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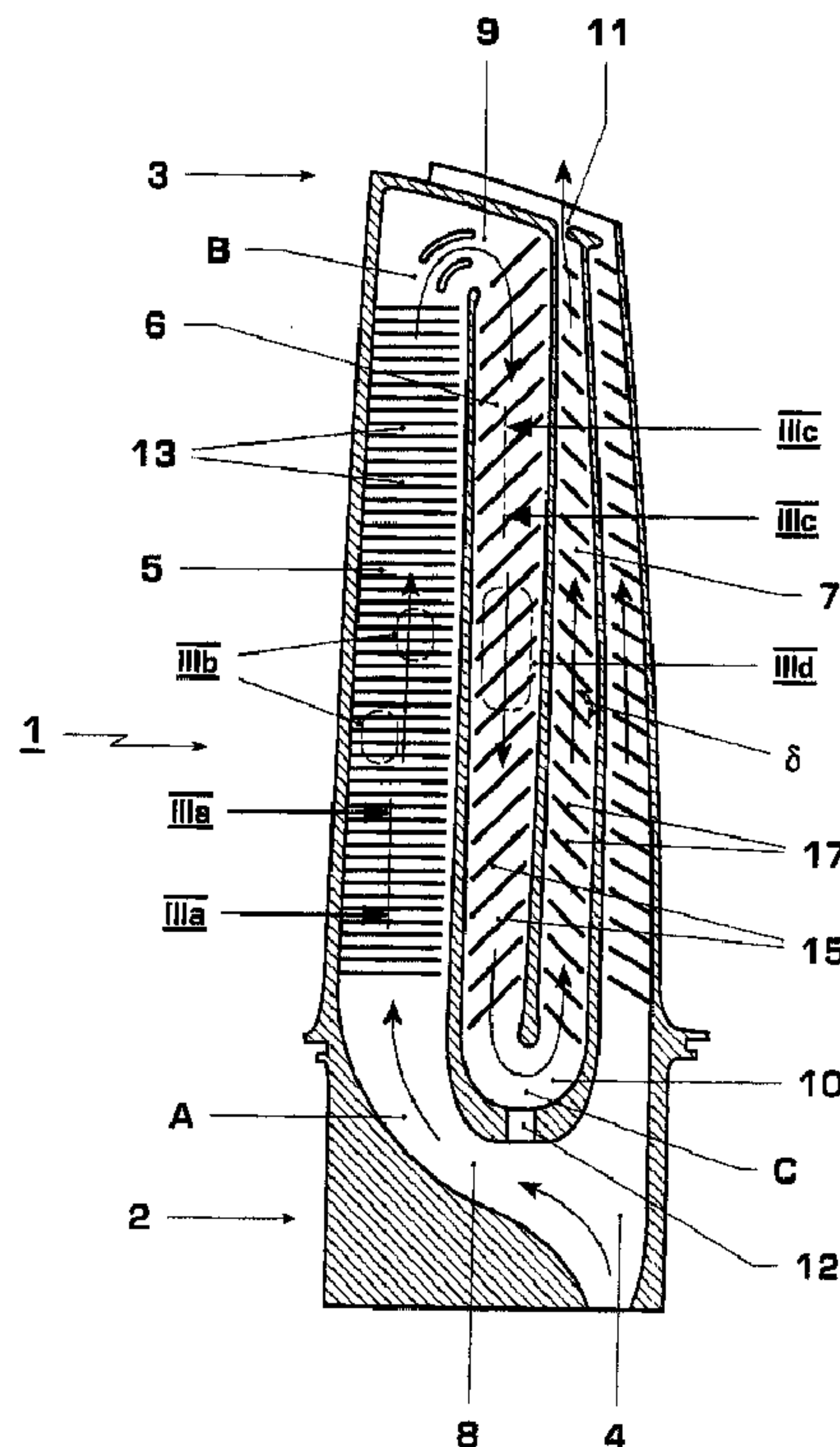
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(54) **Titre : AUBE DE TURBINE AVEC STRUCTURE DE REFROIDISSEMENT INTERNE**

(54) **Title: TURBINE BLADE WITH INTERNAL COOLING STRUCTURE**



(57) **Abrégé/Abstract:**

A rotating blade (1) for a gas turbine comprises an internal cooling structure having at least three cooling air passages (5-7) in fluid connection with one another by means of turns (9, 10). An opening (12) provides an outlet for dissolved core material to be



(57) Abrégé(suite)/Abstract(continued):

removed from the blade following casting of the cooling structure without any residue remaining within. According to the invention, the cooling structure comprises trip strips (13, 15) in the first and second passage (5, 6) with specified ratio of height to distance between trip strips and the trip strips (13) in the first passage being arranged at 90° with respect to the direction of airflow. In a particular embodiment, the trip strips (15) in the second passage (6) are arranged at angle of 45°. The design according to the invention assures sufficient airflow through first and second air passages (5, 6).

Abstract

5 A rotating blade (1) for a gas turbine comprises an internal cooling structure
having at least three cooling air passages (5-7) in fluid connection with one
another by means of turns (9, 10). An opening (12) provides an outlet for
dissolved core material to be removed from the blade following casting of the
cooling structure without any residue remaining within. According to the invention,
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(5, 6) with specified ratio of height to distance between trip strips and the trip strips
(13) in the first passage being arranged at 90° with respect to the direction of
airflow. In a particular embodiment, the trip strips (15) in the second passage (6)
are arranged at angle of 45°. The design according to the invention assures
15 sufficient airflow through first and second air passages (5, 6).

(fig. 2)

Turbine Blade with Internal Cooling Structure

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Technical Field

The present invention relates to cast rotating blades for a gas turbine, and in particular to the design of an internal cooling structure within the blade in view of
10 blade manufacturability.

Background Art

15 Turbine blades for gas turbines are designed and manufactured to withstand high temperatures during the gas turbine operation. Such turbine blades comprise an internal cooling structure through which a cooling fluid, typically air, is passed. Cooling air is typically bled from a compressor of the gas turbine engine. This extraction of air however, reduces the overall performance of the engine. In order
20 to minimize the effect on engine performance by minimizing the air consumption and yet assure sufficient cooling of the blade, the internal blade cooling structure is designed for optimal cooling efficiency. Such designs are disclosed for example in US 6,139,269 and US 5,403,159. US 6,139, 269 discloses a serpentine cooling structure having several passages extending in the blade longitudinal direction
25 and connecting to either an inlet opening at the blade root, to an outlet opening at the blade tip, or to a further longitudinal passage by means of a turn or bend of approximately 180°. The cooling structure furthermore comprises on the walls of the longitudinal passages a multitude of trip strips, oriented at approximately 45° to the direction of flow through the passage. The particular construction in US
30 6,139, 269 comprises furthermore at each 180°-turn near the blade root an air re-supply passage allowing air to enter into the passage from the blade root.

79291-95

2

Turbine blades with internal cooling structure of this type are cast, as a rule, by an investment casting process using a core defining the cooling structure. The core is made of a leachable material such as ceramic. Following the molding process, the ceramic core is removed by a leaching process.

- 5 The leaching process is difficult in regard to the removal of core material in the region of the 180° turns, and a risk remains that residual core material stays behind in the blade cooling channels and thus obstructing the flow of cooling media through the cooling passage. In order to reduce this risk, an opening is provided in the cooling structure wall in the region of the 180° turn for remaining core material to leach out. In
10 some known gas turbine blades, this opening is again closed by means of a plate or plug as disclosed for example in US 6,634,858.

Summary of Invention

According to an aspect of the present invention, there is provided a rotating blade for a gas turbine comprising a blade root and blade tip and an internal cooling structure
15 comprising a first cooling air passage extending essentially in the longitudinal direction of the blade from a plenum in the blade root to the blade tip, a second cooling air passage extending from the blade tip to the blade root and a third cooling air passage extending from the blade root to the blade tip, the first passage being in fluid connection with the second passage by means of a first turn and the second
20 passage being in fluid connection with the third passage by means of a second turn, and the cooling structure further comprising an opening extending from the second turn to the plenum providing a direct outlet for fluids from the blade, wherein the first and second cooling air passages each comprises a plurality of trip strips, the trip strips in the first cooling passage being arranged at an angle of $90\pm 10^\circ$ to the
25 direction of cooling fluid flow in that first passage, the trip strips in the second passage being arranged at an angle of $45^\circ\pm 10^\circ$ in relation to the airflow direction, and additionally, the trip strips in the first and second passages have a height and a

79291-95

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distance between adjacent trip strips, the ratio between the height and the distance being 10 ± 2 .

Some embodiments may provide a gas turbine rotating blade with internal cooling structure having a design that allows improved manufacturability over those of the state of the art while at least maintaining the existing cooling performance of the internal cooling structure.

In some embodiments, a gas turbine rotating blade comprises an internal cooling structure having at least three cooling passages extending in the blade longitudinal direction, at least one inlet opening in the region of the blade root, and at least one outlet opening in the region of the blade tip leading from a cooling passage out of the blade. The blade furthermore comprises in its root region a plenum for cooling air, the inlet opening extending from this plenum to a cooling passage. The first cooling passage extends, in the direction of cooling fluid, from the blade root region to the blade tip region. The second cooling passage extends from the tip to the root region. First and second cooling passages are in fluid connection with one another in the region of the blade tip by means of a bend or turn in the region of the blade tip. The third cooling passage again extends from the root to the tip, while second and

79291-95

3

third cooling passages are in fluid connection with one another by means of a turn or bend in the region of the blade root.

In some embodiments, in order for a core material to be removed from the bend by leaching out with a reduced risk of core material remaining in the bend, an opening is provided in the cooling structure wall extending from the plenum to the bend or turn in the blade root region from the second to the third cooling passage. The opening provides a direct fluid connection from the bend to the root of the blade and to the exterior of the blade. In particular, the opening and root region of the blade is such that a liquid fluid is allowed to flow directly and essentially in the longitudinal blade direction out of the blade internal cooling structure. This allows the fluid core material to exit the blade completely without having to pass through any back turns or dead zones. Thus, it is prevented that fluid core material remains in the structure as residual fluid. The flow of cooling air through the internal cooling structure when the blade is in operation is thus assured.

In some embodiments, for the purposes of simplified and thus cost efficient manufacture of the gas turbine rotating blade, the opening at the bend or 180° turn of the internal structure is not closed up again prior to the operation of the blade in the turbine. Since said opening at the 180° turn has an effect on the aerodynamics of the internal cooling structure and distribution of the cooling air, the design of the cooling passages is adapted and optimized accordingly in view of cooling function and efficiency.

According to an aspect the invention, the first cooling passage extending, in the direction of cooling fluid from the plenum in the root region to the tip region of the blade, comprises a plurality of turbulators or trip strips arranged at an angle of $90 \pm 10^\circ$ to the direction of flow of the cooling fluid. Additionally, the second cooling passage, in fluid connection with the first cooling passage by means of a turn, comprises a plurality of trip strips or turbulators. Finally, in combination with the specific orientation of the trip strips in the first cooling passage, the trip strips in the first and second cooling passages are arranged and dimensioned such that the ratio between their height and the distance between adjacent trip strips is 10 ± 2 .

79291-95

4

In an exemplary embodiment of the invention, the trip strips in the second cooling passage are arranged at an angle of $45^\circ \pm 10^\circ$ in relation to the flow direction.

In a further exemplary embodiment, the third cooling passage comprises a plurality of trip strips arranged at an angle of $45^\circ \pm 10^\circ$ from the direction of flow to
5 the direction of the trip strip.

As mentioned above, the opening at the turn from the second to the third passage affects the cooling air distribution in the cooling structure. In particular, a non-plugged opening at that location would result in a reduction of the airflow from the
10 plenum in the root region through the first and second passage and an increase of airflow from the plenum through the opening directly to the third passage. The design measures according to some embodiments in the form of a particular arrangement of trip strips in the first and second passage may allow an optimization of the cooling airflow and re-establishment of the airflow through the first and second
15 passage. It thereby may assure sufficient and uniform cooling of the entire blade.

The design of the trip strips according to some embodiments may allow compensation of very small hydraulic pressure losses from the beginning of the first passage to the beginning of the third passage. Compensation of the low-pressure losses is achieved by pumping forces in the first and second passages due to a convective
20 temperature increase of the cooling air along these passages.

The flow dynamics of the cooling air are elaborated in connection with the following figures.

25 As mentioned above, the design of the blade cooling structure according to some embodiments may allow for optimized manufacturing due to the opening provided in the turn near the root of the blade. The design requires no measures following the casting for closing of the opening. In some embodiments, the specific design of the trip strips in the cooling passages compensates for hydraulic pressure losses and thereby
30 assures sufficient cooling within the first and second passages. The design therefore allows improved and simplified manufacturing while maintaining cooling performance.

79291-95

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Brief Description of the Drawings

Figure 1 shows a side view of an exemplary gas turbine blade, to which an
5 embodiment of the invention may be applied;
figure 2 shows a cross-sectional view of the blade of figure 1 along II-II showing
the internal blade cooling structure according to an embodiment of the invention;
figures 3a and 3b show respectively, a cross-section of the trip strips along IIIa-IIIa
in figure 2 and the trip strips in detail, in particular the arrangement and relative
10 dimensions of turbulators in the first cooling passage of the blade cooling
structure;
figures 3c and 3d show respectively, a cross-section of the trip strips along IIIc-IIIc
in figure 2 and the trip strips in detail, in particular the arrangement and relative
dimensions of turbulators in the second cooling passage of the blade cooling
15 structure.

Best Modes for Carrying out the Invention

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Figure 1 shows a rotating gas turbine blade 1 extending longitudinally from a root
2 to a tip section 3.

Figure 2 shows the internal cooling structure of the blade having a plenum 4 within
the root region for cooling air entering the cooling structure, a plurality of at least
25 three longitudinal cooling passages 5-7 extending from the plenum 4 at the root 2
to the tip 3 and from the tip 3 to the root 2 respectively. The longitudinal passages
are in fluid connection with one another by means of turns of approximately 180°.

The airflow passes, as indicated by arrows, from the plenum 4 through an inlet
30 opening 8 at the beginning of the first cooling passage 5 to the end of the first
passage at the tip of the blade, and around a turn 9 of approximately 180°. It then
flows along the second cooling passage 6 to a further 180°-turn 10 connecting the
second cooling passage 6 with the third cooling passage 7. The cooling air finally

79291-95

6

flows through the third cooling passage 7 to the tip of the blade and exits the cooling structure through the outlet opening 11 at the tip of the blade.

At the turn 10 near the root of the blade, an opening or channel 12 is provided for leaching out core material after casting and allowing all of the dissolved core material to run out of the cooling structure via the plenum 4 such that no core material remains in the turn 10. Due to this opening 12, cooling air could pass more readily from the plenum 4 directly to the third cooling passage 7 rather than through first and second cooling passages 5 and 6. However, due to the particular design of the first and second cooling passages according to the present embodiment, the pressure drop between position A and position B is such that a cooling airflow is assured through passages 5 and 6.

A pressure loss is due to hydraulic resistance and depends on the square of the air velocity, the shape of the channel, the degree of smoothness of the passage walls as well as the shape of turbulators or trip strips. All these features according to some embodiments result in that the air pressure at position B at the beginning of the third passage 7 is lower than at position A at the beginning of the first passage 5.

Additionally, a pumping effect occurs due to the rotation of the blade. Due to the pumping effect the air pressure increases with increasing radius of the passage, specifically in proportion to the difference of the squares of the radii at a given angular speed. In the first passage 5 therefore, the pressure increases with increasing radius from position A to position B. In the second passage 6, the pressure decreases with decreasing radius from position B to position C, decreasing by the same magnitude as it increased in passage 5. The final effect would therefore be zero. Additionally however, a heat flux is picked up by the cooling air from the heat convective walls of the passages increasing the temperature of the cooling air. As a result, the temperature of the cooling air in the second passage 6 is higher than in the first passage 5. This temperature change also affects the pumping effect in the first and second passages. The higher temperature in the second passage results in that the pumping effect along the second passage 6 is smaller than in the first passage 5. Therefore, the pressure at position B is lower compared to that at position A, resulting in an effective cooling airflow along passages 5 and 6.

As mentioned above, the hydraulic resistance of a cooling passage depends from, among others, on the design of the passage, in particular the design of the turbulators or trip strips 13. Figure 2 shows an embodiment of the invention comprising in the first cooling passage 5 turbulators or trip strips 13 arranged at 5 $90\pm 10^\circ$ in relation to the direction of cooling flow, as indicated by the arrow. Figure 3a shows in cross-section the arrangement and relative dimensions of the trip strips. Each trip strips has a height h measured from the wall 14 of the passage 5, and each trip strip 13 is arranged at a distance d from the adjacent trip strip. The height h and distance d are at a ratio of 10 ± 2 . The trip strips are shown having a 10 rectangular shape. However, they can be of any other aerodynamically suitable cross-sectional shape as well. Figure 3b shows the orientation of the trip strips in relation to the direction of cooling air flow. The angle α is $90^\circ \pm 10^\circ$.

15 Figure 2 further shows the second cooling passage 6 having trip strips 15. Similarly as in passage 5, the trip strips 15 in passage 6 are designed having a height h measured from the wall 16 of the passage 6 and distance d between them such that the ratio of height h to distance d is 10 ± 2 , as shown in figure 3c. Height h is measured from the wall of the passage, and distance d is measured 20 between adjacent trip strips along the direction of cooling airflow.

The trip strips 15 in cooling passage 6 as shown in figure 2 are at a greater distance from each other compared to the distance between adjacent trip strips 13 in passage 5. However, the essential design features of cooling passages in order 25 to assure a sufficient cooling air flow through passages 5 and 6 include the specific orientation of the trip strips in passage 5 and the ratio of height h to distance d between adjacent trip strips of 10 ± 2 for both passages 5 and 6. A further design feature, which enhances the effect includes the specific orientation of the trip strips in passage 6. The trip strips are arranged at an 30 inclination angle β of $45\pm 10^\circ$ in relation to the direction of airflow, as shown in figure 3d. The angle is measured in counter-clockwise direction from the direction of the trip strips to the direction of airflow.

The third passage 7, can also have turbulators 17 of any design in order to enhance cooling efficiency along that passage. In the exemplary embodiment shown, they are arranged at an inclination angle δ to the direction of airflow, the angle being $45 \pm 10^\circ$ in relation to the direction of airflow.

Terms used in Figures

	1	rotating blade
5	2	blade root
	3	blade tip
	4	plenum for cooling air
	5	first cooling air passage
	6	second cooling air passage
10	7	third cooling air passage
	8	inlet opening
	9	turn
	10	turn
	11	outlet opening
15	12	outlet opening for core material
	13	trip strips in first passage
	14	cooling passage wall
	15	trip strips in second passage
	16	wall of second cooling passage
20	17	trip strips in third passage
	h	trip strip height
	d	distance between adjacent trip strips
	α	orientation angle of trip strips 13
	β	orientation angle of trip strips 15
25	δ	orientation angle of trip strips 17
	A	position at beginning of cooling passage 5
	B	position at end of cooling passage 5
	C	position at bend from second passage 6 to third passage 7

79291-95

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CLAIMS:

1. A rotating blade for a gas turbine comprising a blade root and blade tip and an internal cooling structure comprising

5 a first cooling air passage extending essentially in the longitudinal direction of the blade from a plenum in the blade root to the blade tip, a second cooling air passage extending from the blade tip to the blade root and a third cooling air passage extending from the blade root to the blade tip, the first passage being in fluid connection with the second passage by means of a first turn and the second passage being in fluid connection with the third passage by means of a second turn,

10 and the cooling structure further comprising an opening extending from the second turn to the plenum providing a direct outlet for fluids from the blade, wherein the first and second cooling air passages each comprises a plurality of trip strips, the trip strips in the first cooling passage being arranged at an angle of $90\pm 10^\circ$ to the direction of cooling fluid flow in that first passage, the trip strips in the second
15 passage being arranged at an angle of $45^\circ\pm 10^\circ$ in relation to the airflow direction,

and additionally, the trip strips in the first and second passages have a height and a distance between adjacent trip strips, the ratio between the height and the distance being 10 ± 2 .

2. The rotating blade according to claim 1, wherein the third passage
20 comprises a plurality of trip strips arranged at an angle of $45^\circ\pm 10^\circ$.

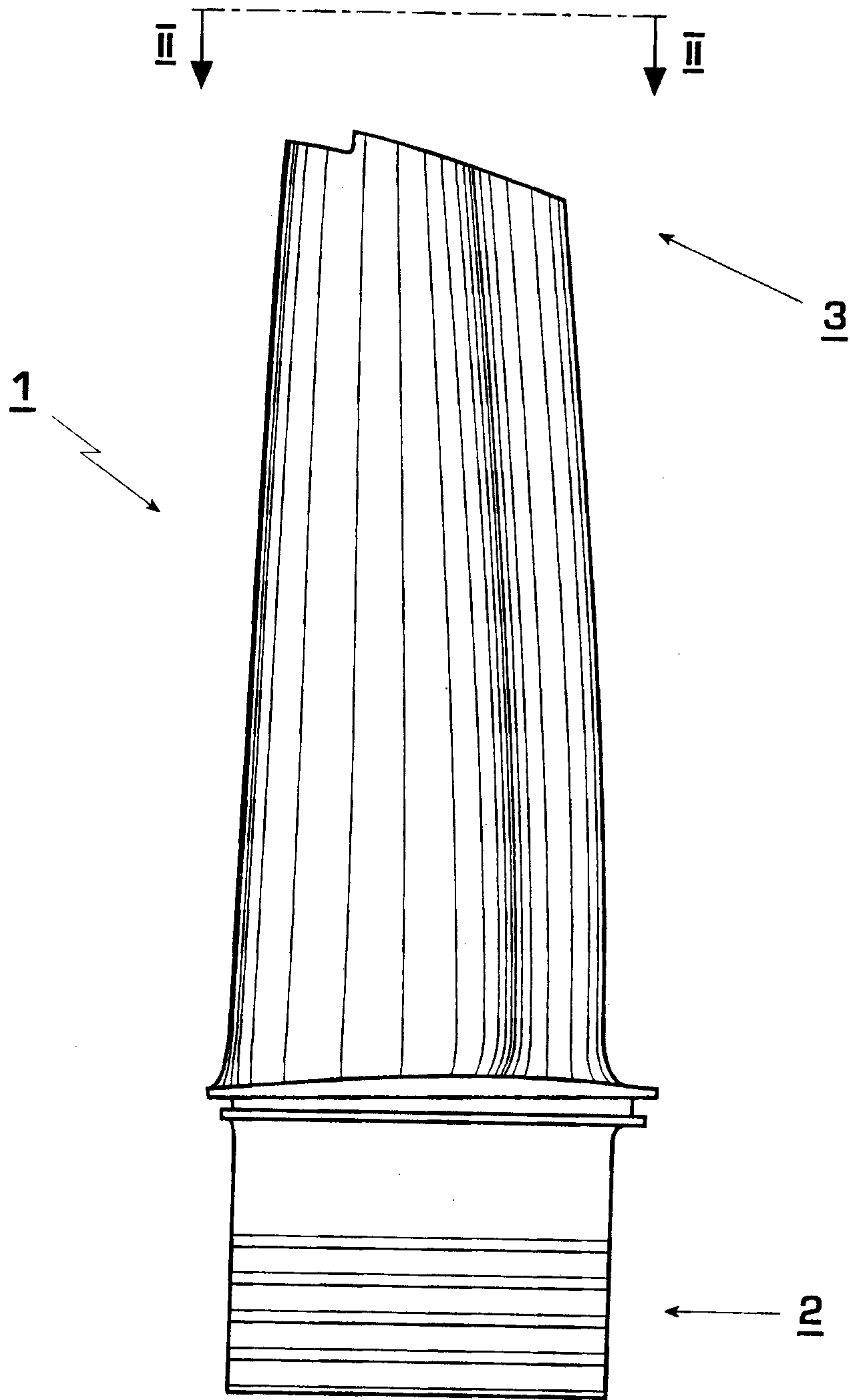


FIG. 1

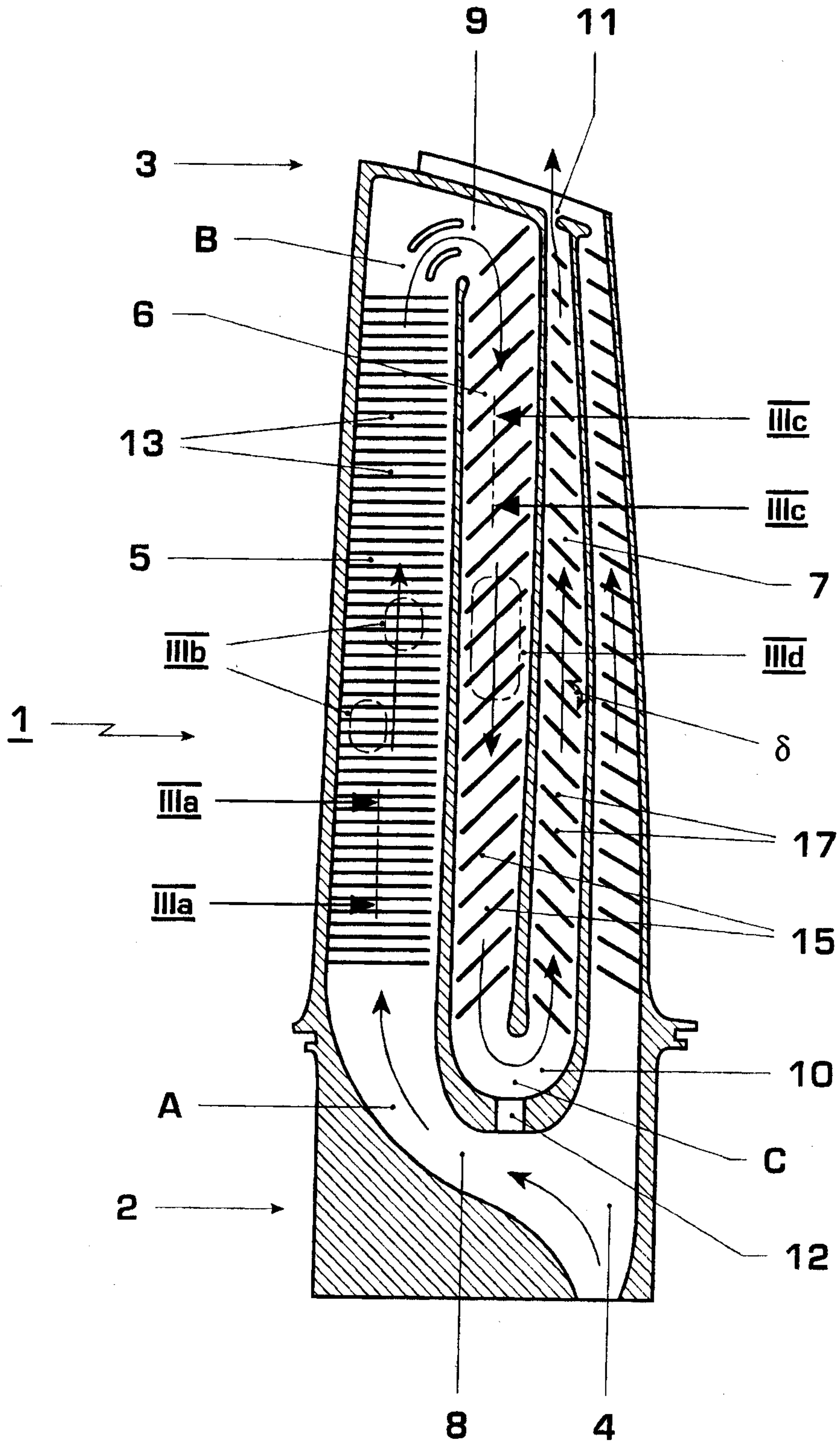


FIG. 2

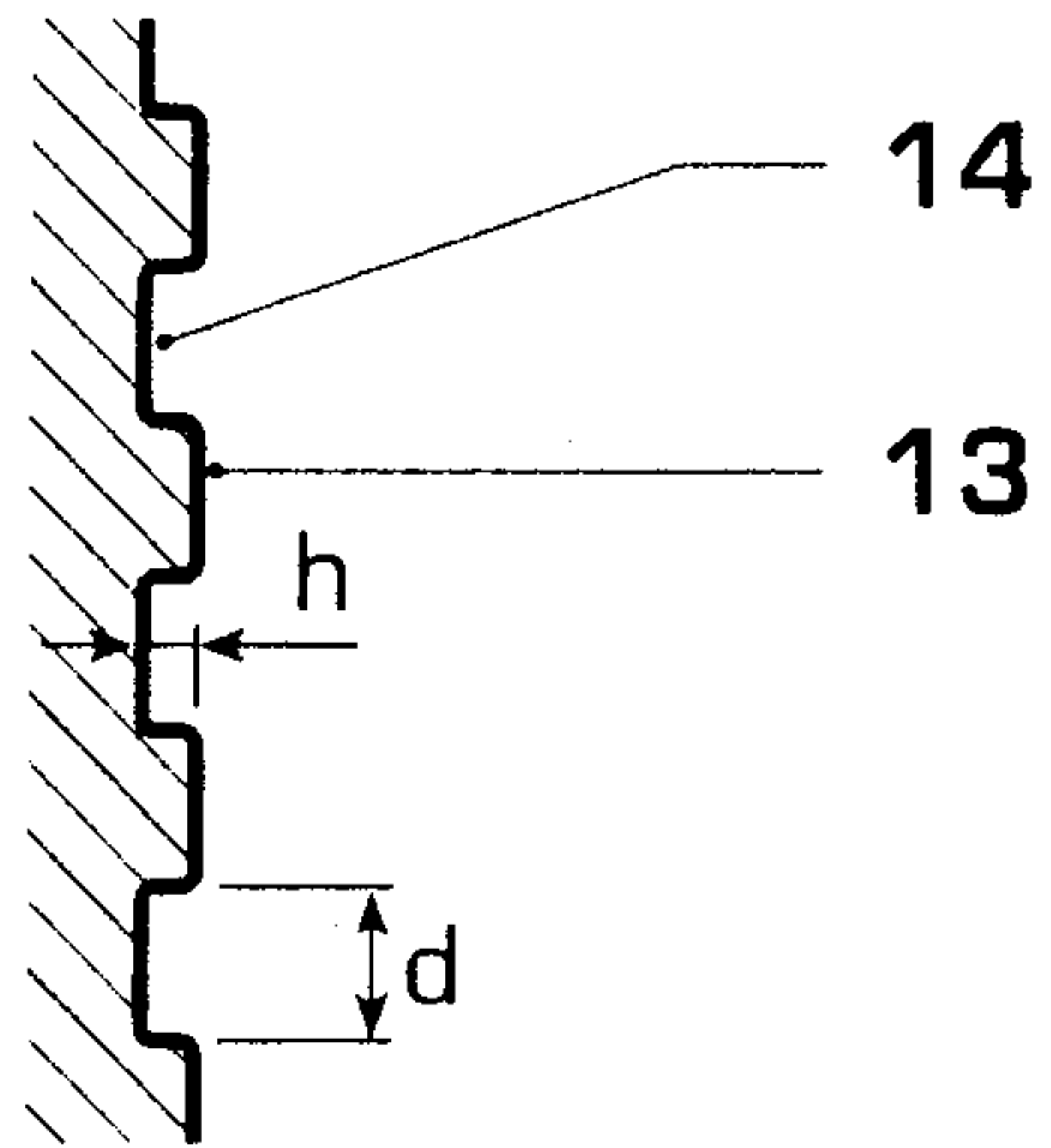


FIG. 3a

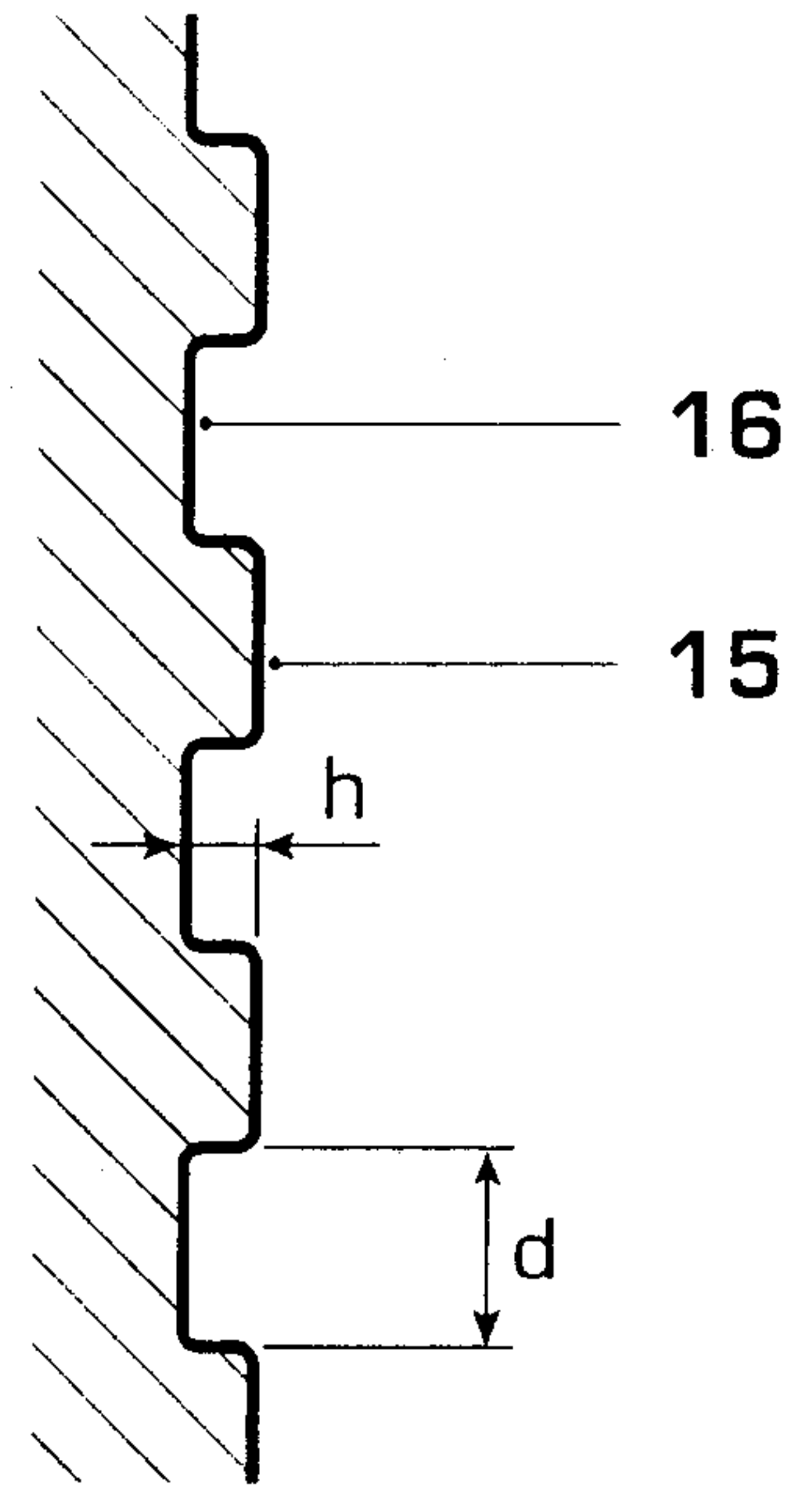


FIG. 3c

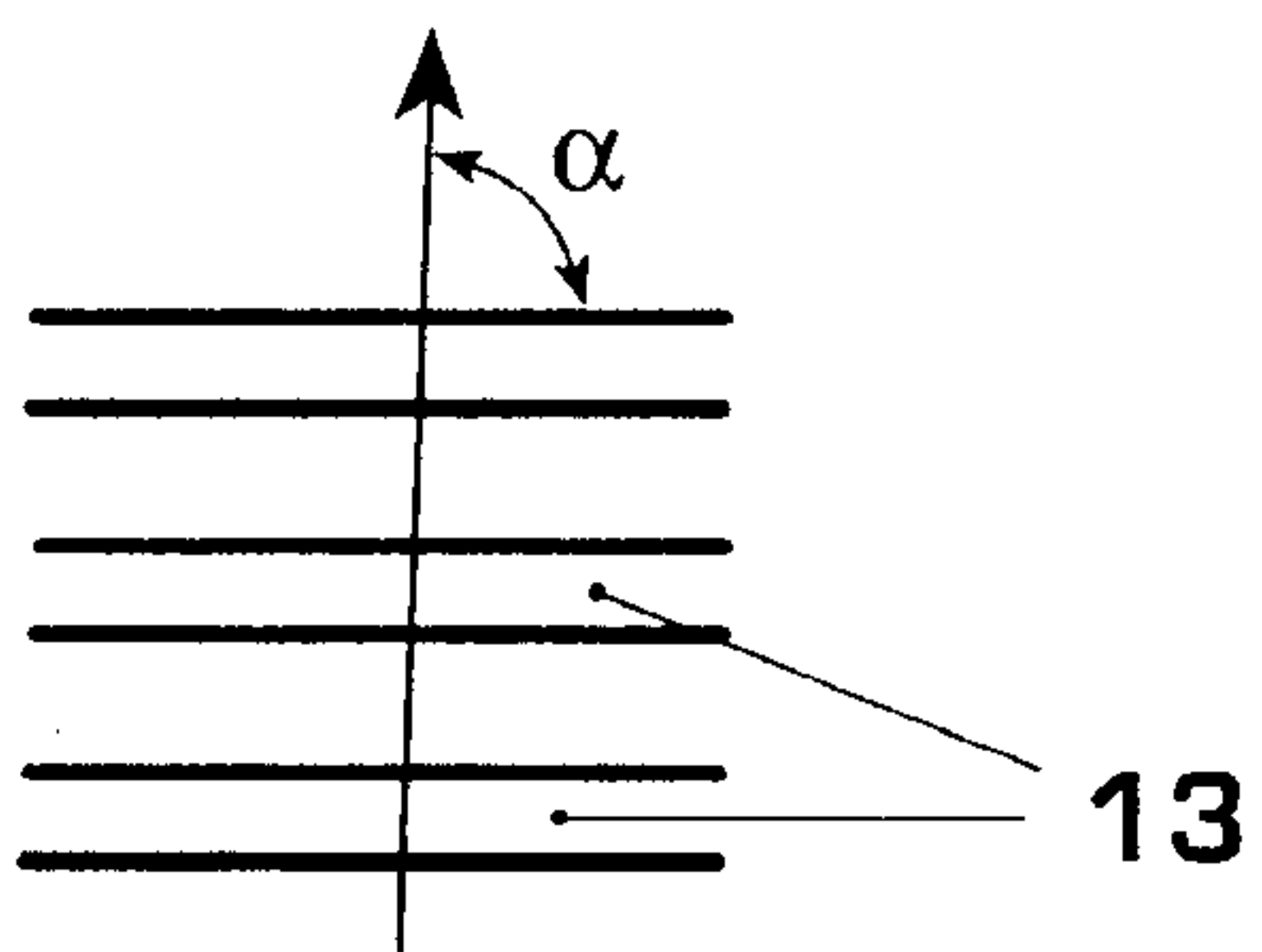


FIG. 3b

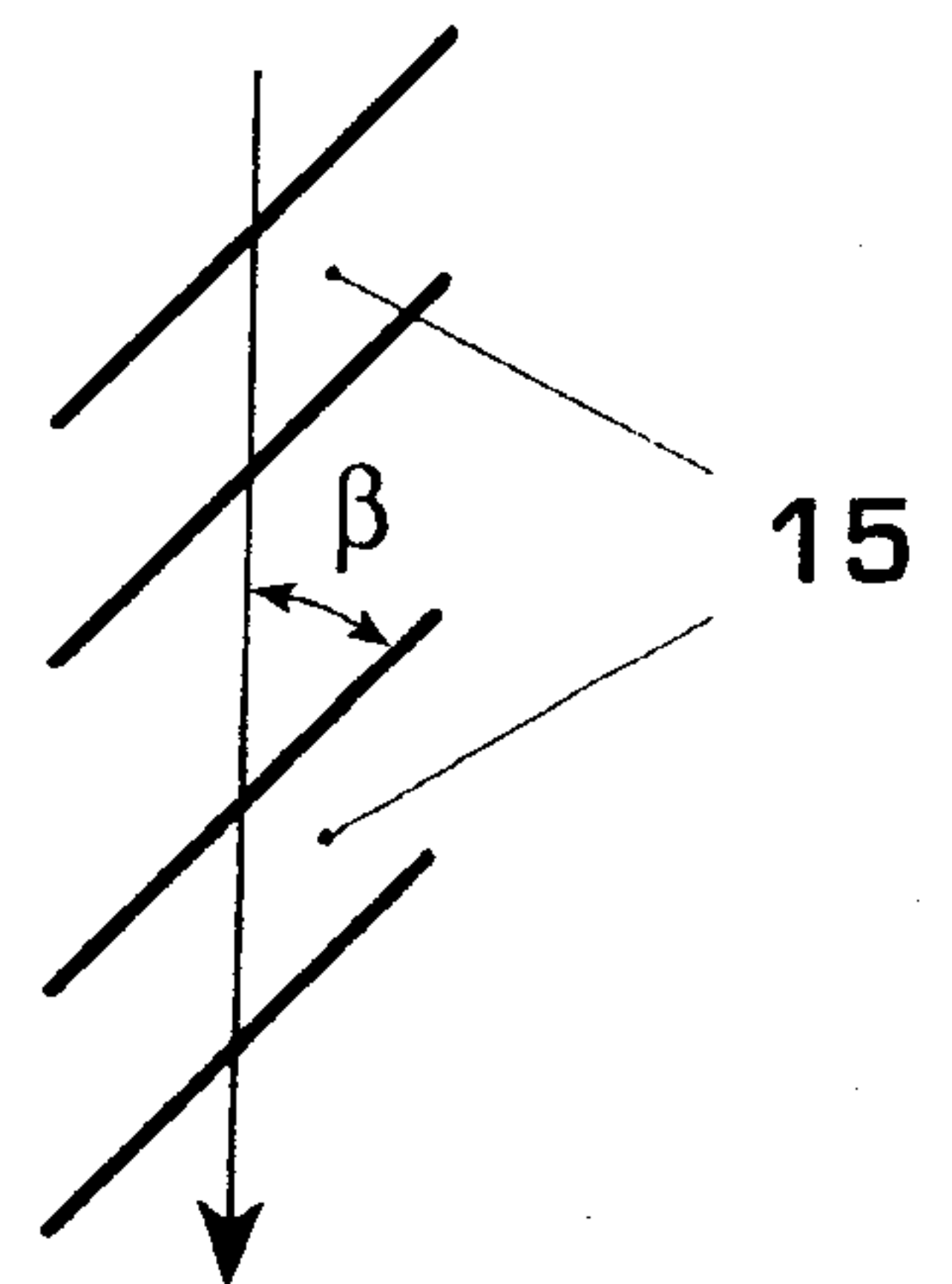


FIG. 3d

