

GOVERNMENT INTEREST STATEMENT

This invention was made in whole or in part with government support under contract number N68335-09-C-0201 with the United States Navy, contract number NNX10CC12P with the National Aeronautics and Space Administration (NASA), and contract number W911W6-06-C-0023 with the United States Army. The government may have certain rights in the invention.

Parent Case Text

RELATED APPLICATION DATA

The present application claims benefit of prior provisional application No. 61/535,526, filed on Sep. 16, 2011, and entitled "METHOD AND SYSTEM FOR PREDICTING SURFACE CONTACT FATIGUE", and prior application 61/536,237, filed on Sep. 19, 2011, and entitled, "METHOD AND SYSTEM FOR PREDICTING SURFACE CONTACT FATIGUE LIFE", both of which are incorporated by reference herein in their entirety.

Claims

What is claimed is:

1. A method of predicting surface contact fatigue life of a bearing in a wind turbine generating electricity, comprising: configuring a computer-based system to predict surface contact fatigue life of the bearing, the computer-based system comprising: an input device configured to receive material properties relating to the bearing; an output device configured to convey information relating to the bearing; memory storing the material properties relating to the bearing and computer-executable instructions to process the material properties relating to the bearing; and a processor; and predicting the surface contact fatigue life of the bearing with the computer-based system according to processes of the computer-executable instructions; wherein the computer-executable instructions cause the processor to predict the surface contact fatigue life of the bearing by: generating a finite element model based on the material properties related to the bearing, wherein the finite element model describes a grain structure of the bearing and represents polycrystalline properties of the bearing, and wherein generating the finite element model comprises generating a random microstructure instance using a tessellation and meshing the random microstructure instance with a convex polygon; generating a surface pressure time history for a simulated loading event on the finite element model, wherein the simulated loading event represents one revolution of the wind turbine and the simulated loading event is divided into discrete time steps, and using the finite element model, a defined load is simulated to travel a distance over the bearing in each time step and simulated to exert different amounts of pressure across the bearing in each time step due to asperity contact, wherein the surface pressure time history is based on a surface roughness, and wherein the surface roughness is numerically generated and characterized by statistical parameters; determining based on the surface pressure time history for a loading event, a finite element solution that describes stress in the grain structure; calculating damage in the finite element solution using a damage model, the damage model including the stress in the grain structure; determining whether the damage exceeds a damage threshold; if damage does not exceed a threshold, repeating at least the generating a surface pressure time history, determining a finite element solution, and calculating damage operations; and if damage does exceed a threshold, outputting via the output device the number of load cycles required for failure of the bearing.
2. The method according to claim 1, wherein generating a surface pressure time history comprises generating a surface traction time history and a bulk loading time history.

3. The method according to claim 1, wherein generating a surface pressure time history is based on one or more parameters related to the geometry and physical properties of the bearing.
4. The method according to claim 3, wherein the one or more loading parameters comprises a surface roughness profile, lubricant properties, and transmitted load.
5. The method according to claim 1, comprising updating the finite element model based on the calculated damage.
6. The method according to claim 1, wherein the material properties related to the bearing comprise parameters related to microstructure geometry and physical composition of the bearing, and the random microstructure instance comprises a random distribution of nucleation points.
7. The method according to claim 1, wherein the random microstructure instance comprises grain boundaries surrounding regions of steady thermodynamic phase change.
8. A method of predicting surface contact fatigue life of a bearing in a wind turbine, comprising: configuring a computer-based system to predict surface contact fatigue life, the computer-based system comprising: an input device configured to receive material properties relating to the bearing; an output device configured to convey information relating to the bearing; memory storing the material properties relating to the bearing and computer-executable instructions to process the material properties relating to the bearing; and a processor; and predicting the surface contact fatigue life of the bearing with the computer-based system according to processes of the computer-executable instructions; wherein the computer-executable instructions cause the processor to predict the surface contact fatigue life of the bearing by: generating a finite element model that models a structure of the bearing, wherein generating the finite element model comprises generating, using a tessellation, a random microstructure instance comprising nucleation points and grain boundaries, wherein the finite element model represents polycrystalline properties of the bearing; determining, based on a surface pressure time history for a simulated loading event, a finite element solution describing stress in the structure wherein the simulated loading event is divided into discrete time steps, and using the finite element model, a defined load is simulated to travel a distance over the bearing in each time step and simulated to exert different amounts of pressure across the bearing in each time step due to asperity contact, wherein the surface pressure history is based on a surface roughness, and wherein the surface roughness is numerically generated and characterized by statistical parameters, wherein the simulated loading event represents one revolution of the wind turbine; calculating a damage level in the finite element solution determined by the stress in the structure; determining whether the calculated damage exceeds a failure threshold for the bearing; determining the number of loading events required for bearing failure; and outputting the number of loading events required for bearing failure using the output device.
9. The method of claim 8, wherein generating the finite element model comprises generating the random microstructure instance using a Voronoi tessellation and meshing the random microstructure instance with a convex polygon.
10. The method of claim 8, wherein the surface pressure history is based on a surface roughness profile, lubricant properties, and transmitted load of the component.
11. A method for modeling stresses and predicting surface contact fatigue life of a power transmission component in a power transmission, comprising: obtaining material properties related to a power transmission component; generating a finite element model based on the material properties related to the power transmission component, wherein the finite element model describes a grain structure of the bearing and represents polycrystalline properties of the power transmission component; generating loading parameters, wherein the loading parameters characterize a surface roughness; simulating a loading event onto the finite element model, wherein the loading event represents one revolution of the power transmission and is divided into discrete time steps, and using the finite element model, a defined load is simulated to travel a distance over the power transmission component in each time step, wherein the defined load is simulated to exert different amounts of

present invention;

FIG. 2 is a flow chart of a method or process according to embodiments of the present invention;

FIG. 3 is an example of a random microstructure instance generated using a Voronoi tessellation, according to embodiments of the present invention;

FIG. 4 is an example of a random microstructure instance generated using Voronoi tessellation and meshed with a triangular element, according to embodiments of the present invention;

FIG. 5 is a diagram of a surface pressure time history, according to embodiments of the invention;

FIG. 6 is an illustration of increasing surface contact fatigue, according to embodiments of the invention; and

FIG. 7A is a graph illustrating different lubrication regimes, according to embodiments of the invention;

FIG. 7B is a graph illustrating the flow of lubricant between solid and lubricated regions, according to embodiments of the invention;

FIG. 8 is a depiction of sample mechanical components according to embodiments of the invention; and

FIG. 9 is a flowchart of a method of determining surface contact fatigue, according to embodiments of the invention.

It will be appreciated that for simplicity and clarity of illustration, elements shown in the figures have not necessarily been drawn to scale. For example, the dimensions of some of the elements may be exaggerated relative to other elements for clarity. Further, where considered appropriate, reference numerals may be repeated among the figures to indicate corresponding or analogous elements.

DETAILED DESCRIPTION OF THE PRESENT INVENTION

In the following detailed description, numerous specific details are set forth in order to provide a thorough understanding of the invention. It will however be understood by those skilled in the art that the present invention may be practiced without these specific details. In other instances, well-known methods, procedures, and components have not been described in detail so as not to obscure the present invention.

Unless specifically stated otherwise, as apparent from the following discussions, it is appreciated that throughout the specification discussions utilizing terms such as "processing," "computing," "storing," "determining," "evaluating," "calculating," "measuring," "providing," "transferring," or the like, refer to the action and/or processes of a computer or computing system, or similar electronic computing device, that manipulates and/or transforms data represented as physical, such as electronic, quantities within the computing system's registers and/or memories into other data similarly represented as physical quantities within the computing system's memories, registers or other such information storage, transmission or display devices.

Embodiments of the present invention may include a system and method for predicting the surface fatigue life of mechanical components such as power transmission components. Surface contact fatigue may be a process by which the active, load transmitting contact surfaces in power transmission components such as bearings, gears, and/or other components degrade over time. Components such as bearings, gears, and/or other components may, for example, degrade over time due to the formation of microscopic cracks, which grow under continued usage. When used herein, power transmission components may generally transmit mechanical power, or perform in mechanical machines or engines, for example. Such mechanical machines may be, for example, wind turbines generating electricity, electrical generating equipment, or other machines.

Embodiments of the present invention may provide accurate, physics-based prediction of surface fatigue life

the way that the nodes are connected to each other. Once accumulated damage may be calculated or determined, by using Eq. 4 for example, the method may determine whether a damage or failure threshold is met or exceeded by the calculated damage. The failure criteria may be defined in many ways, for example, the liberation of some quantity of debris particles from the active surface or based on the number of microcracks initiated in the grain, or other criteria.

If a damage threshold is not met or exceeded, the modified finite element mesh 136 may then be used to reevaluate the stresses in the microstructure through another loading cycle or event, since the presence of microcrack(s) may change the stress field in the grain structure by introducing discontinuities and stress risers. In some embodiments, if the threshold is not met or exceeded, steps or operations such as 120, 122, 124, 126, 130, 132, 134, and 136 may be repeated. Microcracks that have initiated in the grain structure are free to join/coalesce and grow in response to the applied surface tractions under successive loading cycles. This process of stress evaluation 120, followed by damage accumulation and mesh modification 130, is continued until a predefined failure threshold 140 is reached. Once the damage and/or debris level meets or exceeds the threshold, the method may output 142 the number of load cycles or events run by the method. The number of load cycles or events may be output to a monitor (42 in FIG. 1, for example) that is read by a user, or the number of load cycles may be output to a memory (32 in FIG. 1). The number of load cycles required to reach or exceed this threshold may be calculated as the sum of $N_{sub.S,Min.sup.i}$ for all stages, and is recorded as the component surface fatigue life.

.times..times..times. ##EQU00004##

Embodiments of the method for surface contact fatigue described herein are suitable for applications such as rolling contact fatigue and fretting fatigue that are manifest in a wide variety of ways depending on the severity of the contact stress and tangential shear. Further, the embodiments can be extended to predict the initiation and short crack growth phases of more traditional bending fatigue (e.g. gear tooth bending) with no additional effort.

FIG. 3 is an example of a random microstructure instance 102 (see FIG. 2) generated using a Voronoi tessellation, according to embodiments of the invention. Nucleation points 300 may be randomly determined according to the atomic structure or manufacture of the component or object (e.g. a power transmission component). For example, the density of nucleation points 300 may be determined based on the material properties of the component, and a Voronoi tessellation may create a random distribution of points while maintaining the proper density of nucleation points 300. Based on the nucleation points 300, grain boundaries 302 may be determined. Grain boundaries 302 may define the grain structure for any crystalline or polycrystalline material. The boundaries 302 may surround a region of steady thermodynamic phase change. The grain of each region may differ in orientation and the grain boundaries may separate each grain. For a Voronoi tessellation, the boundaries 302 may be the midpoint between any two nucleation points 300. For other tessellations, other kinds of boundaries may be generated. Intersections between grain boundaries 304 may be represented by nodes in a data structure describing the random microstructure instance or finite element model. The nodes 304 may be related to other nodes, depending on whether a grain boundary 302 is shared between nodes 304.

FIG. 4 is an example of a random microstructure instance 102 generated using Voronoi tessellation and meshed with a triangular element. The random microstructure instance may be generated using a Voronoi tessellation, and may be further discretized into smaller finite elements 402 to provide a finite element model, for example. The finite elements 402 may be triangular, as shown, or may be another convex polygon, such as a rhombus or trapezoid. Avoiding the geometric centroid in the triangular elements may increase accuracy in a finite element solution. Boundary intersections 304 may be represented as nodes in a data structure, and the relationship between nodes may reflect the smaller finite elements 402 in the mesh. In both FIGS. 3 and 4, algebraic equations may also describe the elastic or plastic forces present between nodes.

FIG. 5 is a diagram of a surface pressure time history, according to embodiments of the invention. A load event or cycle may be divided into time periods 501-506, which comprise a time history. Length.times.500, in .mu.m or nm, for example, may be the distance that a load travels over a component. As a load moves across a

other embodiments; thus, certain embodiments may be combinations of features of multiple embodiments. The foregoing description of the embodiments of the invention has been presented for the purposes of illustration and description. It is not intended to be exhaustive or to limit the invention to the precise form disclosed. It should be appreciated by persons skilled in the art that many modifications, variations, substitutions, changes, and equivalents are possible in light of the above teaching. It is, therefore, to be understood that the appended claims are intended to cover all such modifications and changes as fall within the true spirit of the invention.

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