United States Patent Application Publication	20250257737
Kind Code	A1
Publication Date	August 14, 2025
Inventor(s)	Zhang; Chao et al.

CENTRIFUGAL COMPRESSOR IMPELLER AND METHOD OF PRODUCING THE SAME

Abstract

A method of producing a centrifugal compressor impeller is provided. The impeller includes a hub with a rotational axis, a forward surface, and an aft surface. The aft surface extends between an outer radial surface of the impeller and a bore centered on the rotational axis. The method includes: analyzing the impeller to determine a stress field having tangential stress data values and radial stress data values as a function of radial position within the impeller hub and as a function of axial position within the impeller hub; contouring the aft surface so that the impeller hub has radial stress data values less than tangential stress data values for any radial position of the hub during operation of the impeller; and producing the impeller with the contoured aft surface.

Inventors: **Zhang; Chao (Vaughan, CA), Mebrahtu; Yosief (Toronto, CA)**

Applicant: **Pratt & Whitney Canada Corp.** (Longueuil, Quebec, CA)

Family ID: **1000008339104**

Appl. No.: **18/440599**

Filed: **February 13, 2024**

Publication Classification

Int. Cl.: **F04D29/24** (20060101); **F04D17/10** (20060101)

U.S. Cl.:

CPC **F04D29/284** (20130101); **F04D17/10** (20130101); F05D2260/94 (20130101)

Background/Summary

BACKGROUND OF THE INVENTION

1. Technical Field

[0001] The present disclosure relates to gas turbine engines in general, and to gas turbine engines that include a centrifugal compressor in particular.

2. Background Information

[0002] A gas turbine engine includes in serial flow communication a compressor section for pressurizing air, a combustor in which the compressed air is mixed with fuel and ignited for generating an annular stream of hot combustion gases, and a turbine section for extracting energy from the combustion gases. A fan section may be disposed forward of the compressor section. Some gas turbine engines utilize one or more centrifugal compressor stages that are driven at considerable rotational speed; e.g., up to about 45,000 revolutions per minute (RPM). During operation, the impeller of the centrifugal compressor will primarily experience tangential stress (S.sub.T) and radial stress (S.sub.R). Tangential stress (sometimes referred to as “hoop stress”) acts in a direction that is perpendicular to both the radius of the impeller and the rotational axis of the impeller. Radial stress acts in a direction that is coplanar with the radius and is perpendicular to the rotational axis of the impeller. Tangential stress and radial stress are functions of the angular velocity of the impeller and both vary as a function of radial distance from the rotational axis of the impeller. There is always a need to improve the durability of engine components, including the impeller of a centrifugal compressor.

SUMMARY

[0003] According to an aspect of the present disclosure, a method of producing a centrifugal compressor impeller is provided. The impeller includes a hub with a rotational axis, a forward surface, and an aft surface. The aft surface extends between an outer radial surface of the impeller and a bore centered on the rotational axis. The method includes: analyzing the impeller to determine a stress field having tangential stress data values and radial stress data values as a function of radial position within the impeller hub and as a function of axial position within the impeller hub; contouring the aft surface so that the impeller hub has radial stress data values less than tangential stress data values for any radial position of the hub during operation of the impeller; and producing the impeller with the contoured aft surface.

[0004] In any of the aspects or embodiments described above and herein, a portion of the aft surface may have a concave arcuate contour that defines a rear cavity.

[0005] In any of the aspects or embodiments described above and herein, the step of contouring the aft surface step may include contouring the rear cavity.

[0006] In any of the aspects or embodiments described above and herein, the step of analyzing may include determining a peak radial stress location and the step of contouring includes contouring a region of the rear cavity adjacent the peak radial stress location.

[0007] In any of the aspects or embodiments described above and herein, the step of contouring the rear cavity may include providing a hub thickness aligned with the rear cavity so that the impeller hub has radial stress data values less than tangential stress data values for any radial position of the hub aligned with the rear cavity during operation of the impeller.

[0008] In any of the aspects or embodiments described above and herein, the impeller may include a plurality of blades extending out from the forward surface.

[0009] According to an aspect of the present disclosure, a method of producing a centrifugal compressor impeller is provided that includes: producing an impeller with a hub configured with a bore centered on a rotational axis, the hub having a forward surface, an aft surface, and a rear cavity, and the impeller includes a plurality of blades extending out from the forward surface; and wherein the hub is configured to have a stress field aligned with the rear cavity that is defined by tangential stress data values and radial stress data values as a function of radial position and axial position, wherein the radial stress data values are less than tangential stress data values within the

stress field during operation of the impeller.
[0010] In any of the aspects or embodiments described above and herein, the rear cavity has a concave arcuate contour, and a peak radial stress location may be aligned with the rear cavity.
[0011] According to an aspect of the present disclosure, a centrifugal compressor impeller is provided that includes a hub, a forward surface, an aft surface, and a rear cavity. The hub has a bore centered on a rotational axis. The aft surface extends between an outer radial surface of the impeller and the bore of the hub. The rear cavity is disposed in the aft surface. The impeller is configured so that a region of the impeller hub aligned with the rear cavity has radial stress data values less than tangential stress data values during operation of the impeller.
[0012] The foregoing features and elements may be combined in various combinations without exclusivity, unless expressly indicated otherwise. For example, aspects and/or embodiments of the present disclosure may include any one or more of the individual features or elements disclosed above and/or below alone or in any combination thereof. These features and elements as well as the operation thereof will become more apparent in light of the following description and the accompanying drawings. It should be understood, however, the following description and drawings are intended to be exemplary in nature and non-limiting.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
[0013] FIG. **1** is a diagrammatic representation of a gas turbine engine with which the present disclosure system may be utilized.
[0014] FIG. **2** is a diagrammatic cross-sectional partial view of a gas turbine engine equipped with a centrifugal compressor having an impeller.
[0015] FIG. **3** is a diagrammatic sectioned view of a centrifugal compressor impeller embodiment.
[0016] FIG. **4** is a diagrammatic rear perspective view of a centrifugal compressor impeller embodiment.
[0017] FIG. **5** is a diagrammatic enlarged partial view of the impeller rear cavity region of the impeller embodiment from the encircled region shown in FIG. **3**.
[0018] FIG. **6** is a graph of normalized stress as a function of impeller radius that is representative of the stress field shown in FIG. **5**.
[0019] FIG. **7** is a diagrammatic enlarged partial view of the impeller rear cavity region of the impeller embodiment from the encircled region shown in FIG. **3**, illustrating a modified impeller.
[0020] FIG. **8** is a graph of normalized stress as a function of impeller radius that is representative of the stress field shown in FIG. **7**.
DETAILED DESCRIPTION
[0021] FIG. **1** illustrates a gas turbine engine **20** that includes in serial flow communication a fan section **22**, a compressor section **24**, a combustion section **26**, and a turbine section **28**. FIG. **1** also illustrates an axial centerline **30** of the gas turbine engine **20**. Although depicted as a turbofan gas turbine engine in the disclosed non-limiting embodiments, it should be understood that the concepts described herein are not limited to use with turbofans as the teachings may be applied to other types of gas turbine engines including those with single-spool or three-spool architectures.
[0022] The compressor section **24** of the gas turbine engine **20** includes one or more compressor stages, at least one of which includes a centrifugal compressor **32**. Referring to FIGS. **2** and **3**, the centrifugal compressor **32** includes a rotatable impeller **34** having a plurality of impeller blades **36** (shown in FIG. **2**) and a downstream diffuser assembly **38**. The impeller **34** is configured to rotate within an annular impeller shroud **40** disposed about the axial centerline **30**. The impeller **34** draws air axially, and rotation of the impeller **34** increases the velocity of a core gas flow **42** through the compressor **32** as the core gas flow **42** is directed though the rotating impeller blades **36**, to flow in

a radially outward direction under centrifugal forces into the diffuser assembly **38**. The compressor **32** is at least partially housed within an engine casing **44** which surrounds and structurally supports the compressor **32**, the impeller shroud **40**, and the diffuser assembly **38**.
[0023] FIG. **2** illustrates a cross-sectional partial view of a gas turbine engine **20** equipped with a centrifugal compressor **32** having an impeller **34**. FIG. **3** diagrammatically illustrates a sectional view of a centrifugal compressor impeller **34**. The impeller **34** includes a plurality of impeller blades **36** extending out from a forward surface **46** of the impeller hub **48**. The impeller blades **36** are disposed around the circumference of the impeller **34**. The impeller hub **48** includes an aft surface **50** that extends from an outer radial surface **52** to a center bore **54** of the hub **48**. The aft surface **50** is arcuately shaped and defines a rear cavity **56**. The rear cavity **56** may be described as having a concave arcuate contour. FIG. **2** also illustrates static structures disposed **58** proximate the centrifugal compressor **32**. The centrifugal compressor impeller **34** examples shown in FIGS. **2** and **3** are provided to facilitate the description herein. The present disclosure is not limited to these centrifugal compressor impeller **34** configurations.
[0024] Centrifugal compressor impellers are driven within a range of rotational speeds (angular velocities). The high end of that range may be a considerable rotational speed; e.g., up to or above 45,000 revolutions per minute (RPM). The core gas being worked by the impeller **34** produces some amount of load on the impeller **34** and consequent stress, but the most substantial stress is associated with the angular velocity of the impeller **34**. During operation, the impeller **34** will primarily experience tangential stress (S.sub.T) and radial stress (S.sub.R). Tangential stress (sometimes referred to as “hoop stress”) acts in a direction that is perpendicular to both the radius of the impeller **34** and the rotational axis of the impeller **34**. Radial stress acts in a direction that is coplanar with the radius and is perpendicular to the rotational axis **60** (typically coincident with the engine centerline **30**) of the impeller **34**. Tangential stress and radial stress are a function of the angular velocity of the impeller **34** and both vary as a function of radial distance from the rotational axis **60** of the impeller **34**.
[0025] The rear cavity **56** of the impeller **34** is subjected to a tension-tension biaxial stress state (i.e., both radial and tangential stresses) during engine operation, and that stress state can be a life-limiting for the impeller **34**. Depending on the impeller **34** configuration, for a given angular velocity the peak radial stress could be equivalent to, or even higher than the tangential stress at a radial position aligned with the rear cavity **56**.
[0026] During manufacturing of an impeller **34**, the rear cavity **56** may be formed by a machining process; e.g., high speed lathe turning. The machining process may produce circumferential machining marks (extending normal to the radial stress direction) in the exposed surface of the rear cavity **56**. The machining mark may give rise to stress concentration factors (Kt) that can lead to hoop crack initiation (i.e., normal to the radial direction). FIG. **4** diagrammatically illustrates a hoop crack **62**. Hoop cracking in the rear cavity **56** may decrease the low cycle fatigue (LCF) life of the impeller **34**.
[0027] The present disclosure reflects the surprising discovery that the tension-tension biaxial stress state (i.e., radial and tangential stresses) that occurs during engine operation (i.e., the normal range of angular velocity during operation) can be substantially improved (and the LCF life as well) when the impeller rear cavity **56** is configured to avoid an equi-axial stress state between radial stress and tangential stress (i.e., where S.sub.R≈S.sub.T). In particular, the tension-tension biaxial stress state that occurs during engine operation is substantially improved when the radial stress (S.sub.R) magnitude is maintained below the tangential stress (ST) magnitude within the rear cavity **56** region of the impeller **34**. The term “engine operation” as used herein refers to the normal range of impeller **34** angular velocities during operation.
[0028] Aspects of the present disclosure include analyzing the impeller hub **48** in the region of the rear cavity **56** to determine stress values (both radial stress and tangential stress) as a function of radial and axial directions. The present disclosure is not limited to any particular method of

determining the stress values. The stress data may also be used to determine a peak radial stress location (designated "MX"). Aspects of the present disclosure also include modifying the geometry of the rear cavity **56** region of the impeller **34** to produce an impeller **34** geometry that is subject to a tension-tension biaxial stress state during engine operation that possesses a radial stress (S.sub.R) magnitude that is below the tangential stress (ST) magnitude.

[0029] FIG. **5** diagrammatically illustrates an unmodified impeller rear cavity **56** region (e.g., see encircled region shown in FIG. **3**) with a stress contour map indicative of stress magnitude data analytically produced as described above. The stress contour map is diagrammatically shown as having four (4) stress regions of different magnitude in an radial/axial plane. The impeller **34** has a uniform geometric configuration around the circumference of the impeller **34**, so the plane diagrammatically shown in not a function of circumferential position. Stress region "SR**1**", which is contiguous with the surface of the rear cavity **56**, possesses the highest level of average stress. Stress region "SR**4**", which is furthest from the surface of the rear cavity **56**, possesses the lowest average level of stress. The average level of stress decreases from region SR**1** to region SR**4**; i.e., SR**1**>SR**2**>SR**3**>SR**4**. The graph shown in FIG. **6** illustrates normalized tangential stress and radial stress values as a function of impeller radius for the unmodified impeller **34**. As can be seen in FIG. **6**, the tangential stress level is equal to the radial stress level ("equi-axial stress state") for a substantial portion of the impeller rear cavity **56** region, including the peak stress location; e.g., peak stress normalized as a value equal to "100" in the graph. As described above, an equi-axial stress state can decrease the LCF capability of the impeller **34** and there decrease the useful life of the impeller **34**.

[0030] FIG. **7** diagrammatically illustrates a modified impeller rear cavity **56** region with a stress contour map indicative of stress magnitude data analytically produced as described above. The modification of the impeller rear cavity **56** region includes altering the original geometric contour of the portion of the impeller rear cavity **56** region that includes the determined peak radial stress location ("MX"). In this example, the modification to the impeller rear cavity **56** region is in the form of an additional amount of the material forming the impeller rear cavity **56** region; i.e., increasing the thickness of the impeller hub **48**. The modification is shown as a dashed line. The radial length of the modification and the thickness (i.e., axial dimension) of the modification may be chosen based on the application at hand, provided the modification results in a tension-tension biaxial stress state during engine operation having a radial stress (S.sub.R) magnitude that is below the tangential stress (ST) magnitude. The radial ends of the modification may be smoothly transitioned to the original geometry of the rear cavity **56** region surface to minimize local stress concentrations. FIG. **7** illustrates a stress contour map having four (4) stress regions of different magnitude in an radial/axial plane; i.e., like that shown in FIG. **5** with regions SR**1**-SR**4**, where SR**1**>SR**2**>SR**3**>SR**4**. FIG. **8** illustrates normalized tangential stress and radial stress values as a function of impeller radius for the modified impeller **34**. As can be seen in FIG. **8**, the radial stress level is below the tangential stress level throughout the impeller rear cavity **56** region. The decrease in radial stress and the avoidance of an equi-axial stress state results in a meaningful increase in the LCF capability of the impeller **34** and the useful life of the impeller **34**.

[0031] While the principles of the disclosure have been described above in connection with specific apparatuses and methods, it is to be clearly understood that this description is made only by way of example and not as limitation on the scope of the disclosure. Specific details are given in the above description to provide a thorough understanding of the embodiments. However, it is understood that the embodiments may be practiced without these specific details.

[0032] It is noted that the embodiments may be described as a process which is depicted as a flowchart, a flow diagram, a block diagram, etc. Although any one of these structures may describe the operations as a sequential process, many of the operations can be performed in parallel or concurrently. In addition, the order of the operations may be rearranged. A process may correspond to a method, a function, a procedure, a subroutine, a subprogram, etc. The singular forms "a," "an," and “the” refer to one or more than one, unless the context clearly dictates otherwise. For example, the term “comprising a specimen” includes single or plural specimens and is considered equivalent to the phrase “comprising at least one specimen.” The term “or” refers to a single element of stated alternative elements or a combination of two or more elements unless the context clearly indicates otherwise. As used herein, “comprises” means “includes.” Thus, “comprising A or B,” means “including A or B, or A and B,” without excluding additional elements.

[0033] It is noted that various connections are set forth between elements in the present description and drawings (the contents of which are included in this disclosure by way of reference). It is noted that these connections are general and, unless specified otherwise, may be direct or indirect and that this specification is not intended to be limiting in this respect. Any reference to attached, fixed, connected or the like may include permanent, removable, temporary, partial, full and/or any other possible attachment option.

[0034] No element, component, or method step in the present disclosure is intended to be dedicated to the public regardless of whether the element, component, or method step is explicitly recited in the claims. No claim element herein is to be construed under the provisions of 35 U.S.C. 112(f) unless the element is expressly recited using the phrase “means for.” As used herein, the terms “comprise”, “comprising”, or any other variation thereof, are intended to cover a non-exclusive inclusion, such that a process, method, article, or apparatus that comprises a list of elements does not include only those elements but may include other elements not expressly listed or inherent to such process, method, article, or apparatus.

[0035] While various inventive aspects, concepts and features of the disclosures may be described and illustrated herein as embodied in combination in the exemplary embodiments, these various aspects, concepts, and features may be used in many alternative embodiments, either individually or in various combinations and sub-combinations thereof. Unless expressly excluded herein all such combinations and sub-combinations are intended to be within the scope of the present application. Still further, while various alternative embodiments as to the various aspects, concepts, and features of the disclosures—such as alternative materials, structures, configurations, methods, devices, and components, and so on—may be described herein, such descriptions are not intended to be a complete or exhaustive list of available alternative embodiments, whether presently known or later developed. Those skilled in the art may readily adopt one or more of the inventive aspects, concepts, or features into additional embodiments and uses within the scope of the present application even if such embodiments are not expressly disclosed herein. For example, in the exemplary embodiments described above within the Detailed Description portion of the present specification, elements may be described as individual units and shown as independent of one another to facilitate the description. In alternative embodiments, such elements may be configured as combined elements. It is further noted that various method or process steps for embodiments of the present disclosure are described herein. The description may present method and/or process steps as a particular sequence. However, to the extent that the method or process does not rely on the particular order of steps set forth herein, the method or process should not be limited to the particular sequence of steps described. As one of ordinary skill in the art would appreciate, other sequences of steps may be possible. Therefore, the particular order of the steps set forth in the description should not be construed as a limitation.

Claims

1. A method of producing a centrifugal compressor impeller, the impeller including a hub with a rotational axis, a forward surface, and an aft surface, the aft surface extending between an outer radial surface of the impeller and a bore centered on the rotational axis, the method comprising: analyzing the impeller to determine a stress field having tangential stress data values and radial stress data values as a function of radial position within the impeller hub and as a function of axial position within the impeller hub; contouring the aft surface so that the impeller hub has radial stress data values less than tangential stress data values for any radial position of the hub during operation of the impeller; and producing the impeller with the contoured aft surface.

2. The method of claim 1, wherein a portion of the aft surface has a concave arcuate contour that defines a rear cavity.

3. The method of claim 2, wherein the step of contouring the aft surface step includes contouring the rear cavity.

4. The method of claim 3, wherein the step of analyzing includes determining a peak radial stress location and the contouring includes contouring a region of the rear cavity adjacent the peak radial stress location.

5. The method of claim 4, wherein the step of contouring the rear cavity includes providing a hub thickness aligned with the rear cavity so that the impeller hub has radial stress data values less than tangential stress data values for any radial position of the hub aligned with the rear cavity during operation of the impeller.

6. The method of claim 5, wherein the impeller includes a plurality of blades extending out from the forward surface.

7. A method of producing a centrifugal compressor impeller, comprising: producing an impeller with a hub configured with a bore centered on a rotational axis, the hub having a forward surface, an aft surface, and a rear cavity, and the impeller includes a plurality of blades extending out from the forward surface; and wherein the hub is configured to have a stress field aligned with the rear cavity that is defined by tangential stress data values and radial stress data values as a function of radial position and axial position, wherein the radial stress data values are less than tangential stress data values within the stress field during operation of the impeller.

8. The method of claim 7, wherein the rear cavity has a concave arcuate contour.

9. The method of claim 8, wherein the hub is configured so that a peak radial stress location is aligned with the rear cavity.

10. A centrifugal compressor impeller, comprising: a hub having a bore centered on a rotational axis; a forward surface; an aft surface, wherein the aft surface extends between an outer radial surface of the impeller and the bore of the hub; and a rear cavity disposed in the aft surface; wherein the impeller is configured so that a region of the impeller hub aligned with the rear cavity has radial stress data values less than tangential stress data values during operation of the impeller.

11. The impeller of claim 10, wherein the rear cavity has a concave arcuate contour.

12. The impeller of claim 11, wherein the rear cavity is positioned to align with a peak radial stress location during operation of the impeller.

13. The impeller of claim 12, wherein the impeller includes a plurality of blades extending out from the forward surface.