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(72) HALL, KENNETH, US
(72) WEIGAND, BERNHARD, DE
(72) WILFERT, GÜNTER, DE
(71) ABB RESEARCH LTD., CH

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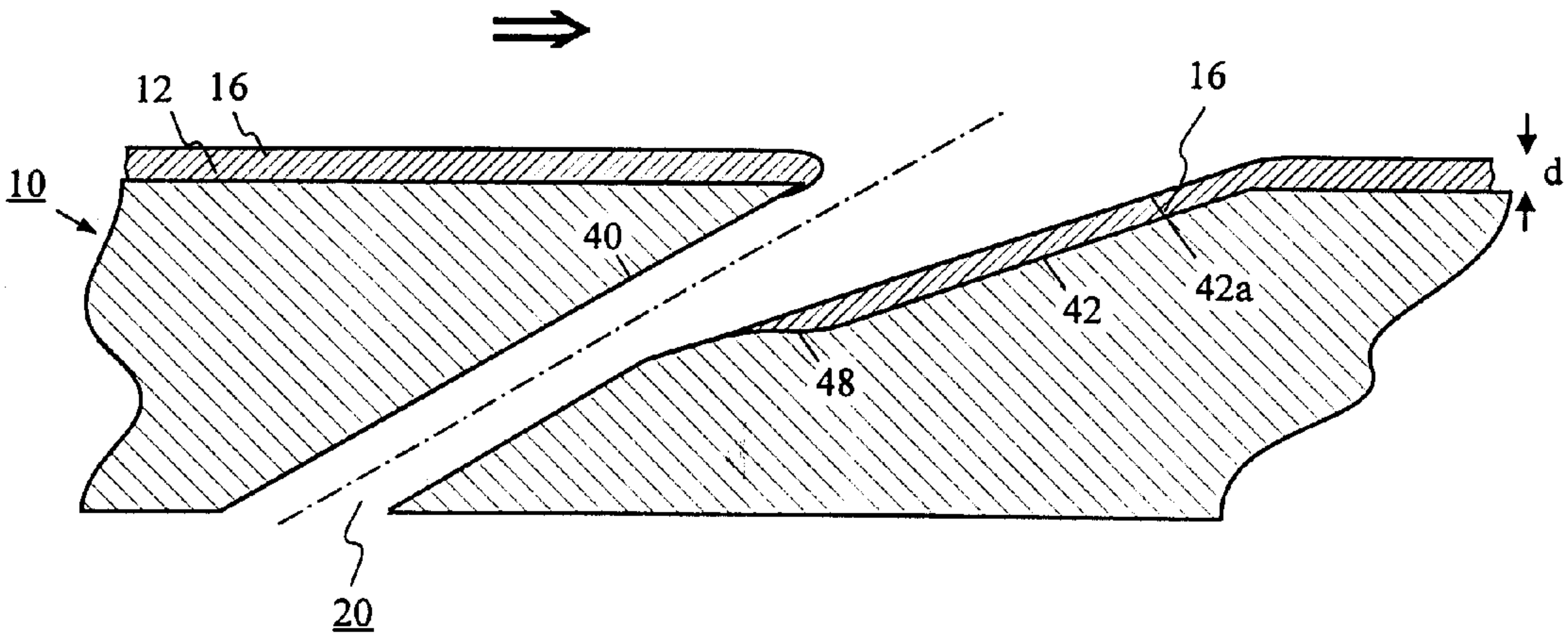
(54) **TROU DE REFROIDISSEMENT PELLICULAIRE ET METHODE DE REALISATION**

(54) **FILM-COOLING HOLE AND METHOD OF PRODUCING IT**



(57) A method of forming a film-cooling hole in a workpiece wall to be coated, the film-cooling hole, in the sequence of flow, having a feed section of constant cross-sectional area and a diffuser section widening toward an outlet at an outer surface of the wall, comprises the following steps: A) selecting the shape and size of the feed section and the diffuser section in order to achieve a desired blow-out rate of cooling air; B) selecting the desired thickness of the coating and the direction from which the coating is effected; and C) producing a film-cooling hole in the wall of the workpiece in such a way that at least portions of the boundary surfaces of the diffuser section are set back in accordance with the desired thickness of the coating, the coating direction and the angle of slope of the boundary surface in the coating direction by such a distance that the original contour selected in step A is essentially obtained after coating with the parameters selected in step B.

FILM-COOLING HOLE AND METHOD OF PRODUCING IT

ABSTRACT OF THE DISCLOSURE

A method of forming a film-cooling hole in a workpiece wall to be coated, the film-cooling hole, in the sequence of flow, having a feed section of constant cross-sectional area and a diffuser section widening toward an outlet at an outer surface of the wall, comprises the following steps: A) selecting the shape and size of the feed section and the diffuser section in order to achieve a desired blow-out rate of cooling air; B) selecting the desired thickness of the coating and the direction from which the coating is effected; and C) producing a film-cooling hole in the wall of the workpiece in such a way that at least portions of the boundary surfaces of the diffuser section are set back in accordance with the desired thickness of the coating, the coating direction and the angle of slope of the boundary surface in the coating direction by such a distance that the original contour selected in step A is essentially obtained after coating with the parameters selected in step B.

(Fig. 4)

TITLE OF THE INVENTION

Film-cooling hole and method of producing it

BACKGROUND OF THE INVENTION

Field of the Invention

The invention relates to a a film-cooling hole, in particular a film-cooling hole in a coated, cooled wall, and to a method of producing such a film-cooling hole.

Discussion of Background

To increase output and efficiency, increasingly higher turbine inlet temperatures are being used in modern gas-turbine plants. In order to protect the turbine blades from the increased hot-gas temperatures, they must be cooled more intensively than hitherto. At correspondingly high inlet temperatures, purely convective cooling is no longer sufficient. The film-cooling method is therefore often used. In this case, the turbine blades are protected from the hot gas by a cooling film. To this end, openings, for example holes, through which the cooling air is blown out, are made in the blades.

In one approach, in order to achieve as high a cooling effect as possible, the cooling air which is blown out is deflected as rapidly as possible in order to flow in a protective manner along the profile surface. In addition, the zones lying between the holes are also protected by rapid lateral spreading of the cooling air. This may be achieved by the cooling-air holes having a diffuser, which on account of the lateral widening permits a wider area of the surface to be covered. To further improve the mixing behavior, diffuser geometries in which the hole is widened not only laterally but also on the downstream side of the hole are used. The blow-out rates in the case of these diffuser geometries are small, so that there is little risk of the cooling air passing through the flow boundary layer. The cooling efficiency can therefore be increased considerably compared with a cylindrical hole. For example, publication EP-B-228 338 describes a cooled wall having a cooling-medium passage which has a dosing section and a diffuser section. The diffuser section contains a plane surface in the downstream and upstream directions respectively. Two side surfaces diverge from one another toward the cooling-medium outlet.

On the other hand, turbine-blade surfaces are often covered with a ceramic protective layer which is a poor conductor of heat. As a result, cooling air can be saved and used in the hot-gas flow, a factor which leads to an increase in the gas-turbine output. The material can then only be prevented from exceeding the admissible temperature if the blades are intensively cooled convectively on the inside. If an electrical discharge machining method is used in this case for drilling the cooling holes, the holes must be produced before the ceramic protective layer is applied, since the protective layer is electrically insulating. The subsequent coating generally covers part of the opening, as a result of which the cooling characteristics of the holes are affected. It then becomes necessary to remove the obstructing material in a further step of the method. For example, publication US-A-5,216,808 describes a method of manufacturing or repairing a gas-turbine component. In this case, after a protective layer has been applied to the component, a UV laser beam is directed toward the position of a film-cooling hole in order to remove obstructing coating material athermally.

If the holes are made by the laser percussion method, the holes may also be produced after the protective layer has been applied. However, cracks frequently develop in the protective layer in the process, and these cracks may lead to flaking of the protective layer during thermal loading. Minimizing the cross-sectional reduction has been achieved by a manufacturing process with laser percussion drilling and ceramic coating (DE-C-195 36 312).

SUMMARY OF THE INVENTION

Accordingly, one object of the invention, as defined in the patent claims, is to avoid the abovementioned disadvantages; in particular, a cooled, coated wall which is provided with cooling holes having high cooling effectiveness is to be provided. Furthermore, a method of producing such cooling holes is to be provided. This object is achieved by the method of forming a film-cooling hole of independent claim 1 and by the cooled wall of independent claim 5. Further advantageous and expedient refinements follow from the dependent claims, the description and the drawings.

The method according to the invention of forming a film-cooling hole in a workpiece wall to be coated, the film-cooling hole, in the sequence of flow, having a feed section of constant cross-sectional area and a diffuser section widening toward an outlet at an outer surface of the wall, comprises the following steps: A) selecting the shape and size of the feed section and the diffuser section in order to achieve a desired blow-out rate of cooling air; B) selecting the desired thickness of the coating and the direction from which the coating is effected; C) producing a film-cooling hole in the wall of the workpiece in such a way that at least portions of the boundary surfaces of the diffuser section are set back in accordance with the desired thickness of the coating, the coating direction and the angle of slope of the boundary surface in the coating direction by such a distance that the original contour selected in step A is essentially obtained after coating with the parameters selected in step B.

The cooled wall according to the invention, having an outer surface and a coating on the outer surface, along which a hot-gas flow flows in the downstream direction, and an inner surface, has at least one film-cooling hole inside the wall, the at least one film-cooling hole having a feed section, a diffuser section and an outlet at the outer surface, the axis of the film-cooling hole being directed in such a way that a cooling-medium flow from the outlet is directed in such a way that it has a velocity component in the downstream direction, the diffuser section having a first internal surface at a distance from a second internal surface, the first and second internal surfaces intersecting the outer surface of the wall, and the intersection edge between the first internal surface and the outer surface forming an upstream edge of the outlet, and the intersection edge between the second internal surface and the outer surface forming a downstream edge of the outlet, and the diffuser section having side surfaces, which face one another, connect the first and second internal surfaces and diverge from one another toward the outlet of the diffuser section.

The invention is accordingly based on the idea of using diffuser film-cooling holes in a coated, cooled wall and increasing the cooling effectiveness of the hole by virtue of the fact that, when the holes are being produced, the boundary surfaces of the diffuser are set back in such a way that the originally desired cooling-hole contour is essentially obtained again after the filling by the coating process.

By the use of diffuser cooling holes, the cooling air used for the convective cooling, after this task has been fulfilled, can still make a substantial contribution to the reduction in the material temperature by the formation of a cooling film. By the provision of additional space for the particles of the coating material, the film-cooling hole still fulfills the design criteria even after coating. A reduction in the cooling-air mass flow and in the film-cooling effectiveness due to partial covering of the opening is thus prevented.

In the method according to the invention, the feed section of the film-cooling hole is preferably produced by electrical discharge machining or by laser percussion drilling, and the diffuser section of the film-cooling hole is preferably produced by electrical discharge machining. It is advantageous if the requisite set-back of the boundary surfaces is calculated from the thickness of the desired coating, the coating direction and the angle of slope of the boundary surface with reference to the solidification conditions of the coating material. Coating may be effected, for example, from a direction perpendicular to the outer surface or else from a direction perpendicular to a boundary surface of the diffuser section. Depending on the coating direction, the ratio of coating thickness on the outer surface to the coating thickness on the boundary surface of the diffuser section may vary, so that the coating direction and the angle of slope of the boundary surface have to be taken into account when determining the requisite set-back.

The wall is preferably then coated with a ceramic protective layer which is a poor conductor of heat, for instance with a so-called thermal barrier coating (TBC). Coating itself is expediently effected by plasma spraying.

In the film-cooling hole described above, the second internal surface of the diffuser section is advantageously set back in the part covered by the coating by a distance corresponding to the thickness of the coating, the coating direction and the angle of slope of the second internal surface, and the set-back of the second internal surface is configured in such a way that it decreases continuously in a transition region toward the part not covered by the coating. The transition is preferably effected continuously, but may also be realized, for example, by a step.

It is also advantageous if the side surfaces of the diffuser section are set back in the part covered by the coating by a distance corresponding to the thickness of the coating, the coating direction and the angle of slope of the side surfaces, and the set-back of the side surfaces decreases continuously in a transition region toward the part not covered by the coating. It is especially preferred, within the scope of the invention, if both the second internal surface and the side surfaces of the diffuser section are set back as described.

In a refinement of the invention, the cooled wall forms the outer wall of a hollow-profile body, in particular of a gas-turbine blade.

BRIEF DESCRIPTION OF THE DRAWINGS

A more complete appreciation of the invention and many of the attendant advantages thereof will be readily obtained as the same becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawings, wherein:

Fig. 1 shows a cross section through a cooled wall with a film-cooling hole according to the prior art;

Fig. 2 shows a partial view of the cooled wall in direction II-II of Fig. 1;

Fig. 3 shows a cross section through a cooled wall with a film-cooling hole according to the invention before coating;

Fig. 4 shows a cross section through a cooled wall with a film-cooling hole according to the invention after coating.

In this case, only the elements essential for the understanding of the invention are shown. Not shown, for example, is the complete hollow-profile body and the entire arrangement of the cooling holes. The direction of flow of the hot-gas flow is designated by arrows.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to the drawings, wherein like reference numerals designate identical or corresponding parts throughout the several views, Figures 1 and 2 show a known diffuser geometry having a downstream widened portion of the film-cooling hole 20. In this case, Figure 1 shows a cross section through a wall 10 of a hollow-profile body of a gas-turbine blade having a film-cooling hole 20. The film-cooling hole 20 extends from the inner surface 14 to the outer surface 12 of the wall 10. Hot gas flows along the outer surface 12 in the direction of the arrow. The inner surface 14 is the boundary surface of a cooling-medium chamber, which contains pressurized cooling air. On the cooling-chamber side, the film-cooling hole has a cylindrical feed section 22, whose cross section at the inlet determines the cooling-air quantity flowing through.

From the feed section 22, the cooling air flows into the diffuser section 24. The diffuser section 24 has two internal surfaces 40, 42, which are at a distance from one another and diverge from one another at an angle β. The axis 26 emerges at an angle γ_1 at the outer surface 12. The internal surfaces 40, 42 form with the outer surface 12 the angles γ_1 and respectively $\gamma_2 = \gamma_1 - \beta$. In this case, β is typically below 30°, for instance between 5° and 10°. The angle γ_1 is between 5° and 50°, preferably between 25° and 35°.

The intersection edges between the internal surfaces 40, 42 and the outer surface are designated by the reference numerals 50 and 52. As can be seen in Fig. 2, the diffuser section also has side surfaces 44 and 46, which intersect the internal surfaces 40, 42. Both side surfaces 44, 46 diverge from the axis 26 of the film-cooling hole toward the outlet 36 of the diffuser section. Lateral spreading of the cooling air is thereby achieved, as a result of which a protective cooling-air film is provided on the outer surface 12 even between the individual film-cooling holes 20.

The cooling-air flow is rapidly deflected by the diffuser in the direction of flow of the hot gas, so that the cooling air which is blown out comes into contact with the profile surface as a protective film. In this case, the blow-out rates are small, so that there is little risk of the cooling air passing through the flow boundary layer.

Figure 3 shows an exemplary embodiment of a film-cooling hole according to the invention. The subsequent coating is effected from direction 60 and is intended to deposit a ceramic layer of thickness *d* on the outer surface 12. After the coating, the diffuser section 24 is to have a contour which is defined by the surfaces 40 and 42a. In accordance with the thickness *d*, the coating direction 60 and the angle of slope γ_2 of the internal surface 42a to be obtained, the size of the requisite set-back is calculated while taking into account the known solidification conditions of the coating material. The set-back contour 42 is thus obtained for the second internal surface. In a transition region 48 below the edge 18, the set-back contour of the diffuser section merges continuously into the unchanged contour 42a. The exact position of the transition region 48 depends on the coating direction 60.

In the exemplary embodiment, the film-cooling hole 20 was produced by means of the laser percussion method for the cylindrical feed section and by means of the electrical discharge machining method for the diffuser section. According to the invention, however, both sections may be produced by electrical discharge machining.

After coating has been effected by plasma spraying, the cooled, coated wall of Fig. 4 results. The outer surface 12 is covered with a protective layer 16 of thickness d. The set-back part of the internal surface 42 is filled with coating material up to the desired original contour 42a, as a result of which virtually the same cooling effectiveness as in the case of a film-cooling hole in an uncoated wall is obtained. However, the coating enables cooling air to be saved and used in the hot-gas flow, a factor which leads to an increase in the gas-turbine output.

In the exemplary embodiment shown here, only the set-back of the internal surface 42 has been described. The side surfaces 44, 46 are set back in accordance with the above explanations.

Obviously, numerous modifications and variations of the present invention are possible in light of the above teachings. It is therefore to be understood that, within the scope of the appended claims, the invention may be practiced otherwise than as specifically described herein.

CLAIMS:

1. A method of forming a film-cooling hole in a workpiece wall to be coated, the film-cooling hole, in the sequence of flow, having a feed section of constant cross-sectional area and a diffuser section widening toward an outlet at an outer surface of the wall, comprising the following steps:

A) selecting the shape and size of the feed section and the diffuser section in order to achieve a desired blow-out rate of cooling air;

B) selecting the desired thickness of the coating and the direction from which the coating is effected; and

C) producing a film-cooling hole in the wall of the workpiece in such a way that at least portions of the boundary surfaces of the diffuser section are set back in accordance with the desired thickness of the coating, the coating direction and the angle of slope of the boundary surface in the coating direction by such a distance that the original contour selected in step A is essentially obtained after coating with the parameters selected in step B.

2. The method as claimed in claim 1, in which, in step C, the feed section of the film-cooling hole is produced by electrical discharge machining or by laser percussion drilling, and the diffuser section of the film-cooling hole is produced by electrical discharge machining.

3. The method as claimed in either of the preceding claims, in which the set-back necessary in step C is calculated from the thickness of the desired coating, the coating direction and the angle of slope of the boundary surface with reference to the solidification conditions of the coating material.

4. The method as claimed in one of the preceding claims, in which the wall is coated in a step D) with a ceramic protective layer which is a poor conductor of heat.

5. A cooled wall (10) having an outer surface (12) and a coating (16) on the outer surface (12), along which a hot-gas flow flows in the downstream direction, and an inner surface (14), and at least one film-cooling hole (20) inside the wall, obtainable by the method as claimed in one of claims 1 to 3, the at least one film-cooling hole (20) having a feed section (22), a diffuser section (24) and an outlet (36) at the outer surface (12), the axis (26) of the film-cooling hole (20) being directed in such a way that a cooling-medium flow from the outlet (36) is directed in such a way that it has a velocity component in the downstream direction, the diffuser section (24) having a first internal surface (40) at a distance from a second internal surface (42), the first and second internal surfaces (40, 42) intersecting the outer surface (12) of the wall, and the intersection edge between the first internal surface (40) and the outer surface (12) forming an upstream edge (50) of the outlet (36), and the intersection edge between the second internal surface (42) and the outer surface (12) forming a downstream edge (52) of the outlet, and the diffuser section (24) having side surfaces (44, 46), which face one another, connect the first and second internal surfaces (40, 42) and diverge from one another toward the outlet (36) of the diffuser section.

6. The cooled wall as claimed in claim 5, in which the coating (16) is a ceramic protective layer which is a poor conductor of heat.

7. The cooled wall as claimed in claim 5 or 6, wherein the second internal surface (42) of the diffuser section (24) is set back in the part covered by the coating (16) by a distance corresponding to the thickness of the coating (16), the coating direction and the angle of slope of the second internal surface (42), and the set-back of the second internal surface (42) decreases continuously in a transition region (48) toward the part not covered by the coating (16).

8. The cooled wall as claimed in one of claims 5 to 7, in which the side surfaces (44, 46) of the diffuser section (24) are set back in the part covered by the coating (16) by a distance corresponding to the thickness of the coating (16), the coating direction and the angle of slope of the side surfaces (44, 46), and the set-back of the side surfaces (44, 46) decreases continuously in a transition region toward the part not covered by the coating (16).

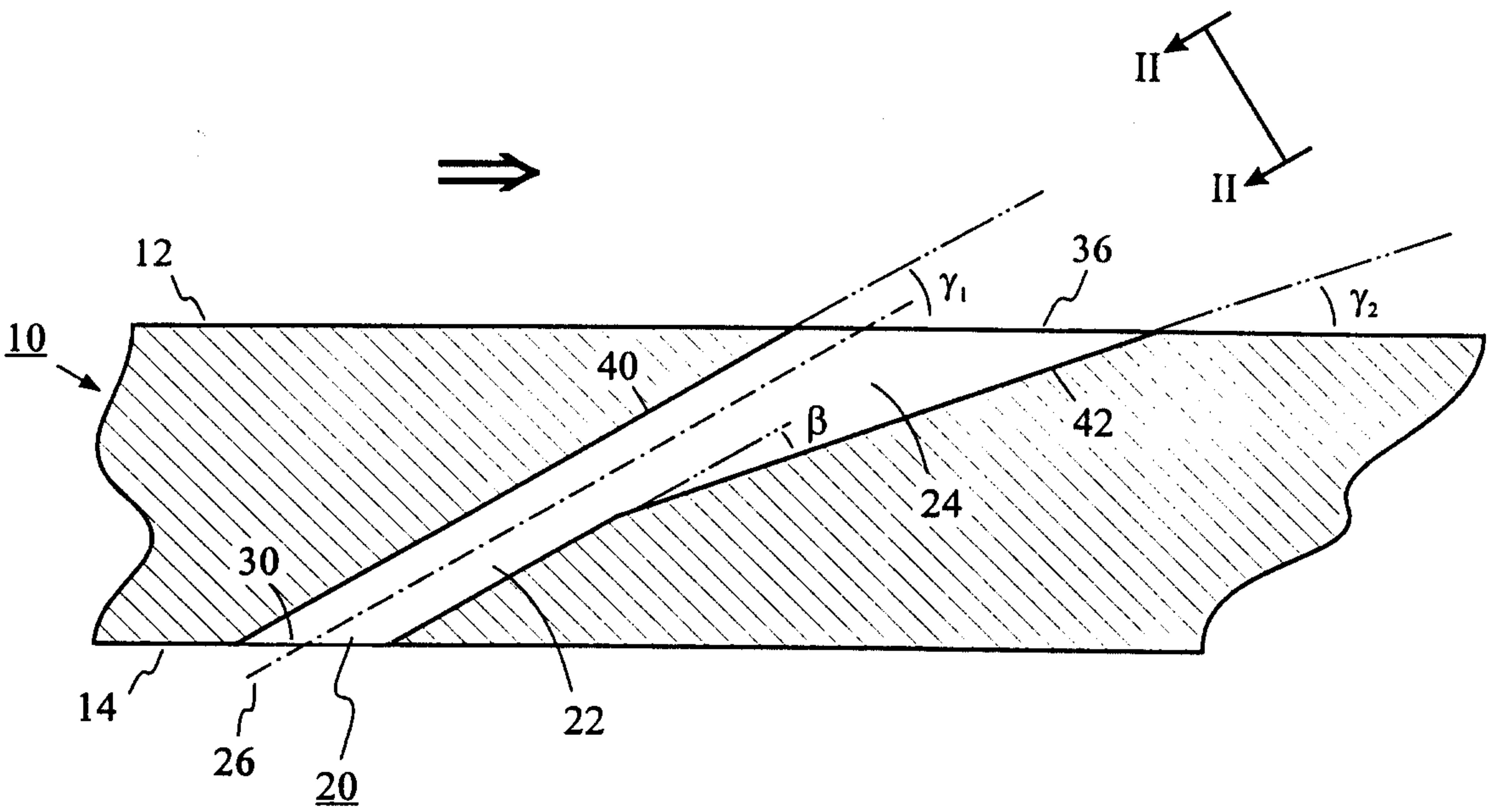


Fig. 1

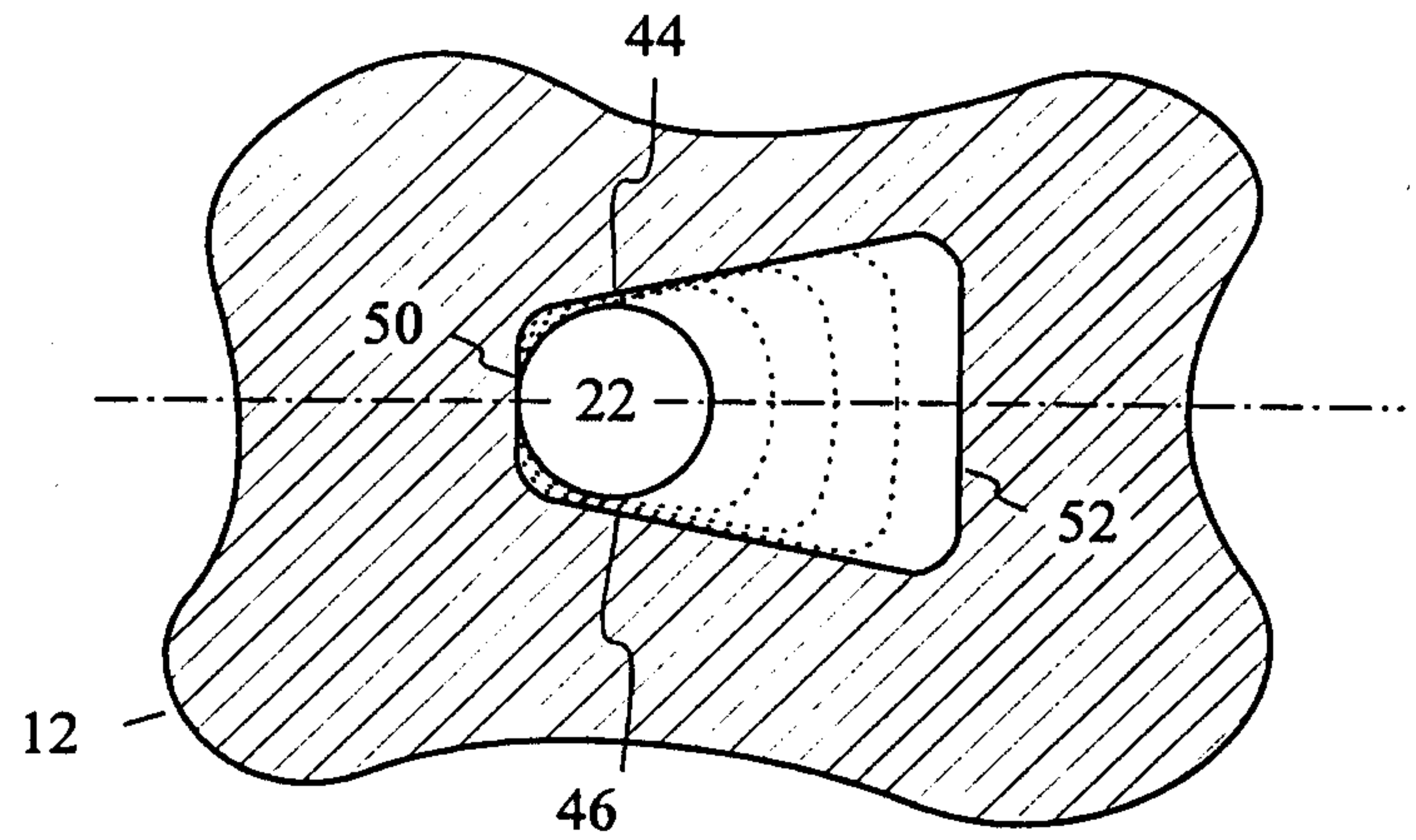


Fig. 2

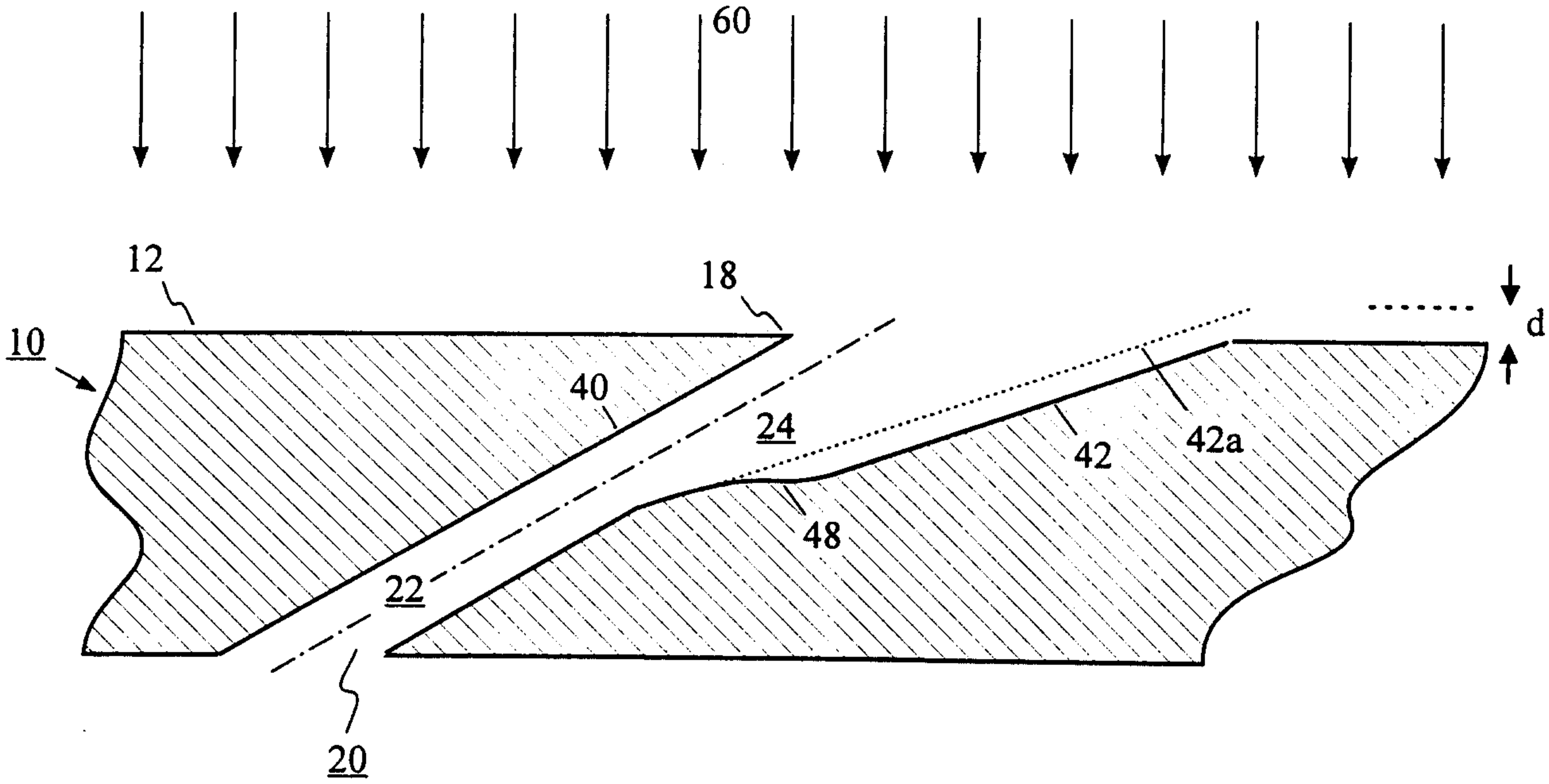


Fig. 3

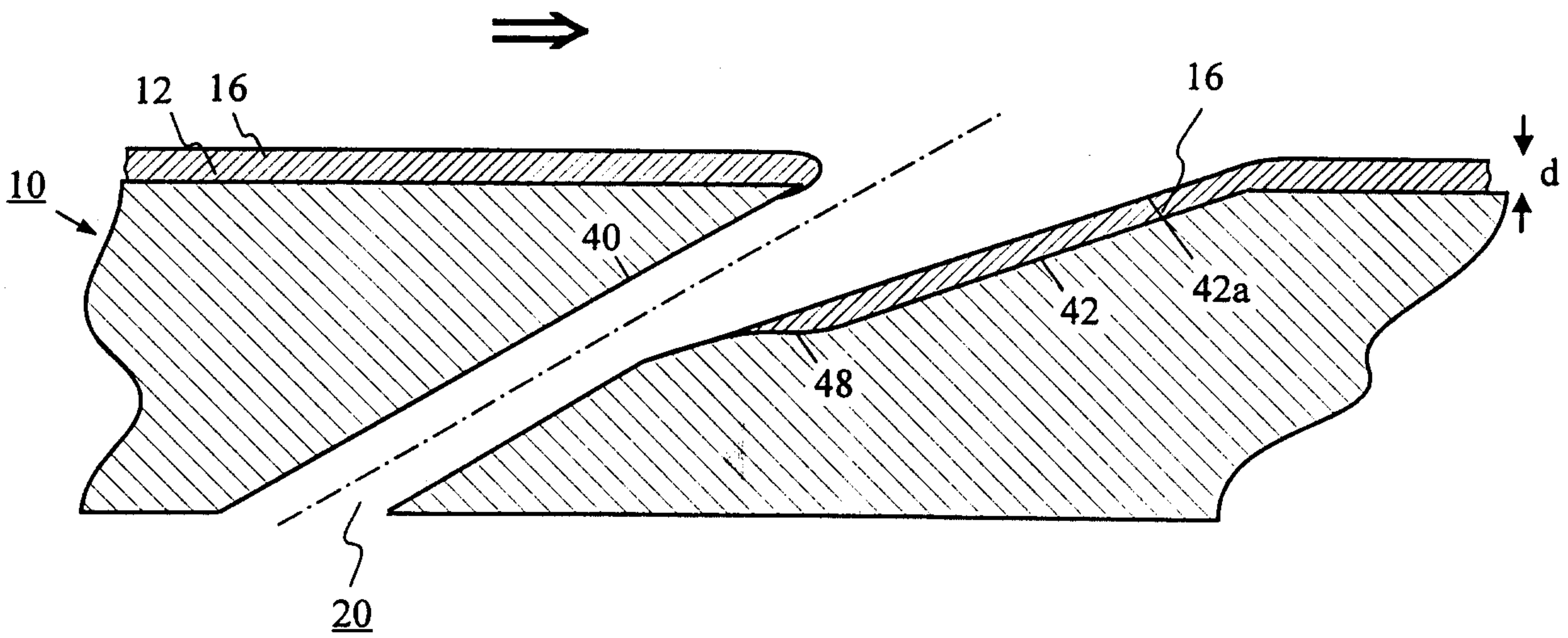


Fig. 4