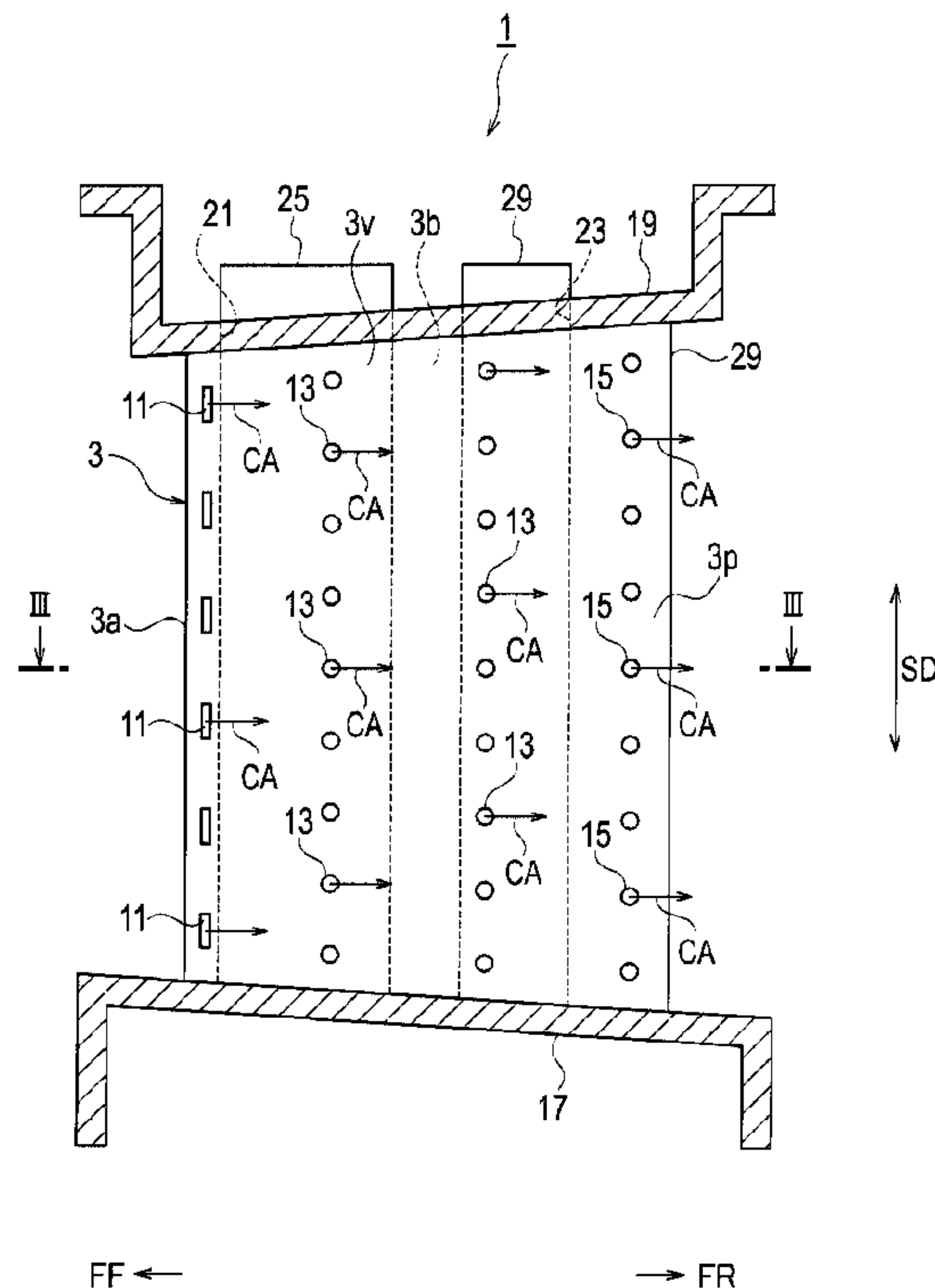




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(54) Titre : AUBE DE TURBINE AVEC TROUS DE REFROIDISSEMENT RECTANGULAIRES
(54) Title: TURBINE VANE WITH RECTANGULAR COOLING HOLES



(57) Abrégé/Abstract:

A plurality of film cooling holes (11) are formed, so as to communicate with a front cooling passage (7), in a vane surface (3a) on the front-edge side of a stator vane body (3) of a turbine stator vane (1). The hole cross-section of each of the film cooling holes (11) has a rectangular long-hole shape extending in a direction (PD) parallel to the cross-section along the span direction (SD) and having a rounded corner. The hole-center line (11c) of each of the film cooling holes (11) is inclined with respect to the thickness direction (TD) in the cross-section along the span direction (SD). The exit-side portion (11e) of the hole wall surface of each of the film cooling holes (11) is inclined with respect to the thickness direction (TD) by a greater degree than that of the hole-center line (11c).



[ABSTRACT]

A plurality of film cooling holes (11) are formed, so as to communicate with a front cooling passage (7), in a vane surface (3a) on the front-edge side of a stator vane body (3) of a turbine stator vane (1). The hole cross-section of each of the film cooling holes (11) has a rectangular long-hole shape extending in a direction (PD) parallel to the cross-section along the span direction (SD) and having a rounded corner. The hole-center line (11c) of each of the film cooling holes (11) is inclined with respect to the thickness direction (TD) in the cross-section along the span direction (SD). The exit-side portion (11e) of the hole wall surface of each of the film cooling holes (11) is inclined with respect to the thickness direction (TD) by a greater degree than that of the hole-center line (11c).

[DESCRIPTION]

[Title of Invention] TURBINE VANE WITH RECTANGULAR COOLING HOLES

[Technical Field]

[0001]

The present invention relates to a turbine vane used in a turbine for gas turbine engines such as an aircraft engine and an industrial gas turbine engine.

[Background Art]

[0002]

In general, turbine vanes to be exposed to a combustion gas while a gas turbine engine is in operation can be cooled by use of cooling air (part of compressed air) extracted from a compressor or a fan of the gas turbine engine.

[0003]

To put it specifically, a cooling passage into which the cooling air can flow is formed inside the turbine vane, and multiple film cooling holes through which the cooling air can jet out are formed in a vane surface of the turbine vane in such a way as to communicate with the cooling passage. For this reason, while the gas turbine engine is in operation, the cooling air flowing into the cooling passage is jetted out through the multiple film cooling holes, thus forms a film cooling layer which covers the vane surface of the turbine vane, and can perform film cooling on the turbine vane.

[0004]

Conventional techniques related to the present invention have been disclosed in PTL 1 and PTL 2.

[Citation List]

[Patent Literature]

[0005]

[PTL 1] JP 2009-162224 A

[PTL 2] JP 07-063002 A

[Summary of Invention]

[Technical Problem]

[0006]

In recent years, there has been increasing demand for higher output from gas turbine engines. To meet the demand, the temperature of a combustion gas tends to become very high at an entrance-side portion of a turbine. Against this background, it is imperative to increase the cooling performance of the turbine vane to a higher level by increasing film efficiency on the vane surface of the turbine vane, particularly around a front edge-side vane surface of the turbine vane (including the front edge-side vane surface) where the temperature of the component is apt to rise due to collisions of the combustion gas.

[0007]

With this taken into consideration, an object of the present invention is to provide a turbine vane having a novel configuration which is capable of fully cooling a front edge-side vane surface and its vicinity.

[Solution to Problem]

[0008]

An aspect of the present invention is a turbine vane for a turbine of a gas turbine engine, and capable of being cooled by cooling air, the turbine vane comprising: a vane body including: a vane surface; a cooling passage allowing the cooling air to flow into the vane body; and a plurality of film cooling holes formed in the vane surface on a front edge side of the vane body so as to communicate with the cooling passage

to jet out the cooling air through the plurality of film cooling holes, a hole cross section of each film cooling hole having a long-hole shape extending in a direction parallel to a cross section along a span direction of the vane body, a hole-center line of each film cooling hole tilting from a thickness direction of the vane body on a cross section of the vane surface along the span direction, and an exit-side and obtuse angle-side portion of a hole wall surface of each film cooling hole tilting further from the thickness direction than the hole-center line on the cross section along the span direction.

[0009]

In the description and scope of claims of this application, the "turbine vane" represents a turbine rotor vane and a turbine stator vane, and the "hole cross section" means a cross section perpendicular to the hole-center line. Furthermore, the "exit side" represents the exit side viewed in the flowing direction of the cooling air, and the "obtuse angle side" represents a side (region) having an obtuse angle defined with the vane surface.

[Advantageous Effects of Invention]

[0010]

The present invention makes it possible to fully diffuse the cooling air, which is jetted out through each film cooling hole, on the front edge-side vane surface of the turbine vane in the span direction while inhibiting the cooling air from coming up away from the front edge-side vane surface of the turbine vane. For this reason, it is possible to increase the film efficiency around the front edge-side vane surface of the turbine vane, and accordingly to increase the cooling performance of the turbine vane to a higher level.

[Brief Description of Drawings]

[0011]

[Fig. 1] Fig. 1 is a perspective view of a turbine stator vane of an embodiment of the present invention.

[Fig. 2] Fig. 2 is a side view of the turbine stator vane of the embodiment of the present invention, which is partially cut away.

[Fig. 3] Fig. 3 is a magnified cross-sectional view of the turbine stator vane taken along a III-III line in Fig. 2.

[Fig. 4] Fig. 4(a) is a cross-sectional view of a part of a front edge-side vane surface of the turbine stator vane of the embodiment of the present invention, which extends in a span direction; Fig. 4(b) is a magnified cross-sectional view taken along a IVB-IVB line in Fig. 4(a); Fig. 4(c) is a magnified view of a portion viewed in a direction indicated with an arrow IVC in Fig. 4(a); and Fig. 4(d) is a magnified view of a portion viewed in a direction indicated with an arrow IVD in Fig. 4(a).

[Fig. 5] Fig. 5(a) is a cross-sectional view of a front edge-side portion of a turbine vane of Invention Example, and Fig. 5(b) is a cross-sectional view taken along a VB-VB line in Fig. 5(a).

[Fig. 6] Fig. 6(a) is a cross-sectional view of a front edge-side portion of a turbine vane of Comparative Example 1, and Fig. 6(b) is a cross-sectional view taken along a XIB-VIB line in Fig. 6(a).

[Fig. 7] Fig. 7(a) is a cross-sectional view of a front edge-side portion of a turbine vane of Comparative Example 2, and Fig. 7(b) is a cross-sectional view taken along a XIIB-VIIB line in Fig. 7(a).

[Fig. 8] Fig. 8 is a schematic diagram for explaining a

stagnation point and the like on the front edge-side vane surface of the turbine vane.

[Fig. 9] Figs. 9(a), 9(b) and 9(c) are diagrams showing how the temperature is distributed around the front edge-side vane surface of the turbine vane of Invention Example.

[Fig. 10] Figs. 10(a), 10(b) and 10(c) are diagrams showing how the temperature is distributed around the front edge-side vane surface of the turbine vane of Comparative Example 1.

[Fig. 11] Figs. 11(a), 11(b) and 11(c) are diagrams showing how the temperature is distributed around the front edge-side vane surface of the turbine vane of Comparative Example 2.

[Fig. 12] Fig. 12 is a diagram showing relationships between the distance from the stagnation point on the front edge-side vane surface and film efficiency regarding the turbine vane of Invention Example, the turbine vane of Comparative Example 1 and the turbine vane of Comparative Example 2.

[Description of Embodiments]

[0012]

Descriptions will be provided for an embodiment of the present invention by referring to Fig. 1 to Fig. 4. It should be noted that in the drawings, reference sign "FF" denotes a frontward direction and reference sign "FR" denotes a rearward direction. The frontward direction means an upstream direction in the light of a flowing direction of a main stream, and the rearward direction means a downstream direction in the light of the flowing direction of the main stream.

[0013]

As shown in Figs. 1, 2 and 3, a turbine stator vane 1 of the embodiment is used for a turbine (not shown) of a gas turbine engine such as an aircraft engine and an industrial gas turbine

engine. The turbine stator vane 1 can be cooled by cooling air (part of compressed air) CA extracted from a compressor (not shown) or a fan (not shown) of the gas turbine engine. The specific configuration of the turbine stator vane 1 is as follows.

[0014]

The turbine stator vane 1 is produced (cast) by lost wax precision casting, for example. As shown in Fig. 1, the turbine stator vane 1 includes a hollow stator vane body (vane body) 3. A rib wall (partition wall) 5 is provided inside the stator vane body 3. The rib wall 5 divides the inside of the stator vane body 3 into front and rear halves, and forms a front cooling passage 7 and a rear cooling passage 9 into which the cooling air CA can flow. In other words, the front cooling passage 7 is formed in the front half of the stator vane body 3, and the rear cooling passage 9 is formed in the rear half of the stator vane body 3.

[0015]

As shown in Fig. 1, the stator vane body 3 has a vane surface 3a in its front edge-side portion. Multiple film cooling holes 11 are formed in the vane surface 3a so as to communicate with the front cooling passage 7. The cooling air CA which flows into the front cooling passage 7 is jetted out through the film cooling holes 11.

[0016]

The stator vane body 3 has a vane surface 3v in its flank portion. Multiple film cooling holes 13 are formed in the vane surface 3v so as to communicate with the front cooling passage 7 or the rear cooling passage 9. The cooling air CA which flows into the front cooling passage 7 or the rear cooling passage

9 is jetted out through the film cooling holes 13.

[0017]

The stator vane body 3 further has a vane surface 3p in its rear edge-side portion. Multiple film cooling holes 15 are formed in the vane surface 3p so as to communicate with the rear cooling passage 9. The cooling air CA which flows into the rear cooling passage 9 is jetted out through the film cooling holes 15.

[0018]

The stator vane body 3 has a vane surface 3b in its back portion. Multiple film cooling holes (not shown) similar to the film cooling holes 11, the film cooling holes 13 and the film cooling holes 15 may be formed in the vane surface 3b. In this case, too, the film cooling holes are formed communicating with the front cooling passage 7 or the rear cooling passage 9 in the same way that has been described. The cooling air which flows into the front cooling passage 7 or the rear cooling passage 9 is jetted out through the film cooling holes (not shown).

[0019]

As shown in Fig. 2, an arc-shaped inner band 17 is integrally formed on a base-side portion of the stator vane body 3 in a span direction SD. In addition, an arc-shaped outer band 19 is integrally formed on a tip-side portion of the stator vane body 3 in the span direction SD. A front insertion hole 21 is formed in the outer band 19 so as to be aligned with the front cooling passage 7 of the stator vane body 3. Meanwhile, a rear insertion hole 23 is formed in the outer band 19 so as to be aligned with the rear cooling passage 9 of the stator vane body 3. In other words, the front insertion hole 21 is formed in

the front half of the outer band 19, and the rear insertion hole 23 is formed in the rear half of the outer band 19. Moreover, the front insertion hole 21 communicates with the front cooling passage 7 of the stator vane body 3, and the rear insertion hole 23 communicates with the rear cooling passage 9 of the stator vane body 3.

[0020]

A pipe-shaped front insert 25 is arranged in the front cooling passage 7 of the stator vane body 3. The upper portion of the front insert 25 is inserted into the front insertion hole 21 of the outer band 19. Multiple front impingement cooling holes 27 are formed in the outer peripheral surface of the front insert 25. The cooling air CA is jetted out to the inner wall surface of the front cooling passage 7 through the front impingement cooling holes 27.

[0021]

A pipe-shaped rear insert 29 is arranged in the rear cooling passage 9 of the stator vane body 3. The upper portion of the rear insert 29 is inserted into the rear insertion hole 23 of the outer band 19. Multiple rear impingement cooling holes 31 are formed in the outer peripheral surface of the rear insert 29. The cooling air CA is jetted out to the inner wall surface of the rear cooling passage 9 of the stator vane body 3 through the rear impingement cooling holes 31.

[0022]

Descriptions will be subsequently provided for a main part of the embodiment of the present invention.

[0023]

As shown in Figs. 4(a), 4(c) and 4(d), an entrance-side opening and an exit-side opening of each film cooling hole 11

have a rectangular long-hole shape extending in the span direction SD, and having rounded corners. In addition, as shown in Fig. 4(a) and 4(b), the hole cross section of each of the film cooling holes 11 has a rectangular long-hole shape extending in a direction PD parallel to the cross section along the span direction SD, and having rounded corners. It should be noted that the cross section shown in Fig. 4(b) is perpendicular to a hole-center line 11c of the film cooling hole 11. In addition, the aspect ratio of the hole cross section of each film cooling hole 11 (or the ratio of the long side to the short side of the long hole viewed on the assumption that there are no rounded corners) is set in a range of 1.1 to 3.0, and preferably in a range of 1.5 to 2.5. The reason for this is that: if the aspect ratio is less than 1.1, it is difficult to fully diffuse the cooling air CA, which is jetted out through each film cooling hole 11, on the vane surface 3a in the span direction SD; and if the aspect ratio is greater than 3.0, it is difficult to process each film cooling hole 11 (for example, by electrical discharge machining).

[0024]

As shown in Fig. 4(a), the hole-center line 11c of each film cooling hole 11 tilts from a thickness direction TD of the stator vane body 3 on the cross section along the span direction SD (the cross section parallel to the span direction SD). In addition, a tilt angle θ_c of each hole-center line 11c from the thickness direction TD is set in a range of 20° to 60° or preferably in a range of 30° to 50° . The reason for this is that: if the tilt angle θ_c is less than 20° , it is difficult to process the film cooling hole 11, and stress concentration increases around the film cooling hole 11; and if the tilt angle

θ_c is greater than 60° , the cooling air CA clearly comes up away (separates) from the stator vane body 3, and the cooling performance accordingly deteriorates.

[0025]

An exit-side and obtuse angle-side portion (predetermined exit-side portion) 11e on the hole wall surface of each film cooling hole 11 tilts further to the span direction SD (or the vane surface 3c) than the hole-center line 11c of the film cooling hole 11 on the cross section along the span direction SD. In addition, a tilt angle θ_e of the predetermined exit-side portion 11e of the hole wall surface of each film cooling hole 11 to the span direction SD (or the vane surface 3a) is in a range of 5° to 20° or preferably in a range of 5° to 10° . The reason for this is that: if the tilt angle θ_e is less than 5° , it is not possible to fully diffuse the cooling air CA in the span direction SD; and if the tilt angle θ_e is greater than 20° , the stream is more likely to separate inside the hole wall surface of the film cooling hole 11, and the cooling performance accordingly deteriorates.

[0026]

Descriptions will be subsequently provided for how the embodiment of the present invention works and for effects of the embodiment.

[0027]

While the gas turbine engine is in operation, the cooling air CA flowing into the front insert 25 is jetted out to the inner wall surface of the front cooling passage 7 of the stator vane body 3 through the multiple front impingement cooling holes 27, and the cooling air CA flowing into the rear insert 29 is jetted out to the inner wall surface of the rear cooling passage

9 of the stator vane body 3 through the multiple rear impingement cooling holes 31. Thereby, the impingement cooling (inner cooling) can be performed on the turbine stator vane 1 (the stator vane body 3).

[0028]

Furthermore, the cooling air CA contributing to the impingement cooling of the turbine stator vane 1, in other words, the cooling air CA flowing into the front cooling passage 7 and the rear cooling passage 9 of the stator vane body 3 is jetted out through the multiple film cooling holes 11, the multiple film cooling holes 13 and the multiple film cooling holes 15. Thereby, the cooling air CA forms a film cooling layer (not shown) covering the front edge-side vane surface 3a, the flank-side vane surface 3v, and the like of the stator vane body 3 of the turbine stator vane 1, and can perform the film cooling on the turbine stator vane 1.

[0029]

In this respect, descriptions will be provided for a result of an analysis using a three-dimensional steady-state viscosity CFD (Computational Fluid Dynamics) on how the turbine vane is cooled by the film cooling holes of the embodiment.

[0030]

Fig. 5(a) is a cross-sectional view of a front edge-side vane surface 41a of a turbine vane 41 of the embodiment of the present invention which was simulated in the above-mentioned analysis, the cross-sectional view taken along a span direction S_1 . Meanwhile, Fig. 5(b) is a cross-sectional view taken along a VB-VB line in Fig. 5(a). This cross section is perpendicular to a hole-center line 43c of a film cooling hole 43.

[0031]

As shown in Fig. 5(a), the film cooling hole 43 is formed in the front edge-side vane surface 41a of the turbine vane 41 (see Fig. 8). In addition, the hole-center line 43c of the film cooling hole 43 tilts from a thickness direction T_1 of the turbine vane 41 at the above-mentioned tilt angle θ_c on the cross section along the span direction S_1 . Moreover, on this cross section, an exit-side and obtuse angle-side portion (predetermined exit-side portion) of the hole wall surface of the film cooling hole 43 tilts to the span direction S_1 at the above-mentioned tilt angle θ_e , and tilts further to the span direction S_1 than the hole center line 43c. As shown in Fig. 5(b), the film cooling hole 43 has a substantially rectangular cross section extending in a direction P_1 in parallel to the cross section along the span direction S_1 . In other words, the film cooling hole 43 is a substantially rectangular long hole extending in the direction P_1 .

[0032]

Fig. 6(a) is a cross-sectional view of a front edge-side vane surface 51a of a turbine vane 51 (see Fig. 8) as Comparative Example 1 which was simulated in the above-mentioned analysis, the cross-sectional view taken along a span direction S_2 . Meanwhile, Fig. 6(b) is a cross-sectional view of the front edge-side vane surface 51a taken along a VIB-VIB line in Fig. 6(a). It should be noted that this cross section is perpendicular to a hole-center line 53c of a film cooling hole 53.

[0033]

As shown in Fig. 6(a), the film cooling hole 53 is formed in the front edge-side vane surface 51a of the turbine vane 51. In addition, the hole-center line 53a of the film cooling hole

53 tilts from a thickness direction T_2 of the turbine vane 51 at the predetermined angle θ_c on the cross section along the span direction S_2 . As shown in Fig. 6(b), the film cooling hole 53 has a circular cross section on a plane perpendicular to the hole-center line 53c. It should be noted that the area of this circle is equal to the cross-sectional area of the film cooling hole 43 shown in Fig. 5(b).

[0034]

Fig. 7(a) is a cross-sectional view of a front edge-side vane surface 61a of a turbine vane 61 (see Fig. 8) as Comparative Example 2 which was simulated in the above-mentioned analysis, the cross-sectional view taken along a span direction S_3 . Meanwhile, Fig. 7(b) is a cross-sectional view of the front edge-side vane surface 61a taken along a VIIB-VIIB line in Fig. 7(a). It should be noted that this cross section is perpendicular to a hole-center line 63c of a film cooling hole 63.

[0035]

As shown in Fig. 7(a), the film cooling hole 63 is formed in the front edge-side vane surface 61a of the turbine vane 61. In addition, the hole-center line 63a of the film cooling hole 63 tilts from a thickness direction T_3 of the turbine vane 61 at the predetermined angle θ_c on the cross section along the span direction S_3 . As shown in Fig. 7(b), the film cooling hole 63 has an elliptical cross section having a major axis along a direction P_3 on a plane perpendicular to the hole-center line 63c. In this respect, the direction P_3 is in parallel to a cross section taken along the span direction S_3 . It should be noted that the area of this ellipse is equal to the cross-sectional area of the film cooling hole 43 shown in Fig. 5(b).

[0036]

Next, descriptions will be provided for conditions for the analysis. As shown in Fig. 8, this analysis was carried out on the assumption that a position of a stagnation point SP was 0° when viewed from the center OR of the curvature of the vane surface 41a of the turbine vane 41, and the exit-side opening portion of the film cooling hole 43 was formed in a position 71 which was displaced downstream of the stagnation point SP at 55° in the direction of a main flow F of a combustion gas. Furthermore, in this analysis, the front edge-side vane surfaces 41a, 51a, 61a of the respective turbine vanes 41, 51, 61 were formed into the same shape. For this reason, it was assumed that, like in the case of the film cooling hole 43, the exit-side opening portion of the film cooling hole 53 of the turbine vane 51 and the exit-side opening portion of the film cooling hole 63 of the turbine vane 61 were each formed in the position 71 which was displaced downstream of the stagnation point SP at 55° .

[0037]

Figs. 9(a) to 9(c), Figs. 10(a) to 10(c) and Figs. 11(a) to 11(c) show results of the analysis using the three-dimensional steady-state viscosity CFD. Figs. 9(a) to 9(c) show temperature distributions around the front edge-side vane surface of the turbine vane 41 of the embodiment. Figs. 10(a) to 10(c) show temperature distributions around the front edge-side vane surface of the turbine vane 51 as Comparative Example 1. Figs. 11(a) to 11(c) show temperature distributions around the front edge-side vane surface of the turbine vane 61 as Comparative Example 2. Furthermore, Fig. 9(a), Fig. 10(a) and Fig. 11(a) show the temperature distributions at the

position 71 (see Fig. 8) which was displaced downstream of the stagnation point SP at 55° in the direction of the main flow F. Similarly, Fig. 9(b), Fig. 10(b) and Fig. 11(b) show the temperature distributions at a position 73 (see Fig. 8) which was displaced downstream of the stagnation point SP at 65° . Moreover, Fig. 9(c), Fig. 10(c) and Fig. 11(c) show the temperature distributions at a position 75 (see Fig. 8) which was displaced downstream of the stagnation point SP at 75° . In this analysis, it was assumed that the Reynolds number and the blow ratio were approximately 9×10^4 and 2.0, respectively, around the front edge-side vane surface.

[0038]

In Fig. 9(a) to Fig. 11(c), an area H represents a high-temperature area corresponding to the combustion gas. On the other hand, an area M represents an area where the mixture of the combustion gas and the cooling gas jetted out through the film cooling hole 43 (53, 63) does not progress so much. In other words, the heat exchange does not progress fully between the combustion gas and the cooling gas in the area M. For this reason, the temperature of the area M is lower than that of the area H. In addition, an area L represents an area where the mixture of the cooling gas and the combustion gas progresses even less than the area M. For this reason, the temperature of the area L is lower than that of the area M.

[0039]

It is learned that the area M and the area L shown in Fig. 9(a) are distributed longer along the span direction S_1 than the area M and the area L shown in each of Fig. 10(a) and Fig. 11(a). This means that: in Fig. 9(a), the cooling air is inhibited from coming up away from the vane surface 41a (in other

words, separating from the front edge-side vane surface); and accordingly, the cooling air is fully diffused on the vane surface 41a in the span direction S_1 . It is learned that the same results are obtained by the comparison of Fig. 9(b) with Fig. 10(b) and Fig. 11(b) as well as the comparison of Fig. 9(c) with Fig. 10(c) and Fig. 11(c). In short, these results show that the film cooling holes 43 inhibit the separation of the cooling air, and obtain the full diffusion of the cooling air on the vane surface 41a.

[0040]

Moreover, Fig. 12 shows a result of an analysis on average film efficiencies of the cooling gas around the front edge-side vane surface along the span direction which was obtained from another three-dimensional steady-state viscosity CFD analysis. It should be noted that the film efficiency is defined as $(T_g - T_f) / (T_g - T_c)$, where: T_g denotes the temperature of the combustion gas; T_f denotes the temperature of the film cooling layer; and T_c denotes the temperature of the cooling air CA. In addition, the conditions for this analysis are the same as those for the foregoing analysis. That is to say, it was assumed that the Reynolds number and the blow ratio were approximately 9×10^4 and 2.0, respectively, around the front edge-side vane surface.

[0041]

In Fig. 12, a solid line indicates a change in average film efficiency η_1 of the turbine vane 41 (see Fig. 5(a) and Fig. 5(b)) of the embodiment which was used in the analysis. In addition, a dotted line indicates a change in average film efficiency η_2 of the turbine vane 51 (see Fig. 6(a) and Fig. 6(b)) of Comparative Example 1. Furthermore, a chain dashed

line indicates a change in average film efficiency η_3 of the turbine vane 61 (see Fig. 7(a) and Fig. 7(b)) of Comparative Example 2. The horizontal axis of the graph shown in Fig. 12 represents the distance of the front edge-side vane surface from the stagnation point SP. However, the distance is converted into a dimensionless distance by dividing the distance by the equivalent diameter of the hole cross section of the film cooling hole (the diameter of a circular hole having the same cross-sectional area). It can be learned from this graph that: the average film efficiency η_1 of the turbine vane 41 of the embodiment is sufficiently higher than the average film efficiencies η_2 , η_3 of the turbine vanes 51, 61 of Comparative Examples 1 and 2; and this tendency can be obtained regardless of how long the distance is.

[0042]

In the embodiment, as described above, the hole cross section of each film cooling hole 11 is shaped like a long hole extending in the direction PD parallel to the cross section along the span direction SD. In addition, the hole-center line 11c of each film cooling hole 11 tilts from the thickness direction TD on the cross section along the span direction SD. Moreover, the predetermined exit-side portion 11e of the hole wall surface of each film cooling hole 11 tilts further from the thickness direction TD than the hole-center line 11c on the cross section along the span direction SD. For this reason, each film cooling hole 11 is capable of more fully diffusing the cooling air CA, which is jetted out through the film cooling hole 11, on the vane surface 3a of the stator vane body 3 in the span direction SD while inhibiting the cooling air CA from coming up (separating) away from the vane surface 3a than the

case where the cross-sectional of the film cooling hole 11 would be shaped like a circle or an ellipse.

[0043]

In addition, the embodiment makes it possible to increase the film efficiency around the vane surface 3a of the stator vane body 3 of the turbine stator vane 1, and accordingly to increase the cooling performance of the turbine stator vane 1 to a higher level.

[0044]

It should be noted that the present invention is not limited to what has been described for the embodiment. The present invention can be carried out in other various modes including, for example, a mode where the technical idea applied to the turbine stator vane 1 is applied to a turbine rotor vane. What is more, the scope of the right included in the present invention is not limited to these embodiments.

[Industrial Applicability]

[0045]

The invention makes it possible to fully diffuse the cooling air, which is jetted out through the film cooling holes, on the front edge-side vane surface of the turbine vane in the span direction of the turbine vane while inhibiting the cooling air from coming up away from the vane surface. Thus, it is possible to increase the film efficiency around the front edge-side vane surface of the turbine vane and to increase the cooling performance of the turbine stator vane to a higher level.

[CLAIMS]

[Claim 1]

A turbine vane for a turbine of a gas turbine engine, and capable of being cooled by cooling air, the turbine vane comprising:

a vane body including:

a vane surface;

a cooling passage allowing the cooling air to flow into the vane body, and

a plurality of film cooling holes formed in the vane surface on a front edge side of the vane body so as to communicate with the cooling passage to jet out the cooling air through the plurality of film cooling holes, a hole cross section of each film cooling hole having a rectangular long-hole shape extending in a direction parallel to a cross section along a span direction of the vane body, a hole-center line of each film cooling hole tilting from a thickness direction of the vane body on a cross section of the vane surface along the span direction, and an exit-side and obtuse angle-side portion of a hole wall surface of each film cooling hole tilting further from the thickness direction than the hole-center line on the cross section along the span direction.

[Claim 2]

The turbine vane according to claim 1, wherein

an aspect ratio of the hole cross section of each film cooling hole is set in a range of 1.1 to 3.0.

[Claim 3]

The turbine vane according to claim 1 or 2, wherein

a tilt angle of the hole-center line of each film cooling hole to the thickness direction is set in a range of 20° to 60°.

[Claim 4]

The turbine vane according to any one of claims 1 to 3, wherein

a tilt angle of the exit-side and obtuse angle-side portion of the wall surface of each film cooling hole to the thickness direction is set in a range of 5° to 20°.

[Claim 5]

The turbine vane according to any one of claims 1 to 4, wherein

a plurality of other film cooling holes through which to jet out the cooling air are formed in a vane surface other than the vane surface on the front-edge side so as to communicate with the cooling passage.

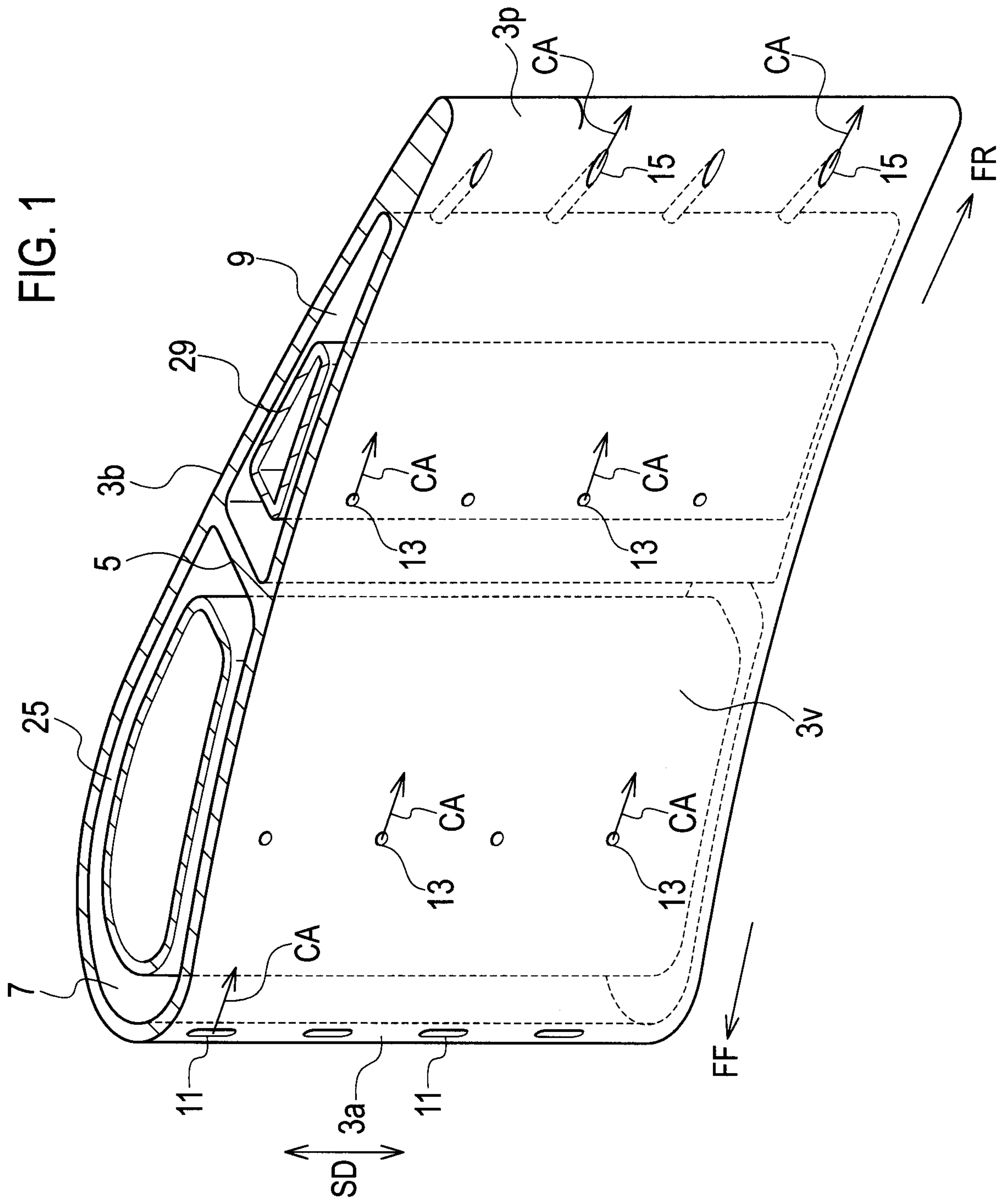


FIG. 2

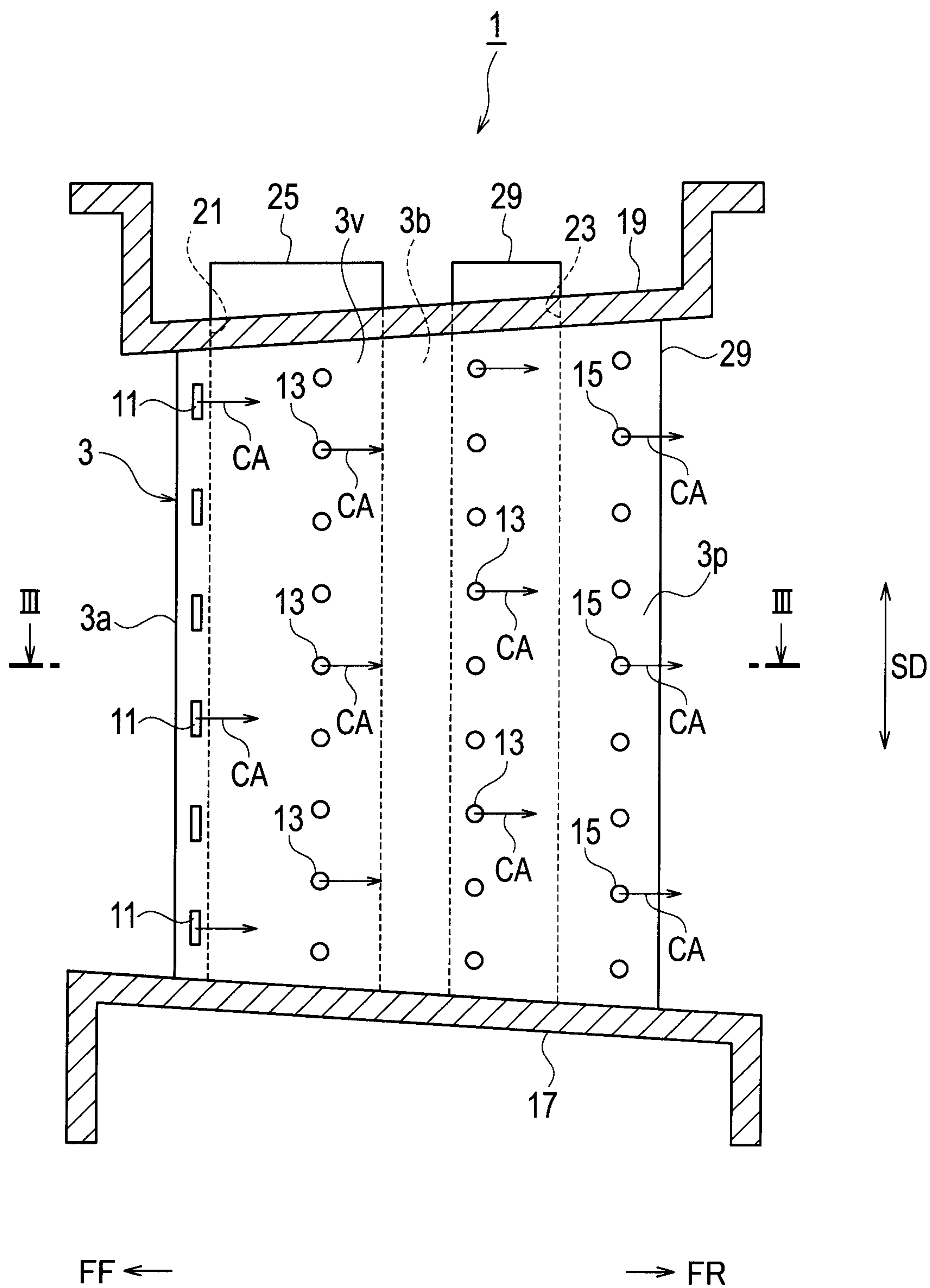
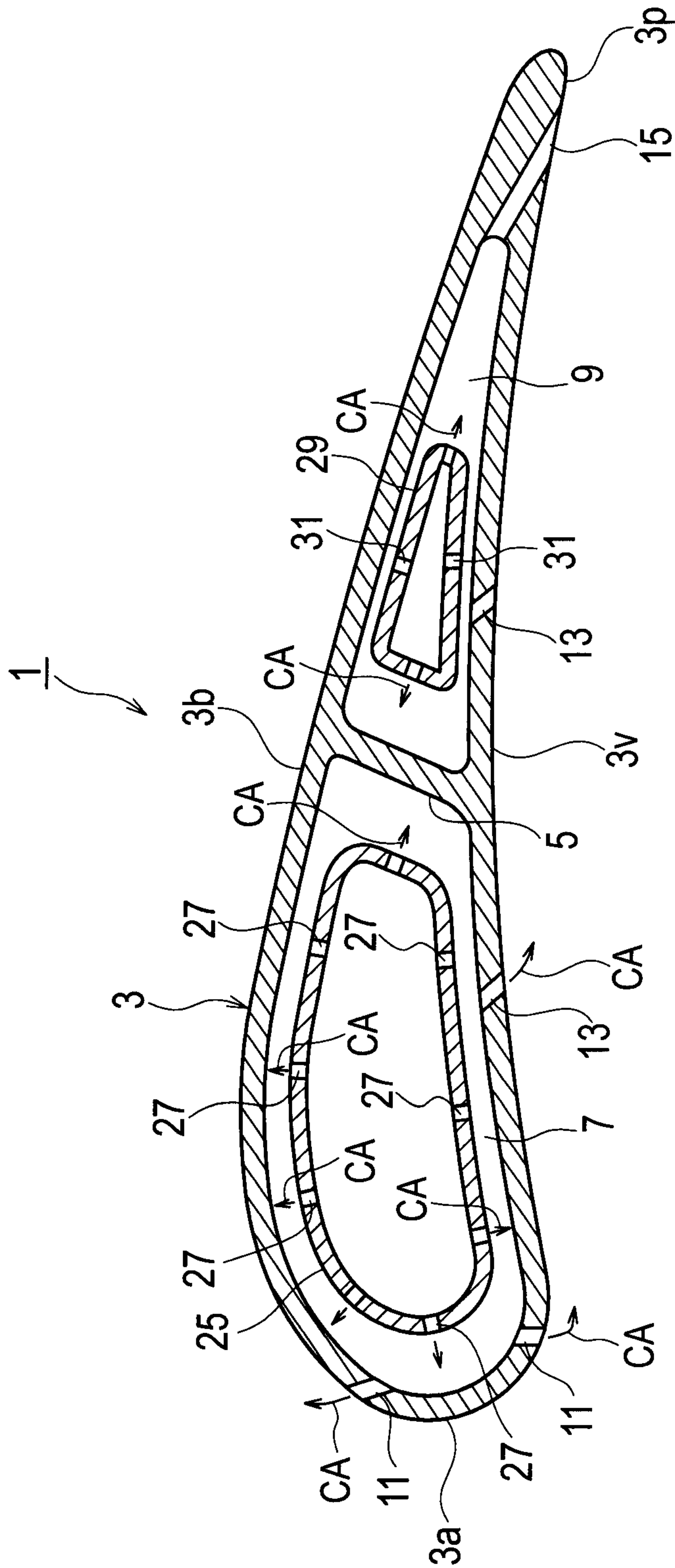


FIG. 3

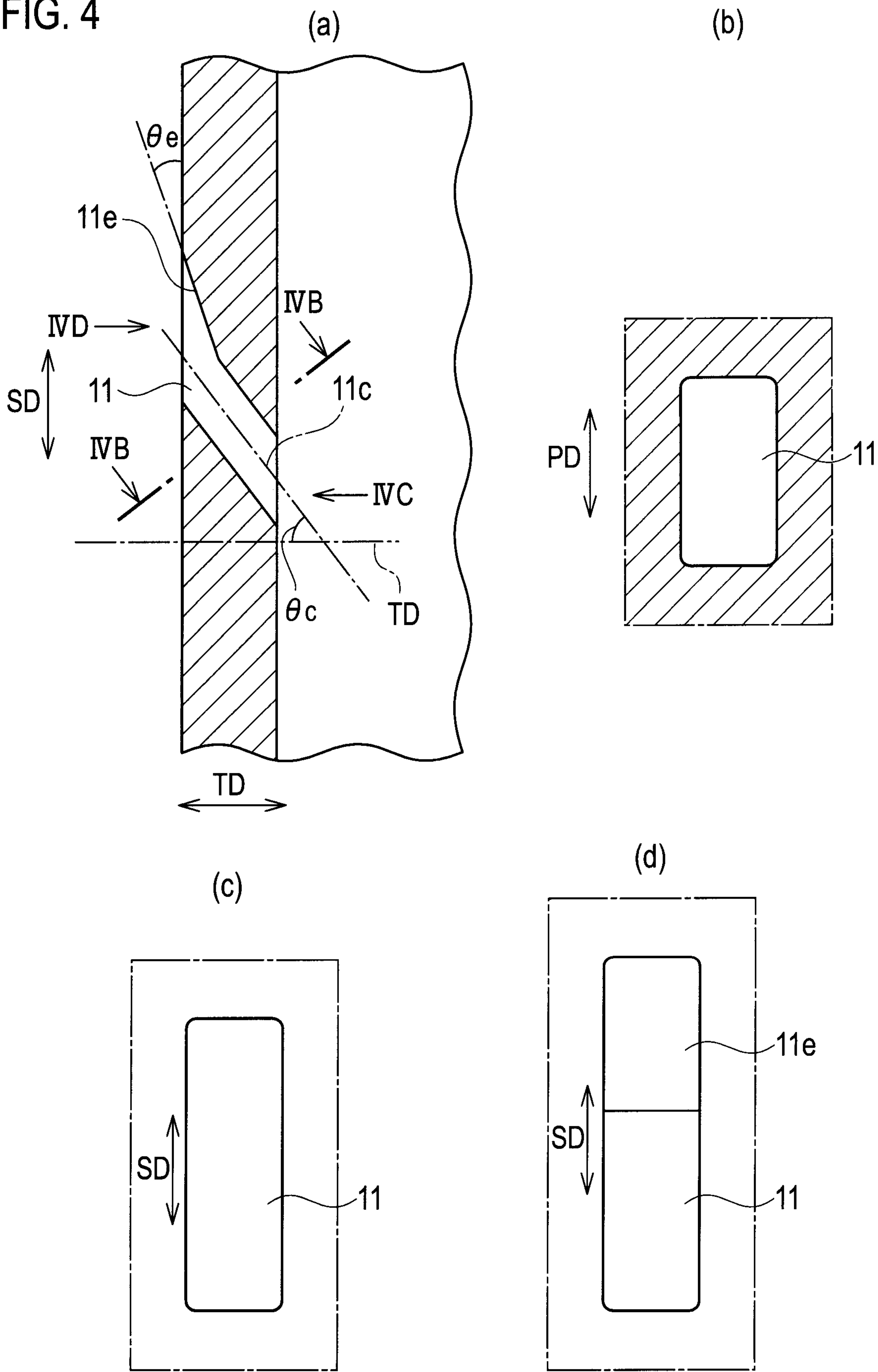


SD
⊙ ⊗

FF ←

→ FR

FIG. 4



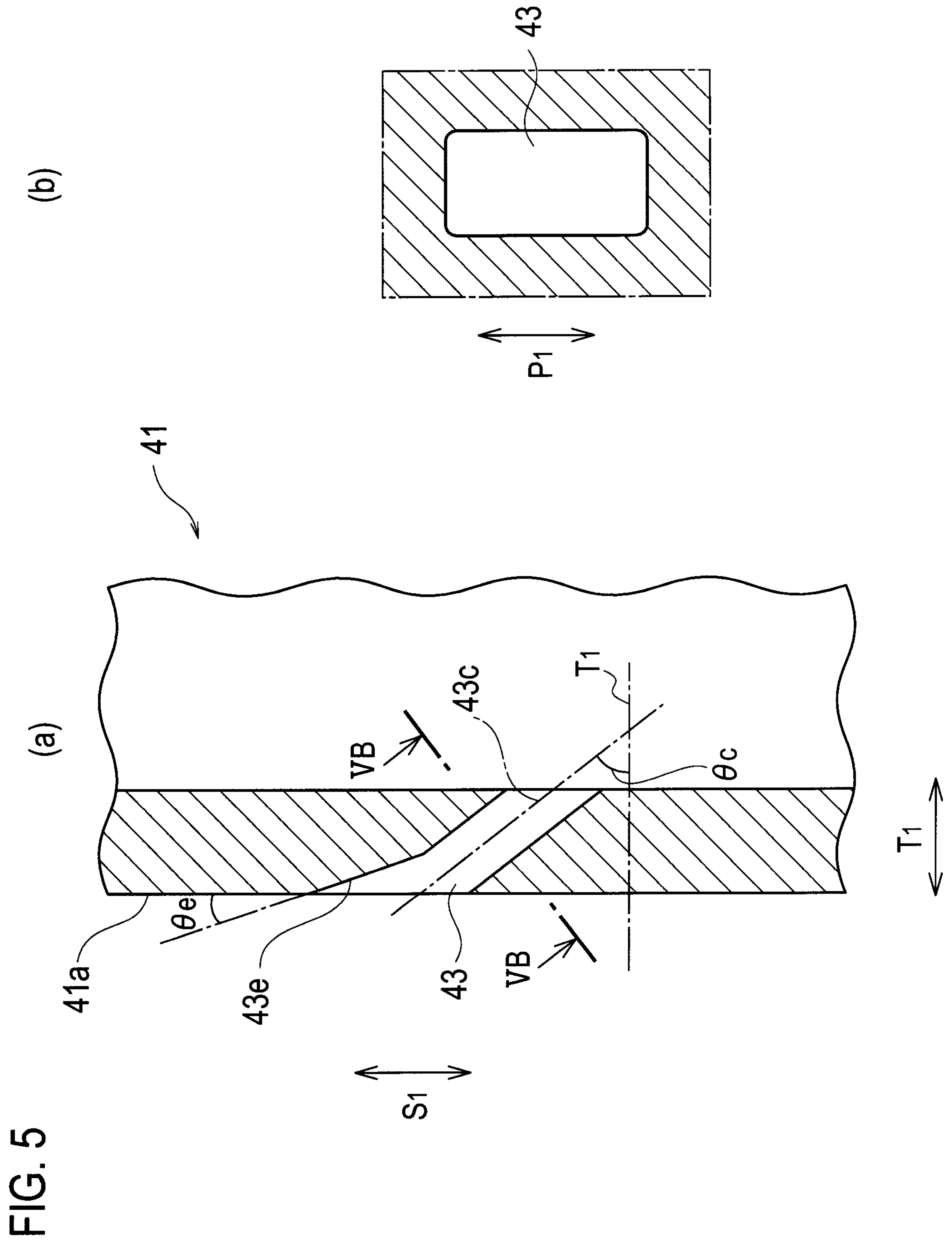
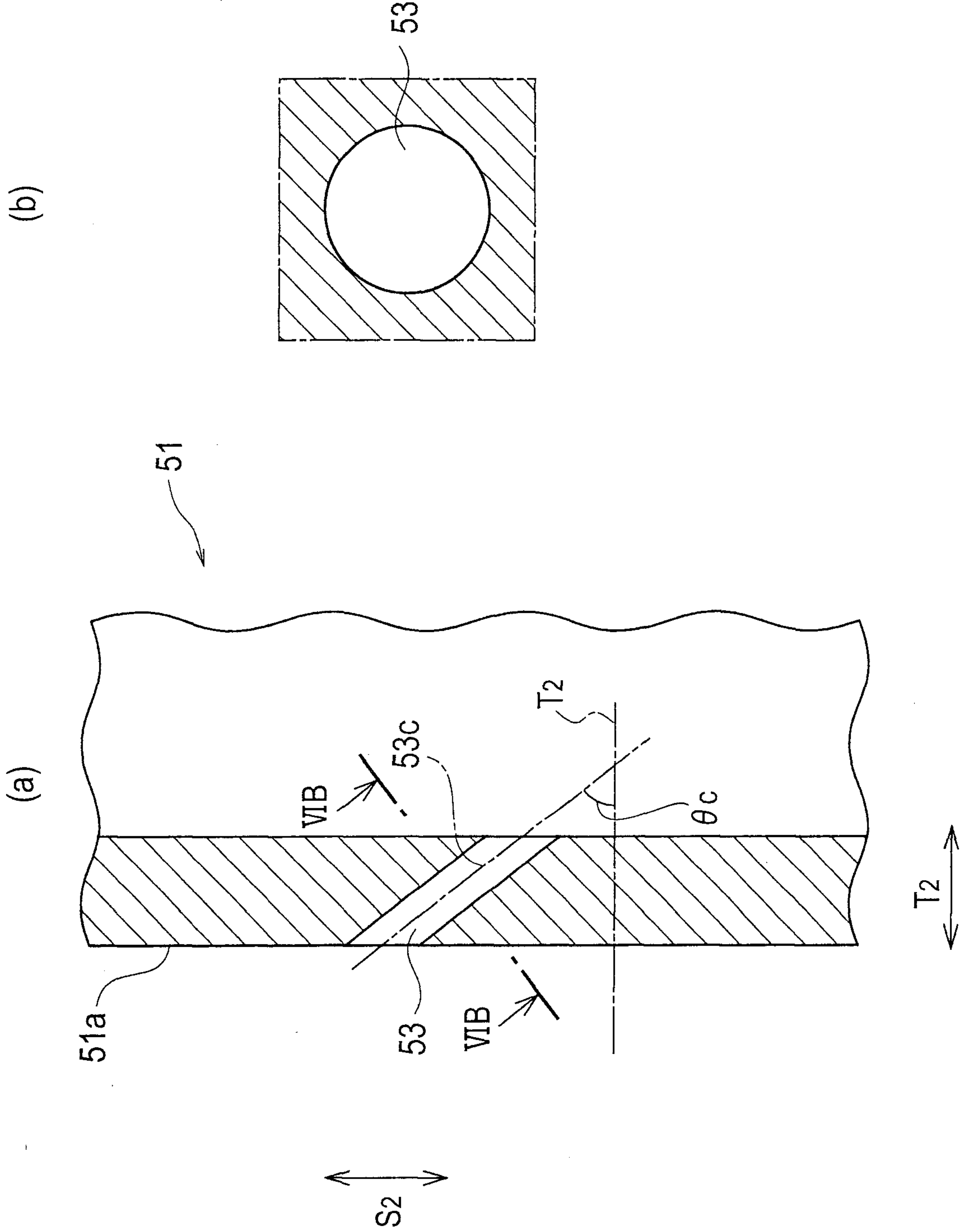
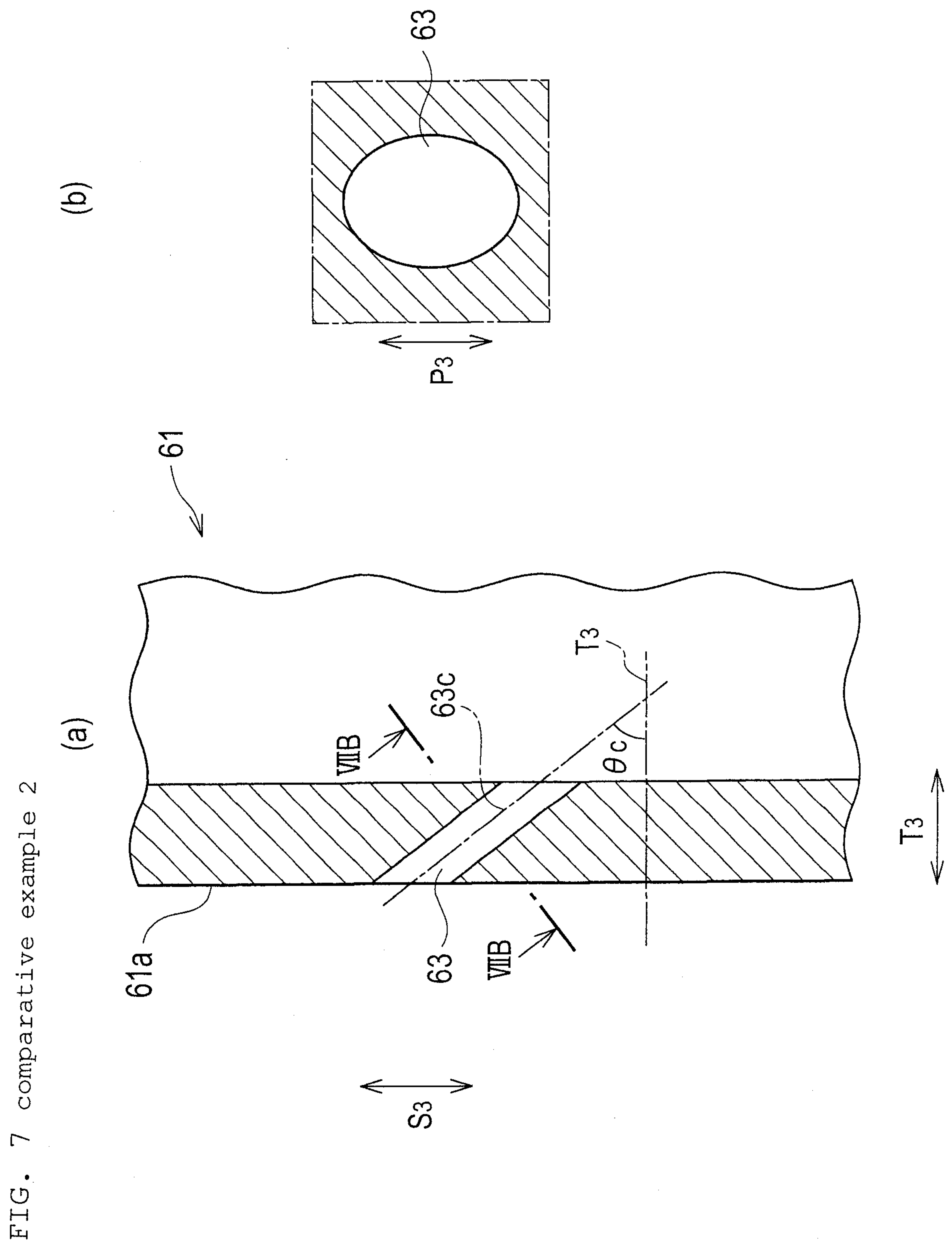


FIG. 6 comparative example 1





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FIG. 8

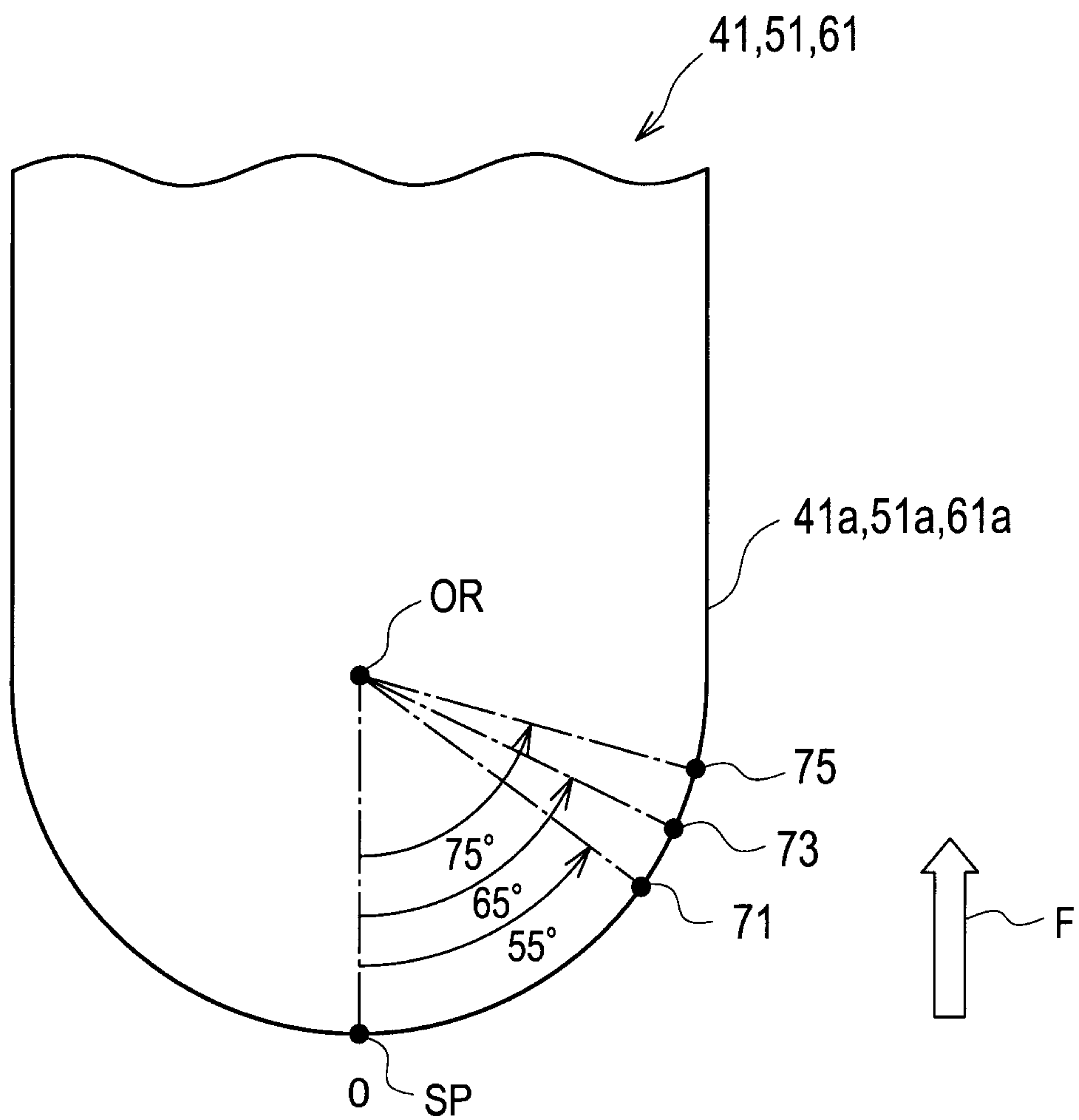


FIG. 9

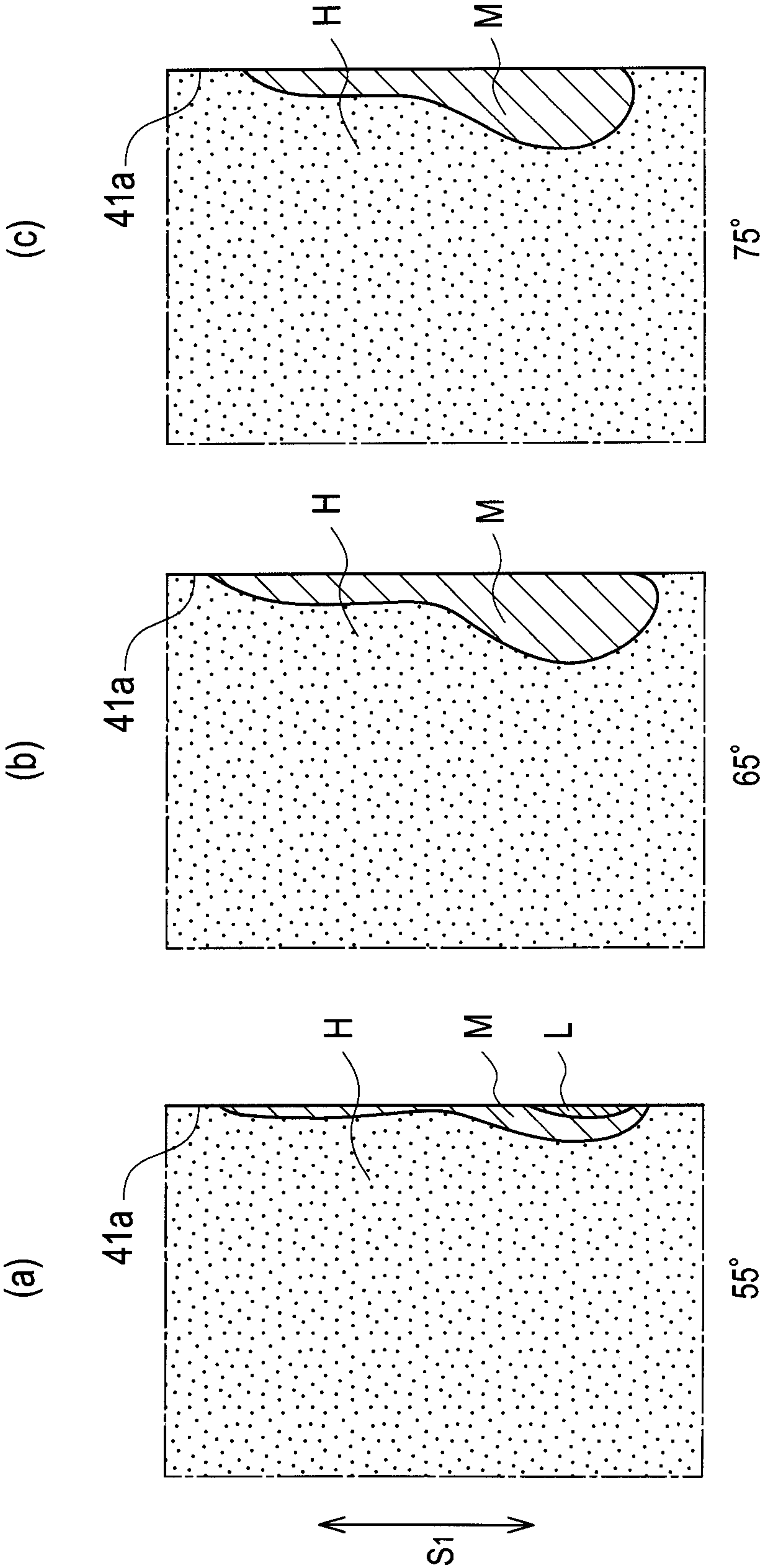


FIG. 10 comparative example 1

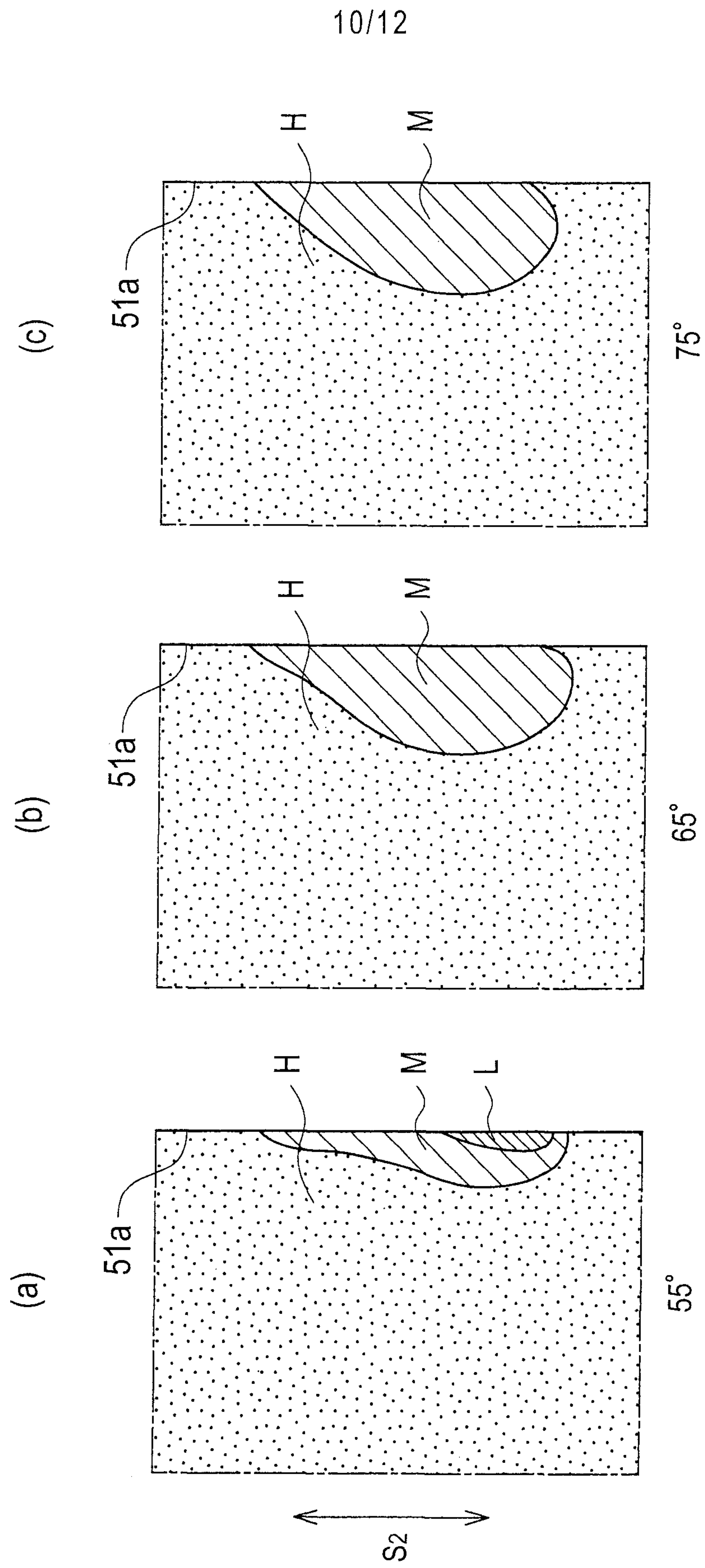


FIG. 11 comparative example 2

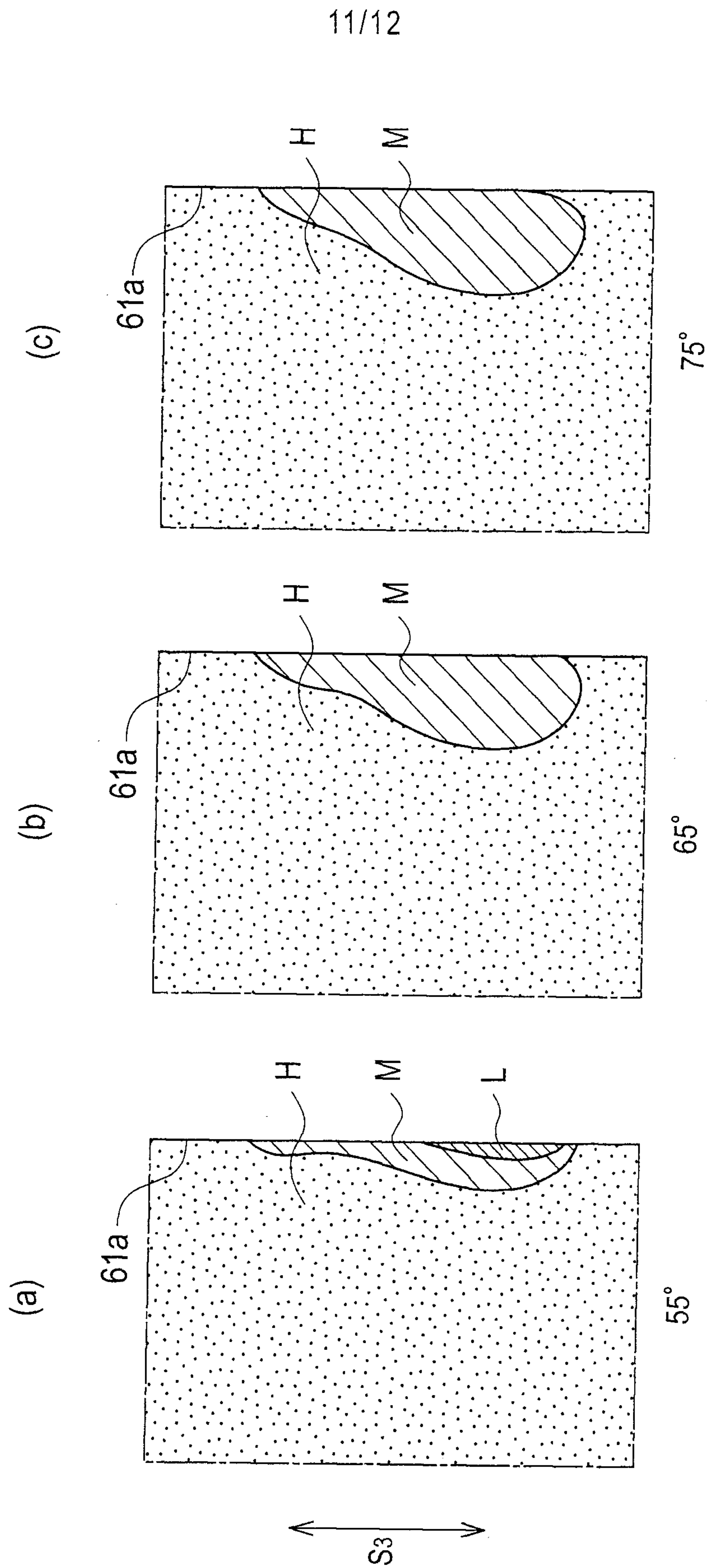
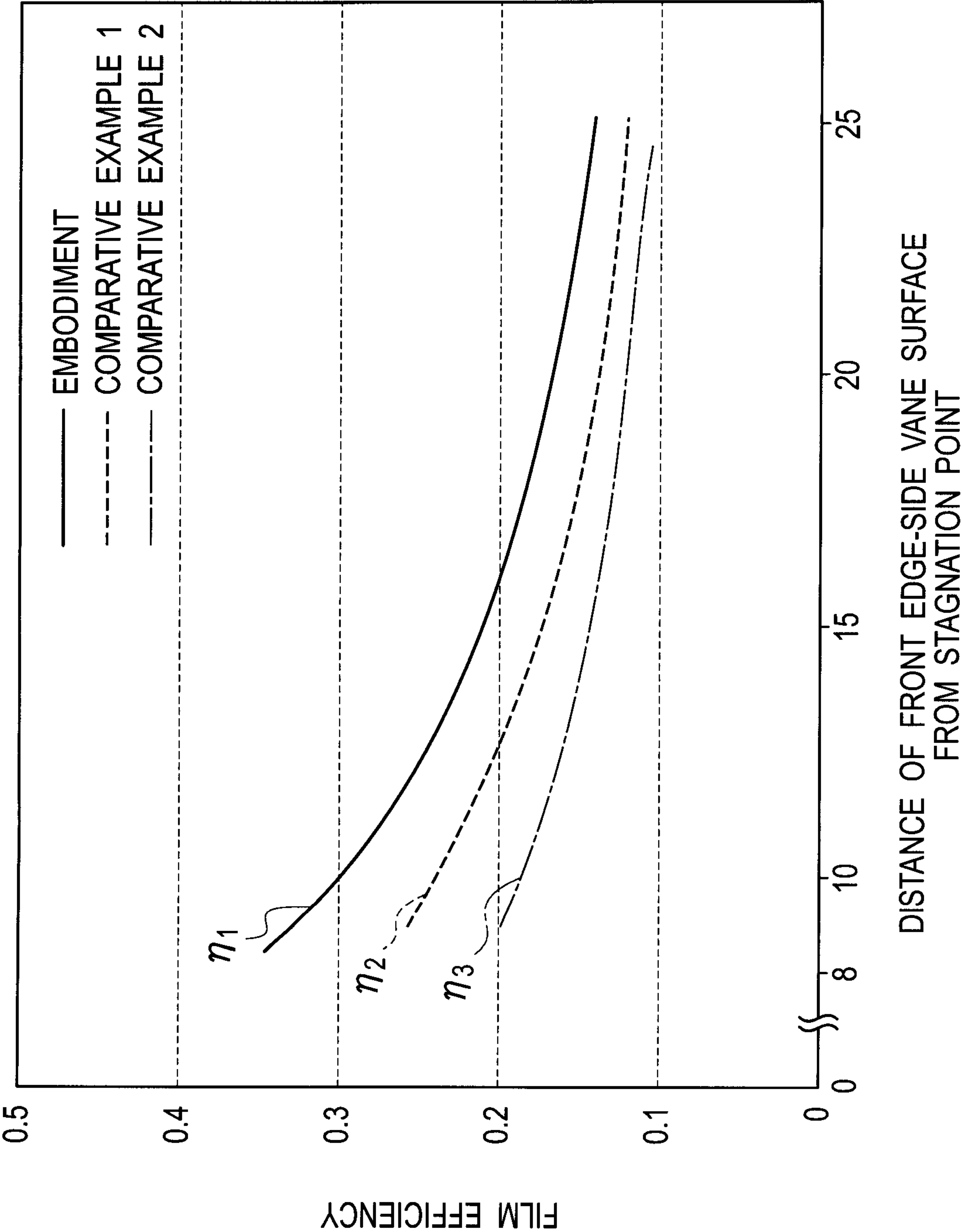


FIG. 12



1

