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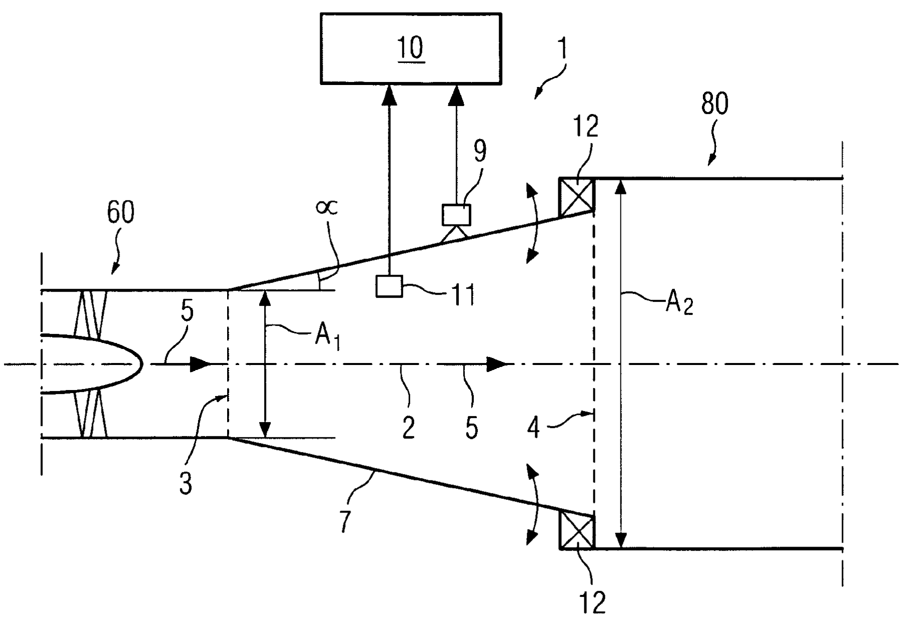
(54) **Exhaust diffuser for a gas turbine, and method thereof**

(57) The present invention relates to an exhaust diffuser assembly (1), particularly for a stationary gas turbine, and a method incorporating the same. The proposed exhaust diffuser assembly (1) comprises a longitudinal axis (2), a diffuser inlet (3) for receiving a turbine mainflow gas (5), a diffuser outlet (4), and a diverging diffuser wall (7) having an adjustable geometry and forming a conduit for flow of said gas (5) therethrough from said diffuser inlet (3) to said diffuser outlet (4). The diffuser wall (7) has a divergence angle 'α' with respect to said longitudinal axis (2). The proposed diffuser assembly (1) further comprises diffuser geometry control means (9,10) for controlling a recovery of pressure from said gas (5) between said diffuser inlet (3) and said diffuser outlet (4) by adjusting said divergence angle 'α' of said diffuser wall (7) to cause a resultant flow field of said gas (5) that is attached to said diffuser wall (7).

FIG 1



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Description

[0001] The present invention relates to exhaust diffusers for gas turbines, particularly for gas turbines in stationary or land based applications.

[0002] In gas turbines, for example those used in power generation, exhaust diffusers serve to reduce the speed of the exhaust flow in a gas turbine and to thus recover pressure from the exhaust gas coming from the last stage of the turbine. The reduction in gas speed reduces the stress associated with the fluid flow on the exhaust equipment and enhances the performance levels of the turbine by recovering pressure from the exhaust gas, thus limiting head loss of the flow.

[0003] In an exhaust diffuser, the pressure recovery from the exhaust gas is directly proportional to the outlet to inlet area ratio of the diffuser, which controls amount of effective flow diffusion following the last turbine stage. However, a high outlet to inlet area ratio for a given axial length of the diffuser (i.e., large diffuser angle) causes rapid expansion of the gas leading to a separation of flow of the gas from the diffuser wall, which, in turn, causes a reduction in the pressure recovery by the diffuser. Past attempts to solve the issue of flow separation from the diffuser wall involve the use of boundary layer control, for example, by suction or blowing, turbulators, among others.

[0004] In practice, exhaust diffusers are designed to have area ratios that provide a maximum pressure recovery at full load, taking into account the flow separation at full load. In such a case, the pressure recovery, and hence the work extracted by the turbine, is substantially reduced when the gas turbine operates at part-load.

[0005] The object of the present invention is to provide an exhaust diffuser assembly for a stationary gas turbine, and a method thereof, for achieving higher pressure recovery at different operating loads by reducing or eliminating excessive flow separation.

[0006] The above object is achieved by the exhaust diffuser assembly according to claim 1 and the method according to claim 11.

[0007] The underlying idea of the present invention is to provide a mechanism of controlling pressure recovery in an exhaust diffuser by controlling the geometry of the diffuser. To that end, the proposed exhaust diffuser assembly has a variable geometry diffuser wall, which allows the divergence angle of the diffuser wall with respect to the longitudinal diffuser axis to be adjusted, so as to cause a resultant flow field of the gas that is attached to the diffuser wall. The variability of diffuser wall geometry allows adaptability of the proposed diffuser assembly for adjustments in mass flows, i.e., operating loads.

[0008] In one embodiment, said diffuser geometry control means comprises one or more actuators disposed on a surface said diffuser wall, said one or more actuators being adapted to exert an adjustable pressure said diffuser wall to resultantly adjust said divergence angle 'α' of said diffuser wall.

[0009] In a preferred embodiment, wherein said one or more actuators are controllable for increasing said divergence angle 'α' to cause a resultant flow field beyond a point of flow separation of said gas from said diffuser wall and subsequently reducing said divergence angle 'α' to re-attach the flow of said gas to said diffuser wall, so as to cause a resultant flow of said gas through said diffuser wall that is substantially proximate and prior to said point of flow separation. Since pressure recovery increases with increase in the rate of expansion (i.e., divergence angle) for attached flow, maintaining the flow field just before separation point for any given mass-flow rate would maximize the pressure recovery at that mass -flow rate

[0010] In one embodiment, the proposed diffuser assembly further comprises a pressure probe disposed in a flow path of said gas through flowing said diffuser wall, wherein said point of flow separation is detected based on a decrease in sensed pressure between two progressively increasing settings of the divergence angle 'α'. The above embodiment provides a simple means to detect flow separation, since pressure in the gas flow path decreases sharply after flow separation occurs

[0011] In an alternate embodiment, the proposed diffuser assembly further comprises a sonic probe disposed in a flow path of said gas inside said diffuser wall to detect said point of flow separation.

[0012] In a still further embodiment, said point of flow separation is determined by flow visualization means adapted for detecting local direction of flow.

[0013] In an exemplary embodiment, said diffuser wall is made of a piece of sheet metal wound to spiral form. Such a diffuser wall provides increased elasticity for adjustment of divergence angle.

[0014] In another exemplary embodiment, said diffuser wall is made from a piece of sheet metal wound into a conical shape, wherein the edges of said piece of sheet metal are slidable against each other. The above embodiment provides manufacturing simplicity.

[0015] In yet another exemplary embodiment, said diffuser wall comprises an adjustable portion having a rectangular cross-section, wherein the diffuser wall at said adjustable portion is flexible attached to a fixed portion by a hinge. The above embodiment provides higher accuracy and increased geometric control.

[0016] In still another embodiment, said diffuser wall has a rectangular cross-sectional geometry formed by angular plates forming corners of the rectangle, said angular plates being interspaced by and flat plates over which said angular plates are slidable such that said rectangular cross-sectional shape is adjustable along diagonal directions. This allows the rectangular geometry of the diffuser wall to be uniformly varied (maintaining the same aspect ratio) along the direction of the diagonals of the rectangle by placing actuators at the corner of the rectangle.

[0017] The present invention is further described hereinafter with reference to illustrated embodiments shown in the accompanying drawings, in which:

FIG 1 a schematic illustration of an exhaust diffuser assembly for a gas turbine,

FIG 2 is an exemplary graphical representation showing variation of pressure of the gas with diffuser geometry, also indicating the point of flow separation,

FIG 3 is a schematic illustration of a first embodiment of an adjustable geometry diffuser wall,

FIG 4 is a schematic illustration of a second embodiment of an adjustable geometry diffuser wall,

FIG 5 is a schematic illustration of a third embodiment of an adjustable geometry diffuser wall,

FIG 6 is a schematic illustration of a fourth embodiment of an adjustable geometry diffuser wall, and

FIG 7 is a schematic illustration of a fifth embodiment of an adjustable geometry diffuser wall.

[0018] Referring now to FIG 1 is illustrated an exhaust diffuser assembly 1 (also referred to as "diffuser 1") for a stationary gas turbine, for example, used in power generation and mechanical drives in land based applications. The diffuser 1 has an inlet 3 having a first cross-sectional area A_1 for receiving a mainflow gas from a last stage of a turbine section 60. The gas 5 flows along a longitudinal axis 2 through a conduit defined by a diverging diffuser wall 7 extending from the diffuser inlet 3 to a diffuser outlet 4 having a second cross-sectional area A_2. The diffuser outlet 4 directs the gas 5 to an exhaust duct 80.

[0019] The diffuser wall 7 serves to recover pressure from the gas by expanding the gas between the inlet 3 and the outlet 4. This reduces the total head loss of the gas, thereby increasing the work extracted from the gas 5. The diffuser wall 7 makes an angle of divergence 'α' with respect to the longitudinal axis 2. In conventional diffusers, the divergence angle is normally fixed at about 5-6°. In accordance with the proposed technique, the pressure recovery from the gas 5 is controlled by controlling the geometry of the diffuser wall 7, i.e., by adjusting the divergence angle 'α', and resultantly, the ratio 'R' of the outlet area A_2 to the inlet area A_1 (where $R=A_2/A_1$). It is to be understood that for fixed length diffusers, the area ratio 'R' increases with increase in divergence angle 'α'. In general, the pressure recovery increases with increase in divergence angle 'α' or area ratio R, till the flow of the gas 5 is separated from the diffuser wall 7. Separation of flow reduces the pressure recovery from the gas 5. To achieve higher pressure recovery, the divergence angle 'α' is adjusted to cause a resultant flow of the gas 5 that is attached to the diffuser wall 7. To that end, the diffuser wall 7 has an adjustable geometry wherein the angle 'α' may be varied. Exemplary embodiments of an adjustable geometry diffuser wall are discussed below referring to FIGS 3-7. Referring back to FIG 1, to accommodate the resulting variation of cross-sectional area A_2 of the outlet 5, variable seals 12 are provided at the connection of the diffuser wall 7 to the exhaust duct 80. In the illustrated embodiment, one or more actuators 9 are disposed on a surface (inner or outer) of the diffuser wall 7. In the illustrated embodiment, the actuators 9 are disposed on the outer surface of the diffuser wall 7. The actuators 9 may comprise, for example, hydraulically or pneumatically operated actuators that are controlled by a controller 10 to exert an adjustable pressure on the diffuser wall 7 to resultantly adjust the divergence angle 'α' of the diffuser wall 7.

[0020] As mentioned above, for attached flow, the pressure recovery increases with increase in divergence angle 'α' or area ratio 'R'. In a preferred embodiment, the pressure recovery is maximized by maintaining a flow field of the gas 5 within the diffuser wall 7 that is just before the point of flow separation. For this, the actuators 9 are controlled to first increase the divergence angle 'α' or area ratio 'R' to cause a resultant flow field beyond a point of flow separation. Subsequently, the actuators 9 are controlled to reduce the divergence angle 'α' or area ratio 'R' to re-attach the flow to the diffuser wall 7 and to cause a resultant flow field that is prior to and proximate to the point of flow separation.

[0021] The point of flow separation is detected by a flow sensor 11 disposed in the flow path of the gas 5 inside the diffuser wall 7. The flow sensor 7 may include, for example, a pressure probe. For attached flow, with increase in the divergence angle 'α', the sensed pressure values by the pressure probe 11 increases. This is illustrated by a curve 13 in FIG 2, wherein the axis 14 represents angle of divergence 'α' and the axis 15 represents the corresponding sensed pressure 'P' by the pressure probe 11 disposed in the flow path of the gas 5. As can be seen, with increase in 'α', the sensed pressure increases till a point 16 is reached where the sensed pressure attains a maximum value, for $\alpha= \alpha_S$. When 'α' is increased beyond this threshold angle α_S, the flow begins to separate from the diffuser wall, as a result of which, the sensed pressure decreases, which is detected by a change in slope of the curve 13 from positive negative. The point 16 of flow separation is thus detected based on a decrease in sensed pressure 'P' between two progressively increasing settings of the divergence angle 'α'. The proposed technique in this embodiment involves increasing 'α' to cause a flow field beyond the point 16 of flow separation, to identify the threshold angle α_S, and to then reduce 'α' to a value α_D less than α_S so as to reattach the flow to the diffuser wall and to cause the resultant flow field to reach a point 17 that is just before the point 16 of flow separation. Typically, a portion of the curve 13 in the region of the separation point 16 is flat having a slope equal or nearly equal to zero. The flow field corresponding to this portion is preferably avoided as this indicates is an unstable flow field where separated and attached flow alternate. The desired point 17 that is "substantially proximate and prior to" the point 16 of flow separation is determined, in this case, as the closest point to the point 16 on the curve 13 that has a positive slope.

[0022] Referring back to FIG 1, in an alternate embodiment, the flow sensor 11 to detect the point of flow separation may comprise a sonic probe. Still alternately, the point of flow separation may be detected using flow visualization or imaging techniques which detect the local direction of flow. In all cases, the adjustable geometry which enables the forcing of the flow beyond the point of flow separation point allows the identification of the point of flow separation. Once the point of flow separation is identified, the geometry of the diffuser may be adjusted to re-attach the flow to the diffuser wall. The adjustable geometry proposed herein allows for adaptability of the technique discussed above to changes in mass-flow, such that the pressure recovery may be maximized even when the gas turbine is operating at part load.

[0023] Referring to FIG 3 is illustrated a first embodiment of an adjustable geometry diffuser wall 7. Herein, the diffuser wall 7 is made of a sheet 18 of metal wound in several turns in a spiral form to form conical shape. The spiral form provides the required elasticity for geometric adjustments. Actuators 9 may be disposed on the outer surface of one or more of these turns to, which, when actuated, apply the required pressure to increase or decrease the divergence angle of the diffuser wall 7. In a second embodiment illustrated in FIG 4, the diffuser wall 7 may be made from a sheet 20 of metal wound in a conical shape, such that the ends 21 and 22 are not welded to each other, but slide against each other on the application of pressure by one or more actuators 9 disposed on the outer surface of the diffuser wall 7, such that divergence angle or area ratio may be varied.

[0024] In a third embodiment illustrated in FIG 5, the diffuser wall 7 is made of sheet metal and includes an adjustable portion 23 having a rectangular cross-section and a fixed portion 24, which may have a circular cross-section at the inlet 3. The rectangular portion 23 is made of flat plates 25, 26, 27, 28, one or more of which are flexibly connected to the fixed portion 24 by means of hinges 29, that allow the respective side 25, 26, 27, 28 to swivel with respect to the fixed portion 24 on application of pressure from the actuator 9 disposed thereon, to thus adjust the divergence angle/area ratio. In the shown example, the plates 25 and 27 are hinged such that the direction of angular movement is as illustrated by the arrows 30. Although the sides 26 and 28 are subject to bending during movement of the sides 25 and 27, this embodiment provides greater accuracy and control of angular movements. In a similar embodiment depicted in FIG 6, the diffuser wall 7 has a rectangular cross-section formed by flat plates 31, 32, 33, 34 that are directly connected to a circular turbine manifold 35 by flexible joints 36 so as to allow angular movements of opposite plates 31 and 33 as depicted by the arrow 37. In yet another embodiment of a rectangular diffuser wall illustrated in FIG 7, the diffuser wall 7 is made of angular plates 38, 39, 40, 41 that define the corners of a rectangle (herein, square). The angular plates 38, 39, 40, 41 are interspaced by flat plates 42, 43, 44, 45, which, together with the angular plates 38, 39, 40, 41 form the sides of the rectangular diffuser wall 7. As illustrated, the angular plates are slidable against the flat plates 42, 43, 44, 45 such that the rectangular cross-sectional geometry of the diffuser wall 7 may be adjusted along diagonal directions 46 and 47 by actuators (not shown) disposed on the corners 48, 49, 50, 51 of the rectangular diffuser wall 7.

[0025] While this invention has been described in detail with reference to certain preferred embodiments, it should be appreciated that the present invention is not limited to those precise embodiments. Rather, in view of the present disclosure which describes the current best mode for practicing the invention, many modifications and variations would present themselves, to those of skill in the art without departing from the scope and spirit of this invention. The scope of the invention is, therefore, indicated by the following claims rather than by the foregoing description. All changes, modifications, and variations coming within the meaning and range of equivalency of the claims are to be considered within their scope.

Claims

1. An exhaust diffuser assembly (1) for a stationary gas turbine, comprising:

   - a longitudinal axis (2),
   - a diffuser inlet (3) for receiving a turbine mainflow gas (5),
   - a diffuser outlet (4),
   - a diverging diffuser wall (7) having an adjustable geometry and forming a conduit for flow of said gas (5) therethrough from said diffuser inlet (3) to said diffuser outlet (4), said diffuser wall (7) having a divergence angle 'α' with respect to said longitudinal axis (2), and
   - diffuser geometry control means (9,10) for controlling a recovery of pressure from said gas (5) between said diffuser inlet (3) and said diffuser outlet (4) by adjusting said divergence angle 'α' of said diffuser wall (7) to cause a resultant flow field of said gas (5) that is attached to said diffuser wall (7).

2. The diffuser assembly (1) according to claim 1, wherein said diffuser geometry control means (9,10) comprises one or more actuators (9) disposed on a surface said diffuser wall (7), said one or more actuators (9) being adapted to exert an adjustable pressure said diffuser wall (7) to resultantly adjust said divergence angle 'α' of said diffuser wall (7).

3. The diffuser assembly (1) according to claim 2, wherein said one or more actuators (9) adapted for increasing said divergence angle 'α' to cause a resultant flow field beyond a point of flow separation of said gas (5) from said diffuser wall (7) and subsequently reducing said divergence angle 'α' to re-attach the flow of said gas (5) to said diffuser wall (7), so as to cause a resultant flow of said gas (5) through said diffuser wall (7) that is substantially proximate and prior to said point of flow separation.

4. The diffuser assembly (1) according to claim 3, further comprising a pressure probe (11) disposed in a flow path of said gas (5) inside said diffuser wall (7), wherein said point of flow separation is detected based on a decrease in sensed pressure between two progressively increasing settings of the divergence angle 'α'.

5. The diffuser assembly (1) according to claim 3, further comprising a sonic probe (11) disposed in a flow path of said gas (5) inside said diffuser wall (7) to detect said point of flow separation.

6. The diffuser assembly (1) according to claim 3, wherein said point of flow separation is determined by flow visualization means adapted for detecting local direction of flow.

7. The diffuser assembly (1) according to any of the preceding claims, wherein said diffuser wall (7) is made of a piece of sheet metal (11) wound to spiral form.

8. The diffuser assembly (1) according to any of the claims 1 to 6, wherein said diffuser wall (7) is made from a piece of sheet metal (20) wound into a conical shape, wherein the edges (21, 22) of said piece of sheet metal are slidable against each other.

9. The diffuser assembly (1) according to any of the claims 1 to 6, wherein said diffuser wall (7) comprises an adjustable portion (23) having a rectangular cross-section, wherein the diffuser wall (7) at said adjustable portion (23) is flexibly attached to a fixed portion (24) by a hinge (29).

10. The diffuser assembly (1) according to any of the claims 1 to 6, wherein said diffuser wall (7) has a rectangular cross-sectional geometry formed by angular plates (38,39,40,41) forming corners of the rectangle, said angular plates (38,39,40,41) being interspaced by and flat plates (42,43,44,45) over which said angular plates (38,39,40,41) are slidable such that said rectangular cross-sectional shape is adjustable along diagonal directions (46,47).

11. A method for operating an exhaust diffuser (1) for a stationary gas turbine, comprising:

- receiving a turbine mainflow gas (5) at a diffuser inlet (3),
- passing said gas (5) through a diverging diffuser wall (7) having an adjustable geometry defining a conduit for flow said gas (5) between said diffuser inlet (3) and a diffuser outlet (4), said diffuser wall (7) having a divergence angle 'α' with respect to a diffuser longitudinal axis (2), and
- controlling a recovery of pressure from said gas (5) between said diffuser inlet (3) and said diffuser outlet (4) by controlling a geometry of said diffuser wall (7), said controlling of said geometry comprising adjusting said divergence angle 'α' of said diffuser wall (7) to cause a resultant flow field of said gas (5) that is attached to said diffuser wall (7).

12. The method according to claim 11, wherein controlling the geometry of said diffuser wall (7) comprises disposing one or more actuators (9) on a surface of said diffuser wall (7) and controlling said one or more actuators (9) to exert an adjustable pressure on said diffuser wall (7) to resultantly adjust said divergence angle 'α' of said diffuser wall (7).

13. The method according to claim 12, comprising controlling said one or more actuators (9) to increase said divergence angle 'α' to cause a resultant flow field beyond a point of flow separation of said gas (5) from said diffuser wall (7) and subsequently reducing said divergence angle 'α' to re-attach the flow of said gas (5) to said diffuser wall (7), so as to cause a resultant flow of said gas (5) through said diffuser wall that is substantially proximate and prior to said point of flow separation.

14. The method according to claim 13, further comprising disposing a pressure probe (11) in a flow path of said gas (5) inside said diffuser wall (7), and detecting said point of flow separation based on a decrease in sensed pressure between two progressively increasing settings of the divergence angle 'α'.

15. The method according to claim 13, further comprising detecting said point of flow separation by a sonic probe (11) disposed in a flow path of said gas (5) inside said diffuser wall (7).

FIG 1

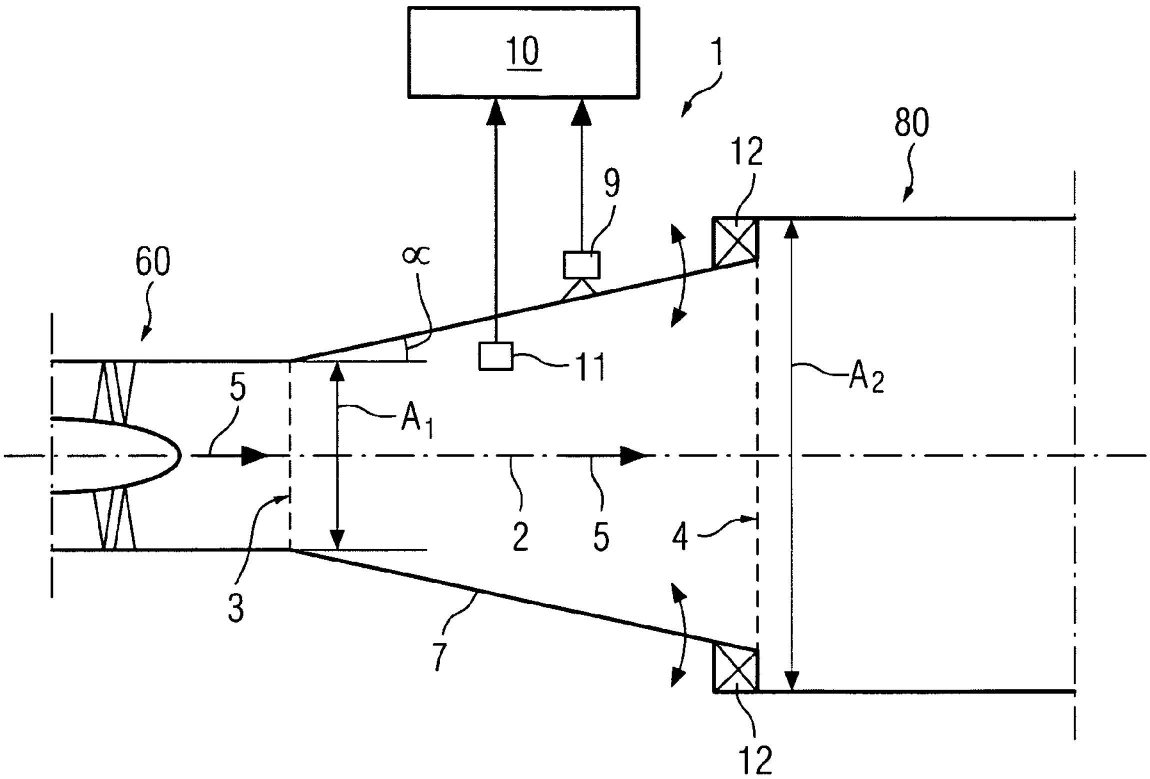


FIG 2

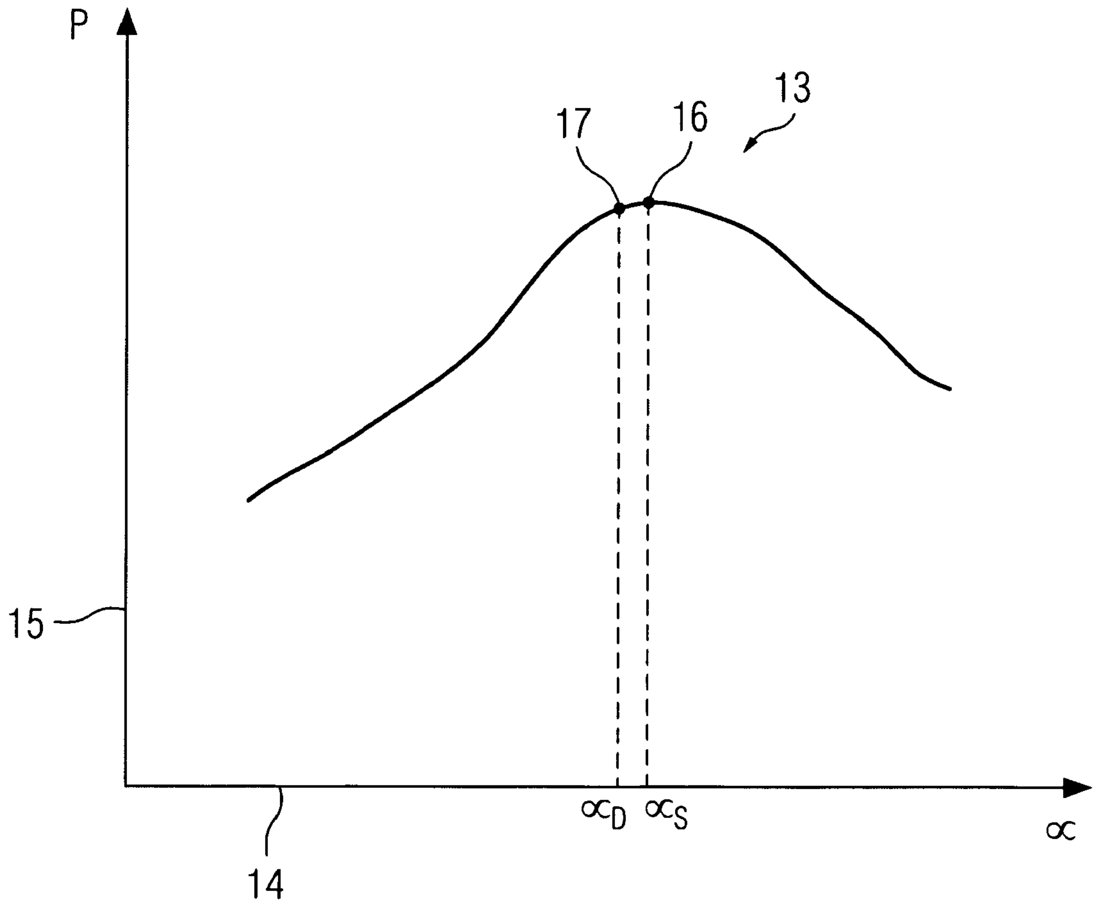


FIG 3

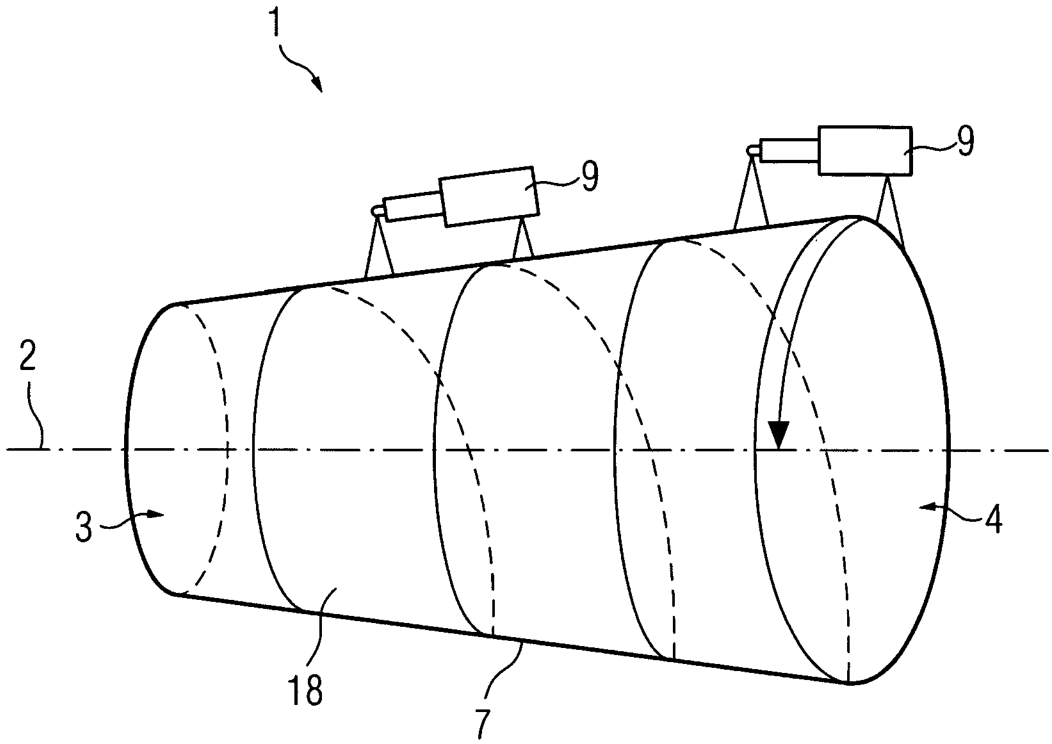


FIG 4

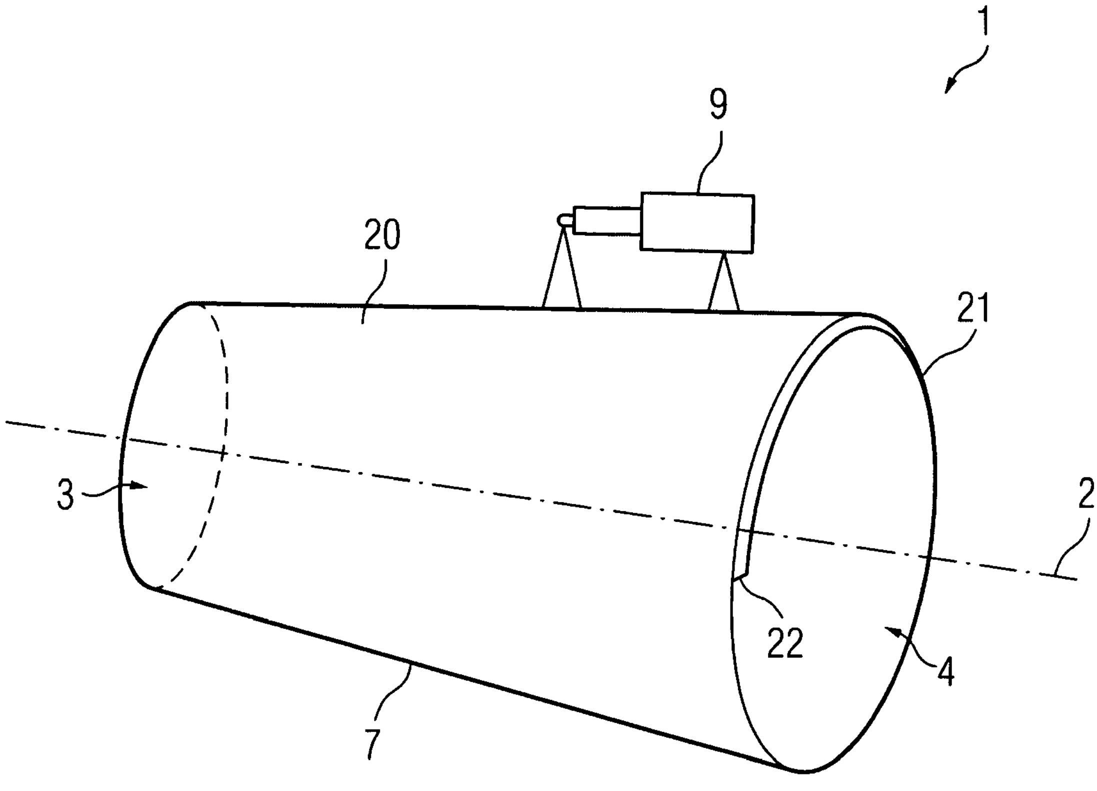


FIG 5

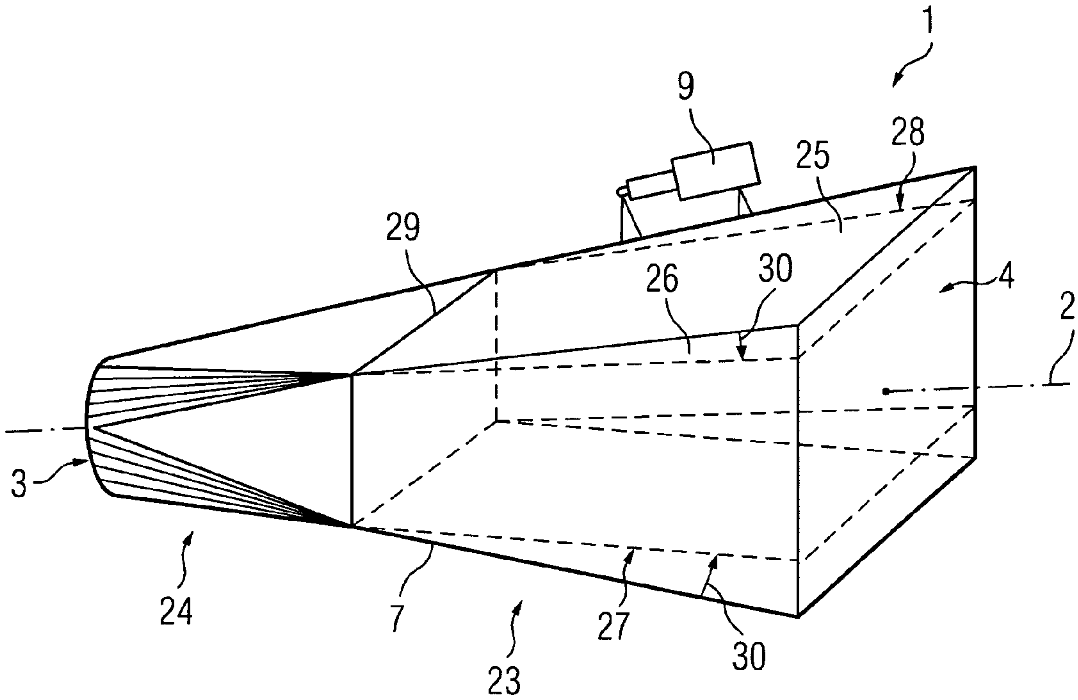


FIG 6

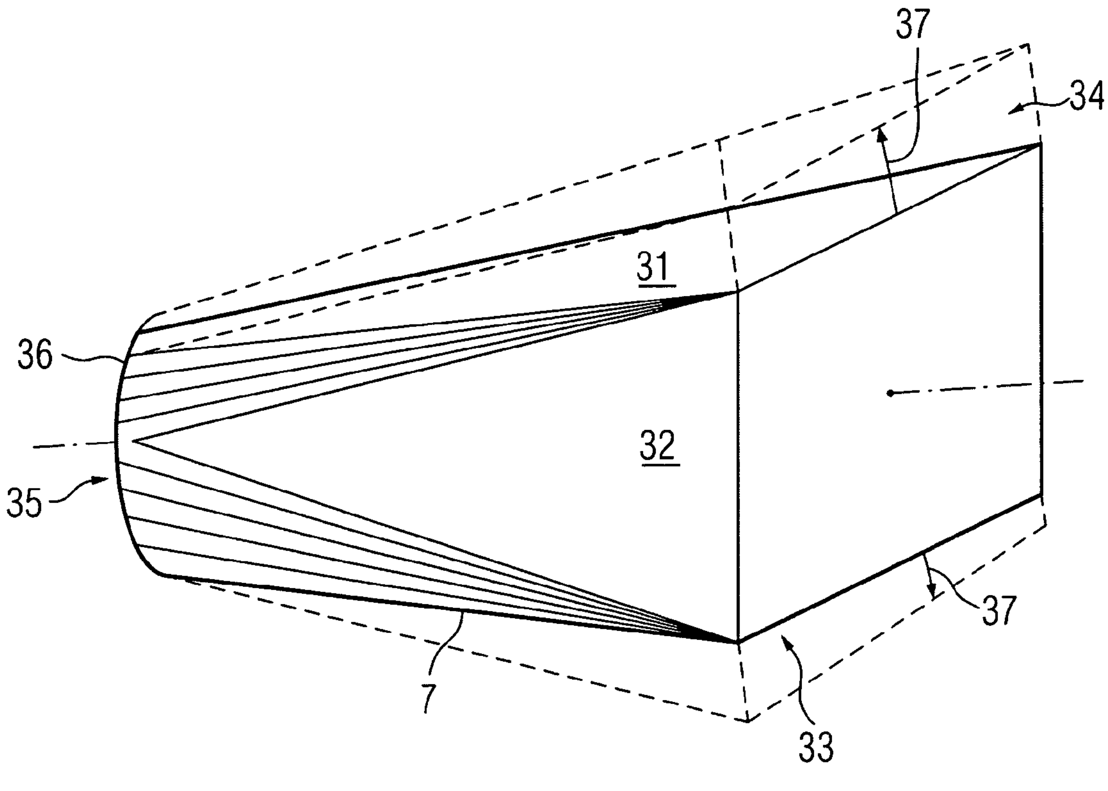
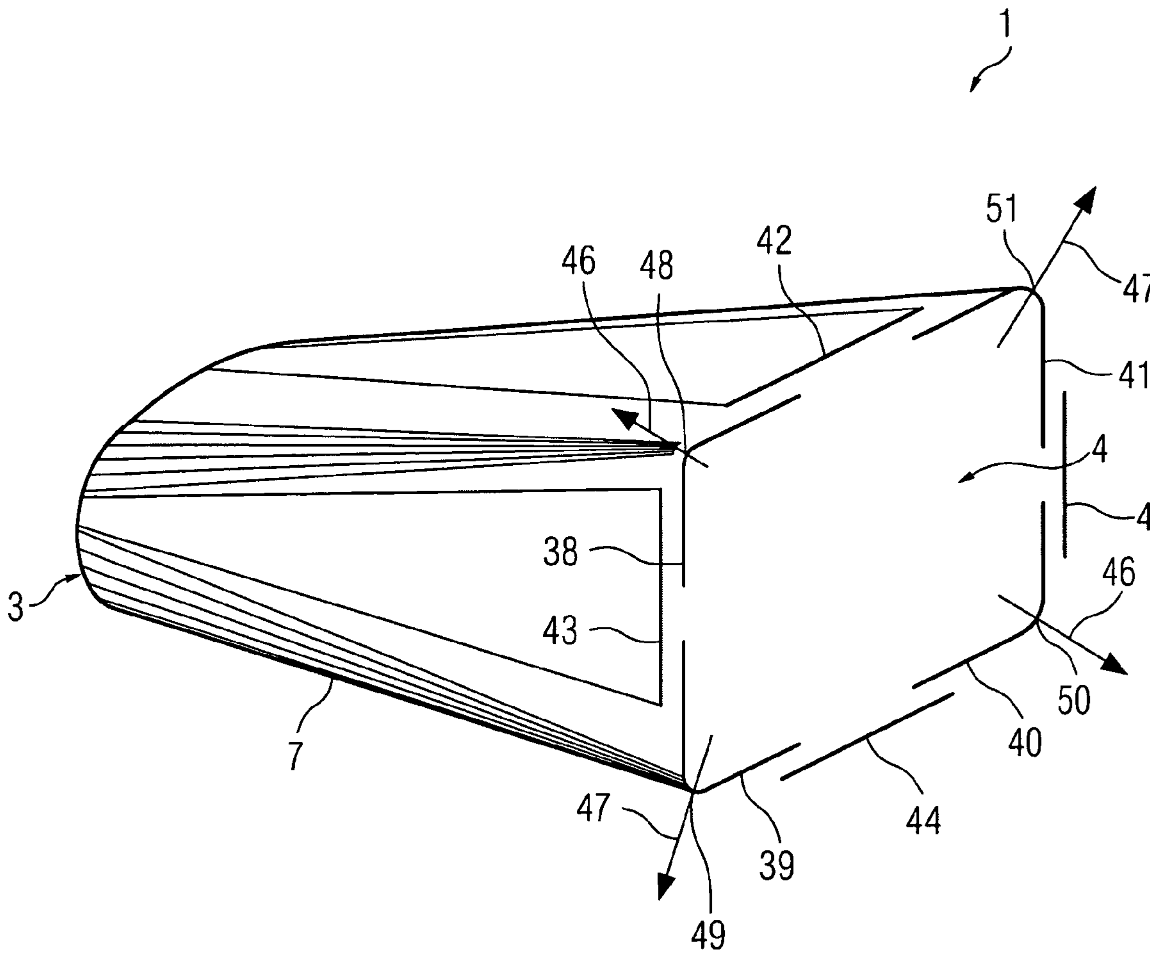


FIG 7



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EUROPEAN SEARCH REPORT

Application Number
EP 10 00 7757

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	US 4 398 865 A (GARKUSHA ANATOLY V [SU] ET AL) 16 August 1983 (1983-08-16) * column 5, lines 35-45; figure 3 * -----	1-3,11, 12	INV. F01D25/30
X	US 2009/068006 A1 (HARDIN JAMES R [US]) 12 March 2009 (2009-03-12) * paragraph [0026]; figure 3 * -----	1-3,11, 12	
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TECHNICAL FIELDS SEARCHED (IPC)

F01D
F02K

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	9 December 2010	Oechsner de Coninck

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