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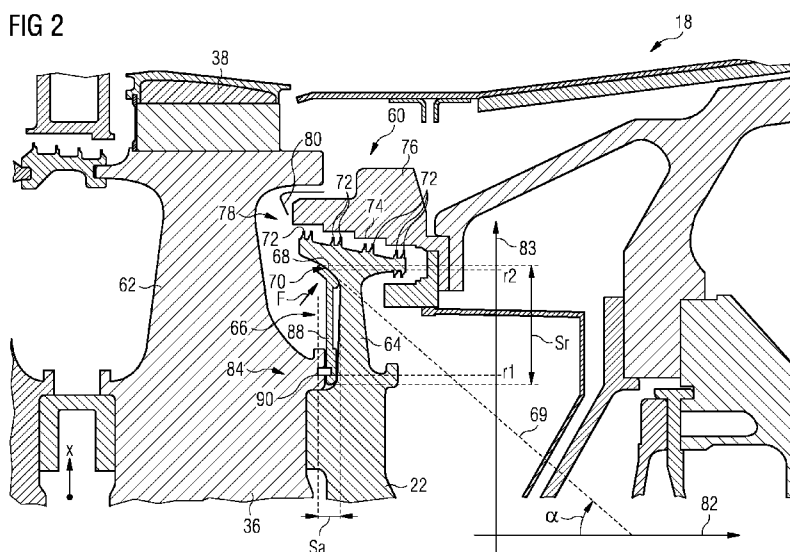
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**(54) Title:** DAMPING VIBRATIONS IN A GAS TURBINE



**(57) Abstract:** Damping vibrations in a gas turbine It is described an arrangement (60) for damping vibrations in a gas turbine (10), comprising: a rotor shaft (22) arranged for rotating; a first rotor component (62) connected to the rotor shaft (22); a second rotor component (64) connected to the rotor shaft (22); a damping structure (66) fixed at the first rotor component (62) or floated between the first and the second rotor component and having a contact surface (68) arranged to press against a contact surface (70) of the second rotor component (64) to damp a vibration of the second rotor component. Furthermore the invention is also directed to a method for damping.

**DESCRIPTION**

Damping vibrations in a gas turbine

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Field of invention

The present invention relates to an arrangement for damping vibrations in a gas turbine and to a method for damping vibrations—in a gas turbine and further relates to a gas turbine comprising the arrangement for damping vibrations in a gas turbine.

15 Art Background

A gas turbine is conventionally used to produce mechanical power or electrical power by burning a fuel. During operation of the gas turbine, vibrations may be excited in different turbine engine components. The vibrations may lead to a damage of components of the gas turbine and may even lead to a catastrophic rotor failure.

US 4,361,213 discloses a vibration damper ring for damping vibration of a structural member of a gas turbine. The damper ring includes an annular recess for receiving an extension, such as a flange, of the structural member and can include radially extending tabs to restrict relative axial movement. The damper ring is preferably severed to allow it to be retained radially against the extension of the structural member.

US 5,733,103 discloses a vibration damper for a turbine engine, the damper including a damper ring having inner and outer radial surfaces, axial retainers extending radially outward from the outer radial surface and an annular stiffener protruding radially inward from the inner radial surface.

US 6,375,428 B1 discloses a turbine blisk rim friction finger damper for reducing vibrations in an integrally bladed turbine disk. The damper includes an annular member and a plurality of fingers and the annular member is configured so that it is coupled to a face of the integrally bladed turbine disk.

The document US 2012/0207603 A1 discloses a trapped spring balance weight and rotor assembly comprising a block-like centerbody, a pair of resilient spring arms extending laterally from opposite sides of the centerbody, at least one locating structure and a limit tab extending radially inward from the distal end of each of the spring arms.

The document EP 1 602 855 A2 discloses a balancing assembly for a turbine rotor comprising a balance weight retention member having a circumferential periphery and a slot formed therein, wherein an opening defines a balance weight engaging section and wherein at least one balance weight is insertable through the opening of the slot and is positionable for movement within the slot and having a pair of spaced apart generally inwardly sloping shoulder surfaces capable of engaging the sidewalls of the slot.

The prior art solutions of damping vibrations in a gas turbine may not in all situations reliably and securely damp components of a gas turbine or it might not even be possible to be integrated into some rotor assemblies.

Thus, there may be a need for an arrangement for damping vibrations in a gas turbine rotor and for a method for damping vibrations in a gas turbine, wherein at least some of the disadvantages of the prior art solutions are overcome and also can be applied in cases that prior art solutions are not possible to be implemented or are not efficient enough.

Summary of the Invention

The need is solved by the subject-matter of the independent claims. The dependent claims specify particular embodiments  
5 of the present invention.

According to an embodiment of the present invention, it is provided an arrangement for damping vibrations in a gas turbine, comprising: a rotor arranged for rotating, a first rotor component connected to the rotor, a second rotor component connected to the rotor, and a damping structure fixed at the first rotor component or floated between the two rotor components and having a contact surface arranged to press against a contact surface of the second rotor component to  
10 damp a vibration or vibration of the second rotor component, wherein the damping structure is designed to exert, during rotation of the rotor at a predetermined rotational speed, a predetermined force to the contact surface of the second rotor component, in order to damp primarily an axial vibration  
15 of the second rotor component.  
20

The first rotor component may for example comprise or be a disk at which plural rotor blades are connected. The first rotor component may in particular be a component which does  
25 not oscillate or at least oscillates only with much smaller amplitude than the second rotor component or which vibrates within acceptable amplitudes.

The second rotor component may in particular be a component  
30 which is axially immediately adjacent to the first rotor component. The second rotor component may in particular not comprise any rotor blades connected to it. The second rotor component may for example be used for or be part of a sealing or system preventing mixture of a cooling gas, such as compressed air with hot gas, or it could be used as a balancing  
35 piston to cancel out axial forces in the rotor. The second rotor component may be axially spaced apart from the first rotor component. In the second rotor component, in particular

during operation of the gas turbine, a number of vibrations may occur. The vibrations may be in the axial direction, in the radial direction and/or in the circumferential direction. Embodiments of the present invention are in particular directed for damping or reducing vibrations of the second rotor component which are in the axial direction. However, the damping structure may also be effective for reducing vibrations in the radial and/or the circumferential direction.

10 The damping structure may be made of an alloy or a super alloy a pure metal and may in particular be configured to have a required rigidity and thermal resistance. During operation, the damping structure may be surrounded for example by a cooling gas, which may have a temperature between 300°C and  
15 500°C. Further, during operation, high centrifugal forces may act on the damping structure which the damping structure should withstand.

The damping structure may be an annular structure running the circumferential direction and forming a closed ring. The damping structure may by itself be rigid but may slightly elongate due to centrifugal forces and/or thermal expansion. The contact surface of the damping structure via which the damping structure touches and presses against the contact  
25 surface of the second rotor component may be spaced apart from a portion where the damping structure is fixed at the first rotor component. In particular, during starting or stopping the gas turbine, i.e. during transient operational periods, second rotor component may move (in particular vibrate) relative to the damping structure and friction may occur between the contact surface of the damping structure and the contact surface of the second rotor component. The friction may reduce the movement of the damping structure and the second rotor component relative to each other and may thus  
35 damp the vibration and reduces the amplitude of the vibration of the second rotor component.

According to an embodiment of the present invention, the damping structure is designed to exert, during rotation of the rotor at a predetermined rotational speed, a predetermined force to the contact surface of the second rotor component, in order to damp an axial vibration of the second rotor component, the contact surface of the second rotor component in particular comprising a coating configured to reduce wear due to friction against the contact surface of the damping surface.

Using a simulation or establishing a physical model, the damping structure (in particular the shape of its contact surface, etc.) may be designed such as to exert a required pressing force towards the contact surface of the second rotor component in order to damp vibrations having an expected amplitude. Using a mechanical model, the surface shapes of the contact surface of the damping structure as well as the contact surface of the second rotor component may be determined and the shape and extension of the damping structure as a whole may be designed, in order to achieve a desired damping force on the contact surface of the second rotor component during operation, i.e. at a particular rotational velocity.

The coating of the region of the contact surface of the second rotor component may comprise a particular alloy layer in order to increase the durability and thereby reduce wear at this region of the second rotor component.

According to an embodiment of the present invention, the contact surface of the second rotor component has an angle against an axial direction between  $30^{\circ}$  and  $75^{\circ}$ , the contact surface having in particular a curved shape, wherein in particular the predetermined force has a predetermined direction.

When the contact surfaces have the specified angle against the axial direction, the pressing force may act substantially

orthogonal to the surface and may then effectively damp vibrations of the second rotor component. By designing the shape of the contact surfaces, the direction of the force may be adjusted, to achieve an effective damping.

5

According to an embodiment of the present invention, the damping structure can comprises a fixing section used to fix the damping structure at the first rotor component, wherein the fixing section of the damping structure is located further radially inwards than the contact surface of the damping structure.

The fixing section may for example comprise a hole to be bolted or hanged, or may comprise a region which may be welded with the first rotor component. When the fixing section is located further radially inwards than the contact surface of the damping structure, a radially outward directed centrifugal force may act on the contact surface of the damping structure and may effectively press the contact surface of the damping structure onto the contact surface of the second rotor component, to effect damping the vibrations of the second rotor component.

According to an embodiment of the present invention, the damping structure further comprises a spacer portion between the fixing section and the contact surface of the damping structure, the spacer portion forming a ring plate.

The spacer portion may allow to protrude to the contact surface of the second rotor component which is best suitable for applying a force for damping the vibrations. The spacer portion may run in the radial and/or in the axial direction. Due to the annular shape of the damping structure, the spacer region also extends in the circumferential direction. The ring plate may be formed by a ring having a constant or variable thickness. The contact surface of the damping structure may have a shape different from the spacer portion in order to

smoothly match the surface shape of the contact surface of the second rotor component.

According to an embodiment of the present invention, the fixing section allows bolting the damping structure to the first rotor component. Thereby, a simple fixing method may be realized.

According to an embodiment of the present invention, the damping structure extends to a larger degree radially than axially. When the damping structure extends to a large degree in the radial direction, a centrifugal force acting during operation may effectively increase a pressing force with increasing rotational speed, in order to effectively damp amplitudes of vibrations which may also increase with increasing rotational speed.

According to an embodiment of the present invention, the damping structure forms a ring, made from a single piece or comprising several sections of a segmented ring. When the ring comprises several ~~ring~~ sections, it may be possible to damp local vibrations, i.e. vibrations which do not occur at all circumferential positions. The ring sections may at least partly be uncoupled from each other although they may be connected to some degree or even rigidly connected in other embodiments.

According to an embodiment of the present invention, the arrangement is part of a turbine section of the gas turbine, wherein the first rotor component may be a disk having rotor blades connected to it. The disk may in particular be a second, third or fourth or fifth disk of the turbine section, i.e. a disk not immediately downstream of an exhaust region of a combustor.

According to an embodiment of the present invention, the second rotor component may comprises at a radially most outward section plural teeth of a labyrinth seal formed against a

stator portion, the labyrinth seal being intended to inhibit flow through of a cooling gas.

5 The plural teeth together with components of a stator portion may form the labyrinth seal. The cooling gas may for example be compressed air generated in a compressor section of the gas turbine. The cooling gas may have a temperature between 300°C and 500°C. Other values are possible.

10 In this embodiment, the contact surface of the damping structure contacts the second rotor component radially inwards from the plural teeth. Thereby, the seal function may not be affected or in particular not deteriorated by providing the damping structure.

15 According to an embodiment of the present invention, flow through of the cooling gas through the labyrinth seal excites vibration of the second rotor component. Other causes of the vibration may be present.

20 According to an embodiment of the present invention, the contact portion of the second rotor component is radially inwards from the teeth. Thereby, the sealing function is not affected, while vibrations may effectively be damped.

25 According to an embodiment it is provided a gas turbine comprising an arrangement for damping vibration according to one of the preceding embodiments.

30 It should be understood that features individually or in any combination disclosed for an arrangement for damping an vibration in a gas turbine or a gas turbine may also be applied, individually or in any combination, to a method for damping vibrations in a gas turbine according to an embodiment of the present invention and vice versa.

35

According to an embodiment of the present invention, it is provided a method for damping vibrations in a gas turbine,

the method comprising: rotating a rotor, exciting a vibration of a second rotor component connected to the rotor, pressing against a contact surface of the second rotor component using a contact surface of a damping structure fixed at a first rotor component that is connected to the rotor, wherein the damping structure is designed to exert, during rotation of the rotor at a predetermined rotational speed, a predetermined force to the contact surface of the second rotor component, in order to damp primarily an axial vibration of the second rotor component.

It has to be noted that embodiments of the invention have been described with reference to different subject matters. In particular, some embodiments have been described with reference to method type claims whereas other embodiments have been described with reference to apparatus type claims. However, a person skilled in the art will gather from the above and the following description that, unless other notified, in addition to any combination of features belonging to one type of subject matter also any combination between features relating to different subject matters, in particular between features of the method type claims and features of the apparatus type claims is considered as to be disclosed with this document.

The aspects defined above and further aspects of the present invention are apparent from the examples of embodiment to be described hereinafter and are explained with reference to the examples of embodiment. The invention will be described in more detail hereinafter with reference to examples of embodiment but to which the invention is not limited.

#### Brief Description of the Drawings

Embodiments of the present invention are now described with reference to the accompanying drawings. The invention is not restricted to the illustrated or described embodiments.

Fig. 1 schematically illustrates a sectional view of a gas turbine according to an embodiment of the present invention; and

5

Fig. 2 schematically illustrates a portion of a turbine section of the gas turbine illustrated in Fig. 1 including an arrangement for damping vibrations in a gas turbine according to an embodiment of the present invention.

10

#### Detailed Description

**Fig. 1** shows an example of a gas turbine engine 10 according to an embodiment of the present invention in a sectional view.

The gas turbine engine 10 comprises, in flow series, an inlet 12, a compressor section 14, a combustor section 16 and a turbine section 18 which are generally arranged in flow series and generally about and in the direction of a longitudinal or rotational axis 20. The gas turbine engine 10 further comprises a rotor shaft 22 which is rotatable about the rotational axis 20 and which extends longitudinally through the gas turbine engine 10. The rotor shaft 22 drivingly connects the turbine section 18 to the compressor section 14.

In operation of the gas turbine engine 10, air 24, which is taken in through the air inlet 12 is compressed by the compressor section 14 and delivered to the combustion section or burner section 16. The burner section 16 comprises a burner plenum 26, one or more combustion chambers 28 and at least one burner 30 fixed to each combustion chamber 28. The combustion chambers 28 and the burners 30 are located inside the burner plenum 26. The compressed air passing through the compressor 14 enters a diffuser 32 and is discharged from the diffuser 32 into the burner plenum 26 from where a portion of the air enters the burner 30 and is mixed with a gaseous or liquid fuel. The air/fuel mixture is then burned and the

combustion gas 34 or working gas from the combustion is channelled through the combustion chamber 28 to the turbine section 18 via a transition duct 17.

5 The exemplary gas turbine engine 10 has an annular combustor section arrangement 16, which is constituted by an annular array of combustor cans 19 each having the burner 30 and the combustion chamber 28, the transition duct 17 has a generally circular inlet that interfaces with the combustor chamber 28  
10 and an outlet in the form of an annular segment. An annular array of transition duct outlets form an annulus for channeling the combustion gases to the turbine 18.

The turbine section 18 comprises a number of blade carrying discs 36 attached to the shaft 22. In the present example,  
15 two discs 36 each carry an annular array of turbine blades 38. However, the number of blade carrying discs could be different, i.e. only one disc or more than two discs. In addition, guiding vanes 40, which are fixed to a stator 42 of the gas turbine engine 10, are disposed between the stages of an-  
20 nular arrays of turbine blades 38. Between the exit of the combustion chamber 28 and the leading turbine blades 38 inlet guiding vanes 44 are provided and turn the flow of working gas onto the turbine blades 38.

25 The combustion gas from the combustion chamber 28 enters the turbine section 18 and drives the turbine blades 38 which in turn rotate the shaft 22. The guiding vanes 40, 44 serve to optimise the angle of the combustion or working gas on the turbine blades 38.

30 The turbine section 18 drives the compressor section 14. The compressor section 14 comprises an axial series of vane stages 46 and rotor blade stages 48. The rotor blade stages 48 comprise a rotor disc supporting an annular array of  
35 blades. The compressor section 14 also comprises a casing 50 that surrounds the rotor stages and supports the vane stages 48. The guide vane stages include an annular array of radially extending vanes that are mounted to the casing 50.

The vanes are provided to present gas flow at an optimal angle for the blades at a given engine operational point. Some of the guide vane stages have variable vanes, where the angle of the vanes, about their own longitudinal axis, can be adjusted for angle according to air flow characteristics that can occur at different engine operations conditions.

The casing 50 defines a radially outer surface 52 of the passage 56 of the compressor 14. A radially inner surface 54 of the passage 56 is at least partly defined by a rotor drum 53 of the rotor which is partly defined by the annular array of blades 48.

The present invention is described with reference to the above exemplary turbine engine having a single shaft or spool connecting a single, multi-stage compressor and a single, one or more stage turbine. However, it should be appreciated that the present invention is equally applicable to two or three shaft engines and which can be used for industrial, aero or marine applications.

The terms upstream and downstream refer to the flow direction of the airflow and/or working gas flow through the engine unless otherwise stated. The terms forward and rearward refer to the general flow of gas through the engine. The terms axial, radial and circumferential are made with reference to the rotational axis 20 of the engine.

Between the rotor blade carrying disks 36 in the turbine section 18 of the gas turbine 10 are not illustrated further rotating components, for example components of a seal and at least one damping structure which are described in more detail with reference to Fig. 2.

**Fig. 2** illustrates in a sectional view a portion of the turbine section 18 of the gas turbine 10 illustrated in Fig. 1. The turbine section 18 comprises an arrangement 60 for damping vibrations. The arrangement 60 comprises a rotor shaft

22, a first rotor component 62 connected to the rotor, a second rotor component 64 connected to the rotor and a damping structure 66 fixed at the first rotor component 62 or floated between first rotor component 62 and second one 64 and having  
5 a contact surface 68 arranged to press against a contact surface 70 of the second rotor component 64 to damp a vibration of the second rotor component 64.

In the illustrated embodiment, the first rotor component 62  
10 is formed by the disk 36 which carries a rotor blade 38, e.g. a third or fourth stage downstream the combustor or can be a disk that carries no blades. Further, in the presently illustrated embodiment, the second rotor component 64 is formed by a disk which does not carry rotor blades but which carries  
15 plural teeth 72 which, together with a profile 74 at a stator portion 76 form a labyrinth seal 78 to inhibit flow-through of a cooling gas 80.

The damping structure 66 is designed to exert, during rotation of the rotor shaft 22 at a predetermined rotational  
20 speed, a predetermined force  $F$  to the contact surface 70 of the second rotor component 64. A tangent 69 taken on the contact surface 68 of the damping structure 66 forms an angle  $\alpha$  with the axial direction 82 (The radial direction is labelled with reference sign 83). The angle  $\alpha$  may be between  $30^\circ$  and  
25 75. Other values are possible. As can be appreciated from Fig. 2, the contact surface 68 of the damping structure 66 has a curved shape, in particular being convex, the contact surface 70 of the second component having a concave shape. In  
30 other embodiments, the contact surface 68 (and also the contact surface 70 of the second component) has a plane or planar shape.

The damping structure 66 comprises a fixing section 84 which  
35 allows for example to fix the damping structure 66 via a bolt 86 (or some other mechanism) to the first rotor component 62, i.e. the disk 36. The radial position of the fixing section is  $r_1$  and the radial position of the (e.g. center of the)

contact surface 68 of the damping structure 66 is  $r_2$ , wherein  $r_2 > r_1$ .

The damping structure 66 further comprises a spacer portion  
5 88 between the fixing section 84 and the contact surface 68.  
By adjusting the length or by designing the length of the  
spacer portion 88, the contact surface 68 of the damping  
structure 66 may advantageously be positioned to be in tight  
contact and to press against the contact surface 70 of the  
10 second rotor component.

The damping structure 66 has a radial extent  $s_r$  and has an  
axial extent toward the second rotor component 64  $s_a$ , wherein  
 $s_a < s_r$ . The teeth 72 are radially outward from the contact  
15 surface 68 of the damping structure 66.

According to an embodiment of the present invention, the  
damping structure consists of a membrane (which also could be  
divided into segments). The membrane may be mounted (floated,  
20 bolted, hooked, etc.) behind the component having the vibra-  
tions to be damped. During engine operation, the membrane may  
be elongated (due to centrifugal force and due to thermal ex-  
pansion) and the contact with the disk 64 may be retained.  
Vibration of the disk 64 results in a relative motion between  
25 the disk 64 and the membrane 66. Due to a relative motion and  
friction between contact surfaces, damping will be introduced  
in the system which helps to reduce disk vibrations. It also  
adds additional stiffness to the critical location on disk  
which is favorable.

30 Embodiments of the present invention allow the possibility to  
solve vibration problems in engines with minimum modifica-  
tions and changes to the engine. Even it allows to easily  
solve the problem in machines which are currently operating  
35 in the field.

It should be noted that the term "comprising" does not ex-  
clude other elements or steps and "a" or "an" does not ex-

clude a plurality. Also elements described in association with different embodiments may be combined. It should also be noted that reference signs in the claims should not be construed as limiting the scope of the claims.

**CLAIMS:**

1. Arrangement (60) for damping vibrations in a gas turbine (10), comprising:
- 5       a rotor shaft (22) arranged for rotating;  
      a first rotor component (62) connected to the rotor shaft (22);  
      a second rotor component (64) connected to the rotor shaft (22);
- 10       a damping structure (66) fixed at the first rotor component (62) or floated and having a contact surface (68) arranged to press against a contact surface (70) of the second rotor component (64) to damp a vibration of the second rotor component,
- 15       wherein the damping structure (66) is designed to exert, during rotation of the rotor at a predetermined rotational speed, a predetermined force (F) to the contact surface (70) of the second rotor component (64), in order to damp primarily an axial vibration of the second rotor component (64).
- 20
2. Arrangement according to claim 1, wherein the contact surface (70) of the second rotor component (64) comprising a coating configured to reduce wear due to friction against the contact surface of the damping surface.
- 25
3. Arrangement according to claim 1 or 2, wherein the contact surface (70) of the second rotor component has an angle ( $\alpha$ ) against an axial direction between 30° and 75°, the contact surface (70) having in particular a curved shape,
- 30       wherein in particular the predetermined force has a predetermined direction.
4. Arrangement according to one of the preceding claims, wherein the damping structure (66) comprises a fixing section
- 35       (84) used to fix the damping structure (66) at the first rotor component (62), wherein the fixing section (84) of the damping structure (66) is located further radially inwards from the contact surface of the damping structure (66).

5. Arrangement according to the preceding claim,  
wherein the damping structure (66) further comprises a spacer  
portion (88) between the fixing section (84) and the contact  
5 surface of the damping structure (66), the spacer portion  
(88) forming a ring plate.

6. Arrangement according to claim 4 or 5, wherein the fixing  
section (84) allows bolting the damping structure (66) to the  
10 first rotor component (62).

7. Arrangement according to one of the preceding claims,  
wherein the damping structure (66) extends to a larger degree  
radially than axially.

15 8. Arrangement according to one of the preceding claims,  
wherein the damping structure (66) forms a ring, made from a  
single piece or comprising several segments that form a ring

20 9. Arrangement according to one of the preceding claims,  
wherein the arrangement is part of a turbine section of the  
gas turbine (10),  
wherein the first rotor component (62) is a disk (36)  
having rotor blades connected to it or wherein the first ro-  
25 tor component (62) is a shaft without connected rotor blades.

10. Arrangement according to the preceding claim,  
wherein the second rotor component (64) comprises at a  
radially most outward section plural teeth (72) of a laby-  
30 rinth seal (78) formed against a stator portion (76), the  
labyrinth seal intended to inhibit flow-through of a cooling  
gas (80).

11. Arrangement according to the preceding claim, wherein  
35 flow-through of the cooling gas (80) through the labyrinth  
seal (78) excites vibration of the second rotor component  
(64).

12. Arrangement according to one of the preceding claims 10 or 11, wherein the contact portion (70) of the second rotor component (64) is radially inwards from the teeth (72).

5 13. Gas turbine (10) comprising an arrangement (60) according to one of the preceding claims.

14. Method for damping vibrations in a gas turbine (10), the method comprising:

10       rotating a rotor shaft (22);  
          exciting a vibration of a second rotor component (64) connected to the rotor shaft (22);  
          pressing against a contact surface (70) of the second rotor component (64) using a contact surface (68) of a damp-  
15   ing structure (66) fixed at a first rotor component (62) that is connected to the rotor shaft (22),  
          wherein the damping structure (66) is designed to exert, during rotation of the rotor at a predetermined rotational speed, a predetermined force (F) to the contact surface (70)  
20   of the second rotor component (64), in order to damp primarily an axial vibration of the second rotor component (64).  
      .

FIG 1

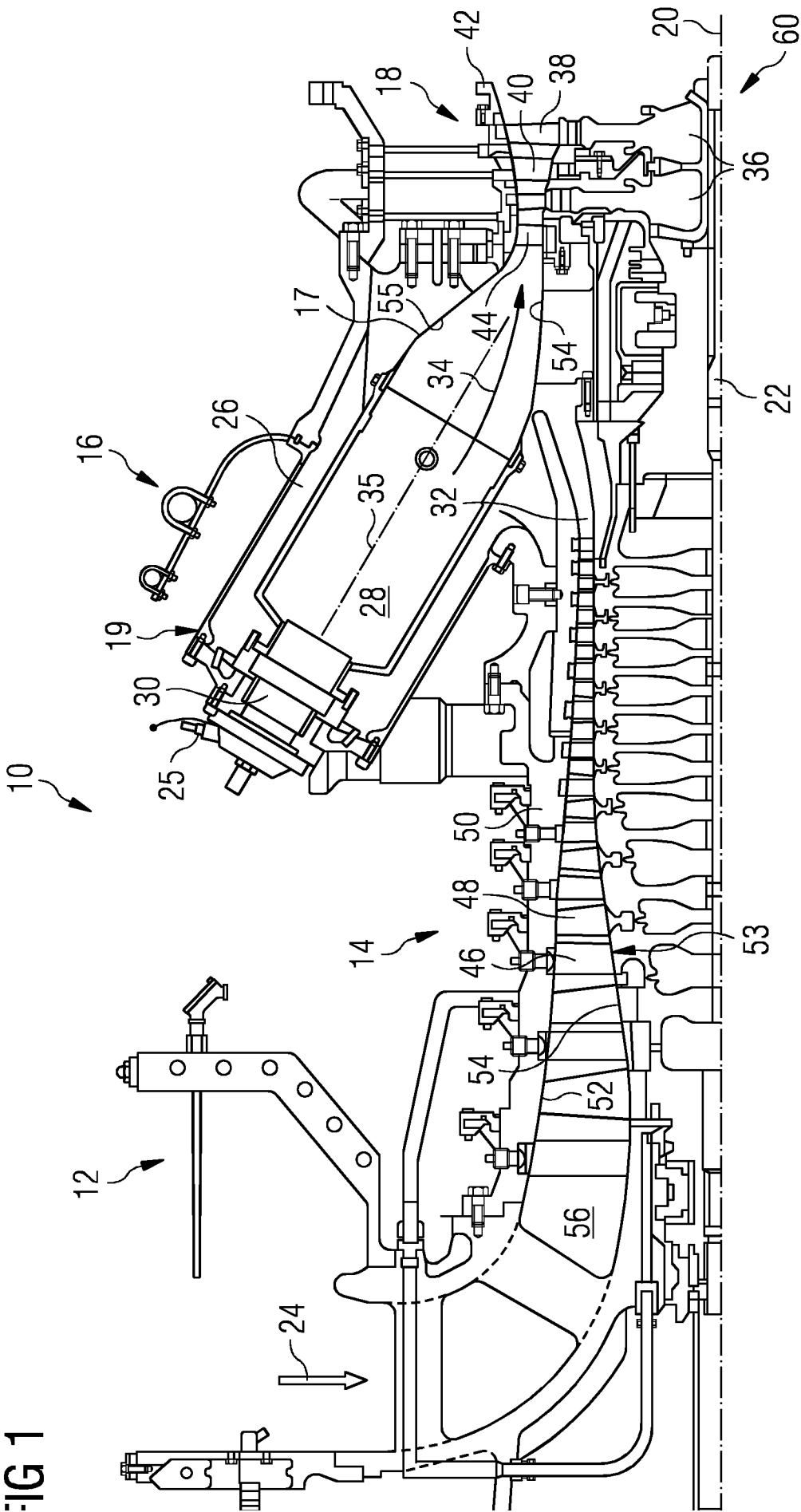
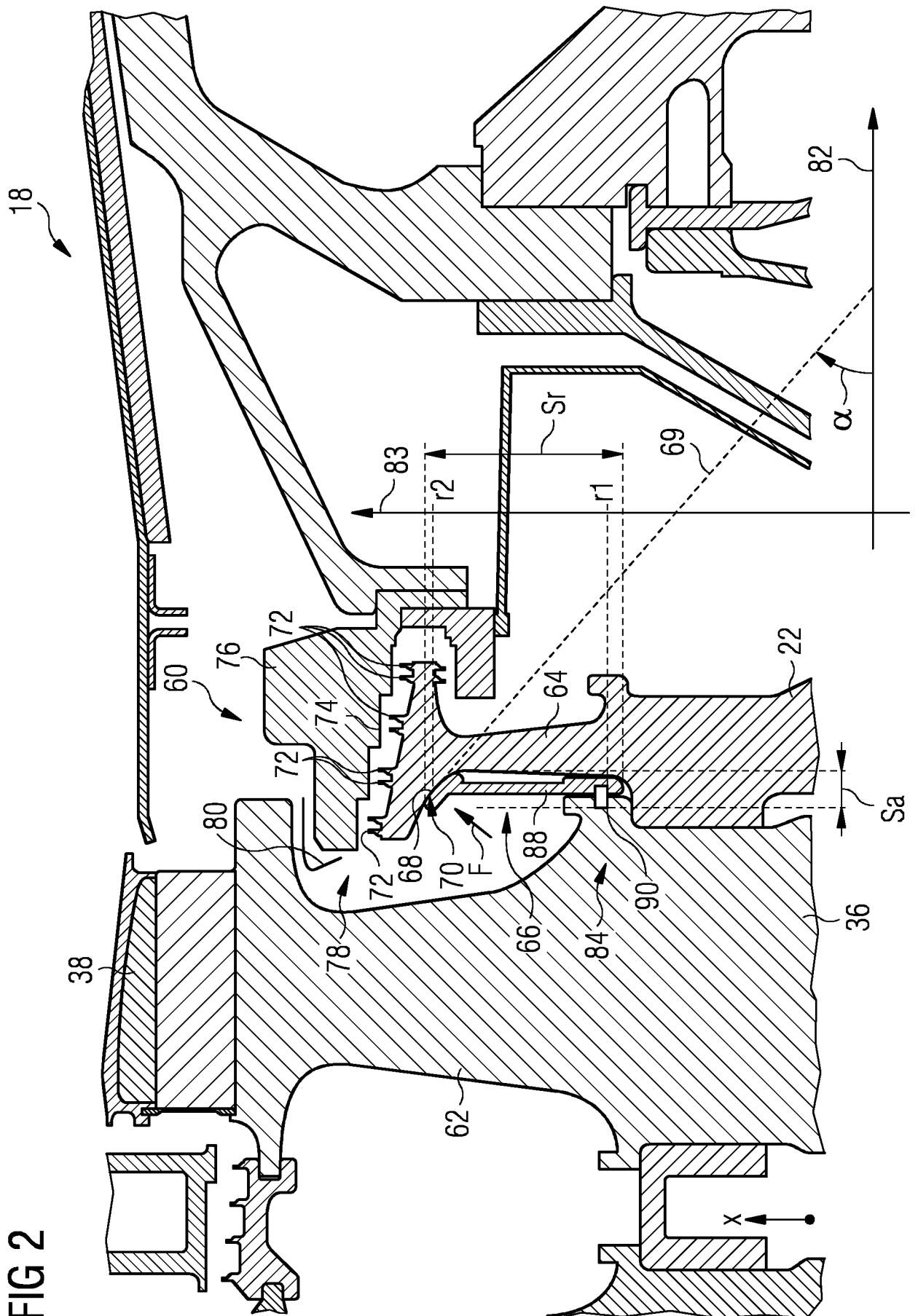


FIG 2



## INTERNATIONAL SEARCH REPORT

International application No  
PCT/EP2017/053103

A. CLASSIFICATION OF SUBJECT MATTER  
INV. F01D5/00 F01D5/10 F01D25/04  
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

| Category* | Citation of document, with indication, where appropriate, of the relevant passages                                                          | Relevant to claim No. |
|-----------|---------------------------------------------------------------------------------------------------------------------------------------------|-----------------------|
| X         | US 2012/207603 A1 (WOODS NATHAN TYLER [US]<br>ET AL) 16 August 2012 (2012-08-16)<br>paragraph [0029] - paragraph [0031];<br>figures 2,3,14  | 1-14                  |
| X         | -----<br>EP 1 584 785 A1 (SNECMA [FR])<br>12 October 2005 (2005-10-12)<br>paragraphs [0029], [0030]; figure 1                               | 1,13,14               |
| X         | -----<br>US 3 666 376 A (DAMLIS NICHOLAS)<br>30 May 1972 (1972-05-30)<br>column 2, line 45 - column 3, line 17;<br>figures 1-4              | 1-14                  |
| X         | -----<br>EP 2 372 094 A2 (PRATT & WHITNEY<br>ROCKETDYNE INC [US])<br>5 October 2011 (2011-10-05)<br>paragraphs [0012] - [0017]; figures 3,5 | 1,13,14               |
|           | -----<br>-/-                                                                                                                                |                       |



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

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