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SEAL ARRANGEMENT WITH HIGHLY ELONGATED FIN TIP

The present invention relates to sealing arrangements employed to prevent a working medium to flow between two parts from a high pressure area to a low pressure area.

- 5 In particular this invention relates to sealing in rotating machines, such as turbines (gas and steam), compressors, pumps, etc.

The control of the working medium (gas, steam, fluid) flow inside rotating machines is of paramount importance with
10 regards to both functionality and effectiveness.

Seal arrangements are interposed between a high pressure area and a low pressure area to provide noncontact sealing. Different sealing techniques are used at various locations in the rotating machines to prevent leakage of the working
15 medium both between

two relatively rotating parts, e.g. a rotor and a stator, and

two relatively stationary parts, e.g. various housing parts, cooling air plenums, etc.

- 20 Among the abovementioned seal arrangements the labyrinth seals, mateface seals, strip seals, rope seals could be distinguished.

In the noncontact seal arrangement a fin gap between a first part and a second part is fixed and must be large enough to
25 accommodate thermal expansion of the parts and thermal changes in the surrounding structure, as well as the centrifugal expansion of the two parts in case of the relatively rotating parts, to avoid any contact between the seal arrangement and the other part. On the other hand, the

performance of the rotating machine depends on the size of such fin gap and can be enhanced by decreasing the leakage of the working medium through the fin gap.

FIG 1 shows a conventionally known seal arrangement 1 in a rotating machine. The seal arrangement 1 is generally comprised of successive fins 2 and cavities 3 formed along the adjacent surfaces 4, 5 of a first part 6 and a second part 7 respectively.

In the following description, for the purpose of explanation, the sealing arrangement 1 is considered for the case when the fins 2 are located on the first part 6. However, the fins 2 can be positioned on one of the first part 6 and the second part 7, or even on both parts 6, 7.

The first part 6 and the second part 7 are arranged in such way that a gap 8 of the height H is formed between them. A fin tip 9 and a surface 4 of the first part form a fin gap 10 of the height h . The working medium flows along the direction 11 from a high pressure area to a low pressure area. One of the basic concepts of any seal arrangement 1 design is to form a fluid barrier between areas of high and low pressure of working medium in order to retard the working medium flow through the seal arrangement 1 to a desired level. Generally, the desired retardation is achieved by forcing a high-velocity working medium to pass sequentially through the fin gaps 10, which are formed between the fin tips 9 and the surface 5 of the second part 7, with the successive entering of the flowing working medium into the caverns 3, where energy of the flowing working medium is largely dissipated into turbulence.

Several origins of the aforementioned turbulence generation within the seal arrangement 1 can be distinguished. One of them is the friction between the high-velocity working medium

and the adjacent seal surfaces, i.e. the surface 4 and/or the surface 5. Another origin is the intense friction of free shear layers between a high velocity working medium jet discharging from a fin gap 10, i.e. slit-like orifice formed between the fin tips 9 and the surface 5 of the second part 7, and a relatively slow moving working medium in the cavern 3 immediately downstream of the fin gap 10.

The efficiency of the conventionally known seal arrangements could be improved by reducing the fin gap 10. However, the fin gap 10 can only be reduced to a limited extent so as to avoid contact between the first part 6 and the second part 7. In particular, such requirement should be satisfied for relatively rotating parts during the operation of the rotating machine since any contact of the first and the second part can result in damage to the parts of the rotating equipment.

The contact can be caused by many factors such as the eccentricity of a rotating part, centrifugal growth, vibrations, manufacturing tolerances, misalignment during assembling etc. As a result, the fin gap 10 has to be sufficiently large to avoid accidental contact between two parts - a stationary part and a rotating part, which in turn impairs the sealing efficiency of the conventionally known seal arrangement.

There are several known approaches for minimizing the flow of the working medium through the seal arrangement while keeping physical fin gap between the first part and the second part.

In one prior art design for relatively rotating parts (US Patent №1 482 031) this is achieved by using of a "stepped" surface of the stationary part, which prevents the working medium to flow through a seal arrangement without entering the cavities between the fins and, thus, increases the losses

due to the friction between a high-velocity flow and seal surfaces and minimizes the leakage flow.

In another configuration (US Patent No. 3 940 153) the seal arrangement employs specially chosen wall positioning and wall curvature to introduce sharp turns in the working medium flow path providing the additional friction in shear layers.

Another way of decreasing the spurious leakage is to use abradable materials at stationary parts, which allows minimizing clearances between rotating and stationary parts.

In that case, fins can cut into the stationary part with the consequent formation of grooves preventing a seal arrangement from being seized. Such approach has been for example proposed in the prior art designs of US Patents No. 2 963 307, No. 4 477 089, and No. 6 652 226, where honeycomb cells have been mounted to stationary members permitting the attainment of small clearances between stationary and rotating members without subjecting a seal to a damage due to a rubbing.

Accordingly, the object of the present invention is to provide another variant of the seal arrangement such that the flow of a working medium from a high pressure area to a low pressure area is minimized, while the fin gap is preserved large enough to avoid contact of the first part and the second part. Therefore, the efficiency of such seal arrangements is increased.

The object of the present invention is achieved by a seal arrangement as defined in claim 1. Advantageous embodiments of the present invention are provided in dependent claims. Features of claim 1 can be combined with features of dependent claims, and features of dependent claims can be combined together.

In an aspect of the present invention, a seal arrangement to minimize flow of a working medium flow from a high pressure area to a low pressure area is presented.

The seal arrangement comprises a first part and a second
5 part, wherein the first part and the second part are located opposite to each other and arranged in such way that there is a gap between the first part and the second part.

The first part and the second part can be configured to be

relatively rotatable parts, e.g. a rotor and a stator,
10 or

relatively stationary parts, e.g. various housing parts
or cooling air plenums etc,

within the rotating machine, e.g. within a gas turbine.

At least one of the first part and the second part has at
15 least one fin extending from there into the gap towards other of the first part and the second part to a fin tip so as to form a barrier against a flow of a working medium between the first part and the second part.

The seal arrangement can include series of the fins that are
20 distributed along either the first part or the second part.

According to the present invention the fin tip extension of the at least one fin along a streamwise direction is larger than a fin gap being formed between the fin tip of the at least one fin and other of the first part and the second
25 part.

The present invention is based on the insight that the additional energy losses of the working medium flow occur due to the growing boundary layer at the fin tip. Indeed, once the fin tip extension along the streamwise direction is

sufficiently large comparing to the height of the fin gap, the thickness of a boundary layer cannot be neglected anymore.

Therefore, the boundary layer has a noticeable displacement effect on the main flow of the working medium. Moreover, the effective fin gap is continuously decreasing with the increase of the fin tip extension. And as a result, the energy losses of the working medium flowing through such fin gap is noticeably larger than those of the prior art design. At the same time, the geometrical sizes of the fin gap still remain large enough to avoid any rubbing between the first part and the second part.

Thus, the present invention is proposed to provide a new seal arrangement with highly elongated fin tip that minimize flow of a working medium from an area of high pressure to an area of low pressure.

Further embodiments of the present invention are subject of the further sub-claims and of the following description, referring to the drawings.

In a possible embodiment of the seal arrangement a ratio of the fin tip extension to the height of the fin gap is 2 or more. In case of the ratio of the fin tip extension to the height of the fin gap is less than 2 (typical for the prior-art designs), the boundary layer formed at the fin tip is thin and does not provide any noticeable displacement effect on the main flow of the working medium. In contrast, as soon as such ratio is 2 or more the boundary layer provides noticeable displacement effect on the main flow of the working medium and the effective gap is decreased.

In other possible embodiment of the seal arrangement one of the first part and the second part is a rotating part and another part is a stationary part.

For example the first part may be, but not limited to a rotor segment of a gas turbine whereas the second part may be, but not limited to, a stator segment of the gas turbine. Alternatively, in another embodiment of the seal arrangement the first part is configured to be stationary and the second part is configured to be rotatable, for example the first part may be, but not limited to a stator segment of a gas turbine whereas the second part may be, but not limited to, a rotor segment of the gas turbine.

Such feature allows applying the seal arrangement in different rotating machines for which the first part and the second part are relatively rotating, e.g. in turbine engines.

In other possible embodiment of the seal arrangement, the other of the first part and the second part has a surface that is opposite to the fin tip, and this surface comprises an abradable material, such as honeycombs, felt metal etc.

This is desirable for some rotating machines to avoid the permanent damage to the second part during the operation.

In enhanced embodiment of the seal arrangement the abradable material is honeycomb cells. In such case a free-shear layer emanating from the honeycomb cell structure is decreasing the effective fin gap.

In enhanced embodiment of the seal arrangement the ratio of the fin tip extension to a width of a cell of the honeycomb cell structure is 1 or more.

In case of the ratio of the fin tip extension to the width of the cell of the honeycomb cell structure is less than 1, the boundary layer from at the fin tip is thin and does not provide any noticeable displacement effect on the main flow of the working medium. In addition, if the fin tip is smaller than the honeycomb cell, the effective clearance is increasing since the flow of the working medium can enter the honeycomb cell upstream of the fin and exit from the cell downstream of the fin without impairing the sealing efficiency. In contrast, as soon as the ratio is 1 or more the boundary layer provides a noticeable displacement effect on the main flow of the working medium and the effective gap is decreased.

For a more complete understanding of the present invention and advantages thereof, reference is now made to the following description taken in accompanying drawings. The invention is explained in more details below using exemplary embodiments which are specified in the schematic figures of the drawings, in which:

Fig. 1 schematically illustrates the conventionally known seal arrangement (prior art);

Fig. 2 schematically illustrates a seal arrangement in accordance with the present invention;

Fig. 3 schematically illustrates an embodiment of the seal arrangement in accordance with the present invention;

Fig. 4 schematically illustrates a honeycomb cell structure (prior art);

Fig. 5 schematically illustrates other embodiment of the seal arrangement in accordance with the present invention;

Various embodiments are described with reference to the drawings, wherein like reference numerals are used to refer to like elements throughout. In the following description, for purpose of explanation, numerous specific details are set forth in order to provide a thorough understanding of one or more embodiments. It may be noted that the illustrated embodiments are intended to explain, and not to limit the invention. It may be evident that such embodiments may be practiced without these specific details.

It may be noted that in the present disclosure, the terms "first", "second", etc. Are used herein only to facilitate discussion, and carry no particular temporal or chronological significance unless otherwise is indicated.

FIG 2 illustrates a seal arrangement 1 to minimize flow of a working medium from a high pressure area 13 to a low pressure area 14 in accordance with the present invention.

The seal arrangement 1 comprises a first part 6 and a second part 7, wherein the first part 6 and the second part 7 are located opposite to each other and arranged in such way that there is a gap 8 of the height H between the first part 6 and the second part 7.

The first part 6 and the second part 7 can be configured to be relatively rotating parts or relatively stationary parts within the rotating machines, such as turbines (gas, steam, etc.), compressors, pumps, etc.

In case of relatively rotating parts, the first part 6 may be, but not limited to, a rotor segment of a gas turbine, whereas the second part 7 may be, but not limited to, a stator segment of the gas turbine. And vice versa, the first part 6 can be configured to be stationary within the rotating equipment and the second part 7 is configured to be rotatable

within the rotating equipment, e.g. the first part 6 may be, but not limited to, a stator segment of a gas turbine, whereas the second part 7 may be, but not limited to, a rotor segment of the gas turbine.

- 5 In case of relatively stationary parts, the first part 6 and the second part 7 can be, e.g. various housing parts, cooling air plenums etc,

At least one of the first part 6 and the second part 7 has at least one fin 2 extending from there into the gap 8 towards
10 other of the first part 6 and the second part 7 to a fin tip 9 so as to form a barrier against a flow of a working medium between the first part 6 and the second part 7.

The at least one fin 2 is positioned on one of the first part 6 and the second part 7. FIG 2 depicts the fin 2 to be
15 positioned on the first part 6, particularly on the surface 4 of the first part 6. The fin 2 extends towards the other part, i.e. in example of FIG 2 the fins 2 extends towards the second part 7, and particularly towards the surface 5 of the second part 7.

- 20 In the enhanced embodiment of the seal arrangement 1 each of the first part 4 and the second part 5 has the at least one fin 2 extending from there into the gap 8 towards other of the first part 6 and the second part 7 to a fin tip 9 as shown on FIG 3.

- 25 In case of the first part 6 and the second part 7 are configured to be relatively rotating, the at least one fin 2, along with the fin tip 9 of the at least one fin 2, forms a circumferential barrier against a flow of a working medium that intends to flow between the first part 6 and the second
30 part 7 i.e. between the surfaces 4 and 5.

The seal arrangement can 1 include one fin 2 or a plurality of the fins 2 that are distributed along either the first part 6 or the second part 7, or both of them 6, 7.

5 The at least one fin 2 is either angled or slanted with respect to a direction 11 of the working medium flow, or alternatively the fin 2 may extend normally from the surface 4 on which the fin 2 positioned.

10 According to the present invention the fin tip 9 extension 1 of the at least one fin 2 along a streamwise direction 11 is larger than the height h of the fin gap 10 being formed between the fin tip 9 of the at least one fin 2 and other of the first part 6 and the second part 7. I.e. in example of FIG 2, the fin tip 9 extension 1 of the at least one fin 2 along the streamwise direction 11 is larger than the height h
15 of the fin gap 10 being formed between the fin tip 9 of the at least one fin 2 and the surface 5 of the second part 7. In the enhanced embodiment of the seal arrangement 1 this ratio equals 2 or more.

20 In embodiment of the seal arrangement 1 the surface 4, 5 of one of the first part 6 or the second part 7 that is opposite to the at least one fin tip 9, comprises abradable material, for example, honeycomb cells, felt metal etc.

The cell 12 width w of the cells of honeycomb cell structure (as shown on FIG 4) of the known abradable material is
25 typically 0.8 mm - 3.2 mm. FIG 5 illustrates the embodiment of the present invention in case the surface 5 of the second part 7 comprises the honeycomb cells. In enhanced embodiment of the seal arrangement 1 the ratio of the fin tip extension 1 to the width w of a cell 12 of the honeycomb cells is 1 or
30 more.

The seal arrangement 1 works as follows. The working medium flows from the area of high pressure 13 to the area of low pressure 14 between the first part 6 and the second part 7. Such flow is nearly blocked by the fin 2 and strongly compressed in the area of the fin tip 9.

However, due to the fact that the fin tip extension 1 of the fin 2 along the streamwise direction 11 is larger than the height h of the fin gap 10, a boundary layer 15 is formed on the surface of the fin tip 9. In addition to that, another boundary layer 16 is formed on the surface 5 of the second part 6. Therefore, the working medium flow enters the fin gap 10 of the effective height h^{eff} , which is formed between two boundary layers 15 and 16 (as shown on FIG 2). Further downstream, the working medium expands into the area of low pressure 14.

Therefore, the effective height h^{eff} of the fin gap 10 is decreased, while the physical height h of the fin gap 10 stays the same.

In case of the ratio of the fin tip extension 1 to the height h of the fin gap 10 is less than 2, the boundary layer 15 is thin and does not provide any noticeable displacement effect on the main flow of the working medium. As soon as the ratio is 2 or more the boundary layer 15 provides noticeable displacement effect on the main flow of the working medium and the effective height h^{eff} of the fin gap 10 is being decreased.

In fact, higher ratio of the fin tip extension 1 to the height h of the fin gap 10 yield more effective sealing, since the relatively thick boundary layer 15 is formed on the surface of the fin tip 9 and, therefore, the effective height h^{eff} of the fin gap 10 is getting smaller.

However, the length l of the fin tip extension is limited by the geometry and physical sizes of the first part 6 and the second part 7. For example, when the second part 7 is manufactured in a «stepped» way (as shown on FIG 1), the length l of the fin tip extension is limited by the size L of the step of the second part 7.

In case of the surface 5 comprising the honeycomb cells, instead of the boundary layer 16, a free-shear layer 17 is formed as it is shown on FIG 5. In case of the ratio of the length l of the fin tip extension to the width w of the cell 12 of the honeycomb cell structure is less than 1, the boundary layer 15 is thin and does not provide noticeable displacement effect on the main flow of the working medium. As soon as the ratio is 1 or more the boundary layer 15 provides a noticeable displacement effect on the main flow of the working medium and the effective height h^{eff} of the fin gap 10 is decreased.

In fact, higher ratios of the length l of fin tip extension to the width w of the cell 12 of the honeycomb cell structure yield more effective sealing, since the relatively thick boundary layer 15 is formed on the surface of the fin tip 9, therefore, the effective height h^{eff} of the fin gap 10 is getting smaller.

However, as it was mentioned above, the length l of the fin tip extension is limited by the geometry and physical sizes of the first part 6 and the second part 7.

While the present invention has been described in detail with the reference to certain embodiments, it should be appreciated that the present invention is not limited to those precise embodiments. Rather, in view of the present disclosure which describes exemplary modes for practicing the invention, many modifications and variations would present

themselves to those skilled in the art without departing from the scope and spirit of this invention. The scope of the invention is, therefore, indicated by the following claims rather than by the foregoing description. All changes, 5 modifications, and variations coming within the meaning and range of equivalency of the claims are to be considered within their scope.

Reference numerals

- 1 - seal arrangement
- 2 - fin
- 3 - cavern
- 5 4 - surface of the first part
- 5 - surface of the second part
- 6 - first part
- 7 - second part
- 8 - gap
- 10 9 - fin tip
- 10 - fin gap
- 11 - streamwise direction
- 12 - cell
- 13 - high pressure area
- 15 14 - low pressure area
- 15, 16 - boundary layer
- 17 - free-shear layer

PATENT CLAIMS

1. A seal arrangement (1) to minimize a flow of a working medium from a high pressure area (13) to a low pressure area (14), comprising

5 a first part (6) and a second part (7),

wherein the first part (6) and the second part (7) are located opposite to each other and arranged in such way that there is a gap (8) between the first part (6) and the second part (7),

10 wherein at least one of the first part (6) and the second part (7) has at least one fin (2) extending from there into the gap (8) towards other of the first part (6) and the second part (7) to a fin tip (9) so as to form a barrier against a flow of a working medium between the first part (6)
15 and the second part (7)

characterized in that the fin tip extension (1) of the at least one fin (2) along a streamwise direction (11) is larger than a fin gap (10) being formed between the fin tip (9) of the at least one fin (2) and other of the first part
20 (6) and the second part (7).

2. The seal arrangement (1) according to claim 1, wherein a ratio of the fin tip extension (1) to the height (h) of the clearance gap (10) is 2 or more.

3. The seal arrangement (1) according any of claims 1 or 2,

25 wherein one of the first part (6) and the second part (7) is configured to be stationary and wherein the other of the first part (6) and the second part (7) is configured to be rotatable.

4. The seal arrangement (1) according any of claims from 1 to 3,

wherein the other of the first part (6) and the second part (7) has a surface (4) that is opposite to the fin tip (9), and

wherein the surface (4) comprises an abradable material.

5. The seal arrangement (1) according claim 4 wherein the abradable material is honeycomb cells.

6. The seal arrangement (1) according claim 5, wherein the ratio of the fin tip extension (1) to a width (w) of a cell (12) of the honeycomb cell structure is 1 or more.

FIG 1

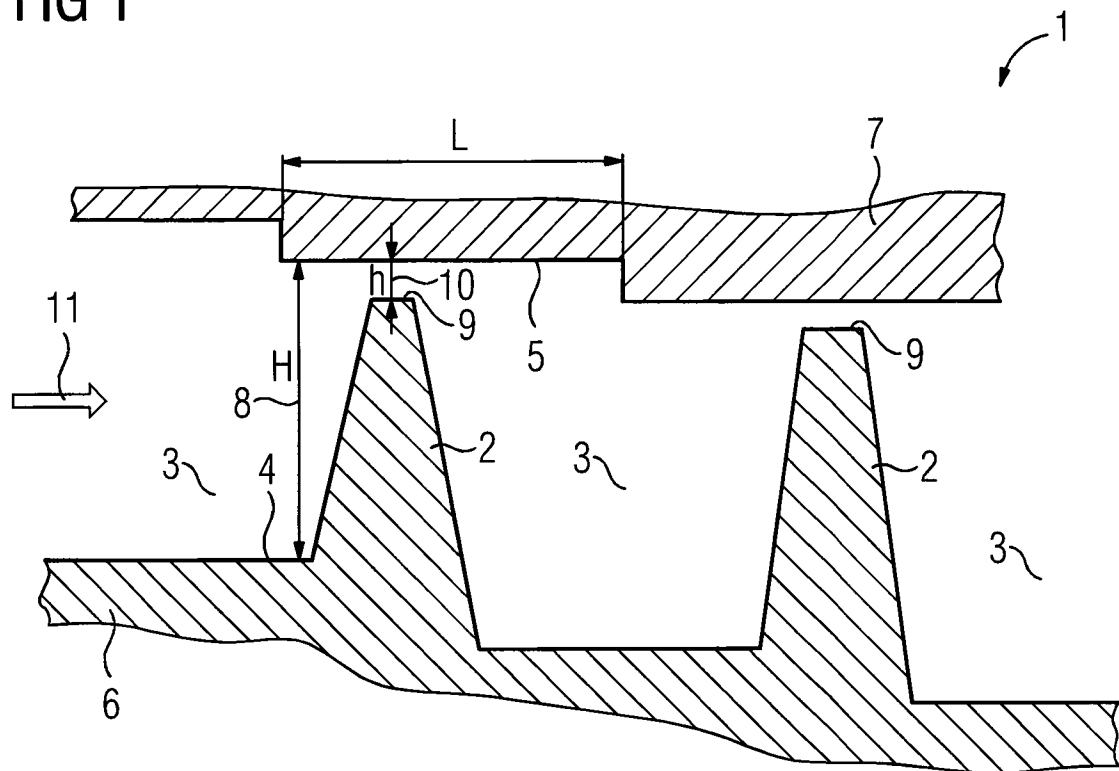


FIG 2

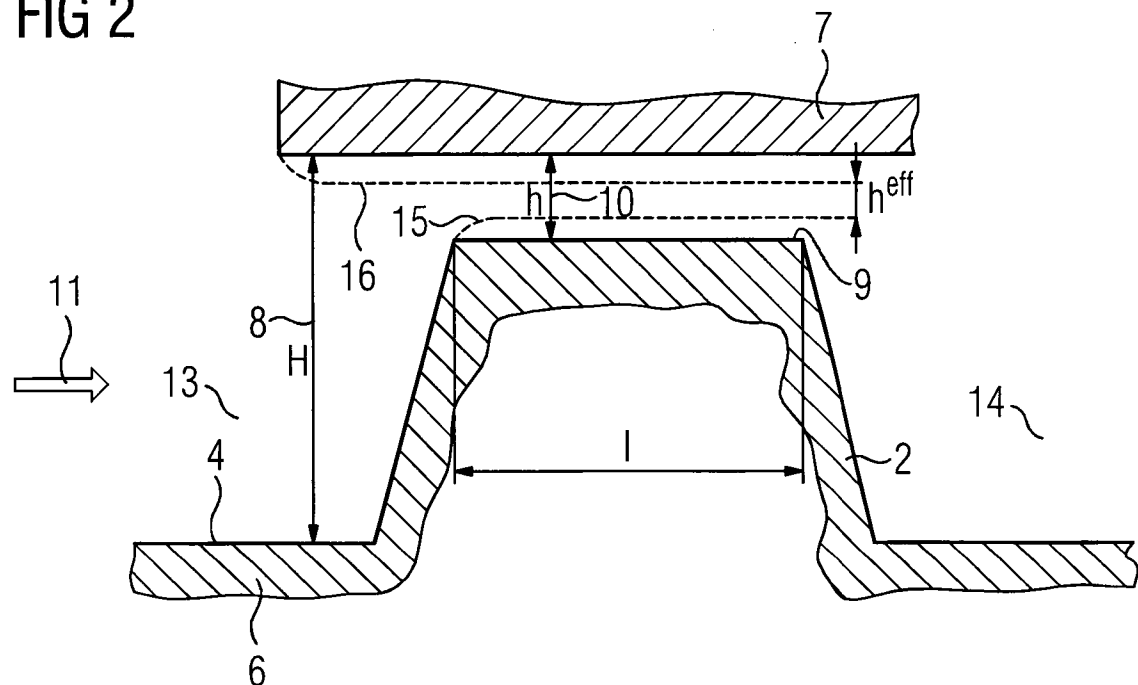


FIG 3

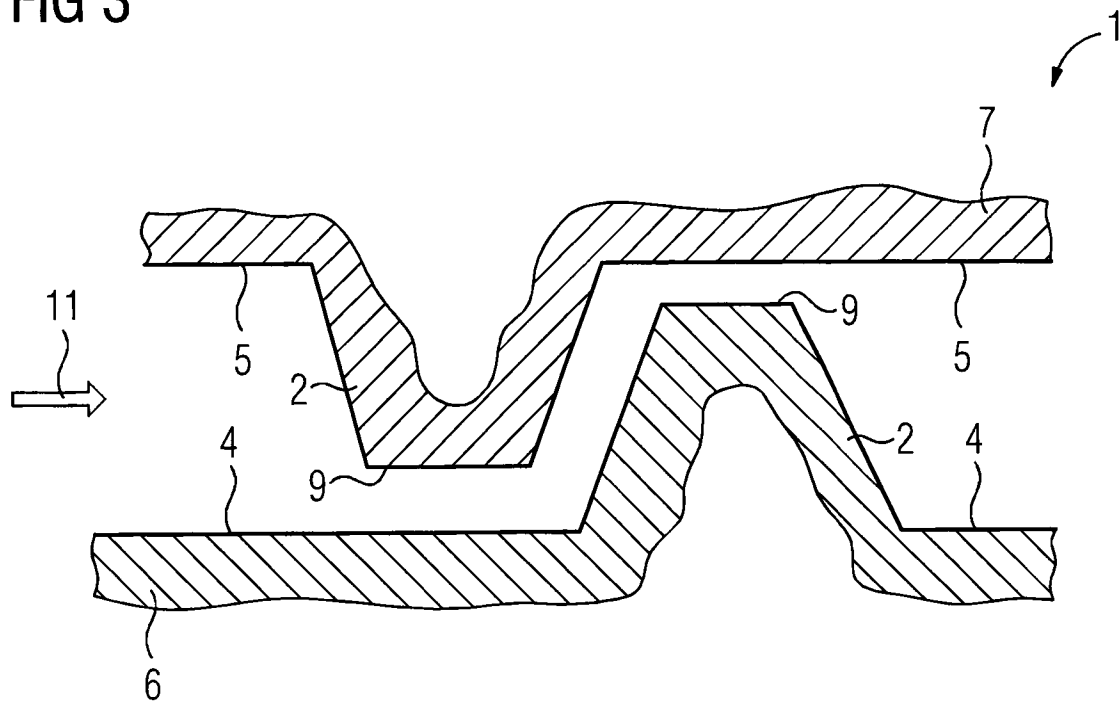


FIG 4

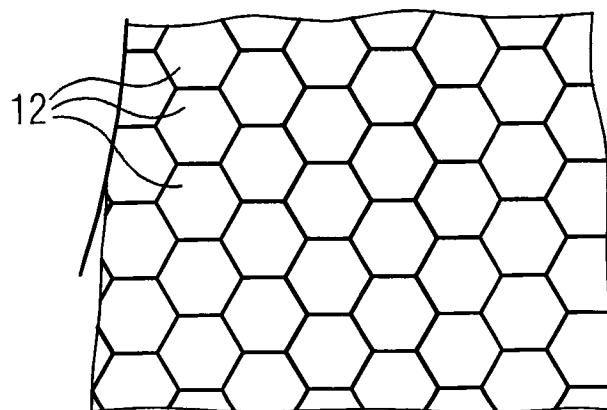
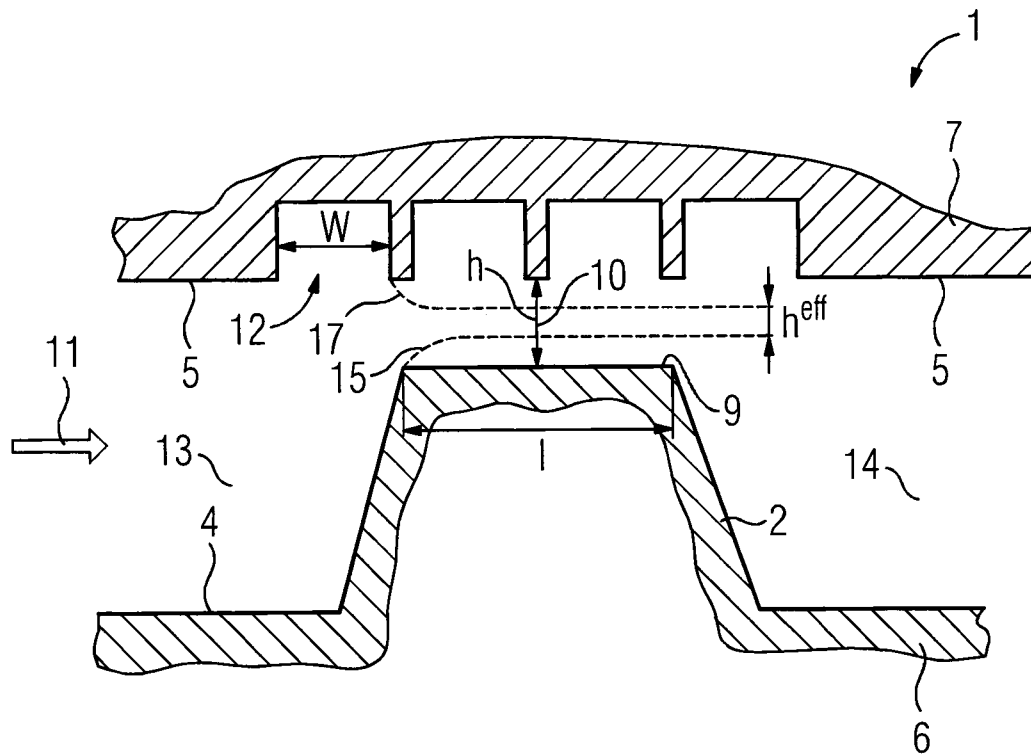


FIG 5



INTERNATIONAL SEARCH REPORT

International application No
PCT/RU2017/000524

A. CLASSIFICATION OF SUBJECT MATTER
INV. F01D11/00 F01D11/08 F01D11/12
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
F01D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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X	US 2011/309585 A1 (UEHARA HIDEKAZU [JP] ET AL) 22 December 2011 (2011-12-22) paragraph [0035] - paragraph [0085]; figures -----	1-5
X	EP 2 613 008 A1 (GEN ELECTRIC [US]) 10 July 2013 (2013-07-10) paragraph [0013] - paragraph [0035]; figures -----	1-5
X	GB 1 221 229 A (GARRETT CORP [US]) 3 February 1971 (1971-02-03) page 1 - page 3; figures ----- -/-	1-4



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

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"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

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Name and mailing address of the ISA/

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INTERNATIONAL SEARCH REPORT

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C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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INTERNATIONAL SEARCH REPORT

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