Title: LOW COEFFICIENT OF FRICTION, WEAR RESISTANT COATING FOR STEAM TURBINE BLADE CONTACT AREAS

Abstract: A coating material defined by a low coefficient of friction, wear resistant coating material is provided to the contacting surfaces of adjacent turbine blades in order to increase the vibration damping provided at the contacting surfaces. In particular, the coating material reduces the coefficient of friction at the adjacent contacting surfaces of snubber and/or shroud regions defined between turbine blades, where additional vibrational energy is absorbed by increased relative movement of the adjacent contacting surfaces. The coating material may be formed of a conventional wear resistant composition having an additive formed by a lubricating material.
LOW COEFFICIENT OF FRICTION, WEAR RESISTANT COATING FOR
STEAM TURBINE BLADE CONTACT AREAS

FIELD OF THE INVENTION
The present invention relates generally to a method of providing damping of
vibration for contacting surfaces, such as blades for steam turbine components and,
more particularly, to a wear resistant coating material having a low coefficient of
friction to increase the damping of vibration energy between contacting surfaces of
adjacent blades.

BACKGROUND OF THE INVENTION
A steam turbine is driven by steam flowing between rotor blades arranged
along the circumference of a rotor so as to form an annular blade arrangement, and
energy is transmitted from the steam to a rotor shaft through the rotor blades. As
the capacity of electric power plants increases, the volume of flow has increased
more and more and the operating conditions (e.g., operating temperature and
pressure) have become increasingly severe. More importantly, the rotor blades
have increased in size to harness more of the energy in the steam to improve
efficiency. A result of all the above is the increased stresses (such as thermal,
vibratory, bending, centrifugal, contact and torsional) the rotor blades are subjected
to.

In order to limit vibrational stresses in the blades, various structures may be
provided to the blades to form a cooperating structure between blades that serves to
dampen the vibrations generated during rotation of the rotor. For example, in a
known steam turbine blade construction, each turbine blade may be provided with
an outer shroud located at an outer edge of the blade and having front and rear
shroud contact surfaces. The front and rear shroud contact surfaces of adjacent
blades are normally separated by a small gap when the rotor in stationary, and move
into contact with each other as the rotor begins to rotate. In addition, mid-span
snubbers, such as cylindrical standoffs, may be provided extending from mid-span
locations on the blades for engagement with each other. Two mid-span snubbers
are located at the same height on either side of a blade with their respective contact
surfaces pointing opposite directions. The snubber contact surfaces on adjacent blades are separated by a small gap when the blades are stationary. However, when the blades rotate at full load and untwist under the effect of the centrifugal forces, snubber surfaces on adjacent blades come in contact with each other. The engagement between the blades at the front and rear shroud contact surfaces and at the snubber contact surfaces is primarily designed to improve the strength of the blades under the tremendous centrifugal forces. An unavoidable outcome of such an arrangement is the immense contact stresses at the snubber and shroud contact areas and the effect of vibration on these contacts. Such severe conditions of high contact stresses and vibrations of the order of 200 Hz lead to fretting wear and eventual distress of snubbers and shroud via fatigue.

Typically a protective wear resistant coating is applied at the shroud and at the mid-span snubber contact surfaces to protect the engaging surfaces against abrasion as the surfaces rub against each other. The blades are usually forged and machined out of high strength steels or titanium alloys with a tungsten carbide/cobalt (WC/Co) wear resistant coating applied directly to the metal surface of the blades in the snubber and shroud contact areas. While such coatings provide excellent wear resistance, by virtue of their relatively higher coefficient of friction, they are unable to dissipate the vibrational energy at the contact surface, which can result in cracking of the coating and/or the snubber and shroud areas, and the blade has the potential to fracture and separate from the rotor, resulting in instability and turbine shutdown.

**SUMMARY OF THE INVENTION**

The present invention provides a wear resistant coating to contacting surfaces of adjacent turbine blades or turbine blade components that has a substantially reduced coefficient of friction. The reduced coefficient of friction improves better sliding of the contact surfaces thus damping more effectively the vibratory stresses to reduce the effects of vibrations transmitted through the turbine blades.

In accordance with one aspect of the invention, a method is provided for damping vibrations in a turbine having blades arranged around a rotor in a turbine circumferential direction, each of two or more of the blades having a respective
blade component, each the blade component having opposing front and rear contact surfaces with respect to a turbine rotational direction, the blade components being arranged in such a way that blade components of two adjacent blades are brought into contact with each other at adjacent front and rear contact surfaces during rotation. The method comprises the steps of providing a low coefficient of friction, wear resistant coating material, and applying the low coefficient of friction, wear resistant coating material to at least one of the adjacent contact surfaces, thereby increasing a damping of vibration energy between the adjacent front and rear contact surfaces when the blade components of the two adjacent blades contact each other.

In accordance with another aspect of the invention, a pair of contacting surfaces are provided in a turbine having blades arranged around a rotor in a turbine circumferential direction, each of two or more of the blades having a respective blade component, each the blade component having opposing front and rear contact surfaces with respect to a turbine rotational direction, the blade components being arranged in such a way that blade components of two adjacent blades are brought into contact with each other at adjacent front and rear contact surfaces during rotation. In addition, a low coefficient of friction, wear resistant coating material is provided to at least one of a pair of the adjacent front and rear contact surfaces to thereby increase a damping of vibration energy between the adjacent pair of contact surfaces during rotation of the rotor.

**BRIEF DESCRIPTION OF THE DRAWINGS**

While the specification concludes with claims particularly pointing out and distinctly claiming the present invention, it is believed that the present invention will be better understood from the following description in conjunction with the accompanying Drawing Figures, in which like reference numerals identify like elements, and wherein:

Fig. 1 is a perspective view of a portion of a turbine rotor assembly including a coating material in accordance with the present invention; and

Fig. 2 is a diagrammatic section view taken through a shroud portion of a turbine blade and illustrating the coating material.
DETAILED DESCRIPTION OF THE INVENTION

In the following detailed description of the preferred embodiment, reference is made to the accompanying drawings that form a part hereof, and in which is shown by way of illustration, and not by way of limitation, a specific preferred embodiment in which the invention may be practiced. It is to be understood that other embodiments may be utilized and that changes may be made without departing from the spirit and scope of the present invention.

The present invention provides a method for damping vibrations in the blades of a turbine. Referring to Fig. 1 a portion of a turbine rotor assembly is illustrated including the L-O row of turbine blades 10 comprising individual blades 12 mounted to a rotor 13, with each blade having a leading edge 14, a trailing edge 16, a center section 18 and an outside edge 20. The center section 18 of each blade 12 includes a front cylindrical standoff 22 and a rear cylindrical standoff 24, where the front and rear cylindrical standoffs 22, 24 define mid-span snubber members, and where "front" and "rear" are referenced with respect to a turbine rotational direction. The front and rear cylindrical standoffs 22, 24 each have a distal end defining respective standoff contact surfaces 26, 28. The standoff contact surfaces 26, 28 of adjacent front and rear cylindrical standoffs 22, 24 form a small gap defining a snubber region therebetween.

The outside edges 20 of each of the blades 12 includes a shroud portion 32, where each shroud portion 32 comprises a front end or contact surface 34 and an opposing rear end or contact surface 36. The front and rear contact surfaces 34, 36 of adjacent blades 12 define an interlocking Z-shroud region 38 comprising a small gap located between the contact surfaces 34, 36. When the turbine is in use, the adjacent front and rear contact surfaces 26, 28 of adjacent cylindrical standoffs 22, 24, and adjacent front and rear contact surfaces 34, 36 of adjacent shroud portions 32, may rub against each other as the blades 12 bend and twist during rotation of the rotor 13. In order to prevent or limit wear of the blade material, a wear resistant coating material is provided to the adjacent contact surfaces 26, 28 of the adjacent cylindrical standoffs 22, 24, as well as to the adjacent contact surfaces 34, 36 of the adjacent shroud portions 32. In the past, while currently known wear resistant
coating materials have provided adequate protection, blade components that have been subjected to severe conditions have been prone to cracking in the areas where adjacent surfaces contact each other. This cracking may be attributed, at least in part, to a high friction factor, i.e., a relatively high coefficient of friction, at the adjacent contacting surfaces that are designed to provide vibration damping. In particular, this effect has been observed when a preferred wear resistant coating material of tungsten carbide/cobalt has been used to prevent premature wear of the contact areas. As is described further below, the present invention provides the turbine blade snubber and shroud regions 30, 38 with a low coefficient of friction, wear resistant coating material, hereinafter referred to as "coating material 40", that comprises a wear resistant composition provided with an additive, or additives, to alter the friction characteristics of the wear resistant composition, resulting in a coating material 40 that effectively increases the damping of vibrations in the blades.

Referring further to Fig. 2, the blades 12 are preferably formed of a titanium alloy material, although other materials may be used and it should be understood that the present invention is not limited to any particular blade material. For the purpose of the present description, the rear contact surface 36 of a shroud portion 32 is referenced in Fig. 2, it being understood that the description of the invention is equally applicable to the other contact surfaces 26, 28 and 34. The surface 36 is shown with a coating comprising the coating material 40 applied directly to the surface 36. The coating material 40 preferably comprises a wear resistant composition 42 that may be a known wear resistant material for application to turbine blades such as, for example, a compound comprising tungsten carbide/cobalt that is currently applied to blade surfaces to provide a wear resistant contact surface. Other wear resistant compositions 42 may also be used in the present invention including, without limitation, chrome carbides, oxides, hard metals, intermetallics, etc. Such a wear resistant composition 42 typically provides a wear resistant coating that is harder than the substrate material of the blade 12.

The coating material 40 further includes an additive comprising a lubricating material 44. The lubricating material is mixed with the compound comprising the wear resistant composition 42 to provide a coating material 40 that may be a
compound or a mixture and, more particularly, may be a compound/element mixture, a compound/compound mixture or may comprise another compound. It should be noted that the coating material 40 shown in Fig. 2 is presented by way of illustration for the present explanation of the invention and is not intended be construed as limiting to the particular structure or the material comprising the coating material 40. Lubricating materials 44 that may provide desirable lubricating or friction reducing characteristics to the wear resistant composition 42 include, without limitation, graphite, sulfur, free carbon, silver, a metal bonded chromium oxide composite containing metal fluoride (e.g. PS300 as described in U.S. Patent No. 5,866,518, which patent is incorporated herein by reference), a high temperature polymer such as polytetrafluoroethylene (sold by E.I. Du Pont de Nemours and Co. under the product designation "TEFLON®"), or molybdenum. The lubricating material 44 provided as an additive to the wear resistant composition 42 may contain at least one, i.e., one or more, of the aforementioned materials, or other equivalent materials. Further, the lubricating material 44 may comprise a combination of the above materials or other materials, such as in the form of a compound containing at least one of the aforementioned materials, for use as an additive to the wear resistant material 42.

The coating material 40 may be applied to the adjacent contact surfaces 26, 28 and 34, 36 by spraying a mixture of the wear resistant composition 42 and the lubricating material 44 directly onto the adjacent contact surfaces 26, 28 and 34, 36. The spraying process may comprise a thermal spray process, as is well known in the art. Alternatively, the spraying process may comprise a cold spray process, such as the cold spray process for applying a wear resistant coating to turbine blades disclosed in U.S. Patent No. 6,780,458, which patent is incorporated herein by reference. The coating material 40 may also be applied by electroplating or by any other process for applying a coating to a substrate. The thickness of the applied coating is preferably within a range of approximately 0.005 inch to 0.010 inch (0.0127cm to 0.0254cm).

By way of example, a coating material 40 in accordance with the present invention may comprise a tungsten carbide/cobalt wear resistant composition 42, i.e., base material, and at least one of the aforementioned lubricating materials 44,
where the lubricating material 44 is preferably provided in an amount of from about 0.25% to about 30% by weight, based on the total weight of the coating material 40, and most preferably, the lubricating material 44 is provided in an amount of from about 0.25% to about 6% by weight, based on the total weight of the coating material 40. Generally, the weight percentages of tungsten, carbide, cobalt and the lubricating material 44 may all be varied within given ranges for each component to make up the total weight of the coating material 40, i.e., to comprise 100% of the component materials. More specifically, in a particular example of a preferred embodiment, the coating material 40 may comprise tungsten in an amount of from about 70% to about 90% by weight, carbon in an amount of from about 2% to about 4%, cobalt in an amount of from about 5% to about 20% by weight and the lubricating material 44 in an amount of from about 0.25% to about 30% by weight, based on the total weight of the coating material 40, where the coating material 40 may comprise at least one of the aforementioned lubricating materials 44 or an equivalent material. Further, in a most preferred embodiment, the coating material 40 may comprise tungsten in an amount of from about 78% to about 84% by weight, carbon in an amount of from about 2% to about 4%, cobalt in an amount of from about 13% to about 17% by weight and the lubricating material 44 in an amount of from about 0.25% to about 6% by weight, based on the total weight of the coating material 40. It should be noted that in the above-described coating materials 40 the carbon combines with the tungsten to form tungsten carbide.

It should be noted that in the above example the percentage by weight of the tungsten carbide may be balanced against the percentage by weight of the lubricating material 44, based on the total weight of the coating material 40.

Typically, the lubricating material 44 exhibits less wear resistance than the tungsten carbide, and it is therefore generally preferable to incorporate a lower percentage of the lubricating material into the coating material 40 and, additionally, to select a lubricating material with harder or more wear resistant properties which will minimize any decrease in the hardness or durability provided by the base material comprising the wear resistant composition 42. Accordingly, a low coefficient of friction, wear resistant coating 40 in accordance with the present invention provides an additive or lubricating material 44 that lowers the coefficient of friction of the wear resistant
composition 42 to increase the clamping properties at the adjacent contact surfaces 26, 28 and 34, 36, while also continuing to provide wear resistant characteristics that do not substantially alter those of the base material, i.e., the wear resistant composition 42.

In a preferred embodiment, providing the additive lubricating material 44 to the wear resistant composition 42 provides a decrease in the coefficient of friction between the pairs of adjacent contact surfaces 26, 28 and 34, 36 by approximately 30-70% relative to the coefficient of friction provided by the base wear resistant composition 42.

Generally, the current application of the coating material 40 is particularly useful where the adjacent turbine blade contact surfaces 26, 28 and 34, 36 vibrate under high frequencies, i.e., on the order of 200 Hz, and amplitudes of a few microns. The reduction of the coefficient of friction permits relative movement between the adjacent turbine blade contact surfaces 26, 28 and 34, 36, facilitating conversion of the vibratory energy into another form of energy, such as heat energy, at the contact surfaces. Further, the coating material 40 comprises a material that is essentially self lubricating and which substantially retains its low coefficient of friction properties as wear of the coating material 40 occurs.

It should be understand that, although the present invention has been described with particular reference to application of a low coefficient of friction, wear resistant coating to contacting surfaces of steam turbine blades, the invention is equally applicable to other contacting surfaces that are subject to vibration. For example, the invention may be applied to contacting blade surfaces within other rotating machines including gas turbines, aviation turbines, compressors and fans.

While particular embodiments of the present invention have been illustrated and described, it would be obvious to those skilled in the art that various other changes and modifications can be made without departing from the spirit and scope of the invention. It is therefore intended to cover in the appended claims all such changes and modifications that are within the scope of this invention.
What is claimed is:

1. A method for damping vibrations in a turbine having blades arranged around a rotor in a turbine circumferential direction, each of two or more of said blades having a respective blade component, each said blade component having opposing front and rear contact surfaces with respect to a turbine rotational direction, said blade components being arranged in such a way that blade components of two adjacent blades are brought into contact with each other at adjacent front and rear contact surfaces during rotation, said method comprising:
   - providing a low coefficient of friction, wear resistant coating material; and
   - applying said low coefficient of friction, wear resistant coating material to at least one of said adjacent contact surfaces, thereby increasing a damping of vibration energy between said adjacent front and rear contact surfaces when said blade components of said two adjacent blades contact each other.

2. The method of claim 1, wherein said low coefficient of friction, wear resistant coating material has a hardness greater than the hardness of said at least one contact surface.

3. The method of claim 1, wherein said low coefficient of friction, wear resistant coating material comprises a compound or a mixture including a wear resistant composition and a lubricating material.

4. The method of claim 3, wherein said step of applying said low coefficient of friction, wear resistant coating material comprises spraying a mixture comprising said wear resistant composition and said lubricating material onto said at least one contact surface.

5. The method of claim 3, wherein said low coefficient of friction, wear resistant coating material comprises a lubricating material in an amount of from about 0.25%
to about 30% by weight, based on the total weight of said low coefficient of friction, wear resistant material.

6. The method of claim 3, wherein said wear resistant composition comprises tungsten carbide/cobalt.

7. The method of claim 6, wherein said low coefficient of friction, wear resistant coating material comprises tungsten in an amount of from about 70% to about 90% by weight, carbon in an amount of from about 2% to about 4%, cobalt in an amount of from about 5% to about 20% by weight and the lubricating material in an amount of from about 0.25% to about 30% by weight, based on the total weight of said low coefficient of friction, wear resistant coating material.

8. The method of claim 3, wherein said lubricating material comprises at least one of polytetrafluoroethylene, molybdenum, graphite, sulfur, free carbon, silver, or a metal bonded chromium oxide composite containing metal fluoride.

9. The method of claim 1, wherein each of said two or more blades include a shroud portion formed integrally therewith at a radially outer end thereof, said shroud portions being arranged in such a way that shroud portions of adjacent blades are brought into contact with each other at adjacent shroud contact surfaces to define said adjacent contact surfaces, said low coefficient of friction, wear resistant coating material being provided to at least one of said adjacent shroud contact surfaces, thereby increasing a damping of vibration energy between said adjacent shroud contact surfaces when said shroud portions of two adjacent blades contact each other.

10. The method of claim 9, wherein said each of two of or more blades include a mid-span snubber, said mid-span snubbers being arranged in such a way that mid-span snubbers of two adjacent blades are brought into contact with each other at adjacent snubber contact surfaces during rotation to define further adjacent contact surfaces, said low coefficient of friction, wear resistant coating material being
provided to at least one of said adjacent mid-span snubber contact surfaces, thereby increasing a damping of vibration energy between said adjacent mid-span snubber contact surfaces when said mid-span snubbers of two adjacent blades contact each other.

11. The method of claim 1, wherein said each of two of or more blades include a mid-span snubber, said mid-span snubbers being arranged in such a way that mid-span snubbers of two adjacent blades are brought into contact with each other at adjacent snubber contact surfaces during rotation to define said adjacent contact surfaces, said low coefficient of friction, wear resistant coating material being provided to at least one of said adjacent mid-span snubber contact surfaces, thereby increasing a damping of vibration energy between said adjacent mid-span snubber contact surfaces when said mid-span snubbers of two adjacent blades contact each other.

12. A pair of contacting surfaces in a turbine having blades arranged around a rotor in a turbine circumferential direction, each of two or more of said blades having a respective blade component, each said blade component having opposing front and rear contact surfaces with respect to a turbine rotational direction, said blade components being arranged in such a way that blade components of two adjacent blades are brought into contact with each other at adjacent front and rear contact surfaces during rotation, and a low coefficient of friction, wear resistant coating material provided to at least one of a pair of said adjacent front and rear shroud contact surfaces and said adjacent mid-span snubber contact surfaces to thereby increase a damping of vibration energy between said adjacent pair of contact surfaces during rotation of said rotor.

13. The pair of contact surfaces of claim 12, wherein said low coefficient of friction, wear resistant coating material decreases the coefficient of friction between said pair of contact surfaces by approximately 30-70% relative to said wear resistant composition without said lubricating material.
14. The pair of contact surfaces of claim 12, wherein said low coefficient of friction, wear resistant coating material comprises a compound or mixture including a wear resistant composition and a lubricating material.

15. The pair of contact surfaces of claim 14, wherein said low coefficient of friction, wear resistant coating material comprises a lubricating material in an amount of from about 0.25% to about 30% by weight, based on the total weight of said low coefficient of friction, wear resistant material.

16. The pair of contact surfaces of claim 14, wherein said lubricating material comprises at least one of polytetrafluoroethylene, molybdenum, graphite, sulfur, free carbon, silver, or a metal bonded chromium oxide composite containing metal fluoride.

17. The pair of contact surfaces of claim 14, wherein said wear resistant composition comprises tungsten carbide/cobalt.

18. The pair of contact surfaces of claim 17, wherein said low coefficient of friction, wear resistant coating material comprises tungsten in an amount of from about 70% to about 90% by weight, carbon in an amount of from about 2% to about 4%, cobalt in an amount of from about 5% to about 20% by weight and the lubricating material 44 in an amount of from about 0.25% to about 30% by weight, based on the total weight of said low coefficient of friction, wear resistant coating material.

19. The pair of contact surfaces of claim 12, wherein each of said two or more blades include a shroud portion formed integrally therewith at a radially outer end thereof, said shroud portions being arranged in such a way that shroud portions of adjacent blades are brought into contact with each other at adjacent shroud contact surfaces to define said adjacent contact surfaces, said low coefficient of friction, wear resistant coating material being provided to at least one of said adjacent shroud contact surfaces, thereby increasing a damping of vibration energy between
said adjacent shroud contact surfaces when said shroud portions of two adjacent blades contact each other.

20. The pair of contact surfaces of claim 12, wherein said each of two of or more blades include a mid-span snubber, said mid-span snubbers being arranged in such a way that mid-span snubbers of two adjacent blades are brought into contact with each other at adjacent snubber contact surfaces during rotation to define said adjacent contact surfaces, said low coefficient of friction, wear resistant coating material being provided to at least one of said adjacent mid-span snubber contact surfaces, thereby increasing a damping of vibration energy between said adjacent mid-span snubber contact surfaces when said mid-span snubbers of two adjacent blades contact each other.