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• **Memmer, John David**

Greenville, SC South Carolina 29615 (US)

• **Desai, Tushar Sharadchandra**

Greenville, SC South Carolina 29615 (US)

(74) Representative: **Cleary, Fidelma et al**

GPO Europe

GE International Inc.

The Ark

201 Talgarth Road

Hammersmith

London W6 8BJ (GB)

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(71) Applicant: **General Electric Company**

Schenectady, New York 12345 (US)

(72) Inventors:

• **Smith, Charles Alexander**

Greenville, SC South Carolina 29615 (US)

(54) In-situ gas turbine rotor blade and casing clearance control

(57) A method and system for protecting the rotor blade tips of rotary machines, particularly the compressors (30) of gas turbine engines, comprising a rotor assembly having a plurality of circumferentially spaced-apart rotor blades (50), with each blade extending radially outwardly from an inner wheel disk (54); a stator assembly comprising one or more rows of spaced-apart vanes

(52) extending between adjacent rows of the rotor blades (50); a casing extending circumferentially around the rotor and stator assemblies; and an abradable ceramic coating applied to selected areas of the interior cylindrical surface of the rotor casing (36) to thereby provide a minimum clearance between the casing and rotor blades during start up and to thereafter ensure an effective compressor seal for compressed gas flow.

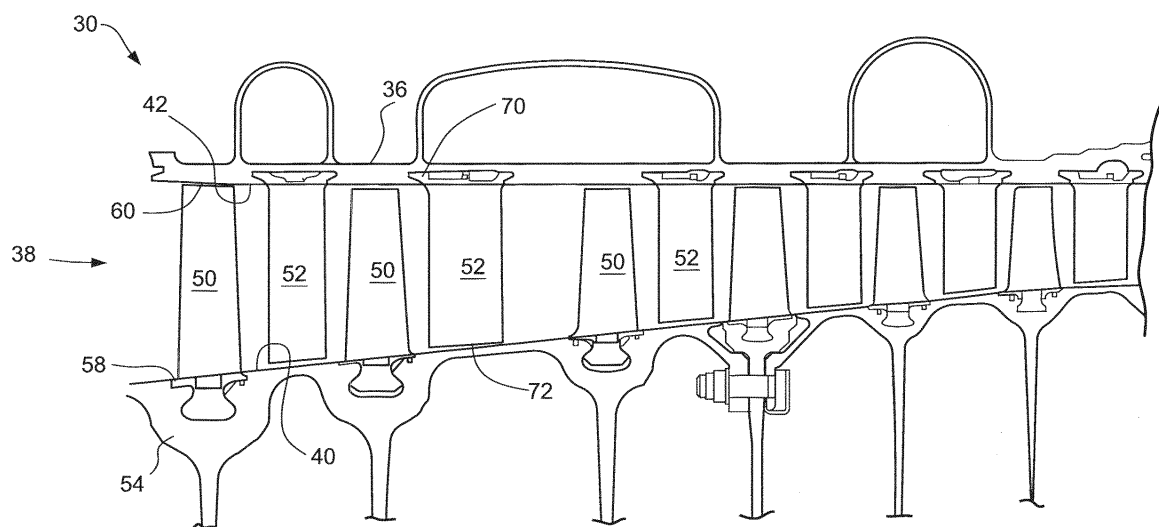


FIG. 3

EP 2 639 410 A2

Description

[0001] The present disclosure relates to gas turbine engines and, more particularly, to a method and system for minimizing the clearance between the stationary rotor casing of a compressor and the rotor blades without damaging the tips of the blades, particularly during startup and shutdown. The improved rotor casing design and method for coating the casing interior increases the efficiency, long term performance and reliability of the rotor, as well as the efficiency of the gas turbine engine.

[0002] Gas turbine engines typically include a compressor, a plurality of combustors and a gas turbine section. Compressed ambient air from the compressor mixes with a hydrocarbon fuel fed to the combustor. The fuel and compressed air mixture are then ignited, generating high temperature, expanded combustion gases. The exhaust gas is channeled through nozzles into the gas turbine in order to extract energy from the expanded gases and produce power via an electrical generator. Most gas turbines include a rotor assembly and cooperating stator that receive and redirect the hot combustion gases from one or more of the gas combustors to produce rotational energy. In like manner, the compressor section upstream of the turbine typically includes a rotor assembly comprising one or more rows of circumferentially-spaced rotor blades surrounded by a casing with the blades positioned between axially-spaced rows of corresponding circumferentially-spaced stator vanes. The rotor blades in the compressor are coupled to a rotating disk, with each blade extending from a base platform radially outward to the blade tip. In operation, ambient air flows through the rotor assembly to be directed inward by the rotor blades and then radially outward through a plurality of shrouds. The stator assembly includes a corresponding plurality of stator vanes that extend radially from a base platform out to the blade tips with an outer band for mounting the stator assembly within the casing.

[0003] During startup of the gas turbine engine, the operating temperature of both the rotor and stator assemblies increases up to a maximum anticipated level as the compressor and gas turbine engine reach a normal running speed and steady state condition. As the compressor assembly rotates, the higher metal temperatures tend to migrate from the rotor blade base toward the tip of each blade. Over time, the increased operating temperature of the blades may cause the tips to weaken, fracture or even deteriorate at the distal ends, causing an inevitable increase in the annular space between the blade tips and casing (sometimes referred to as the increased "sealing gap"). Any such increase in space between the blade tips and casing during normal operation translates into a reduction of both rotor and stator efficiency, which in turn decreases the overall compressor and engine efficiency.

[0004] In order to improve or at least maintain the continued efficiency of the compressor and gas turbine, the sealing gap between the rotor blade tips and casing of

the compressor should remain as small as possible without adversely restricting gas flow or effecting free blade rotation during normal operating conditions.

[0005] It has now been found that incorporating an abradable coating on selected target areas of the inner cylindrical surface of the casing will ensure a minimum amount of blade clearance while preserving the structural integrity and strength of the blade tips and without damaging the blade tips in the process. It has also been found that applying an abradable coating to the inner rotor casing using the method described herein results in a more uniform, structurally sound ceramic coating that is more effective in minimizing and controlling the space (sealing gap) between the blades and casing over long periods of operation, thereby improving overall rotor and engine efficiency.

[0006] By way of summary, an aspect of the invention provides a system for protecting the tips of rotor blades used in various types of rotary machines, particularly gas turbine engines and compressors. An exemplary embodiment of a rotor assembly includes a plurality of circumferentially spaced-apart rotor blades with each blade extending radially outward from an inner wheel disk; a cooperating stator assembly comprising one or more rows of spaced-apart stator vanes extending between adjacent rows of rotor blades; a casing extending circumferentially around the rotor and stator assemblies forming a plurality of inner flow paths defined by the rotor blades and stator vanes; and an abradable ceramic coating applied to the casing interior surface at specified locations. The abradable ceramic is applied in an amount that can be abraded to form a minimum annular gap between the inner circumferential surface of the casing and tips of the rotor blades. An exemplary ceramic coating applied to the casing comprises a powder containing alumina (Al_2O_3) applied *in situ* using, for example, a plasma spray technique.

FIG. 1 is schematic depiction of the major working components of an exemplary gas turbine engine, including the compressor section that directly benefits from the subject invention, namely the *in situ* clearance control of the rotor assembly using abradable ceramic coatings;

FIG. 2 is a cross sectional view of the components of a gas turbine engine, including the rotor and stator assemblies for the compressor section, illustrating the relative location of the abradable ceramic coatings according to the invention as applied to portions of the interior compressor casing;

FIG. 3 is a cross-sectional illustration of a portion of a rotating machine (such as a gas turbine engine compressor) that includes exemplary rotor and stator assemblies and ceramic coatings applied in the manner described herein; and

FIG. 4 is a further cross sectional view of a select number of the rotor blades and stator vanes as depicted in FIG. 3 showing the orientation of adjacent blades and vanes relative to the casing with a ceramic coating applied in accordance with the invention.

[0007] As indicated above, the coating method according to the invention can be implemented on a wide variety of rotating assemblies, particularly compressors that include a rotor rotating about a central longitudinal axis and a plurality of blades mounted to a wheel disk that extend radially outward. Most rotor assemblies also include an outer casing having a generally cylindrical shape and an inner circumferential surface spaced radially outwardly from the rotor and blades to define a narrow annular gap between the inner circumferential surface of the casing and end tips of the rotor blades.

[0008] The abrasible coatings according to the invention are applied to select portions of the inner circumference of the casing in an amount sufficient to define a minimum annular gap following abrasion as defined by the inner casing circumference and tips of the rotary blades. During periods of differential growth of the rotor (for example, due to the heat conducted up through the blades and rotor assembly as the engine and compressor reach nominal operating conditions), the coating on the casing will be abraded due to slight contact with the moving blade tips as the engine and compressor reach their normal operating speed. Thereafter, the moving blade tips no longer impact the casing and the clearance between the casing and moving rotor blades becomes fixed a minimum threshold amount.

[0009] In a related exemplary method according to the invention, the protective ceramic coating is applied to the rotor casing using a plasma spray technique. The coating comprises an abrasible ceramic capable of being abraded by the rotor blades without damaging the blades as the compressor approaches its normal operating speed and the temperature of the system increases over time. Preferably, the ceramic coating is applied *in situ*, for example when the gas turbine engine is shut down for routine maintenance or before engine/compressor start-up. As the engine is started, the rotor blade tips contact the coated rotor casing only at the tips thereof and only a prescribed portion of the abrasible ceramic applied to the casing is abraded as the compressor section reaches a steady state condition as the temperature of the blades and casing increases.

[0010] Exemplary abrasible ceramic materials useful in practicing the invention include both "structured" and "non-structured" compositions including, by way of non-limiting example, ceramics applied in the form of a spray powder containing alumina (Al_2O_3). Other potentially useful ceramics include hafnia (Hf_2), ceria (CeO_2), magnesia (MgO), Yttria (Y_2O_3), magnesium aluminate ($\text{MgO-Al}_2\text{O}_3$) and zirconium silicate ($\text{ZrO}_2\text{-SiO}_2$). Preferably, the powders are applied using plasma spray,

chemical vapor deposition or a comparable thermal spray technique while the engine is shut down and idle.

[0011] The preferred thickness for ceramic layers applied to the compressor casing varies depending on the end use involved, including the aerodynamic design of the rotor blades and rotor assembly, the maximum anticipated operating temperatures of the blades, and the composition and maximum temperature of air being fed into and through the rotor and stator assemblies. Preferably, the ceramic layer is applied in a thickness of about 4-8 mils up to a maximum of about 20 mils. As such, the ceramic coating ensures that the desired minimum clearance will be maintained between the blades and casing while also serving as a protective layer against abrasion and a thermal barrier coating. The coatings tend to cool the rotor casing slightly and thus indirectly decrease thermal gradients in the rotor assembly.

[0012] Before applying the ceramic coating, it has been found the surfaces of the rotor blades and stator vanes should be roughened slightly using, for example, grit blasting to increase the adherence of the bond coat when applied by a plasma spray technique. It has been found that the level of roughness on the surface should be about 100 micro inches RMS (root mean square) to achieve the best results in applying the ceramic coatings to selected portions of the rotor casing. In some instances, it may also be useful to include additional granular particles consisting of a different, harder, ceramic material (such as corundum) to provide a more controlled and structurally sound ceramic coating that remains stable at higher anticipated operating temperatures once the compressor and engine reach a steady state condition.

[0013] The use of abrasible ceramics as described above can be applied to other components of the gas turbine engine, as well as to other forms of rotating equipment that rely on rotating components inside a rotor or stator assembly. Apart from the rotor assembly, the invention could be used to protect and minimize the clearance of stator vanes in the stator assembly.

[0014] As noted above, the casing and rotor blade tip clearance control system according to the invention can be carried out *in situ*, that is during a period of gas turbine engine down time (such as for routine, scheduled maintenance). In the end, the new coating system results in significantly tighter rotor blade clearances, reduces the "secondary flow" around the blade tips and substantially improves turbine (and/or compressor) efficiency. During an initial start up run (normally the worst case scenario in providing a transient clearance condition for the rotor blades), the tips of the blades become precisely positioned relative to the casing as the engine is started. This controlled "run-in" process slowly increases the clearance to an exact degree as the compressor and engine reach their anticipated high speed operating conditions.

[0015] Turning to the figures, FIG. 1 is schematic illustration of the major working components of an exemplary gas turbine engine 10 coupled to electric generator 16, including a compressor section 12 that directly ben-

efits from the *in situ* blade clearance control. Gas turbine engine 10, compressor 12, turbine 14 and generator 16 are depicted in a single monolithic configuration with shaft 18. Shaft 18 can be segmented into a plurality of segments, wherein each segment is coupled to an adjacent shaft segment. Compressor 12 supplies compressed air to a combustor 20 where the air is mixed with fuel 22. In one embodiment, engine 10 could be a 6C type gas turbine engine commercially available from the General Electric Company in Greenville, S.C. In operation, air flows through compressor 12 and compressed air is supplied to combustor 20. Combustion gases 28 from combustor 20 propels turbine 14 which rotates shaft 18, compressor 12, and electric generator 16 about a common longitudinal axis.

[0016] FIG. 2 is a cross sectional view of the major components of an exemplary gas turbine engine labeled as shown, including rotor and stator assemblies for the compressor section, illustrating the relative location of the abradable ceramic coatings according to the invention as applied to selected portions of the compressor rotor casing. FIG. 2 thus illustrates the general location of the rotor blades and stator vanes relative to the rim surfaces of the wheel disks and casing, all of which directly benefit from the abradable coating system described above as a result of the narrow gas flow path created between the casing and rotor blade tips following abrasion.

[0017] FIG. 3 is another cross-sectional illustration of a portion of a rotating machine (such as a compressor or turbine) that includes exemplary rotor and stator assemblies and ceramic coatings applied in the manner described herein. FIG. 3 illustrates the orientation of adjacent blades and stator vanes relative to the coated casing assembled within the compressor section. Compressor 30 includes a rotor assembly and a stator assembly positioned within casing 36 to define a general gas flow path 38. The rotor assembly also defines an inner flow path boundary 40 of flow path 38, while the stator assembly defines an outer flow path boundary 42 of flow path 38. Compressor 30 includes a plurality of stages, with each stage including a row of circumferentially-spaced rotor blades 50 and a row of stator vane assemblies 52. In this embodiment, rotor blades 50 are coupled to a rotor disk 54 with each rotor blade extending radially outwardly from rotor disk 54. Each blade includes an airfoil that extends radially from an inner blade platform 58 to rotor blade tip 60.

[0018] In like manner, the stator assembly includes a plurality of rows of stator vane assemblies 52 with each row of vane assemblies positioned between adjacent rows of rotor blades. The compressor stages are configured to cooperate with a gas working fluid, such as ambient air, with the fluid being compressed in succeeding stages. Each row of vane assemblies 52 includes a plurality of circumferentially-spaced stator vanes that each extend radially inward from stator casing 36 and includes an airfoil that extends from an outer vane platform 70 to

a vane tip 72. Each airfoil includes a leading edge and a trailing edge as shown.

[0019] FIG. 4 illustrates how the abradable ceramic coatings according to the invention can be applied to selected portions of the casing interior surface, including the rim surfaces of the wheel disks connected to adjacent stator vanes. A plurality of rotor blades and stator vanes 80 are shown in cross section. Each of the two rotor blades 85 and 86, respectively, will abrade a portion of the ceramic applied to the casing as described above, namely ceramic coatings 81 and 88. Each blade is connected to corresponding wheel disks 82 and 87, respectively. If desired, a comparable uniform coating of abradable ceramic could be applied to rim surface 89 adjacent to stator vane 83.

[0020] Once the abradable ceramic coatings according to the invention have been applied *in situ*, the rotation of the compressor will abrade a precise amount of the ceramic proximate the peripheral edges of the blade tips, casing and rim surfaces in the manner described above. The abrasion will continue and increase slightly as heat is generated and conducted into and along each of the rotor blades and stator vanes until the turbine or compressor reaches a steady state condition. The abrasion, as controlled, ensures that a narrow sealing gap will eventually exist between the various moving rotor and stator components, thus ensuring that very little air leakage occurs between the blades, vanes and casing.

[0021] While the invention has been described in connection with what is presently considered to be the most practical embodiment, it is to be understood that the invention is not to be limited to the disclosed embodiment, but on the contrary, is intended to cover various modifications and equivalent arrangements included within the scope of the appended claims.

Claims

1. A compressor (12,30) for a gas turbine engine (10), comprising:
 - a rotor assembly for said turbine (14) comprising a plurality of circumferentially spaced-apart rotor blades (50), each blade extending radially outwardly from an inner wheel disk (54);
 - a casing (36) extending circumferentially around said rotor assembly forming a plurality of inner flow paths defined by said rotor blades (50) cooperating with stator vanes (52); and
 - an abradable ceramic coating applied to the interior of said casing (36) proximate said rotor blades (50).
2. A compressor according to claim 1, wherein said abradable ceramic coating comprises a powder containing alumina (Al₂O₃).

3. A compressor according to claim 1 or claim 2, wherein said abrasible ceramic coating is applied to the rim surfaces of said inner wheel disk (54).
4. A compressor according to claim 1, 2 or 3, wherein said abrasible ceramic coating comprises hafnia (Hf_2), ceria (CeO_2), magnesia (MgO), Yttria (Y_2O_3), magnesium aluminate ($\text{MgO-Al}_2\text{O}_3$) or zirconium silicate ($\text{ZrO}_2\text{-SiO}_2$).
5. A compressor according to any preceding claim, wherein said abrasible ceramic coating is formed *in situ* on said rotor casing (36).
6. A compressor according to any preceding claim, wherein said abrasible ceramic coating is applied to said interior rotor casing surface using plasma spray.
7. A compressor according to any preceding claim, wherein said abrasible ceramic coating is applied to said interior casing surface at a thickness of between 4 and 8 mils.
8. A compressor according to any preceding claim, wherein said abrasible ceramic coating further comprises granular particles comprising a second, thermally stable ceramic material.
9. A compressor according to claim 8, wherein said granular particles comprise corundum.
10. A gas turbine engine (10) comprising:
 - a turbine (14);
 - one or more hydrocarbon gas combustors (20);
 - and
 - an air compressor (12,30) according to any preceding claim, comprising;
 - a compressor rotor assembly for said compressor (12,30), comprising a plurality of circumferentially spaced-apart rotor blades (50) extending radially outwardly from an inner wheel disk (54);
 - a compressor stator assembly comprising one or more rows of spaced-apart stator vanes (52) extending between adjacent rows of said rotor blades (50);
 - a casing (36) extending circumferentially around said rotor and stator assemblies forming a plurality of inner and outer flow paths defined by said rotor blades (50) and said stator vanes (52);
 - and
 - a ceramic coating applied to the interior of said casing (36) in an amount sufficient to cause the tips of said rotor blades (50) to abrade portions of said ceramic coating during start-up and provide a minimum amount of clearance between

said rotor blades (50) and said casing (36).

11. A gas turbine engine according to claim 10, wherein the surfaces of said rotor casing (36) further comprise a roughened interior cylindrical surface for adhering to said abrasible ceramic coating.

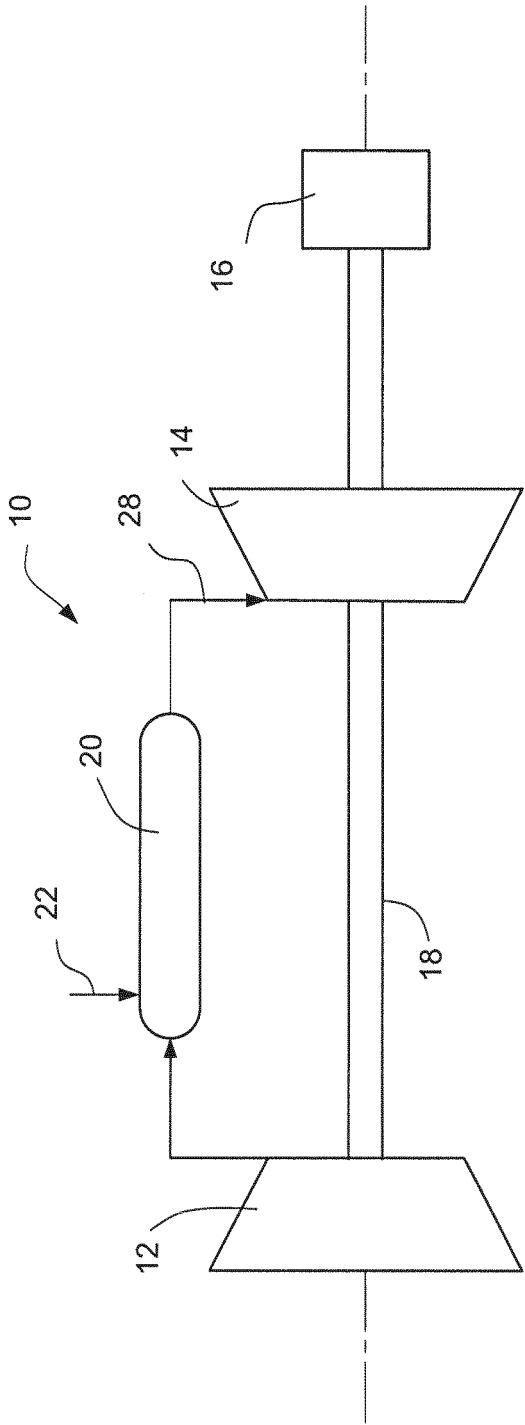


FIG. 1

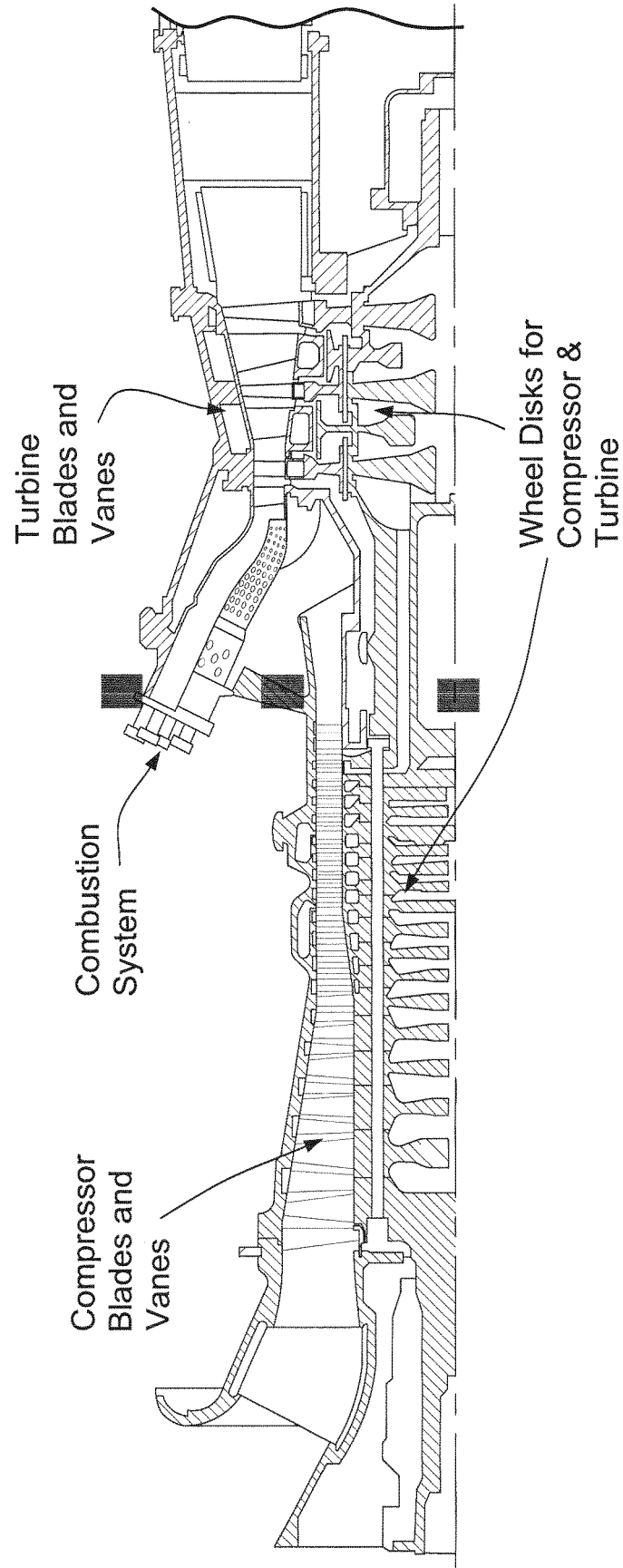
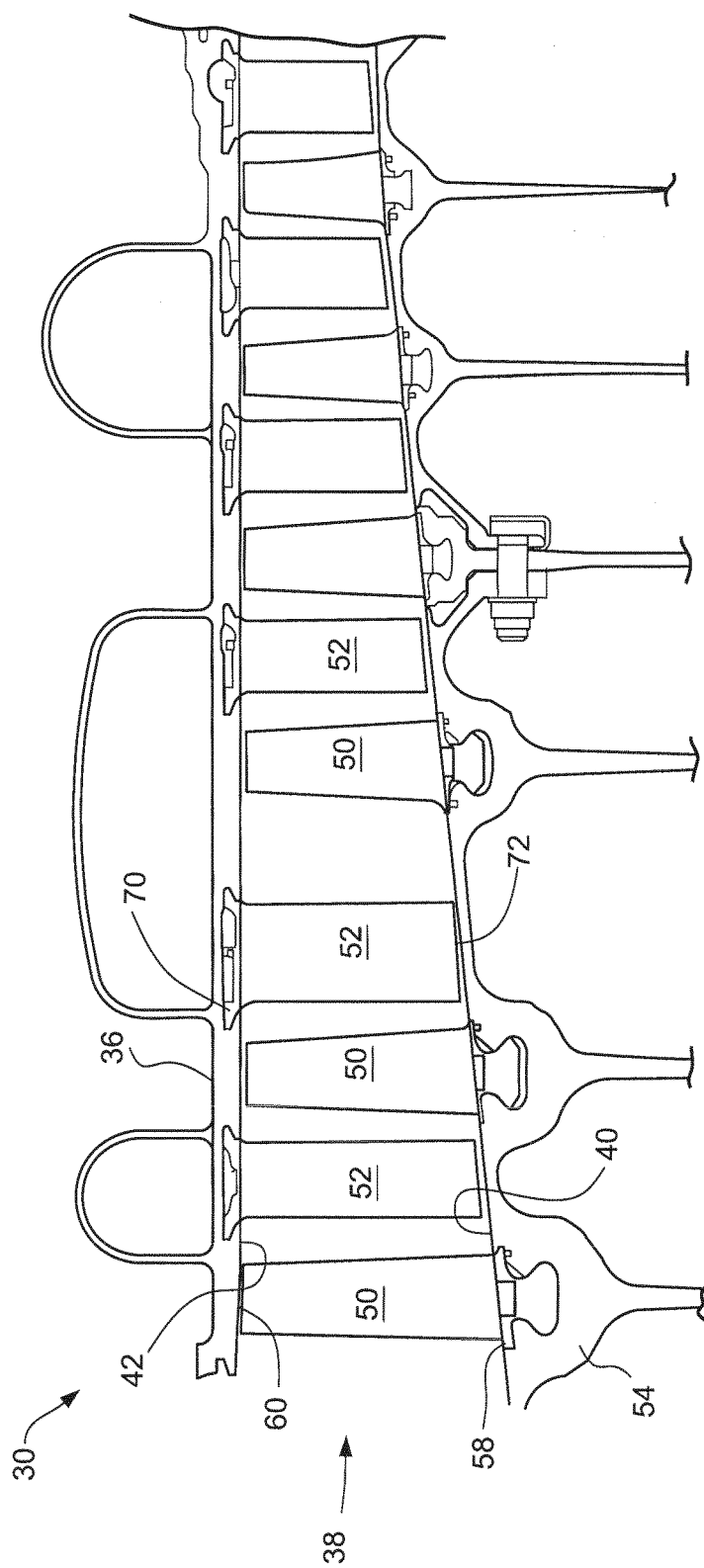


FIG. 2



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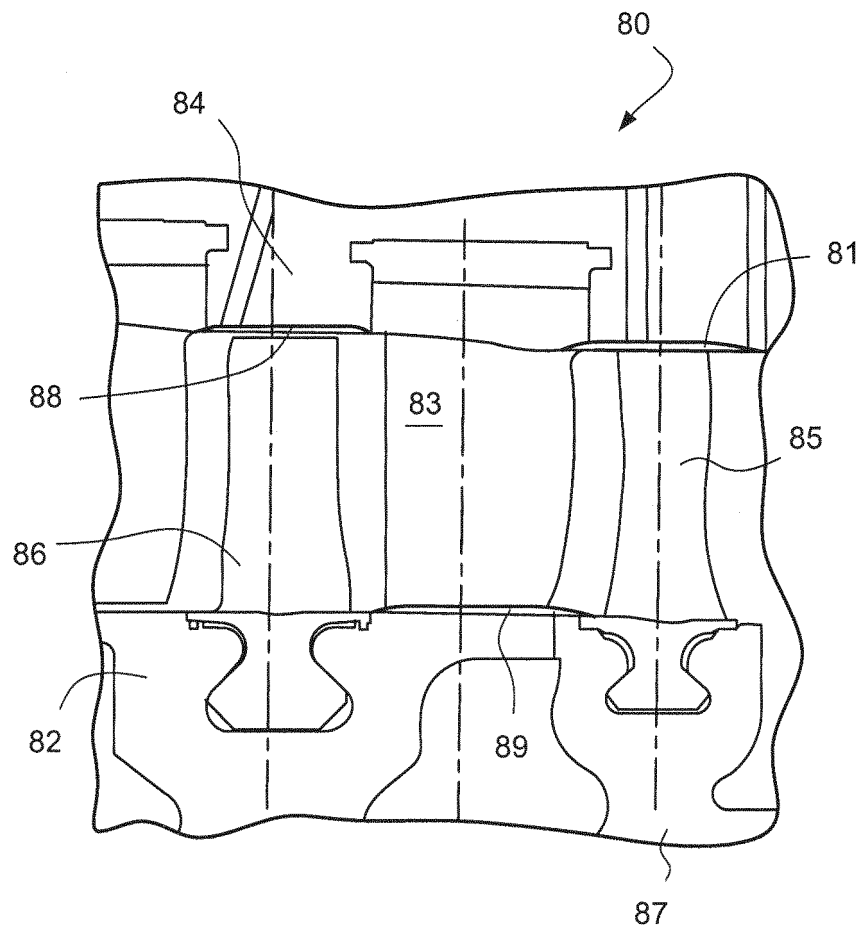


FIG. 4