loading, impacts, high temperatures and the like during operation. Such indications may lead to the scheduling of further evaluation, maintenance and/or replacement of the structural components at appropriate times.

Summary of the Disclosure

In one aspect of the present disclosure, a multi-layer structural component is disclosed. The multi-layer structural component may include a first outer layer, a second outer layer, and a first patterned layer disposed between the first outer layer and the second outer layer. The first patterned layer may include a first geometric pattern of grooves on a first surface of the first patterned layer, with the first geometric pattern of grooves having a first set of grooves each having a first groove width. Strain on the multi-layer structural component caused by exposure to an environmental condition can cause changes to the first geometric pattern wherein the first groove width increases or decreases for at least a portion of the first set of grooves. A first projected beam of EM energy having a first wavelength corresponding to the first groove width may be diffracted when the first projected beam of EM energy hits the first set of grooves and creates a first diffracted beam of diffracted EM energy having a first diffracted wavelength. Changes in the first groove width due to the strain on the multi-layer structural component cause changes in the first diffracted wavelength that correspond to the strain on the multi-layer structural component. At least one of the first outer layer and the second outer layer may be fabricated from an outer layer material that is transparent with respect to the first projected beam of EM energy and the first diffracted beam of diffracted EM energy.

In another aspect of the present invention, an inspection system for assessing strain in a structural component is disclosed. The inspection system may include a first geometric pattern of grooves within the structural component having a first set of grooves each having a first groove width, and a first EM energy source projecting a first projected beam of electromagnetic energy at a first wavelength that corresponds to the first groove width. Strain on the structural component caused by exposure to an environmental condition can cause changes to the first geometric pattern wherein the first groove width increases or decreases for at least a portion of the first set of grooves. When the first projected beam of EM energy is projected onto the structural component, the first projected beam of EM energy passes through the structural component to the first geometric pattern of grooves, and is diffracted by the first set of grooves to create a first diffracted beam of diffracted EM energy having a first diffracted

wavelength. Changes in the first groove width due to the strain on the structural component cause changes in the first diffracted wavelength that correspond to the strain on the structural component. The inspection may further include an EM energy detector detecting the first diffracted wavelength of the first diffracted beam

of diffracted EM energy from the first set of grooves as the first EM energy source projects the first projected beam of EM energy onto the structural component, and a processor operatively connected to the EM energy detector and configured to receive the first diffracted wavelength of the first diffracted beam of diffracted EM energy from the EM energy detector and to correlate the first diffracted wavelength to the strain in the structural component.

In a further aspect of the present disclosure, a method for assessing strain in a structural component is disclosed. The structural component may have a first geometric pattern of grooves within the structural component, the first geometric pattern of grooves having a first set of grooves each having a first groove width. Strain on the multi-layer structural component caused by exposure to an environmental condition can cause changes to the first geometric pattern wherein the first groove width increases or decreases for at least a portion of the first set of grooves. The method for assessing strain may include projecting a first projected beam of EM energy through the structural component to the first geometric pattern of grooves, wherein the first projected beam of EM energy has a first wavelength that corresponds to the first groove width, and wherein the first set of grooves diffracts the first projected beam of EM energy to create a first diffracted beam of diffracted EM energy having a first diffracted wavelength. Changes in the first groove width due to the strain on the structural component cause changes in the first diffracted wavelength that correspond to the strain on the structural component. The method for assessing strain may further include detecting the first diffracted wavelength of the first diffracted beam of diffracted EM energy from the first set of grooves as the first projected beam of EM energy is projected onto the structural component, and correlating the first diffracted wavelength of the first diffracted beam of diffracted EM energy from the first geometric pattern of grooves to the strain in the structural component.

Additional aspects are defined by the claims of this patent.

Brief Description of the Drawings

Fig. 1 is an isometric view of a structural component of a mechanical system having a geometric pattern of grooves in accordance with the present disclosure;

Fig. 2 is a partial cross-sectional view of the structural component of Fig. 1 having the geometric pattern of grooves;

Fig. 3 is a partial cross-sectional view of an alternative embodiment of a structural component having an alternative geometric pattern of grooves;

Claims

1. A multi-layer structural component comprising:

a first outer layer;

a second outer layer; and

a first patterned layer disposed between the first outer layer and the second outer layer and having a first geometric pattern of grooves on a first surface of the first patterned layer, the first geometric pattern of grooves having a first set of grooves each having a first groove width, wherein strain on the multi-layer structural component caused by exposure to an environmental condition can cause changes to the first geometric pattern wherein the first groove width increases or decreases for at least a portion of the first set of grooves, wherein a first projected beam of electromagnetic (EM) energy having a first wavelength corresponding to the first groove width is diffracted when the first projected beam of EM energy hits the first set of grooves and creates a first diffracted beam of diffracted EM energy having a first diffracted wavelength, wherein changes in the first groove width due to the strain on the multi-layer structural component cause changes in the first diffracted wavelength that correspond to the strain on the multi-layer structural component, and wherein at least one of the first outer layer and the second outer layer is fabricated from an outer layer material that is transparent with respect to the first projected beam of EM energy and the first diffracted beam of diffracted EM energy.

2. The multi-layer structural component according to claim 1, wherein the first patterned layer is fabricated from a metallic material.

3. The multi-layer structural component according to claim 1, wherein the first outer layer is fabricated from the outer layer material, and wherein the first patterned layer reflects the first projected beam of EM energy passing through the first outer layer to transmit the first diffracted beam of diffracted EM energy through the first outer layer.

4. The multi-layer structural component according to claim 1, wherein the first outer layer and the second outer layer are fabricated from the outer layer material, and wherein, when the first projected beam of EM energy passes through the first outer layer to the first patterned layer, the first diffracted beam of diffracted EM energy passes through the second outer layer and out of the multi-layer structural component.

5. The multi-layer structural component according to claim 1, comprising:

an intermediate layer between the first outer layer and the second outer layer with the first patterned layer disposed between the first outer layer and the intermediate layer; and

a second patterned layer disposed between the intermediate layer and the second outer layer and having a second geometric pattern of grooves on a second surface of the second patterned layer, the second geometric pattern of grooves having a second set of grooves each having a second groove width that is different than the first groove width, wherein a second projected beam of EM energy having a second wavelength corresponding to the second groove width is diffracted when the second projected beam of EM energy hits the second set of grooves and creates a second diffracted beam of diffracted EM energy having a second diffracted wavelength indicating changes in the second groove width due to the strain caused when the multi-layer structural component is exposed to the environmental condition, and wherein the outer layer material is transparent with respect to the second projected beam of EM energy and the second diffracted beam of diffracted EM energy.

6. The multi-layer structural component according to claim 5, wherein the second groove width is greater than the first groove width and the second wavelength is greater than the first wavelength so that the second projected beam of EM energy passes through the first geometric pattern of grooves without being diffracted.

7. The multi-layer structural component according to claim 1, wherein the first geometric pattern of grooves comprises a two-dimensional geometric pattern having a

second set of grooves each having a second groove width and spaced in a second direction that is not parallel to a first direction in which the first set of grooves is spaced.

8. The multi-layer structural component according to claim 7, wherein the second groove width is not equal to the first groove width, wherein a second projected beam of EM energy having a second wavelength corresponding to the second groove width is diffracted when the second projected beam of EM energy hits the second set of grooves and creates a second diffracted beam of diffracted EM energy having a second diffracted wavelength indicating changes in the second groove width due to the strain caused when the multi-layer structural component is exposed to the environmental condition, and wherein the outer layer material is transparent with respect to the second projected beam of EM energy and the second diffracted beam of diffracted EM energy.

9. The multi-layer structural component according to claim 1, wherein grooves of the first set of grooves have a similar geometric shape and define increasing areas, with the grooves being arranged concentrically to form the first geometric pattern of grooves.

10. The multi-layer structural component according to claim 9, wherein a groove spacing distance between adjacent grooves of the first geometric pattern increases as the first geometric pattern extends outward from a central point.

11. The multi-layer structural component according to claim 1, wherein the first geometric pattern of grooves has a second set of grooves each having a second groove width, wherein a second projected beam of EM energy having a second wavelength corresponding to the second groove width is diffracted when the second projected beam of EM energy hits the second set of grooves and creates a second diffracted beam of diffracted EM energy having a second diffracted wavelength indicating changes in the second groove width due to the strain caused when the multi-layer structural component is exposed to the environmental condition, and wherein the outer layer material is transparent

with respect to the second projected beam of EM energy and the second diffracted beam of diffracted EM energy.

12. The multi-layer structural component according to claim 1, wherein the first patterned layer comprises a plurality of parallel wires defining the first geometric pattern of grooves, wherein the first groove width of the grooves is equal to a wire spacing distance between adjacent ones of the plurality of parallel wires.

13. The multi-layer structural component according to claim 1, wherein the first patterned layer comprises a wire mesh scrim defining the first geometric pattern of grooves, wherein the wire mesh scrim comprises:

a first set of parallel wires oriented in a first direction, wherein the first groove width is equal to a first wire spacing distance between adjacent ones of the first set of parallel wires; and

a second set of parallel wires oriented in a second direction that is not parallel to the first direction, wherein a second groove width of the grooves is equal to a second wire spacing distance between adjacent ones of the second set of parallel wires.

14. The multi-layer structural component according to claim 13, wherein the first set of parallel wires is woven together with the second set of parallel wires.

15. The multi-layer structural component according to claim 13, wherein the first groove width is not equal to the second groove width.

16. An inspection system for assessing strain in a structural component, comprising:

a first geometric pattern of grooves within the structural component having a first set of grooves each having a first groove width, wherein strain on the structural component caused by exposure to an environmental condition can cause changes to the first geometric

pattern wherein the first groove width increases or decreases for at least a portion of the first set of grooves;

a first electromagnetic (EM) energy source projecting a first projected beam of EM energy at a first wavelength that corresponds to the first groove width, wherein, when the first projected beam of EM energy is projected onto the structural component, the first projected beam of EM energy passes through the structural component to the first geometric pattern of grooves, and is diffracted by the first set of grooves to create a first diffracted beam of diffracted EM energy having a first diffracted wavelength, wherein changes in the first groove width due to the strain on the structural component cause changes in the first diffracted wavelength that correspond to the strain on the structural component;

an EM energy detector detecting the first diffracted wavelength of the first diffracted beam of diffracted EM energy from the first set of grooves as the first EM energy source projects the first projected beam of EM energy onto the structural component; and

a processor operatively connected to the EM energy detector and configured to receive the first diffracted wavelength of the first diffracted beam of diffracted EM energy from the EM energy detector and to correlate the first diffracted wavelength to the strain in the structural component.

17. The inspection system according to claim 16, wherein the first geometric pattern of grooves reflects the first projected beam of EM energy to transmit the first diffracted beam of diffracted EM energy back through the structural component, and wherein the first EM energy source and the EM energy detector are positioned on the same side of the structural component.

18. The inspection system according to claim 16, wherein the first diffracted beam of diffracted EM energy is transmitted through the structural component on an opposite side of the first geometric pattern of grooves from the first projected beam of EM energy, and wherein the first EM energy source and the EM energy detector are positioned on opposite sides of the structural component.

19. The inspection system according to claim 16, wherein the first geometric pattern of grooves has a second set of grooves each having a second groove width, wherein the inspection system comprises a second EM energy source projecting a second projected beam of EM energy at a second wavelength that corresponds to the second groove width, wherein, when the second projected beam of EM energy is projected onto the structural component, the second projected beam of EM energy passes through the structural component to the first geometric pattern of grooves, and is diffracted by the second set of grooves to create a second diffracted beam of diffracted EM energy having a second diffracted wavelength indicating changes in the second groove width due to the strain caused when the structural component is exposed to the environmental condition,

wherein the second diffracted wavelength of the second diffracted beam of diffracted EM energy reflected from the second set of grooves is detected by the EM energy detector as the second EM energy source projects the second projected beam of EM energy onto the structural component, and

wherein the processor is configured to receive the second diffracted wavelength of the second diffracted beam of diffracted EM energy from the EM energy detector and to correlate the second diffracted wavelength to the strain in the structural component.

20. The inspection system according to claim 16, comprising:

a second geometric pattern of grooves within the structural component at a different depth from an outer surface of the structural component than the first geometric pattern of grooves, the second geometric pattern of grooves having a second set of grooves each having a second groove width; and

a second EM energy source projecting a second projected beam of EM energy at a second wavelength that corresponds to the second groove width, wherein, when the second projected beam of EM energy is projected onto the structural component, the second projected beam of EM energy passes through the structural component to the second geometric pattern of grooves, and is diffracted by the second set of grooves to create a second diffracted beam of diffracted EM energy having a second diffracted wavelength indicating changes in the second groove width due to the strain caused when the structural component is exposed to the environmental condition,

wherein the second diffracted wavelength of the second diffracted beam of diffracted EM energy reflected from the second set of grooves is detected by the EM energy detector as the second EM energy source projects the second projected beam of EM energy onto the structural component, and

wherein the processor is configured to receive the second diffracted wavelength of the second diffracted beam of diffracted EM energy from the EM energy detector and to correlate the second diffracted wavelength to the strain in the structural component.

21. The inspection system according to claim 20, wherein the second groove width is greater than the first groove width and the second wavelength is greater than the first wavelength so that the second projected beam of EM energy passes through the first set of grooves without being diffracted.

22. The inspection system according to claim 16, wherein the first geometric pattern of grooves comprises a two-dimensional geometric pattern having the first set of grooves spaced in a first direction and a second set of grooves spaced in a second direction that is not parallel to the first direction.

23. The inspection system according to claim 22, wherein the first set of grooves has the first groove width and the second set of grooves has a second groove width that is not equal to the first groove width, wherein the first EM energy source projects a second projected beam of EM energy having a second wavelength corresponding to the second groove width, wherein the second projected beam of EM energy is diffracted by the second set of grooves to create a second diffracted beam of diffracted EM energy having a second diffracted wavelength indicating changes in the second groove width due to the strain caused when the structural component is exposed to the environmental condition, wherein the second diffracted wavelength of the second diffracted beam of diffracted EM energy reflected from the second set of grooves is detected by the EM energy detector as the first EM energy source projects the second projected beam of EM energy onto the structural component, and wherein the processor is configured to receive the second diffracted wavelength of the second diffracted beam of

diffracted EM energy from the EM energy detector and to correlate the second diffracted wavelength to the strain in the structural component.

24. The inspection system according to claim 16, comprising a portable inspection device containing the first EM energy source and the EM energy detector, and transmitting the first diffracted wavelength of the first diffracted beam of diffracted EM energy to the processor via wireless communications.

25. A method for assessing strain in a structural component having a first geometric pattern of grooves within the structural component, the first geometric pattern of grooves having a first set of grooves each having a first groove width, wherein strain on the multi-layer structural component caused by exposure to an environmental condition can cause changes to the first geometric pattern wherein the first groove width increases or decreases for at least a portion of the first set of grooves, the method for assessing strain comprising:

projecting a first projected beam of electromagnetic (EM) energy through the structural component to the first geometric pattern of grooves, wherein the first projected beam of EM energy has a first wavelength that corresponds to the first groove width, and wherein the first set of grooves diffracts the first projected beam of EM energy to create a first diffracted beam of diffracted EM energy having a first diffracted wavelength, wherein changes in the first groove width due to the strain on the structural component cause changes in the first diffracted wavelength that correspond to the strain on the structural component;

detecting the first diffracted wavelength of the first diffracted beam of diffracted EM energy from the first set of grooves as the first projected beam of EM energy is projected onto the structural component; and

correlating the first diffracted wavelength of the first diffracted beam of diffracted EM energy from the first geometric pattern of grooves to the strain in the structural component.

26. The method for assessing strain according to claim 25, wherein the first geometric pattern of grooves has a second set of grooves each having a second groove width, and wherein the method for assessing strain comprises:

projecting a second projected beam of EM energy through the structural component to the first geometric pattern of grooves, wherein the second projected beam of EM energy has a second wavelength that corresponds to the second groove width, and wherein the second set of grooves diffracts the second projected beam of EM energy to create a second diffracted beam of diffracted EM energy having a second diffracted wavelength indicating changes in the second groove width due to the strain caused when the structural component is exposed to the environmental condition;

detecting the second diffracted wavelength of the second diffracted beam of diffracted EM energy from the second set of grooves as the second projected beam of EM energy is projected onto the structural component; and

correlating the second diffracted wavelength of the second diffracted beam of diffracted EM energy from the second set of grooves to the strain in the structural component.

27. The method for assessing strain according to claim 25, comprises:

projecting the first projected beam of EM energy onto the structural component a first time before the structural component is exposed to the environmental condition;

detecting a baseline diffracted wavelength of the first diffracted beam of diffracted EM energy from the first set of grooves as the first projected beam of EM energy is projected onto the structural component the first time;

projecting the first projected beam of EM energy onto the structural component a second time after the structural component is exposed to the environmental condition;

detecting the first diffracted wavelength of the first diffracted beam of diffracted EM energy from the first set of grooves as the first projected beam of EM energy is projected onto the structural component the second time; and

comparing the first diffracted wavelength of the first diffracted beam of diffracted EM energy to the baseline diffracted wavelength as the first projected beam of EM energy

is projected onto the structural component the second time to determine changes in the strain at corresponding locations of the structural component.

28. The method for assessing strain according to claim 25, wherein the structural component has a second geometric pattern of grooves within the structural component at a different depth from a surface of the structural component than the first geometric pattern of grooves, the second geometric pattern of grooves having a second set of grooves each having a second groove width, the method for assessing strain comprises:

projecting a second projected beam of EM energy through the structural component to the second geometric pattern of grooves, wherein the second projected beam of EM energy has a second wavelength that corresponds to the second groove width, and wherein the second set of grooves diffracts the second projected beam of EM energy to create a second diffracted beam of diffracted EM energy having a second diffracted wavelength indicating changes in the second groove width due to the strain caused when the structural component is exposed to the environmental condition;

detecting the second diffracted wavelength of the second diffracted beam of diffracted EM energy from the second geometric pattern of grooves as the second projected beam of EM energy is projected onto the structural component; and

correlating the second diffracted wavelength of the second diffracted beam of diffracted EM energy from the second geometric pattern of grooves to the strain in the structural component.

29. The method for assessing strain according to claim 25, wherein the first set of grooves reflects the first projected beam of EM energy to transmit the first diffracted beam of diffracted EM energy back through the structural component, and wherein the method for assessing strain comprises projecting the first projected beam of EM energy onto the structural component and detecting the first diffracted wavelength on the same side of the structural component.

30. The method for assessing strain according to claim 25, wherein the first diffracted beam of diffracted EM energy is transmitted through the structural component

on an opposite side of the first geometric pattern of grooves from the first projected beam of EM energy, and the method for assessing strain comprises projecting the first projected beam of EM energy onto the structural component and detecting the first diffracted wavelength on opposite sides of the structural component.

31. The method for assessing strain according to claim 25, comprising:

comparing the strain on the structural component to a minimum strain value; and

conducting further inspection of the structural component in response to determining that the strain on the structural component is greater than the minimum strain value.

32. The method for assessing strain according to claim 25, comprising:

generating and displaying a strain pattern derived from the strain in the structural component, wherein the strain pattern is a graphical representation of strain values in an inspected area of the structural component; and

conducting further inspection of the structural component in response to determining that the strain pattern is different than an expected strain pattern on the structural component.