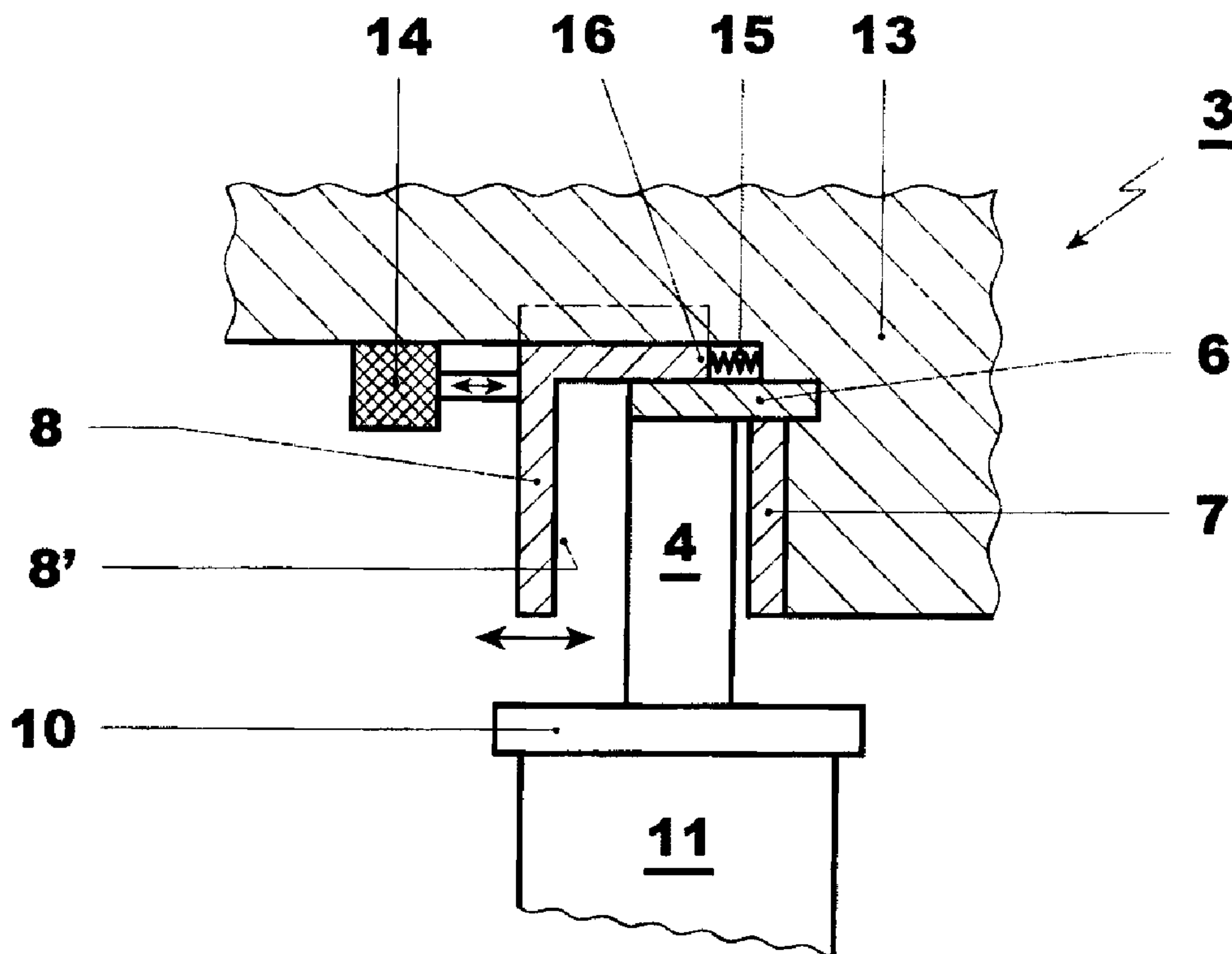




(22) Date de dépôt/Filing Date: 2009/03/26  
 (41) Mise à la disp. pub./Open to Public Insp.: 2009/09/28  
 (45) Date de délivrance/Issue Date: 2016/03/01  
 (30) Priorité/Priority: 2008/03/28 (CH00459/08)

(51) Cl.Int./Int.Cl. *F01D 11/00* (2006.01),  
*F16J 15/44* (2006.01), *F16J 15/54* (2006.01)  
 (72) Inventeurs/Inventors:  
OLMES, SVEN, CH;  
HURTERN, JONAS, CH  
 (73) Propriétaire/Owner:  
ALSTOM TECHNOLOGY LTD., CH  
 (74) Agent: SMART & BIGGAR

(54) Titre : GARNITURE D'ETANCHEITE LAMELLAIRE POUR TURBOMACHINE  
 (54) Title: LEAF SEAL FOR TURBOMACHINE



(57) **Abrégé/Abstract:**

A leaf seal (3) for sealing a radial gap between a stator and rotor (1) of a turbomachine has a plurality of metallic sealing leaves (4), which are arranged in a row, and are attached to a carrier (6), and are arranged concentrically around the circumference of the rotor (1) of the turbomachine. The seal (3) has a front plate and a rear plate (8) which are attached to the carrier (6) and extend over the circumference of the seal (3) on both sides of the sealing leaves (4). According to the invention, the seal (3) has an apparatus (14) for controlled variation of the axial distance (d) between the rear plate (8) and the sealing leaves (4) during operation of the turbomachine. The deliberate variation of the gap width (d) makes it possible to optimize the sealing effect, with minimized wear of the seal, and therefore makes possible an increased operating life of the seal.

## Abstract

A leaf seal (3) for sealing a radial gap between a stator and rotor (1) of a turbomachine has a plurality of metallic sealing leaves (4), which are arranged in a row, and are attached to a carrier (6), and are arranged concentrically around the circumference of the rotor (1) of the turbomachine. The seal (3) has a front plate and a rear plate (8) which are attached to the carrier (6) and extend over the circumference of the seal (3) on both sides of the sealing leaves (4). According to the invention, the seal (3) has an apparatus (14) for controlled variation of the axial distance (d) between the rear plate (8) and the sealing leaves (4) during operation of the turbomachine. The deliberate variation of the gap width (d) makes it possible to optimize the sealing effect, with minimized wear of the seal, and therefore makes possible an increased operating life of the seal.

(Figure 3a)

**Leaf seal for turbomachine**

## Technical field

5

The invention relates to a leaf seal for sealing between a stator and rotor of a turbomachine, for example a gas turbine or a compressor.

10

## Prior art

Leaf seals, also referred to as sealing leaves, are frequently used in turbomachines for sealing gaps between the rotating shaft and the stator (casing, stator blades), whose radial extent varies during machine operation. Leaf seals allow these gaps to be sealed, because of their flexible sealing elements.

By way of example, leaf seals of this type are known from US 6,343,792. They comprise a plurality of individual metallic leaves, which are arranged in a row and form a ring at a predetermined distance between the sealing leaves, which ring is attached to the stator and is arranged around the rotor of the machine. In this case, the metal leaves are at an angle to the radial direction of the rotor, in which case this angle may either be of equal magnitude or may vary slightly over the length of the leaf, that is to say the leaves are slightly curved. They are highly flexible in the circumferential direction. In contrast, in the axial direction of the machine, that is to say in the direction of the pressure differential, they are highly rigid, which makes it possible to withstand a greater pressure difference while maintaining a radial freedom of movement. Leaf seals of this type are furthermore distinguished in that, in comparison to other flexible seals such as brush seals, they have a low friction resistance. This is a result of a dynamic pressure which is created in the area of the sealing leaves on

the shaft during machine operation, allowing the leaf ends to be lifted off by a minimum distance of the order of magnitude of micrometers, thus reducing the friction.

5

An end plate is frequently arranged in each case on the high-pressure side and on the low-pressure side of the sealing leaves. These are separated axially from the sealing leaves as shown in Figures 12 and 13 in  
10 US 6,343,792, in such a way as to allow the leaves to move without friction. The radial extent of the end plates is in this case approximately equal to that of the sealing leaves.

15 Further leaf seals for turbines with end plates of this type are disclosed, for example, in EP 1 231 416. There, the seal has an annular element 50, which maintains the distance between the end plate and the sealing leaves on the low-pressure side of the sealing  
20 leaves, and thus predetermines the pressure distribution over the seal.

DE 10 2004 020 378 discloses a leaf seal for a turbine, and in particular a separation between the individual  
25 sealing leaves, which allows an air gap and an air flow through the seal which, depending on the extent of the air flow, initiates a so-called blow-down or blow-up effect. In the case of a blow-down effect, the sealing leaves are pressed against the shaft while, in the case  
30 of a blow-up effect, they are pressed away from the shaft. The extent of the air flow and the corresponding behavior of the sealing leaves during machine operation can be predetermined by using spacing elements to select the distance between the sealing leaves.  
35 Furthermore, the air flow can also be predetermined by a selected and fixed axial distance between the end plates and the sealing leaves on the high-pressure side and on the low-pressure side, as disclosed in Figure 3 there.

Leaf seals of this type are typically produced by mechanical techniques such as firm clamping, welding or brazing, or a combination of these techniques.

5

EP 1 626 210 discloses a leaf seal of this type with sealing leaves with a T-shaped cross section and with end plates on the high-pressure side and low-pressure side, which are each fixed in a groove on the sealing  
10 leaves. The distances between the end plates and the sides of the sealing leaves are thus fixed. The end plate on the low-pressure side is formed with a step, such that the distance between end plate and sealing leaf is greater in an area close to the rotor than in  
15 an area further away from the rotor. The distance on the low-pressure side is in each case greater than the distance on the high-pressure side.

WO 2006/016098 discloses a further leaf seal, in which  
20 the sealing leaves are radially inclined at their edge on the high-pressure side, and an end plate on the high-pressure side has a projection on its rotor-side edge, which projection extends axially toward the sealing leaves. When the sealing leaves bend, the  
25 incline results in the gap between the end plate and the sealing leaves being enlarged, as a result of which the aerodynamic forces change in a corresponding manner. Different embodiments have different, predetermined inclines for specific machines, which  
30 point either toward the high-pressure side of the seal or toward the low-pressure side, with the axial projections on the end plate having predetermined shapes which differ for specific machines.

35

#### Description of the invention

The present invention is based on the object of providing a leaf seal for sealing the radial gap between the stator and rotor of a turbomachine, which

has a longer operating life than leaf seals from the prior art and thus allows more cost-effective sealing.

A leaf seal for a turbomachine in order to seal a radial gap between the stator and rotor of the turbo-  
5 machine has a plurality of metallic sealing leaves which are arranged in a row and are attached to an annular carrier, and are arranged concentrically over the circumference of a rotor of the turbomachine. The  
10 sealing leaves are in this case arranged inclined at an angle to the radial direction of the rotor and in the opposite direction to the rotation direction. Furthermore, the seal has a front plate and a rear plate which are connected to the carrier and extend  
15 over the circumference of the seal, and are at an axial distance from the plurality of sealing leaves with respect to the rotor of the turbomachine. The front plate is in this case located on the high-pressure side and the rear plate on the low-pressure side of the  
20 sealing leaves. According to the invention, the leaf seal has an apparatus for actively controlled variation, during machine operation, of the axial distance between the edges of the sealing leaves and the rear plate on the low-pressure side.

25

By variation of the distance between the rear plate and the sealing leaves, the seal according to the invention allows an optimum setting of the blow-down effect and blow-up effect for each operating state of the machine.  
30 For each operating state, both in the transient and steady-state operating states and for the radial gap sizes which occur in this case, this ensures an optimum sealing function in which case, at the same time, a minimal amount of wear to the sealing leaves, which  
35 would be created by the leaves rubbing against the rotor, can be set to a minimal extent. Minimal wear ensures correspondingly optimized life of the seal. The active setting of the distance between the end plates and the sealing leaves results in an optimum compromise

between the sealing effect and wear to the sealing leaves for each operating state of the machine. The minimized wear ensures an increased operating life thus reducing the operating costs of the turbomachine, in that the seals, which are produced by complex and costly processes, need be replaced less often.

During transient operating states, for example while the turbomachine is being started up and shut down, the pressure drop across the seal is small in comparison to that during steady-state operation. The sealing leaves are not yet in contact with the rotor. When the pressure in the machine increases, this results in a blow-down effect and in contact with the rotor. The radial gap is in this case closed, although this results in a large amount of friction between the sealing leaves and the rotor. The apparatus for active variation of the distance of the rear plate on the low-pressure side allows deliberate regulation of the contact-pressure force of the sealing leaves against the rotor corresponding to the operating state, in that the blow-down effect is deliberately reduced or a deliberate blow-up effect is created. The closure of the radial gap is thus maintained, but the friction of the leaves on the rotor is minimized.

In a first embodiment of the invention, the seal has an apparatus for variation of the distance between the rear plate and the edge of the sealing leaves on the low-pressure side, with the apparatus being activated by control signals. As a result of this measure, the effect is greatest on the low-pressure side, because variation of the distance on the low-pressure side of the sealing leaves means that only a blow-down behavior of the seal is initiated.

In a further embodiment of the invention, the seal has an apparatus for active variation of the distance between the sealing leaves and the rear plate and, in

addition, the distance between the edge of the sealing leaves on the high-pressure side and the front plate. In particular, the distances are varied such that, when one distance is varied, the second distance is varied  
5 as a function of the first distance.

In one specific embodiment, the seal and the apparatus for variation of the distances are designed such that the sum of the distance between the sealing leaves and the rear plate and the distance between the sealing  
10 leaves and the front plate always remains constant. This is achieved, for example, by means of a holder in the form of a bracket or a U-shaped holder, which extends over the sealing leaves and is attached to both  
15 the front plate and the rear plate. This embodiment has the special technical advantage of a less complex design of the seal. In addition, it makes it possible to move the seal over a very wide operating range.

20 In all the embodiments, the control range of the active variation of the distance extends from zero to about one third of the axial extent of the sealing leaves. At a distance of about one third or less, the influence on the pressure ratios in the seal ceases. Outside this  
25 range, the influence on operation of the machine is too small.

Active variation of the distance to the rear plate or the distances to the two end plates can be achieved,  
30 for example, by a pneumatic or electromechanical apparatus.

In order to guarantee that the distance is set as accurately as possible and that the seal operates  
35 optimally in terms of life and sealing function, the seal has an apparatus for distance measurement between the end plate and the edge of the sealing leaves, as well as a line for transmission of the distance measured values to a control loop. The control loop is

used to compare the distances of the end plate or end plates with predetermined target values for the distance, and if necessary to adapt them. These target values are preset for example between the housing and the rotor or between the housing and the rotating blade tips, depending on the type of seal fitted.

In a further embodiment of the invention, the edges of the sealing leaves are profiled, such that the sealing leaves are narrower in an area closer to the rotor than in an area which is further away from the rotor and is closer to the carrier. This guarantees a minimum distance between the sealing leaves and the end plates, and reduces the risk of lateral friction, or even of mechanical jamming.

In a further embodiment of the seal according to the invention, the seal is arranged between a stator of the turbomachine and the rotating blade tips of the rotor. The gap between the stator and the blade tips has a pronounced large radial clearance such that, when using a conventional leaf seal, either the gap is not always closed or particularly rapid wear occurs. The arrangement of the seal according to the invention results in the particular advantage that this gap is also closed with a large radial clearance in all operating states, with the wear being minimized and the operating life being correspondingly increased, in turn. The radial extent of the front plate and rear plate should not be greater than a given maximum size, bearing in mind the relatively large range of the radial clearance between the blade tips and the stator, thus ensuring a clearance between the front plate and rear plate and the blade tips, and thus the full radial freedom of movement, in all operating states, in order to prevent rubbing of the plates. On the other hand, the minimum radial size of the end plates must be designed so as to ensure coverage of the area which leads to gaps between the sealing leaves when the

79291-85

8

sealing leaves are making contact. As already mentioned, this may be about one third of the axial extent of the sealing leaves.

In one embodiment, there is provided a leaf seal for sealing a radial gap between a stator and rotor of a turbomachine has a plurality of metallic sealing leaves, which are arranged in a row, and are attached to a carrier, and are arranged concentrically around the circumference of the rotor of the turbomachine and is arranged inclined at an angle to the radial direction of the rotor and in the opposite direction to the rotation direction, with the seal having a front plate and a rear plate which are connected to the carrier and extend over the circumference of the seal on both sides of the sealing leaves, and a first axial distance exists between the rear plate and the sealing leaves, and a second axial distance exists between the front plate and the sealing leaves, wherein the seal has a movement controlling apparatus for actively controlled variation, during the operation of the turbomachine, of the first axial distance between the sealing leaves and the rear plate.

79291-85

8a

## Brief description of the drawings

Figure 1 shows a perspective view of a leaf seal arranged between the stator and rotor blade tips of a turbomachine. The figure shows a fundamental basic form of a leaf seal, in which a carrier plate and a front plate and rear plate are arranged in a general form.

Figure 2 shows a cross section through a seal according to the invention, based on a section along II-II in Figure 1. In this case, the carrier plate, front plate and rear plate are arranged according to the first embodiment of the invention.

Figure 3 shows a detail of the leaf seal according to the invention, based on the detail III as indicated in Figure 2, in particular in the area of the sealing leaves and the rear plate.

Figure 3a shows the seal from Figure 3 and its installation in the stator of a turbomachine.

Figure 3b shows a seal according to one embodiment of the invention, with a schematic diagram of a circuit for controlling the seal.

Figure 4 shows a cross section of a seal according to the invention, based on a section along II-II in Figure 1. In this case, the carrier, front plate and rear plate are formed integrally in the form of a bracket.

Figure 5 shows a cross section of an embodiment of a seal according to the invention the same as that in

Figure 4, with the sealing leaves additionally having profiled edges.

The same reference symbols in the various figures in  
5 each case indicate the same components.

#### Embodiment of the invention

The following exemplary embodiments can be used in  
10 various turbomachines, such as gas turbines, compressors, steam turbines.

Figure 1 shows a rotor 1 of a turbomachine, for example a gas turbine or compressor, with the rotor 1 rotating  
15 in the direction R around a rotor axis 2. A stator, which is not illustrated, surrounds the rotor of the machine, with a seal 3 being attached to the stator, which seal 3 can close a radial gap between the stator and the rotor 1. The gap has an extent in the radial  
20 direction Ra which can vary during transient operation of the machine, in particular during starting up and shutting down, and during load changes. The sealing of the gap between the stator and the rotor prevents leakage of the flow of a working fluid, which is  
25 flowing in the direction of the arrow annotated S. The seal 3 is a leaf seal and has a plurality of sealing leaves 4, which are arranged inclined at an angle  $\alpha$  to the radial direction Ra and in the opposite direction to the rotation direction R of the rotor. A spacing  
30 element 5 is arranged between each of the individual sealing leaves 4. The sealing leaves 4 are attached at a carrier 6 on the stator, for example by means of welding. The carrier 6 and the row of sealing leaves 4 attached to it extend in an annular shape and  
35 concentrically over the circumference of the rotor 1. Furthermore, on the carrier 6, a front plate 7 is arranged on the high-pressure side of the seal 3, and a rear plate 8 is arranged on the low-pressure side of the seal 3.

The seal 3 can be arranged either between a stator and a shaft or between a stator and the tips of rotor blades. A blow-up effect or blow-down effect results on the sealing leaves 4, depending on the pressure ratios, on the basis of which the sealing leaves are pressed away from the rotor 1 or are pressed toward the rotor 1. In the case of a strong blow-down effect, the contact-pressure force of the sealing leaves 4 on the rotor surface is increased, and thus the sealing effect, as a result of which the gap is closed, although the friction and the wear of the sealing leaves are also increased at the same time. In the case of a blow-up effect, on the other hand, the contact-pressure force and the sealing effect are reduced, with the friction likewise being reduced. According to the invention, the seal has an apparatus for actively controlled variation of the axial gap between the rear plate 8 and the edge 9 of the sealing leaves 4 on the low-pressure side in order to control the blow-up effect or blow-down effect, as shown in Figures 2, 3, 3a and 3b.

Figures 2 and 3 show a seal according to the invention with one of the sealing leaves 4 and the front plate 7 on the high-pressure side, the rear plate 8 on the low-pressure side and the carrier ring 6. The illustrated seal 3 is arranged between a stator, which is not illustrated, and the blade tip 10 of a turbine rotor blade 11 or compressor blade. A leakage flow, which occurs between the stator and the rotor if the gap is not closed completely, is indicated by the arrow 12. There is a gap or first axial distance of width  $d$  between the rear plate 8 on the low-pressure side, in particular the inner edge 8', and the edge 9 of the sealing leaves 4, which gap can be varied according to the operating state of the turbine. There is a second axial distance of width  $t$  between the edge of the sealing leaves 4 on the high-pressure side and the

front plate 7. Figure 3a shows the seal from Figure 3, in which, for example, the carrier 6 and the front plate 7 are in the form of an integral part of the stator 13. The gap between edge 8' of the rear plate and the sealing leaf 4 is varied, for example, by means of a pneumatic or electromechanical apparatus 14. In this case, a minimum width of the gap between the axial end 16 of the rear plate 8 and the stator 13 can be ensured by means of a spring 15.

10

In one embodiment of the invention, the apparatus 14 is designed such that the gap width  $d$  can be varied from zero up to a third of the axial extent or of the width  $B$  of the sealing leaves during machine operation. The front plate 7 is attached to the high-pressure side of the sealing leaves 4, with there being a gap of width  $t$  between the inner wall 7' of the front plate 7 and the edges of the sealing leaves 4. In one embodiment of the seal, this width is fixed. In this case, the width  $d$  of the gap on the rear plate is always less than the gap width  $t$ .

According to a further embodiment of the seal 3, as is shown in Figure 3b, a sensor 19 for measurement of the gap width  $d$  is integrated in the rear plate 8. A signal line 21 leads from this to a control unit 18 which has means for comparison of the measured gap width  $d$  with a predetermined target value for the gap width, and for generation of a control signal for adaptation of the gap width  $d$ . The control signals from the unit 18 are transmitted by means of the signal line 17 to the apparatus 14 for movement of the rear plate relative to the sealing leaves. The sensor 19 for distance measurement of the gap width  $d$  is also used to prevent the gap being reduced to zero and to minimize friction of the sealing leaf edge on the end plate. Furthermore, signals can be sent via the signal line 23 to the movement apparatus 14 from the turbomachine, for example a trip signal from the unit 22. A trip signal

such as this can initiate a movement of the rear plate 8 to a position with a maximum distance  $d$ .

Figure 4 shows a further embodiment of the rear plate and front plate in an embodiment of an integral part 20, which allows simultaneous movement of the front plate and rear plate, in which case the sum of the gap between the sealing leaves and the rear plate and the gap between the sealing leaves and the front plate always remains constant. For this purpose, the end plates are manufactured as an integral part 20 with a cross section in the form of a bracket, or with a U-shaped cross section. An axial movement of the part 20 relative to the sealing leaves 4 is provided either by attaching the sealing leaves to the stator and an apparatus for movement of the part 20. For this purpose, for example, the sealing leaves together with their carrier 6 can be connected to the stator by means of a plurality of bushings, which lead through openings through the part 20.

Alternatively, the axial movement of the part 20 relative to the sealing leaves 4 can be provided by means of a fixed attachment of the part 20 to the stator, with the sealing leaves 4 and the carrier 6 being moved axially by means of bushings and corresponding guide openings in the part 20.

The simultaneous variation makes it possible to completely exploit the blow-up and blow-down potential of the seal. Furthermore, intermediate states can be set in a continuously variable manner, and the force can be deliberately applied to the metal leaves. When the turbine is in special operating states, for example a trip, the seal could be brought immediately to the maximum blow-up response, preventing rubbing, since in this case it is possible for states to occur which lead to maximum radial movement into the seal. In a further operating state, a so-called "hot restart", a maximum amount of radial movement is demanded, which the seal

withstands best when it is operated in a blow-up configuration.

A further embodiment of the seal 3, as shown in  
5 Figure 5, essentially has the same seal design as that  
in Figure 4 with regard to the arrangement of the rear  
plate and front plate. In addition, in this case, the  
sealing leaves 4 have a profile on the respective edges  
4a and 4b on the low-pressure side and high-pressure  
10 side of the sealing leaves 4. In particular, the  
profile is designed such that only a portion of the  
edge of the sealing leaves can come into contact with  
the end plate in the area of the end plates, and a  
small gap with width  $m$  is guaranteed over the rest of  
15 the edge. By way of example, the reduction in the width  
of the sealing leaf 4 extends over a region  $a/2$  or half  
the region  $a$  of the sealing leaves which is covered by  
the end plates. The minimum step along the edges 4a and  
4b has a width  $m$  of, for example, 0.2 mm or an extent  
20 which would avoid friction of the sealing leaves on the  
end plate. The maximum gap width  $t$  is, for example,  
2 mm, or about one third of the width or of the axial  
extent  $B$  of the sealing leaves.

## List of reference symbols

1	Rotor
2	Rotor axis
3	Seal
4	Sealing leaves
4a, 4b	Lateral profile of the sealing leaves
5	Spacing elements
6	Carrier
7	Front plate
7'	Inner surface of the front plate
8	Rear plate
8'	Inner surface of the rear plate
9	Edge of the sealing leaf
10	Blade tip
11	Blade
12	Leakage flow
13	Stator
14	Movement apparatus
15	Spring
16	End of the rear plate element 8
17	Signal line
18	Control unit
19	Sensor
20	Integral part for the front plate and rear plate
21	Signal line
22	Control unit
23	Signal line
R	Rotation direction of the rotor
Ra	Radial direction with respect to the rotor axis
S	Flow direction of the working fluid
$\alpha$	Angle of the sealing leaves with respect to the radial direction Ra
t, d	Gap width between the sealing leaves and the front plate and rear plate, respectively
B	Width of the sealing leaves
m	Width of the step on the profile of the sealing leaves

a Length of the end plates over the sealing  
leaves

79291-85

16

CLAIMS:

1. A leaf seal for sealing a radial gap between a stator and rotor of a turbomachine has a plurality of metallic sealing leaves, which are arranged in a row, and are attached to a carrier, and are arranged concentrically around the circumference of the rotor of the turbomachine and is arranged inclined at an angle to the radial direction of the rotor and in the opposite direction to the rotation direction, with the seal having a front plate and a rear plate which are connected to the carrier and extend over the circumference of the seal on both sides of the sealing leaves, and a first axial distance exists between the rear plate and the sealing leaves, and a second axial distance exists between the front plate and the sealing leaves,

15 wherein

the seal has a movement controlling apparatus for actively controlled variation, during the operation of the turbomachine, of the first axial distance between the sealing leaves and the rear plate.

20 2. The seal as claimed in claim 1,

wherein

the movement controlling apparatus is for controlled variation of the axial distances both between the front plate and the sealing leaves and between the rear plate and the sealing leaves in a mutually dependent movement.

25 3. The seal as claimed in claim 2,

79291-85

17

wherein

the sum of the first axial distance between the rear plate and the sealing leaves and of the second axial distance between the front plate and the sealing leaves is always constant.

5 4. The seal as claimed in any one of claims 1 to 3,

wherein

the apparatus for controlled variation of the axial distances is pneumatic or electromechanical apparatus.

5. The seal as claimed in claim 3,

10 wherein

the front plate and the rear plate are attached to a holder, or the front plate and the rear plate together with a holder form an integral part, with the holder extending over the carrier of the sealing leaves.

15 6. The seal as claimed in any one of claims 1 to 5,

wherein

a control range of the controlled variation of the distance between the rear plate and the sealing leaves extends from zero to about one third of the axial extent of the sealing leaves.

20 7. The seal as claimed in any one of claims 1 to 6,

wherein

79291-85

18

the seal has a sensor for measurement of the distance between the rear plate and the sealing leaves, and a line for transmission of distance measured values to a control unit for adaptation of the distance between the rear plate and the  
5 sealing leaves.

8. The seal as claimed in any one of claims 1 to 7,  
wherein

the edges of the sealing leaves have a profile with a step in the area of the rear plate and front plate.

10 9. The seal as claimed in any one of claims 1 to 8,  
wherein

the seal is arranged between a stator and the rotating blade tips of the turbomachines.

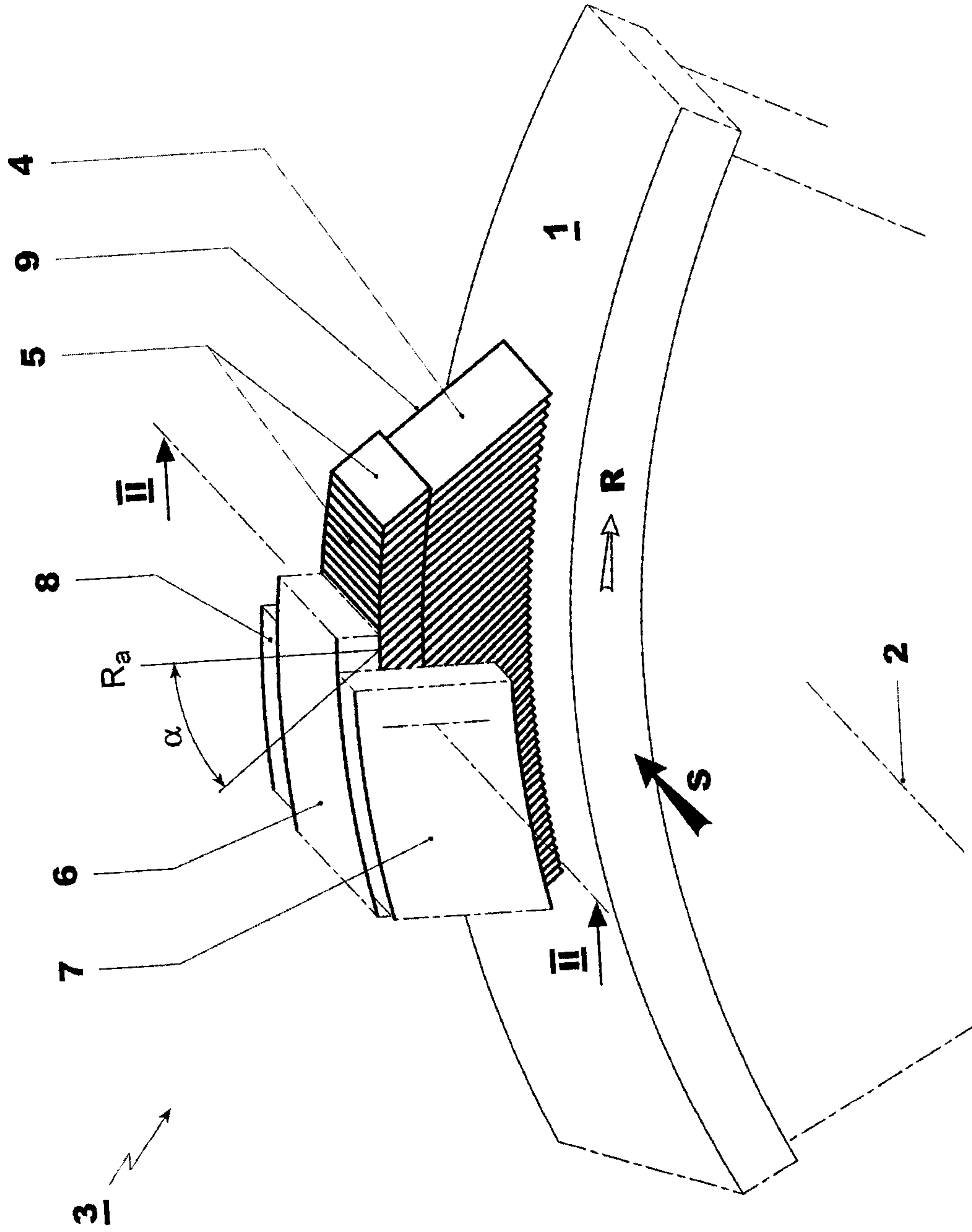
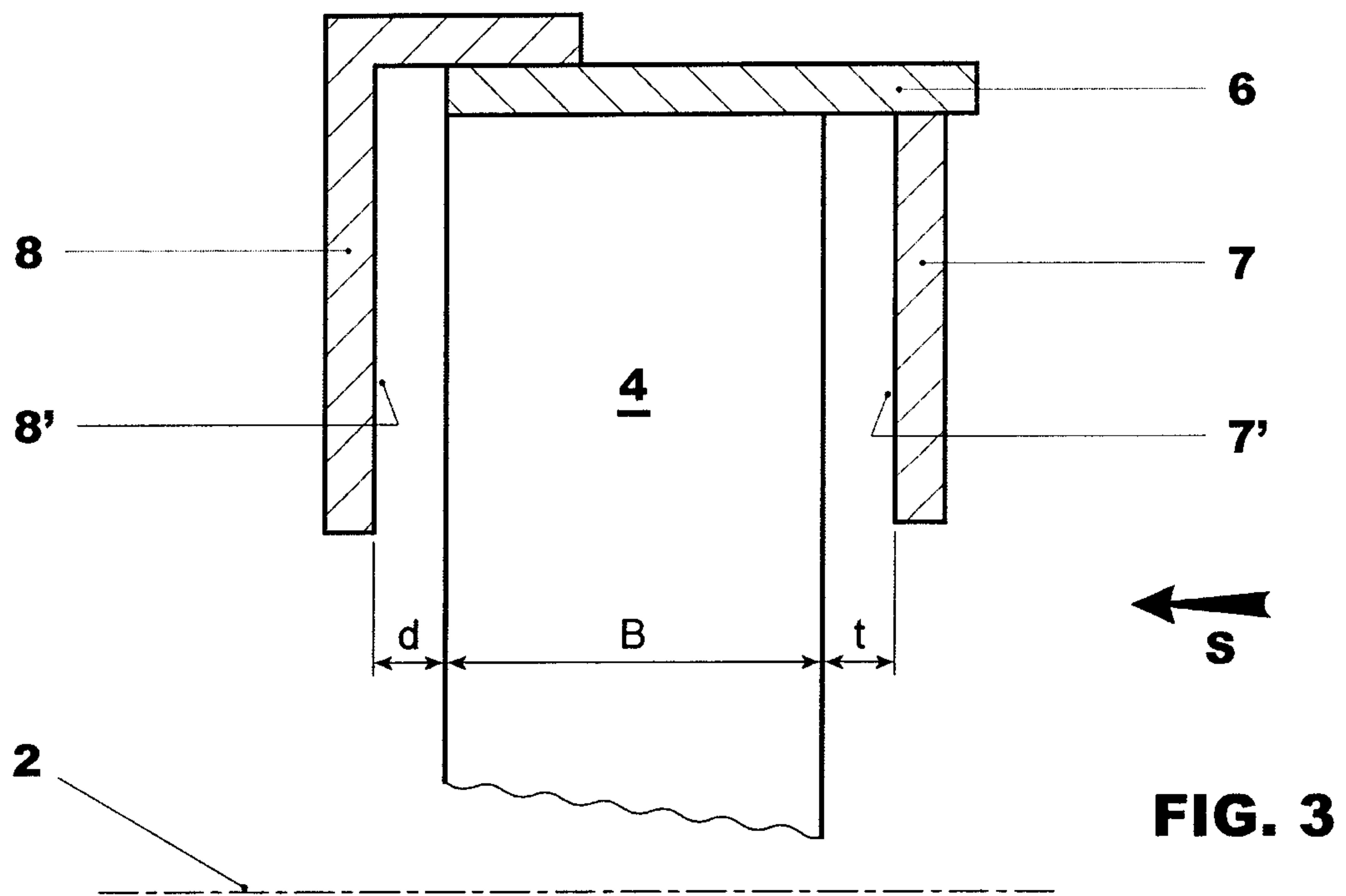
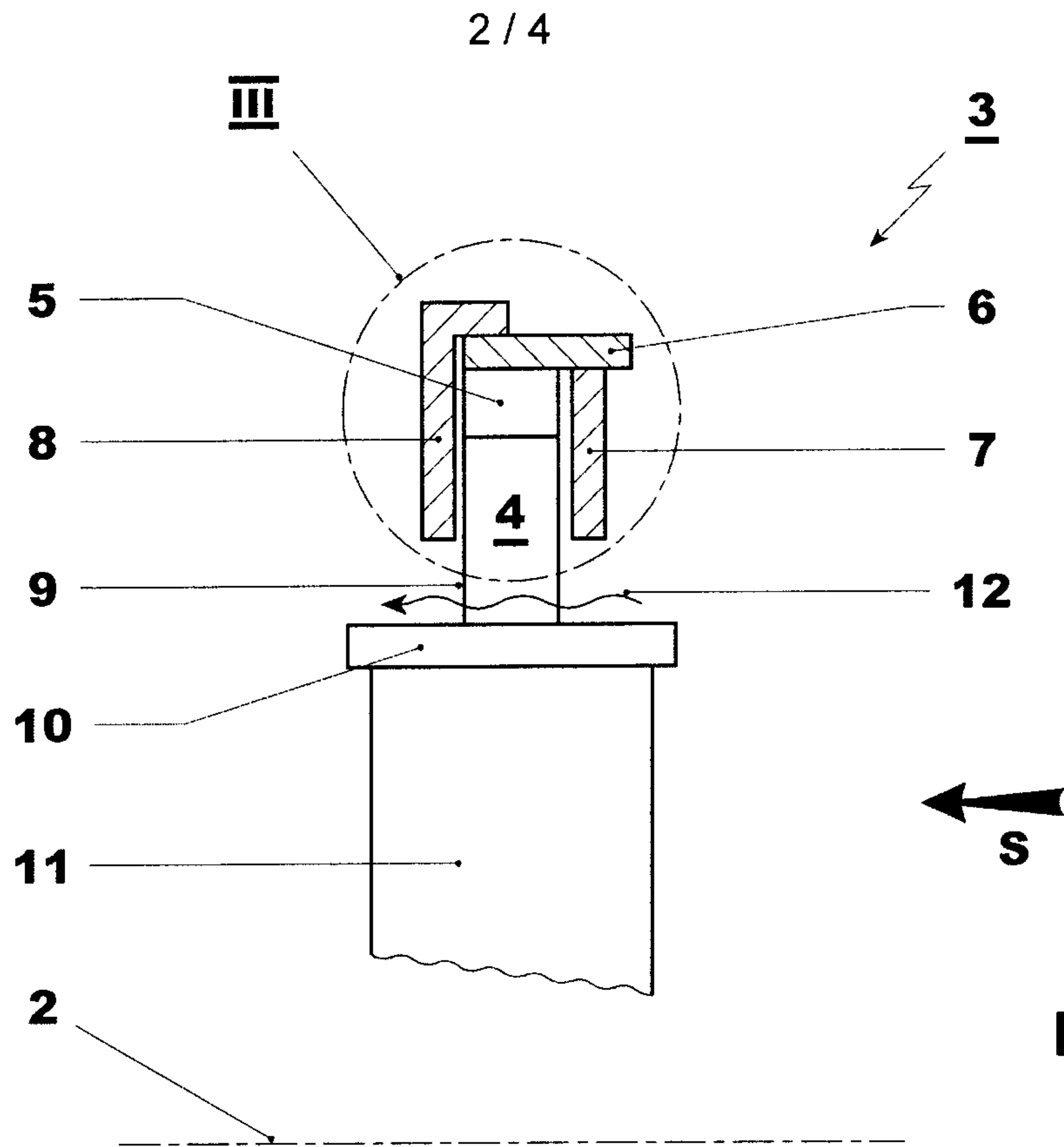


FIG. 1



3/4

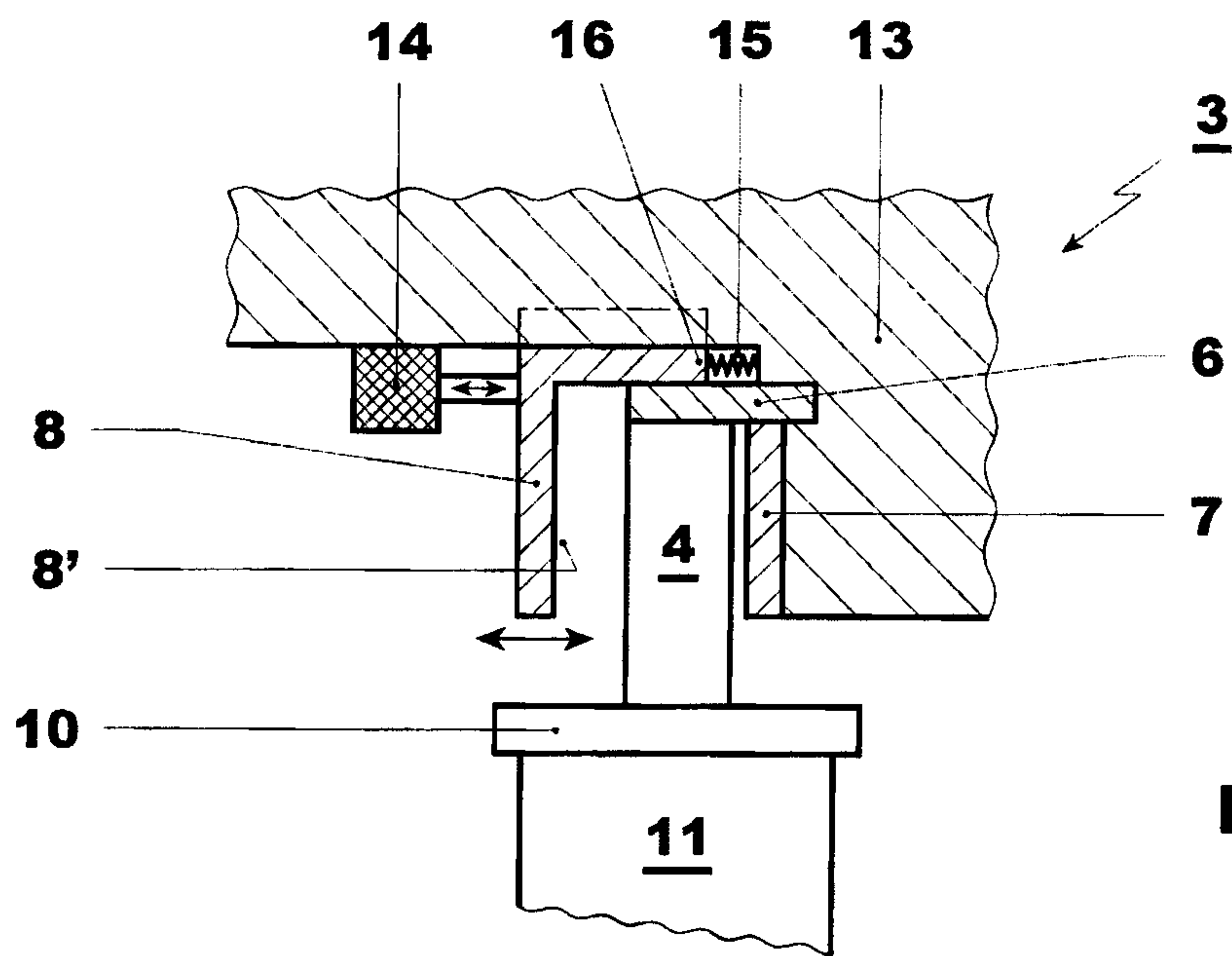


FIG. 3a

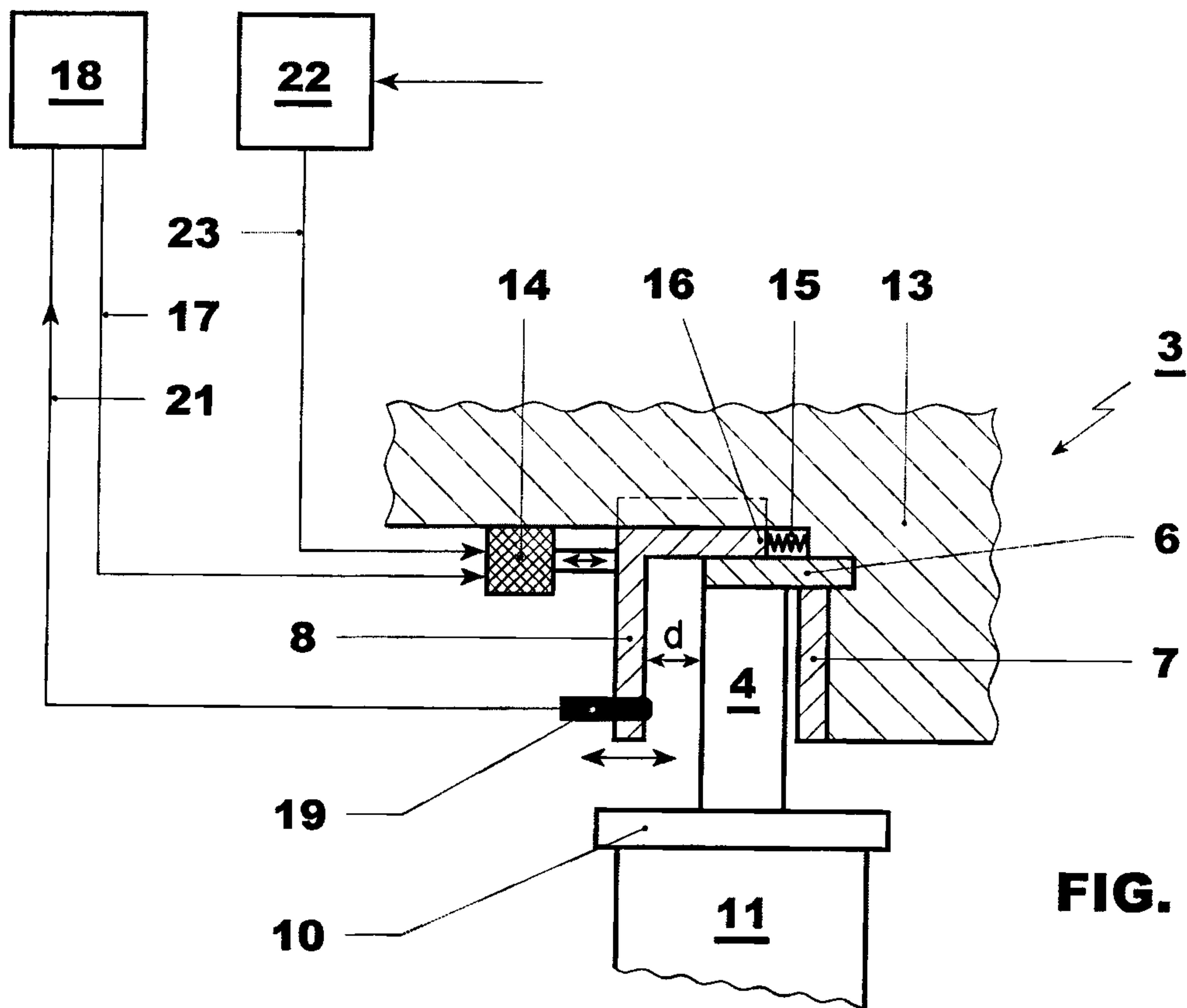


FIG. 3b

4 / 4

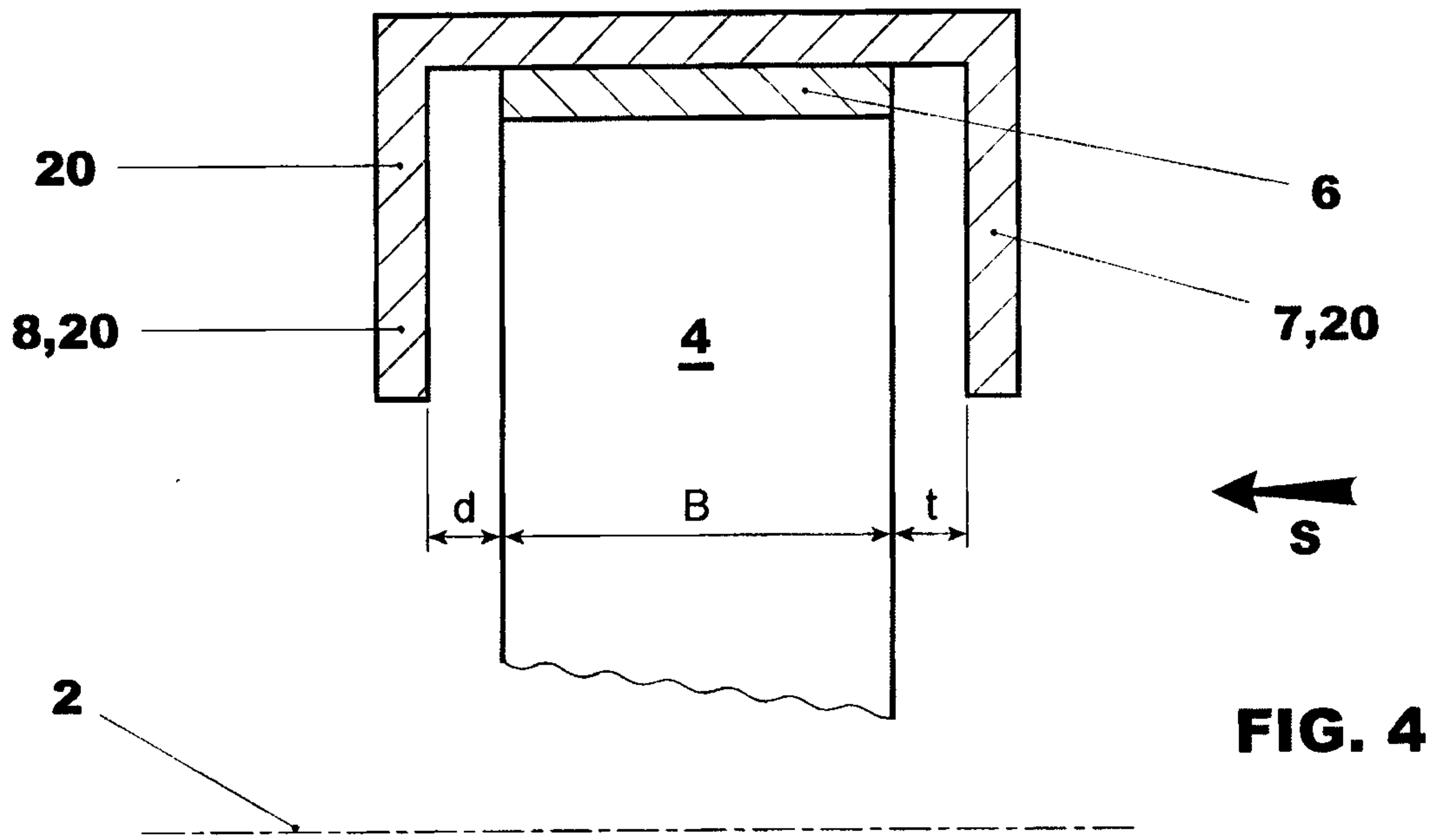


FIG. 4

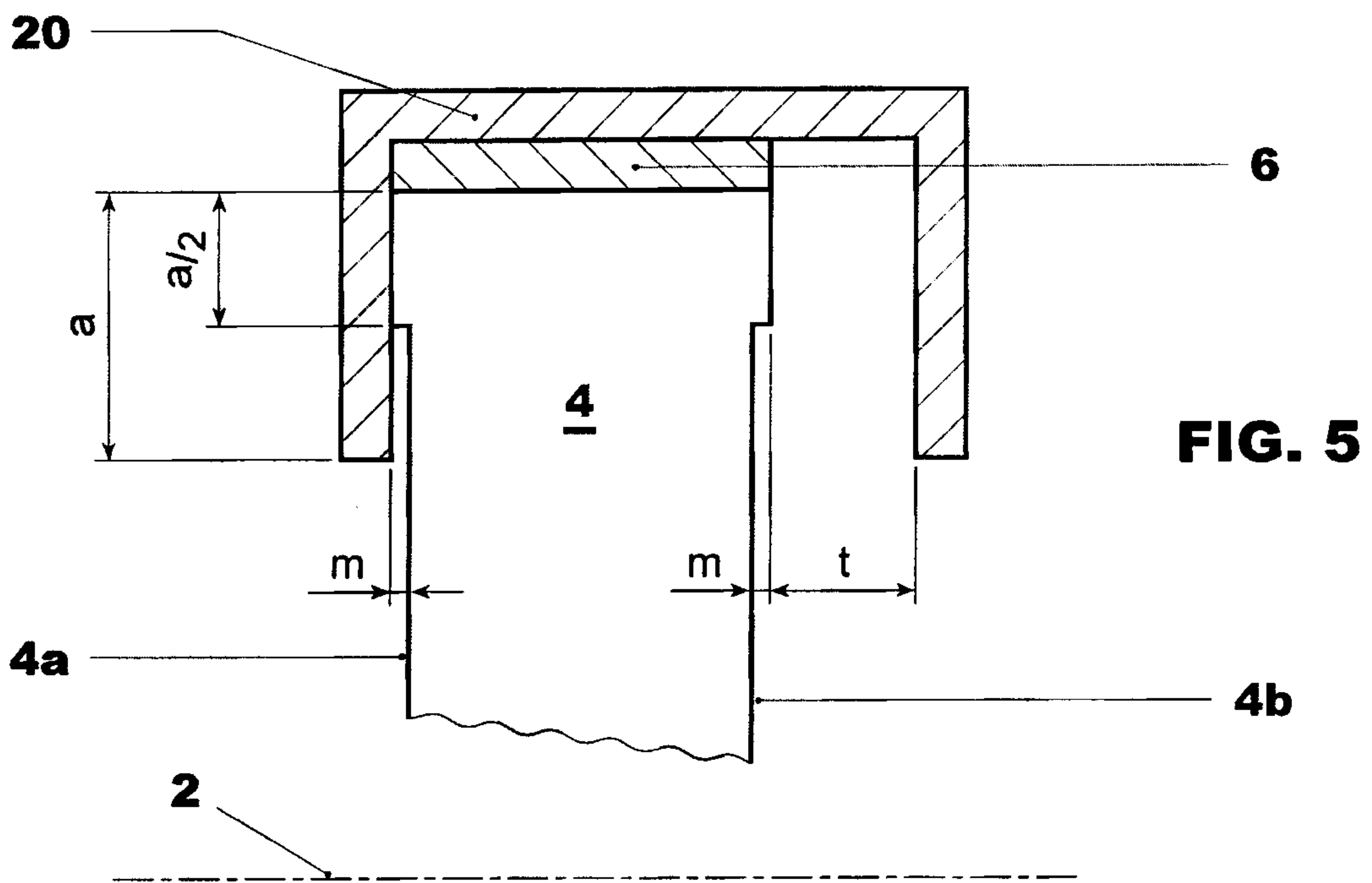


FIG. 5

