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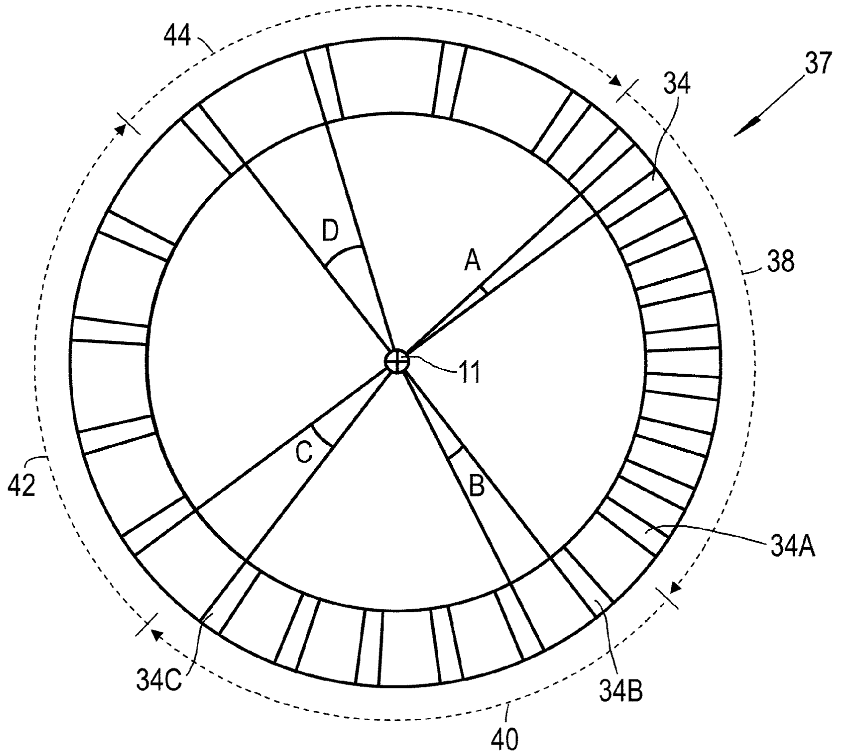
The application is published incomplete as filed (Rule 68(1) EPC).

(54) **Stator vane array**

(57) A stator vane assembly (37) for a gas turbine engine (10), for which the vane assembly has an array of vanes circumferentially spaced about a common axis (11). The array of vanes comprises three or more sub-arrays (38,40,42,44), which are configured such that the vane spacing in one sub-array is different from the vane spacing in the other sub-arrays.

Fig.3



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Description

[0001] The present invention relates to a stator vane assembly for fluid flow machines such as a gas turbine engine or a sub-assembly thereof.

[0002] Within axial flow machines, such as gas turbine engines, there are provided adjacent rotor and stator arrays. Vanes within stator arrays are typically provided to redirect gas flow either upstream or downstream of a corresponding bladed rotor array. For example, within a compressor of a gas turbine engine, successive rows of circumferentially spaced rotor blades may be spaced in an axial direction by an array of intermediate stator vanes.

[0003] Problems associated with the vibrations are known to impact on the operation of gas turbine engines. Vibration behaviour can impact not only the aerodynamic performance of bladed rotors but also the operational life of the engine or sub-assemblies thereof. It is generally acknowledged to attempt to avoid resonance and reduce the level of vibrations within the rotor and stator blade assemblies as far as possible. However, when it is considered that the bladed arrays have a series of natural frequencies and that there is a need to accommodate a range of engine operation without significant detriment to aerodynamic efficiency, it will be appreciated that the reduction of vibration represents a highly complex problem, for which any solution must strike a suitable balance between conflicting engineering considerations.

[0004] Scattered forcing or non-uniform vane spacing has previously been used to reduce excitation of neighbouring stator/rotor components in relative motion. One known method of scattered forcing involves the division of the stator casing into two half-stator casings, wherein one half has one more vane than the other half so as to generate different forcing frequencies.

[0005] European Patent Application 05252332.1 (published as EP 1 586 741 A2) discloses an alternative stator vane arrangement in which the stator vanes are arranged in sectors, such that the vanes within each sector are equally spaced in a circumferential direction but the sectors are circumferentially separated by a larger spacing. Such an arrangement is proposed to facilitate ease of assembly, without substantially jeapordising conventionally-accepted levels of vibration-induced stress reduction. A similar vane arrangement is also disclosed for turbine stator vanes in US Patent 1,534,721 (see Figure 4) with the aim of preventing vibration-induced failure.

[0006] US 1,534,721 also discloses, with reference to Figure 2 of that document, an alternative embodiment in which the vane spacing is continually varied around the entire circumference.

[0007] It is an aim of the present invention to provide an alternative vane arrangement, which can offer reduced forcing over the desired range of operation. It may be considered an additional or alternative aim to provide a vane arrangement which can strike a different balance between the above-described conflicting engineering considerations.

[0008] According to the present invention there is provided a vane assembly for a fluid flow machine, the vane assembly comprising an array of vanes circumferentially spaced about a common axis, wherein the array of vanes comprises three or more sub-arrays, wherein the vane spacing within one sub-array is different from the vane spacing within the other sub-arrays.

[0009] Each vane of a sub-array may be substantially equally spaced from the adjacent vane(s) in that sub-array. The vane spacing within a sub-array may be substantially constant. The vane spacing through the entirety of a sub-array may be constant.

[0010] The vane spacing within a first sub-array may be a first circumferential distance. The vane spacing within a second sub-array may be a second circumferential distance. The vane spacing within a third sub-array may be a third circumferential distance. The spacing of the vanes may change in a stepwise fashion between sub-arrays.

[0011] The provision of vanes of equal spacing in each sub-array allows the vanes and/or associated spacing members in each sub-array to be formed to a common design.

[0012] The array of vanes may extend through a complete revolution about the axis. The vane assembly or array may comprise an annular array of vanes. One or each sub-array may extend only part way about the axis. One or each sub-array may extend through only a fraction or portion of a single revolution about the axis. One or each sub-array may comprise a section, sector or segment of the array. Each sub array may comprise vanes spaced along the path of a circular arc. The length of the arc for each sub-array may be substantially equal.

[0013] Each sub-array may comprise an equal number of vanes. Alternatively one sub-array may comprise a number of vanes which is different from the number of vanes in one or more further sub-array.

[0014] Each sub-array may comprise a leading and a trailing vane in a circumferential direction. Each sub-array typically comprises a plurality of vanes disposed between the leading and trailing vanes of that sub-array. The leading vane of a first sub-array may be adjacent to (or adjacently spaced from) the trailing vane of a second sub-array. The trailing vane of the first sub-array may be adjacent to (or adjacently spaced from) a leading vane of a third sub-array.

[0015] The vane spacing between the leading vane of a first sub-array and the trailing vane of a second, adjacent, sub-array may be equal to the vane spacing of the first sub-array. Accordingly the inter-sub-array vane spacing may be equal to the intra-sub-array vane spacing. Thus each sub-array can be defined as a plurality of vanes sharing a common vane spacing. This is in contrast to the teachings of EP1586741 which defines vane sectors by the vane spacing between the sectors.

[0016] The vane spacing may vary in a non-cyclic manner through the array. That is to say, the pattern of variation in vane spacing may repeat only with every complete revolution of the array. The vane spacing between sub-arrays and/or through the array may vary in a monotonic manner. That is to say the vane spacing may only increase with passage through the array in a first circumferential direction and may only decrease with passage through the array in the opposing direction.

[0017] Whilst it is possible in other embodiments to arrange the sub-arrays to provide cyclic or sinusoidal variations in vane spacing through the array, it has been found that varying the vane spacing monotically provides a reduction in peak forcing for the same range of vane spacings.

[0018] A nominal or average vane spacing may be defined over the array. At least one sub-array may have a vane spacing which is greater than the nominal value. At least one sub-array may have a vane spacing which is less than the nominal value. The magnitude of the deviation in vane spacing from the nominal value may be equal for two of the sub-arrays within the array. A plurality of such pairs of sub-arrays may be provided, for example in embodiments in which four or more sub-arrays are provided. One sub-array may have a vane spacing which is equal to the nominal value, for example in an embodiment in which an odd number of sub-arrays are provided. In an alternative embodiment, for example where there is an even number of sub-arrays, it is possible that all of the sub-arrays will have a vane spacing which differs from the nominal spacing.

[0019] The vane assembly may comprise a compressor vane assembly. The vane assembly may comprise a turbine vane assembly. The vane assembly may comprise a casing and the vanes of the array may depend radially inwardly from the casing. The common axis may define an axis of the casing. The vane assembly may comprise a gas turbine engine vane assembly.

[0020] According to a further aspect of the invention, there is provided a compressor comprising a plurality of rows of rotor blades arranged in serial flow arrangement and a stator vane assembly disposed in the flow path between said rows of rotor blades, the rotor blades and stator vane assembly being arranged about a common axis such that the rotor blades can rotate relative to the stator vane assembly in use, wherein the stator vane assembly comprises an array of vanes circumferentially spaced about a common axis, said array comprising three or more sub-arrays, wherein the vane spacing in one sub-array is different from the vane spacing in the other sub-arrays.

[0021] The rotor blades within each row may be substantially uniformly spaced in a circumferential direction about the axis. Each row may comprise a circumferential array of rotor blades. The stator vanes may be angled so as to deflect and/or decelerate the flow either upstream or downstream of an adjacent row of rotor blades. The rotor blades of a row may be mounted on a common rotor or disk and may depend radially outwardly therefrom.

[0022] The difference in spacing between the stator vanes according to the present invention may serve to reduce vibrations cause by aerodynamic interaction between the rotor blades and stator vanes in use.

[0023] According to a further aspect of the invention, there is provided a gas turbine engine comprising either a vane assembly according to the first aspect or a compressor according to the second aspect.

[0024] Any or any combination of the optional features described in relation to any one aspect above may be applied to any further aspect wherever practicable.

[0025] The vane spacing may be defined as the distance between the leading edges of adjacent vanes. Alternatively the vane spacing may be defined as the distance between any other common feature or position on adjacent vanes. Alternatively the vane spacing may be defined as the minimum gap between adjacent vanes.

[0026] Workable embodiments of the present invention are described in further detail below with reference to the accompanying drawings, of which:

Figure 1 shows a half longitudinal section through a gas turbine engine according to the present invention;

Figure 2 shows a sectional schematic of a portion of a compressor according to the invention;

Figure 3 shows a plan view of a stator vane assembly according to the invention;

Figure 4 shows a plot of the vane spacing for the assembly of Figure 3;

Figures 5A-5C show plots of the relative strength of vibrations at a variety of engine orders for different vane arrangements; and

Figure 6 shows a plot of peak forcing against the percentage variation in vane spacing used for different numbers of vane sub-arrays.

[0027] The present invention may be considered to derive from the general premise that it has been found to be possible to modify the circumferential spacing between vanes in a stator assembly in such a way that excitation of the corresponding rotor in use is, at least to some extent, cancelled or limited.

[0028] With reference to Figure 1, a ducted fan gas turbine engine generally indicated at 10 has a principal and rotational axis 11. The engine 10 comprises, in axial flow series, an air intake 12, a propulsive fan 13, an intermediate pressure compressor 14, a high-pressure compressor 15, combustion equipment 16, a high-pressure turbine 17, and intermediate pressure turbine 18, a low-pressure turbine 19 and a core engine exhaust nozzle 20. A nacelle 21 generally surrounds the engine 10 and defines the intake 12, a bypass duct 22 and a bypass exhaust nozzle 23.

[0029] The gas turbine engine 10 works in a conventional manner so that air entering the intake 12 is accelerated by the fan 13 to produce two air flows: a first air flow into the intermediate pressure compressor 14 and a second air flow which passes through a bypass duct 22 to provide propulsive thrust. The intermediate pressure compressor 14 compresses the air flow directed into it before delivering that air to the high pressure compressor 15 where further compression takes place.

[0030] The compressed air exhausted from the high-pressure compressor 15 is directed into the combustion equipment 16 where it is mixed with fuel and the mixture combusted. The resultant hot combustion products then expand through, and thereby drive the high, intermediate and low-pressure turbines 17, 18, 19 before being exhausted through the nozzle 20 to provide additional propulsive thrust. The high, intermediate and low-pressure turbines 17, 18, 19 respectively drive the high and intermediate pressure compressors 15, 14 and the fan 13 by suitable interconnecting shafts.

[0031] Alternative gas turbine engine arrangements may comprise a two, as opposed to three, shaft arrangement and/or may provide for different bypass ratios. Other configurations known to the skilled person include open rotor designs, such as turboprop engines, or else turbojets, in which the bypass duct is removed such that all air flow passes through the core engine. The various available gas turbine engine configurations are typically adapted to suit an intended operation which may include aerospace, marine, power generation amongst other propulsion or industrial pumping applications.

[0032] The intermediate 14 and high 15 pressure compressors each comprise a series of rows or stages of rotor blades. A schematic section view of one such compressor 14 is shown more clearly in Figure 2, which comprises a compressor rotor 24, which carries a plurality of axially spaced stages of rotor blades 26. The rotor blades 26 in each stage are circumferentially spaced and extend radially outwardly from the compressor rotor 24 into the flow passage 28, which is generally annular in cross-section.

[0033] The compressor 14 also comprises a stator casing 30 which carries one or more stages of stator vanes 32, in this example there are a plurality of stages of stator vanes 32. The stator vanes 32 in each stage are circumferentially spaced in a manner to be described below and extend radially inwardly from the compressor casing 30. The stator vanes are provided immediately upstream and/or downstream of a corresponding row of rotor blades. In this embodiment, the stator vane arrays are provided between successive rows of blades.

[0034] In this embodiment a variable stator vane arrangement is provided, in which each vane 32 comprises a spindle 34 which locates in and extends through a respective aperture 36 in the compressor casing 30 to pivotally mount the variable stator vane 34 in the compressor casing 30. The spindle 34 of each variable stator vane 32 may be driven by a actuation mechanism (not shown) in order to vary the orientation of the vanes32 in the flow passage. Various different mountings for actuable vane configurations as well as corresponding actuation mechanisms may be provided according to different implementations of the invention. Also the present invention is equally applicable to static vane arrangements, in which the orientation of the vanes is fixed.

[0035] It will be appreciated by the skilled person that the rotor blades 26 of the compressor 14 may be mounted to a common rotor arrangement which comprises a series of disks arranged about the axis 11. Each disk has an array or row of compressor blades depending radially outwardly therefrom into the gas flow passage.

[0036] The compressor blades are aerofoil in profile and arranged in a generally uniform array with equal spacing between each blade. The rotation of the rotor 24 causes the blades 26 to rotate in unison so as drive the gas flow through the compressor. The flow from an upstream row of rotor blades is deflected by the vanes 32 onto a downstream row of rotor blades such that each successive stage further compresses the gas flow through the passage 28.

[0037] The passage of the rotor blades driving the gas flow causes pressure fluctuations within the gas flow which are felt by the blades and the stator vanes. The blade and/or vane assemblies have natural frequencies which typically fall somewhere within the desired range of rotor speeds during normal operation. Thus if the pressure fluctuation in the gas flow caused by the rotation of the rotor blades 26 matches, or comes close to, a natural frequency of the system, excessive vibration can occur. The arrangement of the vanes described below with reference to Figures 3 to 6 aims to avoids any such excessive forced vibrations.

[0038] Turning now to Figure 3, there is shown a plan view of a schematic stator vane assembly 37 according to one example of the present invention. The vanes are circumferentially spaced about axis 11 so as to provide an annular array of vanes. The array is sub-divided into four zones indicated in Figure 3 by the length of the arcs 38, 40, 42 and 44.

[0039] Each zone represents a sub-array of the larger vane array in that it comprises a subset of the vanes of the array. A sub-array in the context of the present invention may be defined as a plurality of vanes arranged in a side-by-side relationship, wherein the spacing between each vane and its adjacent vane(s) is constant. It can be seen in Figure

3 that the vane spacing between the vanes in sub-array 38 is constant but that the spacing between the vanes 34A and 34B changes. Thus vane 34A represents the final vane in the sub-array 38 and vane 34B represents the first vane in the sub-array 40. The spacing between all the vanes in sub-array 40 is constant until vane 34C, after which a larger vane spacing is provided. Thus vane 34C represents the final vane in the sub-array 40. This pattern continues around the complete circumference of the array so as to define the four separate sub-arrays 38-44. In this regard the sub-arrays are arranged adjacently rather than being interspersed.

[0040] In this embodiment, each arc represents approximately a quarter of a revolution such that the sub-arrays are approximately equal in length. In further examples of the invention, comprising different numbers of sub-arrays, the length of the array may also be approximately equal. However it is not crucial that the arrays are exactly equal in length and it is likely that the sub-arrays would be of slightly different length in order to accommodate the different vane spacing. It is possible in other embodiments that each sub-array could be arranged, for example so as to contain the same number of vanes as the other sub-arrays, such that the length of each sub-array could differ for example by up to 10%.

[0041] The different vane spacing in each sub-array can be seen by the difference between the angles A, B, C and D in Figure 3. It is to be noted that the difference in spacing is exaggerated in Figure 3 for clarity and it is envisaged in a practicable embodiment that the maximum difference in vane spacing throughout the array would likely not exceed 10% or 20%.

[0042] Turning now to Figure 4 there is shown a graph of the vane spacing (Y-axis) against circumferential distance. A similar plot could be provided for the angular spacing of the vanes. In the graph it can be seen that a nominal vane spacing value 46 is set for the whole array. That value may be equal to a conventional fixed vane spacing for a corresponding stator vane assembly. The spacing of the vanes in the different sub-assemblies is modified about the nominal value 46 such that for every sub-array having a vane spacing which is less than the nominal value, there is provided a further vane sub-array for which the vane spacing is larger than the nominal value by the same magnitude.

[0043] A maximum relative difference or ratio of vane spacing over the array can thus be defined as:

$$\Delta_{max} = (S_{max} - S_{nominal})/S_{nominal}$$

[0044] Where the number of zones or sub-arrays is given as N, the vane spacing for the i^{th} zone, S_i of the array can be defined as:

$$S_i = S_{nominal} . (1 + \Delta_{max}) . (2.i - N - 1)/(N - 1)$$

[0045] Thus an even distribution of vane spacing is provided between the maximum and minimum values over the array as shown Figure 4. Despite the vane spacing differences being evenly distributed it will be appreciated that there are discontinuities or step changes between the different sub-arrays, represented by the vertical lines in the graph. In this regard the sub-arrays can be delineated by step changes in vane spacing.

[0046] In the present embodiment, the vane spacing increases with passage from the first sub-array 38 in a clockwise direction around the stator assembly until the last vane in the array 44, at which point the vane spacing drops back down to the minimum vane spacing for the array. In this regard, the change in vane spacing is non-cyclic within a single revolution such that the pattern of vane spacing repeats only with each complete revolution of the stator vane assembly.

[0047] It is found that the monotonic variation in vane spacing around the array in this manner provides the best reduction in peak forcing for a given change in maximum vane spacing. Thus such an arrangement can be considered to offer improved or optimal efficiency in the context of the invention. A sinusoidal variation in spacing might be expected to give good results, but is found to require a larger maximum change in spacing to achieve a given level of forcing reduction. That is to say, a sinusoidal variation in spacing around the vane assembly would require a larger range of vane spacing to be used in order to achieve the same level of force reduction.

[0048] Using stepwise changes in vane spacing also has the benefit over smoothly varying spacing distributions in that it requires fewer different parts to build the assembly.

[0049] The definition of different sub-arrays, as described above, is particularly advantageous in that the different sub-arrays can be configured such that the vane spacing is selected to equalise a corresponding number of dominant forcing frequencies for the assembly. Thus if three or more sub-assemblies are selected, they can be configured to equalise three or more dominant forcing frequencies. The process of equalising the dominant forcing frequencies ensures the minimum possible forcing is achieved across the speed range.

[0050] In an example of the invention in which three sub-assemblies are chosen, an array of stator vanes will be divided into three adjacent sub-arrays of roughly equal size with respective vane spacing: a required amount below nominal; nominal; and, a required amount above nominal. The magnitude of the difference between the vane spacing of the first sub-array and the nominal vane spacing for the array (i.e. the degree of vane spacing compression) can be systematically varied whilst observing the harmonic content of the whole set in order to arrive at a desired vane spacing.

[0051] It has been found that if the strength of only the most dominant frequency is reduced, then the strength of the side bands - either side of that dominant frequency - will typically increase. Thus if one concentrates purely on reducing/removing the effect of the dominant frequency, the benefit of such an approach is capped at the point at which the strength of the dominant frequency and the two adjacent side bands is equal. Such a condition is shown in Figure 5A, which is referred to as a first point balancing forcing condition, in which the primary engine order 48 is of a relative strength which is equal to the two flanking engine orders 50.This is in effect the optimal configuration for a vane assembly having only two sub-assemblies.

[0052] Thus, in one aspect, the invention can be considered to derive from a sweep of the available vane spacing domain in terms of real numbers, rather than integers, in order to provide a reduced peak forcing over the possible engine orders.

[0053] However it has been found that if one continues to add further sub-arrays and carefully selects the vane spacing for the arrays with the aim of achieving a point at which further engine orders 52 are substantially equalised with the primary 48 and flanking 50 engine orders, then an improved response for the whole array can be achieved. An example is shown in Figure 5B, in which the primary engine order 48 and flanking engine orders 50 are substantially equalised with further flanking engine orders 52. In this regard, the relative strengths of those engine orders can be tailored such that they differ by a value of, for example, less than 20 or 30%. Most preferably those values would be within 10% or 5% of each other, although this is not essential.

[0054] Since the further flanking engine orders 52 are themselves adjacent outer engine orders 54, it can be seen that the process of equalisation can be further continued to accommodate further engine orders, for example by increasing the number of sub-assemblies. However, as demonstrated by Figure 5C, there are diminishing returns to some extent such that a suitable balance between vibration response benefits and complexity of assembly is likely to be achieved with three or four sub-assemblies.

[0055] This process of continuing past the first point at which the three strengths are equalised to a second, or subsequent, point at which the three or more largest signals are equal yields a significant further reduction in maximum signal strength. Furthermore this departs from what might be considered a conventional mindset, which focuses purely on reducing the primary engine order (i.e. the dominant frequency) in order to improve the system behaviour.

[0056] The process of arriving at a desired solution can be achieved by setting an initial step wise variation in vane spacing (of the type shown in Figure 4) and then searching over the available possible values within the available deviation to find the desired minima. This has the practical effect of limiting the degrees of freedom and thereby easing convergence upon a suitable solution. However it will be appreciated that one could alternatively introduce a further degree of freedom by allowing variation in both the maximum possible divergence from the nominal spacing value and also the magnitudes of the step changes between sub-arrays. Such an approach could potentially lead to improved results but at a greater computational cost.

[0057] Figure 6 exemplifies this by plotting relative peak forcing for the assembly against the total or maximum range of vane spacing over the array. Here it can be seen that the use of only two zones or sub-arrays provides little or no additional advantage beyond approximately 5% variation in vane spacing. However the use of three, four or five sub-arrays can yield additional reductions in peak forcing for greater variations in vane spacing. For example, in the scenario of Figure 6, a three sub-array arrangement provides a significant reduction in peak forcing compared to a two sub-array arrangement in the range of a 7-8% variation in vane spacing.

[0058] Whilst the invention is described with reference to a gas turbine engine compressor, it will be appreciated that similar principles could be applied to turbine stator vanes and/or other axial flow machines having a compressor or turbine in which adjacent rows of stator vanes and rotor blades are provided such that aerodynamic interaction between the rotor blades and stator vanes in use can lead to vibration.

Claims

1. A vane assembly (37) for a gas flow machine, the vane assembly comprising an array of vanes circumferentially spaced about a common axis, wherein the array of vanes comprises three or more sub-arrays (38, 40, 42, 44), wherein the vane spacing within one sub-array is different from the vane spacing within the other sub-arrays; wherein each sub-array comprises a plurality of adjacent vanes (34), each vane of a sub-array being substantially equally spaced from an adjacent vane in that sub-array.

3. A vane assembly according to claim 1, wherein each sub-array extends through a portion of a revolution about said axis and the sub-arrays are arranged in an end to end arrangement such that the array forms a complete revolution about the axis.

4. A vane assembly according to any preceding claim wherein a step change in vane spacing occurs upon passage from one sub-array to an adjacent sub-array.

5. A vane assembly according to any preceding claim wherein the vane spacing varies in a non-cyclic manner through a single revolution of the array about the axis.

6. A vane assembly according to any preceding claim wherein at least a pair of sub-arrays have a vane spacing which differs from an average vane spacing for the array by an equal magnitude.

7. A vane assembly according to any preceding claim comprising a casing disposed about the axis, wherein each vane of the array depends inwardly from the casing towards the axis from the casing.

8. A vane assembly according to any preceding claim comprising a stator vane assembly for a gas turbine engine.

9. A gas flow machine (10) comprising:

a plurality of rows of rotor blades arranged in serial flow arrangement; and
a stator vane assembly (37) disposed in the flow path between said rows of rotor blades,
the rotor blades and stator vane assembly being arranged about a common axis (11) such that the rotor blades can rotate relative to the stator vane assembly in use,
wherein the stator vane assembly comprises an array of vanes circumferentially spaced about a common axis, said array comprising three or more sub-arrays (38, 40, 42, 44),
wherein each sub-array comprises a plurality of adjacent vanes (34), each vane of a sub-array being substantially equally spaced from an adjacent vane in that sub-array,
wherein the vane spacing in one sub-array is different from the vane spacing in the other sub-arrays.

10. A gas flow machine according to claim 9, wherein the stator vanes are angled so as to deflect the flow generated by the rotation of an adjacent row of rotor blades.

11. An axial flow machine according to claim 9 or 10, wherein said machine comprises a compressor.

12. A vane assembly according to any of claims 9 to 11, wherein each sub-array extends through a portion of a revolution about said axis and the sub-arrays are arranged in an end to end arrangement such that the array forms a complete revolution about the axis.

13. A vane assembly according to any of claims 9 to 12, wherein a step change in vane spacing occurs upon passage from one sub-array to an adjacent sub-array.

14. A vane assembly according to any of claims 9 to 13, wherein the vane spacing varies in a non-cyclic manner through a single revolution of the array about the axis.

15. A vane assembly according to any of claims 9 to 14, wherein at least a pair of sub-arrays have a vane spacing which differs from an average vane spacing for the array by an equal magnitude.

Fig.1

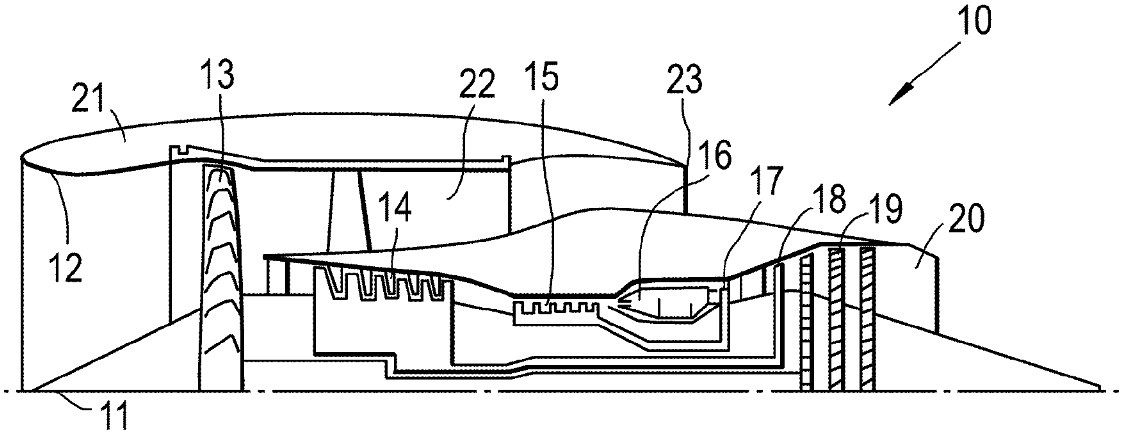
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Fig.2

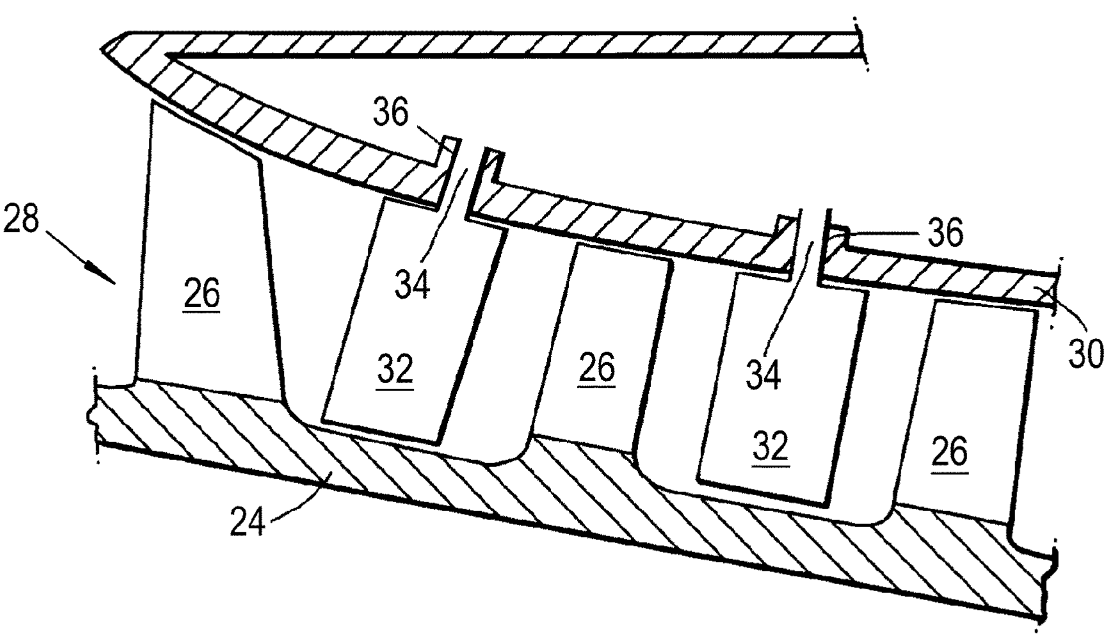
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Fig.3

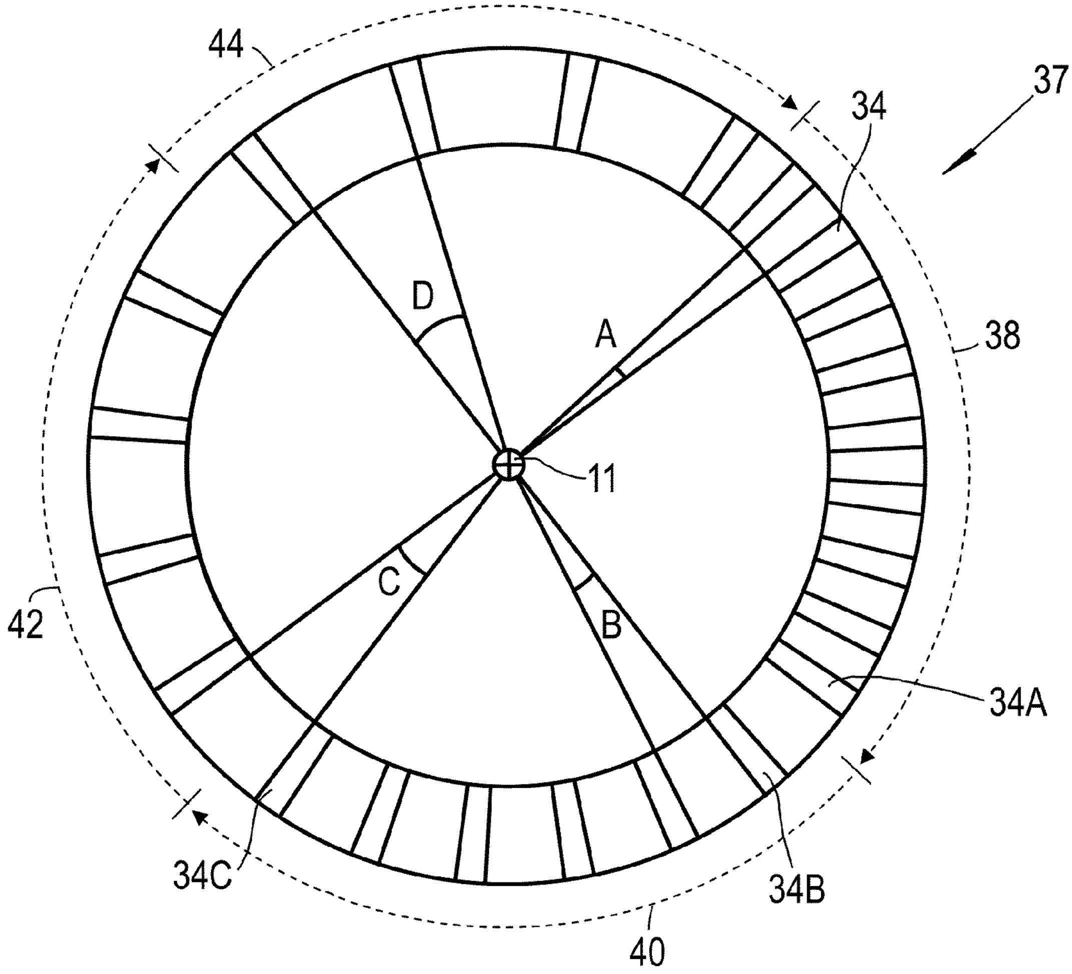
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Fig.4

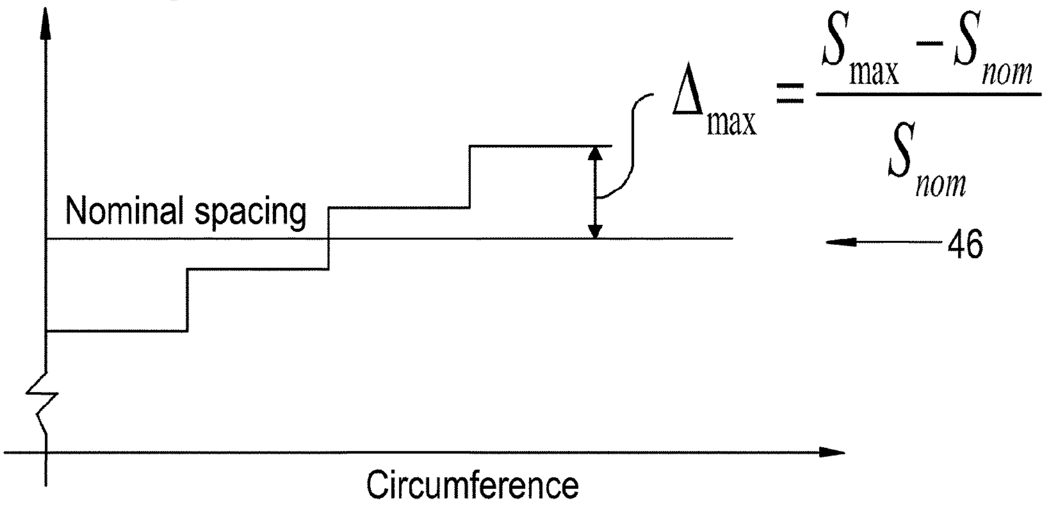

$\Delta_{\max} = \frac{S_{\max} - S_{nom}}{S_{nom}}$
Nominal spacing
46
Circumference

Fig.5A

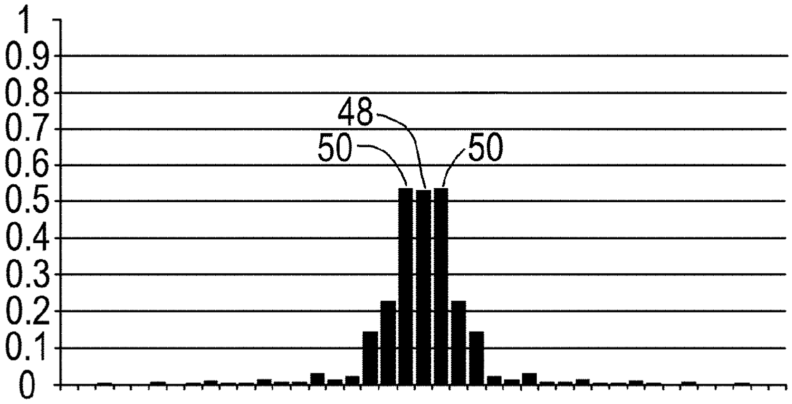


Fig.5B

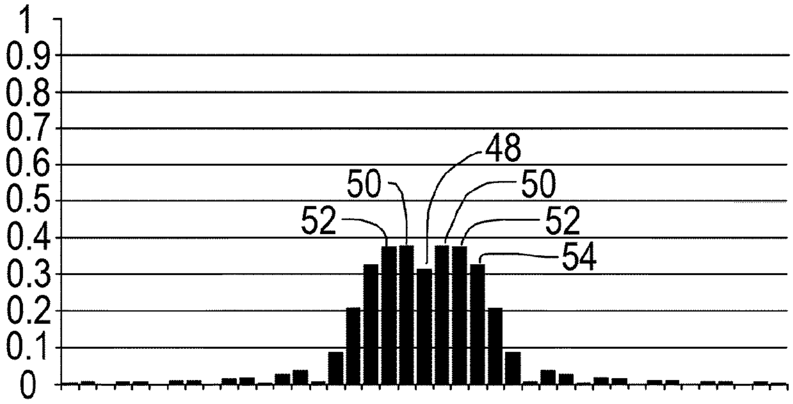


Fig.5C

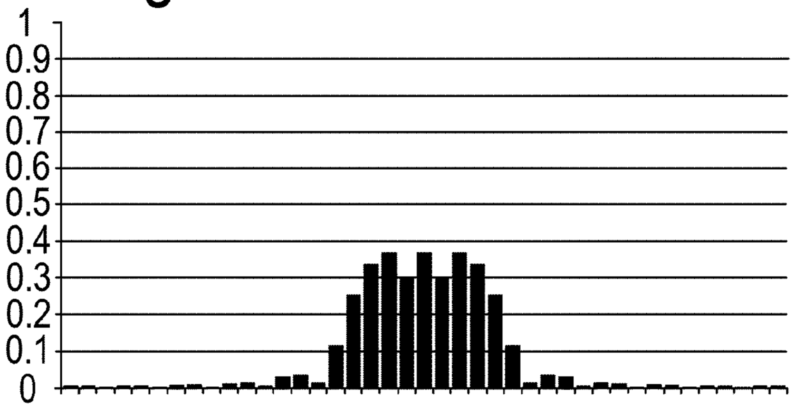
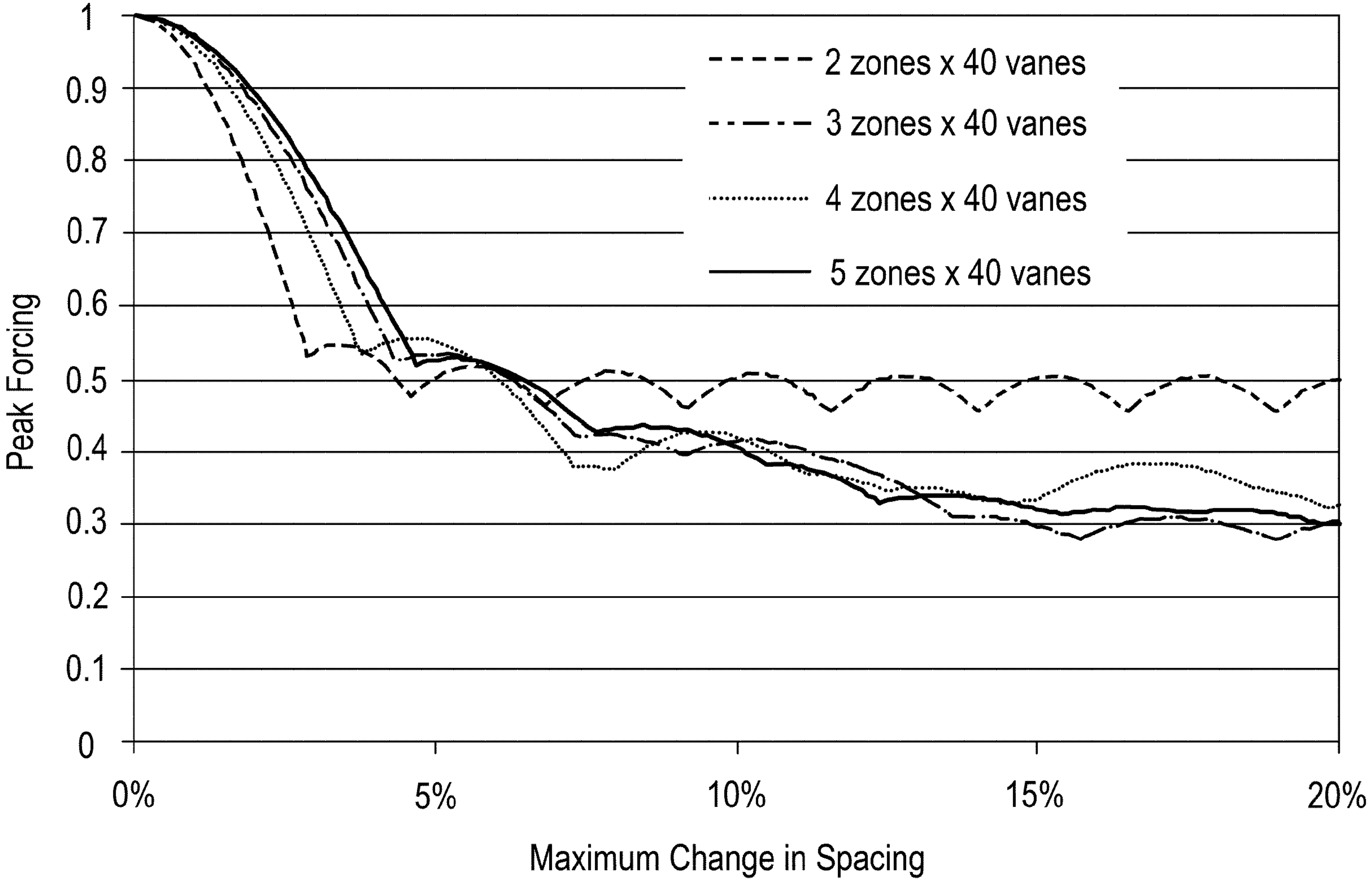


Fig.6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5%
10%
15%
20%
Maximum Change in Spacing
2 zones x 40 vanes
3 zones x 40 vanes
4 zones x 40 vanes
5 zones x 40 vanes

REFERENCES CITED IN THE DESCRIPTION

Patent documents cited in the description

- EP 05252332 A **[0005]**
- EP 1586741 A2 **[0005]**
- US 1534721 A **[0005] [0006]**
- EP 1586741 A **[0015]**