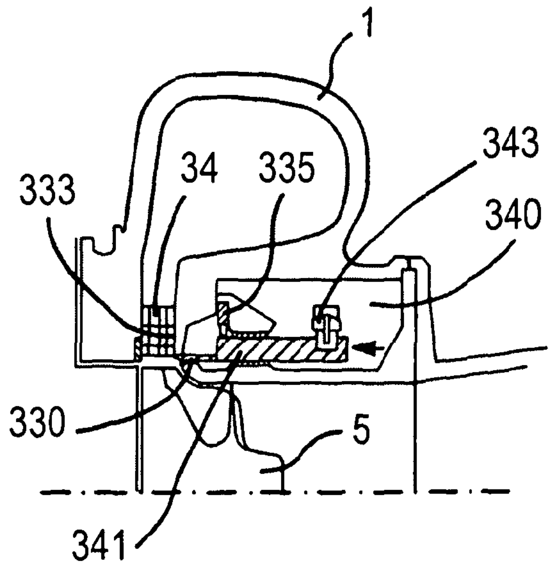


Fig. 28b

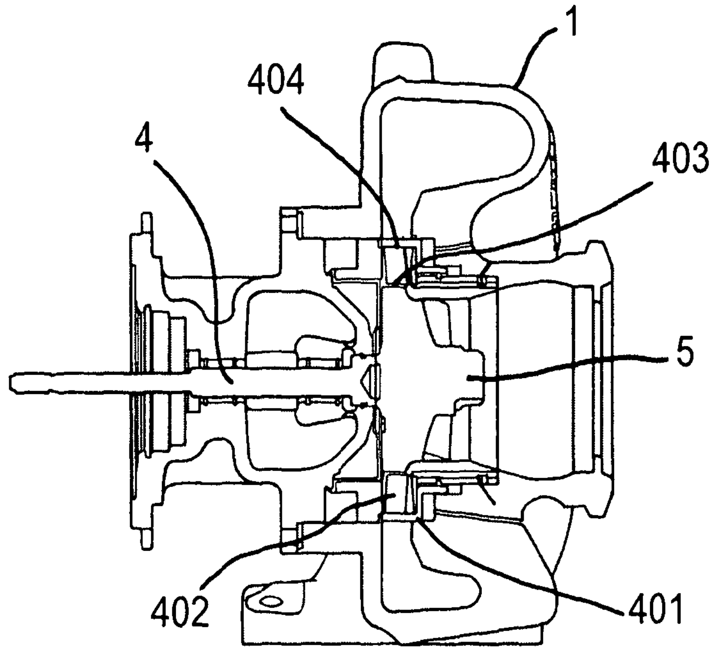


Fig. 31

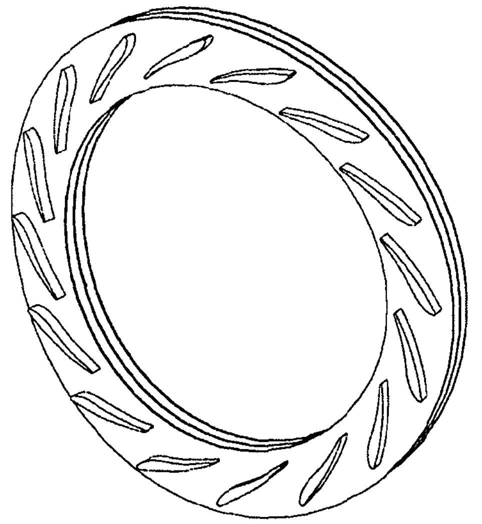

Fig. 32a

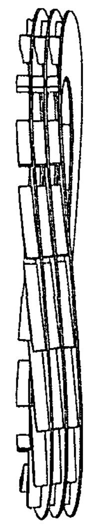

Fig. 32b

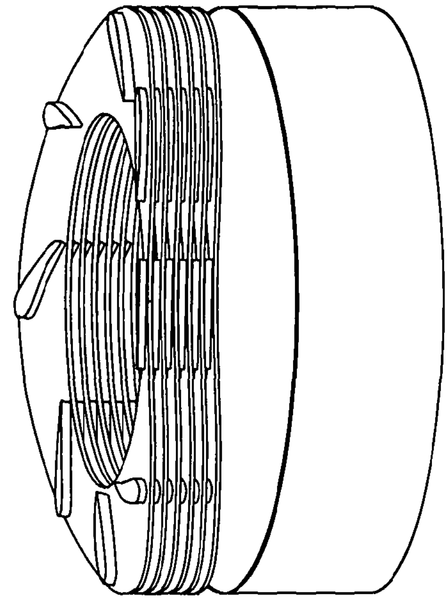

Fig. 33

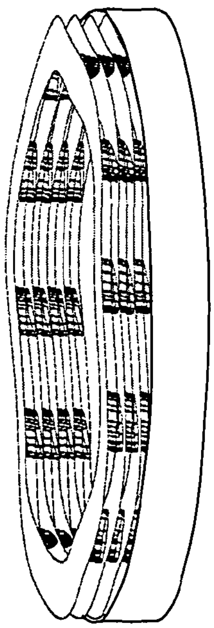

Fig. 34