

(19)



(11)

EP 3 088 672 A1

(12)

EUROPEAN PATENT APPLICATION

(43) Date of publication:
02.11.2016 Bulletin 2016/44

(51) Int Cl.:
F01D 5/20 (2006.01) **F01D 11/08** (2006.01)
F01D 11/14 (2006.01) **F04D 29/52** (2006.01)

(21) Application number: **15165253.4**

(22) Date of filing: **27.04.2015**

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME
Designated Validation States:
MA

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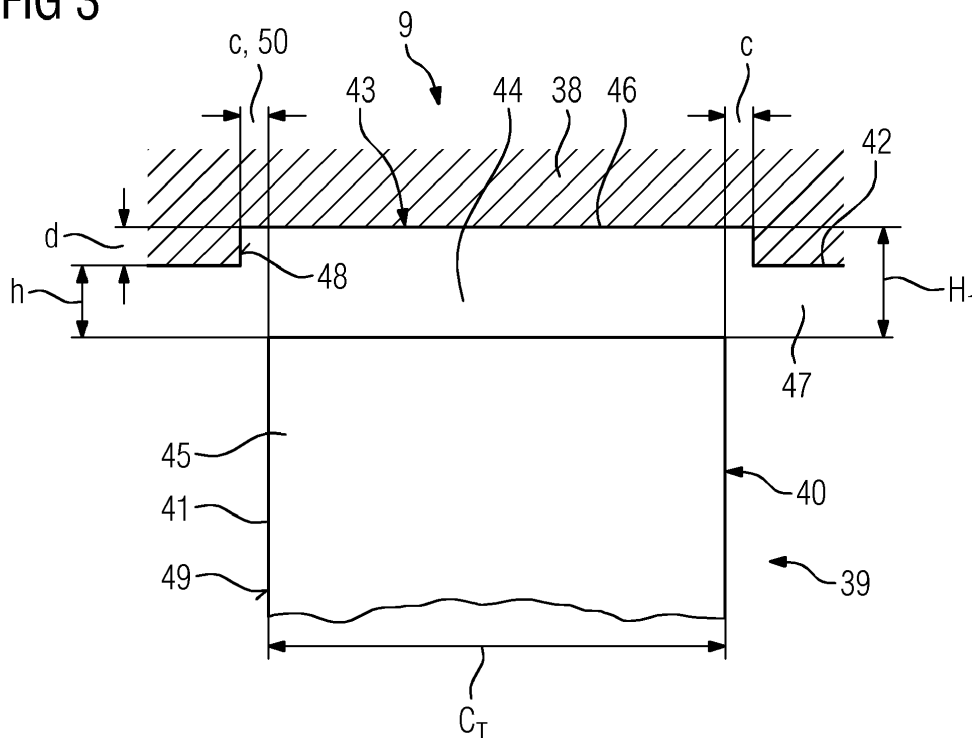
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(54) **METHOD FOR DESIGNING A FLUID FLOW ENGINE AND FLUID FLOW ENGINE**

(57) The invention relates to a fluid flow engine (9), in particular compressor or turbine of a gas turbine engine (10), having a stationary engine casing (38) and a rotor assembly (39) rotatable supported in the engine casing, the rotor assembly comprising at least one circumferentially extending rotor blade row (40) with a plurality of radially extending unshrouded rotor blades (41), an inner

surface (42) of the engine casing comprising at least one circumferentially extending slot (43) arranged radially outside of the rotor blade row, wherein a gap (44) is provided between tips (45) of the rotor blades and a base (46) of said slot, the depth (d) of said slot (43) being less than the gap height (H₁) of the gap (44).

FIG 3**EP 3 088 672 A1**

Description

[0001] The invention relates to a method for designing a fluid flow engine, in particular a compressor or a turbine of a gas turbine engine.

[0002] Moreover, the invention relates to a fluid flow engine, in particular a compressor or a turbine of a gas turbine engine, having a stationary engine casing and a rotor assembly rotatable supported in the engine casing, the rotor assembly comprising at least one circumferentially extending rotor blade row with a plurality of radially extending unshrouded rotor blades, an inner surface of the engine casing comprising at least one circumferentially extending slot arranged radially outside of the rotor blade row, wherein a gap is provided between tips of the rotor blades and a base of said slot.

[0003] A fluid flow engine has a stationary engine casing and a rotor assembly rotatable supported in the engine casing. The rotor assembly comprises at least one circumferentially extending rotor blade row with a plurality of radially extending unshrouded rotor blades. Conventionally, a clearance gap is provided between tips of the rotor blades and an inner surface of the engine casing to prevent or at least reduce occurrence of a radial contact, in particular physical rubbing, between the tips and the inner surface as far as possible. However, due to thermal growth and centrifugal growth of the rotor blades in certain operating states of the fluid flow engine, a temporary radial contact between blade tips and the inner surface of the engine casing may still occur.

[0004] To provide such a clearance gap conventionally the length of the rotor blades is reduced. Through this, the load carrying capacity of the rotor blades is reduced leading to a fluid flow engine with reduced efficiency.

[0005] To reduce losses caused by leakage of a working fluid through the gap between rotor blade tips and the inner surface of the engine casing it is known to provide the inner surface with at least one circumferentially extending slot arranged radially outside of the rotor blade row. A gap is provided between tips of the rotor blades and a base of said slot. Such fluid flow engines are for example disclosed by US 4 738 586 A and US 4 645 417 A.

[0006] It is an object of the invention to enhance the efficiency of a fluid flow engine.

[0007] This object is solved by the independent claims. Advantageous embodiments are disclosed in the dependent claims which either by taken alone or in any combination with each other may relate to an aspect of the invention.

[0008] A method according to the invention for designing a fluid flow engine, in particular a compressor or a turbine of a gas turbine engine, comprises the steps of:

- determining a minimum gap height of a required gap between tips of a rotatable supported circumferential row of radially extending rotor blades and an inner surface of a stationary engine casing of a conven-

tional fluid flow engine, wherein the gap is required to prevent radial contact between the tips and the inner surface as far as possible;

- manufacturing an engine casing with at least one circumferentially extending slot at an inner surface of the engine casing, such that a depth of said slot is less than the determined minimum gap height;
- manufacturing rotor blades for at least one circumferentially extending rotor blade row that can be arranged radially inside of said slot, such that a gap height of a gap between the tips of the rotor blades and a base of said slot equals the determined minimum gap height.

[0009] According to the invention the engine casing and the rotor blades are manufactured in such a way that the conventionally given minimum gap height of the gap between tips of the rotor blades and the inner surface of the engine casing of a conventional fluid flow engine is preserved. Because the gap according to the invention is not arranged between the tips of the rotor blades and the inner surface of the engine casing without an inventive slot, but between said tips and the base of the slot, the rotor blades according to the invention can be manufactured longer than conventional rotor blades. Since longer rotor blades have a higher load carrying capacity the inventive fluid flow engine, compared with conventional fluid flow engines, has a higher efficiency. In particular, with longer rotor blades more work can be done on the working fluid.

[0010] Determination of the minimum gap height may include measuring of this minimum gap height at a conventional fluid flow engine or considering known values for the minimum gap height. Additionally, specific constructive characteristics of the fluid flow engine to be designed and/or specific technical requirements may be considered when determining the minimum gap height.

[0011] The engine casing with the at least one circumferentially extending slot at the inner surface of the engine casing may be manufactured in a single production step. Alternatively, the engine casing may be manufactured without said slot in a first production step and may be machined in a following production step to produce said slot. Because the depth of said slot is less than the determined minimum gap height the rotor blades, in a starting condition of the inventive fluid flow engine, do not engage said slot and the tips of the rotor blades are not line-on-line with the inner surface of the engine casing without the slot. The engine casing may comprise two or more corresponding slots. Preferably, the number of slots arranged at the inner surface of the engine casing is equal to the number of circumferentially extending rotor blade rows of the fluid flow engine.

[0012] The rotor blades for the at least one circumferentially extending rotor blade row are manufactured according to the invention with such a length that the gap height of the gap between the tips of the rotor blades and the base of said slot equals the determined minimum gap

height.

[0013] A further advantage of the invention is that radial contacts between the tips of the rotor blades and the engine casing, and therefore tip rubs, can be reduced as far as possible. Moreover, even when the gap between the rotor blade tips and the base of the slot opens up at lower engine speeds, leading to lower temperature effects and lower centrifugal effects compared with a design speed, the gap between the rotor blade tips and the inner surface of the engine casing without the slot is still lower compared with a gap of a conventional fluid flow engine that does not comprise an inventive slot. This effects the stall margin at lower engine speeds because the tip stall is delayed when the gap between the rotor blade tips and the inner surface of the engine casing without the slot is lower.

[0014] Preferably, the engine casing is manufactured in such a way that the depth of said slot lies within a range of 50% to 95% of the determined minimum gap height. Accordingly, the rotor blades may be about 50% to 95% of the determined minimum gap height longer than conventional rotor blades. Correspondingly, the gap between the rotor blade tips and the inner surface without slots lies within a range of 5% to 50% of the determined minimum gap height. The depth of the slot and the length of the rotor blades is preferably selected under consideration of the expected thermal and centrifugal growth of the rotor blades. In particular, the depth of the slot and the length of the rotor blades can be chosen to avoid engagement of the rotor blades in the slot, except during transient operation states of the fluid flow engine. Preferably, the engine casing is manufactured in such a way that a cross section of said slot is rectangular-shaped. Therefore, in the cross section, the slot has a flat base and two parallel lateral surfaces arranged perpendicular to the base. The rotor blades may have correspondingly rectangular-shaped tips, wherein the width of the slot is greater than the width of the tips. Preferably, a gap between a lateral surface of the slot and lateral surfaces of the rotor blade tips is equal to or less than 1% of the width of the tips.

[0015] A fluid flow engine, in particular a compressor or turbine of a gas turbine engine, according to the invention comprises a stationary engine casing and a rotor assembly rotatable supported in the engine casing, the rotor assembly comprising at least one circumferentially extending rotor blade row with a plurality of radially extending unshrouded rotor blades, an inner surface of the engine casing comprising at least one circumferentially extending slot arranged radially outside of the rotor blade row, wherein a gap is provided between tips of the rotor blades and a base of said slot, and wherein a depth of said slot is less than the gap height of the gap.

[0016] The above mentioned advantages connected with the method are correspondingly connected with the inventive fluid flow engine. The rotor assembly may comprise two or more circumferentially extending rotor blade rows, each provided with a plurality of radially extending

unshrouded rotor blades. Preferably, the number of slots of the engine casing is equal to the number of rotor blade rows.

[0017] Preferably, the depth of said slot lies within a range of 50% to 95% of the gap height of the gap. The above mentioned advantages connected with the corresponding embodiment of the method are correspondingly connected with the present embodiment.

[0018] Preferably, a cross section of said slot is rectangular-shaped. The above mentioned advantages connected with the corresponding embodiment of the method are correspondingly connected with the present embodiment.

BRIEF DESCRIPTION OF THE DRAWINGS

[0019] The above mentioned attributes and other features and advantages of this invention and the manner of attaining them will become more apparent and the invention itself will be better understood by reference to the following description of embodiments of the invention taken in conjunction with the accompanying drawings, wherein

FIG. 1 shows a part of a turbine engine in a schematic sectional view,

FIG. 2 shows a detail of a conventional fluid flow engine in a schematic sectional view, and

FIG. 3 shows a detail of an embodiment of the inventive fluid flow engine in a schematic sectional view.

DETAILED DESCRIPTION OF INVENTION

[0020] Figure 1 is a schematic illustration of a general arrangement of a gas turbine engine 10 having an inlet 12, a compressor 14, a combustor system 16, a turbine system 18, an exhaust duct 20 and a twin-shaft arrangement 22, 24. The gas turbine engine 10 is generally arranged about an axis 26 which for rotating components is their rotational axis. The arrangements 22, 24 may have the same or opposite directions of rotation.

[0021] The combustion system 16 comprises an annular array of combustor units, i.e. burner 36, only one of which is shown. In one example, there are six burners 36 evenly spaced about the engine 10.

[0022] The turbine system 18 includes a high-pressure turbine 28 drivingly connected to the compressor 14 by a first shaft 22 of the twin-shaft arrangement 22, 24. The turbine system 18 also includes a low-pressure turbine 30 drivingly connected to a load (not shown) via a second shaft 24 of the twin-shaft arrangement.

[0023] The term axial is with respect to the axis 26. The terms upstream and downstream are with respect to the general direction of gas flow through the engine 10 and as seen in FIG.1 is generally from left to right.

[0024] The compressor 14 comprises an axial series of stator vanes and rotor blades mounted in a conventional manner. The stator or compressor vanes may be fixed or have variable geometry to improve the airflow onto the downstream rotor or compressor blades.

[0025] Each turbine 28, 30 comprises an axial series of stator vanes and rotor blades mounted via rotor discs arranged and operating in a conventional manner. A rotor assembly comprises an annular array of rotor blades or blades and the rotor disc.

[0026] In operation air 32 is drawn into the engine 10 through the inlet 12 and into the compressor 14 where the successive stages of vanes and blades compress the air before delivering the compressed air into the combustion system 16. In a combustion chamber of the combustion system 16 the mixture of compressed air and fuel is ignited. The resultant hot working gas flow is directed into, expands and drives the high-pressure turbine 28 which in turn drives the compressor 14 via the first shaft 22. After passing through the high-pressure turbine 28, the hot working gas flow is directed into the low-pressure turbine 30 which drives the load via the second shaft 24.

[0027] The low-pressure turbine 30 can also be referred to as a power turbine and the second shaft 24 can also be referred to as a power shaft. The load is typically an electrical machine for generating electricity or a mechanical machine such as a pump or a process compressor. Other known loads may be driven via the low-pressure turbine 30. The fuel may be in gaseous and/or liquid form.

[0028] The turbine engine 10 shown and described with reference to FIG.1 is just one example of a number of engines or turbomachinery in which this invention can be incorporated. Such engines can be gas turbines or steam turbine and include single, double and triple shaft engines applied in marine, industrial and aerospace sectors.

[0029] Figure 2 shows a detail of a conventional fluid flow engine 1 in a schematic sectional view. The fluid flow engine 1 comprises a stationary engine casing 2 and a rotor assembly 3 rotatable supported in the engine casing 2. The rotor assembly 3 comprises at least one circumferentially extending rotor blade row 4 with a plurality of radially extending unshrouded rotor blades 5.

[0030] A gap 6 is provided between tips 7 of the rotor blades 5 and an inner surface 8 of the engine casing 2. The gap 6 is required to prevent radial contact between the tips 7 and the inner surface 8 as far as possible. The gap 6 has a minimum gap height H. This minimum gap height H can be determined to carry out the method according to the invention, i.e. to design an inventive fluid flow engine.

[0031] Figure 3 shows a detail of an embodiment of the inventive fluid flow engine 9 in a schematic sectional view. The fluid flow engine 9 can be used as compressor for a gas turbine engine according to FIG.1.

[0032] The fluid flow engine 9 comprises a stationary engine casing 38 and a rotor assembly 39 rotatable sup-

ported in the engine casing 38. The rotor assembly 39 comprises at least one circumferentially extending rotor blade row 40 with a plurality of radially extending unshrouded rotor blades 41. An inner surface 42 of the engine casing 38 comprises at least one circumferentially extending slot 43 arranged radially outside of the rotor blade row 40. A gap 44 is provided between tips 45 of the rotor blades 41 and a base 46 of said slot 43.

[0033] A depth d of said slot 43 is less than the gap height H_1 of the gap 44. Preferably, the depth d of said slot 43 lies within a range of 50% to 95% of the gap height H_1 of the gap 44. Therefore, a gap 47 between the rotor blade tips 45 and the inner surface 42 without the slot 43 has a gap height h that is less than the gap height H_1 of the gap 44. The gap height h lies within a range of 5% to 40% of the gap height H_1 of the gap 44. The rotor blades 41 are longer than the conventional rotor blades according to FIG.2 about 50% to 95% of the gap height H_1 of the gap 44. The gap height H_1 may be equal to the minimum gap height H of FIG.2.

[0034] A cross section of said slot 43 is rectangular-shaped. Also the tips 45 of the rotor blades 41 are rectangular-shaped. The width C_T of the rotor blade tips 45 is less than the width of the slot 43, in particular the width of the base 46 of the slot 43. Between a lateral surface 48 of the slot 43 and a lateral surface 49 of a rotor blade tip 45 a gap 50 is provided having a gap height c. Preferably, the gap height c is equal to or less than 1% of the width C_T of the rotor blade tips 45.

[0035] It shall be clear that the invention is also applicable to guide vanes of a fluid flow engine arranged in a circumferentially extending row, wherein a slot is arranged radially inside of the row at an outer surface of a rotor hub.

[0036] Although the invention has been explained and described in detail in connection with the preferred embodiments it is noted that the invention is not limited to the disclosed embodiments. A person skilled in the art can derive from these embodiments other variations without leaving the scope of protection of the invention.

Claims

1. A method for designing a fluid flow engine (9), in particular a compressor or a turbine of a gas turbine engine (10), comprising the steps of:

- determining a minimum gap height (H) of a required gap (6) between tips (7) of a rotatable supported circumferential row (4) of radially extending rotor blades (5) and an inner surface (8) of a stationary engine casing (2) of a conventional fluid flow engine (1), wherein the gap (6) is required to prevent radial contact between the tips (7) and the inner surface (8) as far as possible;
- manufacturing an engine casing (38) with at

least one circumferentially extending slot (43) at an inner surface (42) of the engine casing (38), such that a depth (d) of said slot (43) is less than the determined minimum gap height (H);

- manufacturing rotor blades (41) for at least one circumferentially extending rotor blade row (40) that can be arranged radially inside of said slot (43), such that a gap height (H_1) of a gap (44) between the tips (45) of the rotor blades (41) and a base (46) of said slot (43) equals the determined minimum gap height (H). 5
2. The method according to claim 1, wherein the engine casing (38) is manufactured in such a way that the depth (d) of said slot (43) lies within a range of 50% to 95% of the determined minimum gap height (H). 15
 3. The method according to claim 1 or 2, wherein the engine casing (38) is manufactured in such a way that a cross section of said slot (43) is rectangular-shaped. 20
 4. A fluid flow engine (9), in particular compressor or turbine of a gas turbine engine (10), having a stationary engine casing (38) and a rotor assembly (39) rotatable supported in the engine casing (38), the rotor assembly (39) comprising at least one circumferentially extending rotor blade row (40) with a plurality of radially extending unshrouded rotor blades (41), an inner surface (42) of the engine casing (38) comprising at least one circumferentially extending slot (43) arranged radially outside of the rotor blade row (40), wherein a gap (44) is provided between tips (45) of the rotor blades (41) and a base (46) of said slot (43), **characterized in that** a depth (d) of said slot (43) is less than the gap height (H_1) of the gap (44). 25
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 5. The fluid flow engine (9) according to claim 4, wherein the depth (d) of said slot (43) lies within a range of 50% to 95% of the gap height (H_1) of the gap (44). 40
 6. The fluid flow engine (9) according to claim 4 or 5, wherein a cross section of said slot (43) is rectangular-shaped. 45

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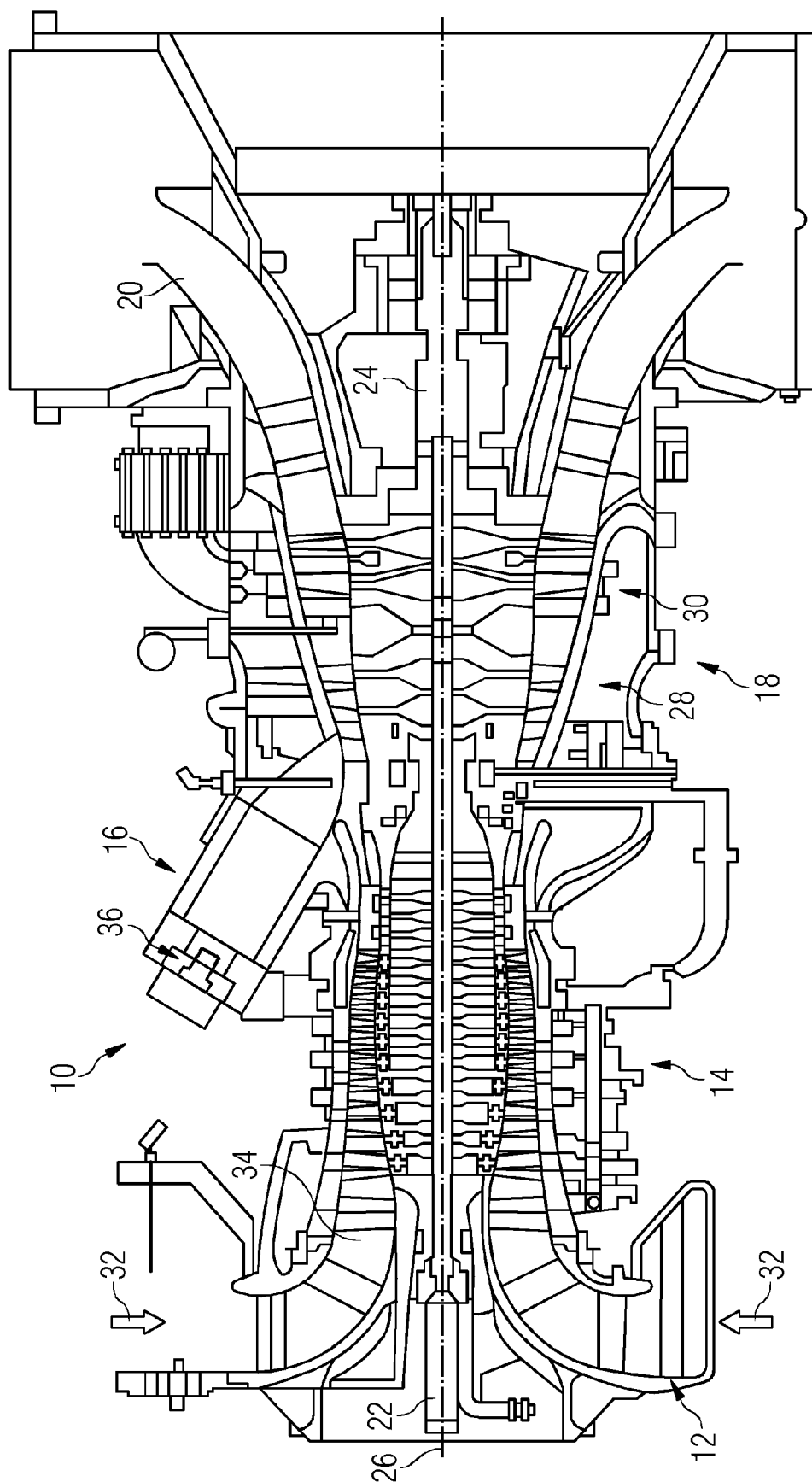


FIG 1

FIG 2

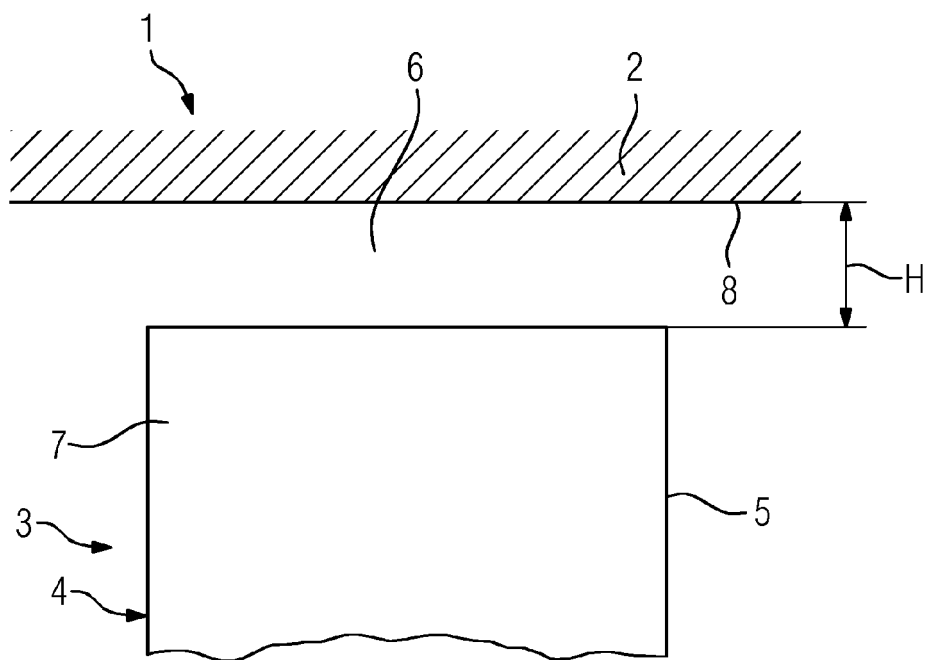
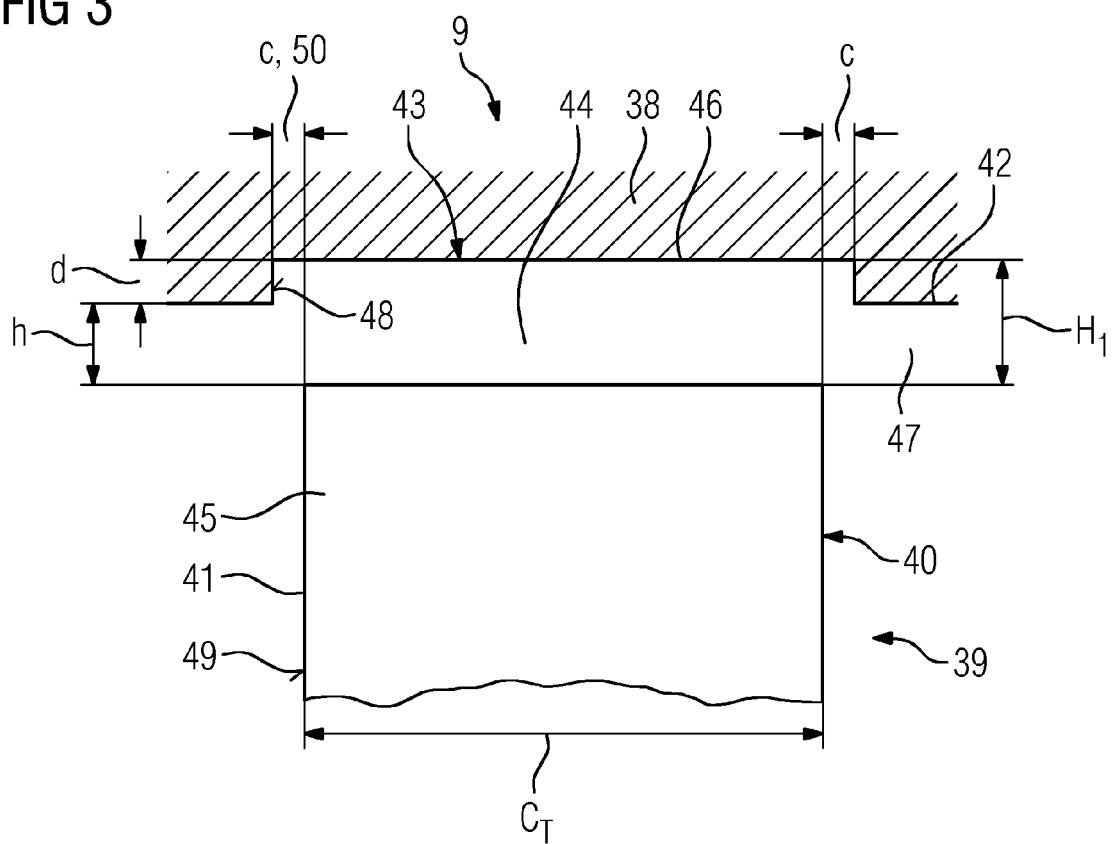


FIG 3





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Application Number
EP 15 16 5253

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Place of search Munich		Date of completion of the search 15 October 2015	Examiner Teusch, Reinhold
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

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**ANNEX TO THE EUROPEAN SEARCH REPORT
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