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(54) IMPROVEMENTS IN CONTAMINATION REMOVAL METHOD

(71) We, GENERAL ELECTRIC COMPANY, a corporation organized and existing under the laws of the State of New York, United States of America, residing at 1, River Road, Schenectady, 12305, State of New York, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:–

This invention relates to a method of removing contaminants from the surface of an article and, more particularly, a method of removing contaminants from the internal components of an air-breathing machine such as an aircraft gas turbine engine. The invention finds specific application in the removal of contaminants from vanes and blades associated with the compressor of an aircraft gas turbine engine of the high by-pass fan type.

In a high by-pass fan type gas turbine, a compressor supplies air under pressure to a combustion chamber in which fuel is mixed with the pressurized air and the mixture burned. The hot products of combustion are passed sequentially through a pair of turbines, the first of which extracts kinetic energy from the expanding hot gases to power the compressor and the second of which extracts additional kinetic energy from the hot gases to power a fan adapted to generate the major portion of the thrust associated with the engine. After passing through the second turbine the hot gases are expelled from the engine, thereby generating the remaining portion of the thrust associated with the engine.

The overall efficiency of the gas turbine engie is heavily dependent upon the efficiency of the compressor. The pressure ratio of the compressor, that is to say the ratio of air pressure at the compressor outlet to air pressure at compressor inlet, is one of the significant parameters which determines the operating efficiency of the compressor. The higher the pressure ratio at a given compressor rotational speed, the greater the efficiency. The higher the air pressure at the outlet of the compressor, the greater the energy available to drive the turbines downstream of the compressor and hence to provide thrust generation by the engine.

In axial flow compressors, pressurization of air is accomplished in a multiplicity of compressor stages or sections, each stage being comprised of a rotating multi-bladed rotor and a nonrotating multi-vaned stator. Within each stage the airflow is accelerated by the rotor blades and decelerated by the stator vanes with a resulting rise in pressure. Each blade and vane has a precisely defined airfoil surface configuration or shape whereby the air flowing over the blade or vane is accelerated or decelerated respectively. The degree of air pressurization achieved across each blade-vane stage is directly and significantly related to the aforementioned precise airfoil surface shape.

It has been found that, in service, the surfaces of the compressor blades and vanes become coated with contaminants of various types. Oil and dirt from airfield runways have been found adhered to the blade and vane surfaces. Aluminum and other metal substances erode from the other portions, such as clearance seals, of the engine and are depositedon the blades and vanes. These surface contaminants alter the above-mentioned precise airfoil surface shape, disturbing the desired airflow over the blades and vanes and cause reduced pressure rises across the various compressor stages and hence a drop in compressor efficiency. Typically, the drop in efficiency results in reduced thrust output for a given engine speed. While thrust levels can be maintained by operating the engine at overspeed conditions, such operation results in increased engine maintenance and reduced engine life.

Removal of the aforedescribed contaminants from blades and vanes of in-service compressors is desirable to restore compressor and engine efficiency. Since it is both time-consuming and expensive to disassemble the engine from the aircraft and thence the compressor from the engine, it is also desirable to remove the aforedescribed contaminants while the engine is on-wing. Furthermore, any method utilized to remove the contaminants must not interfere with the structural or metallurgical integrity of other components of the engine. By way of example, an acceptable method must remove aluminum contaminants adhering to the blades and vanes of the compressor without deleteriously affecting other aluminum components of the engine. In this regard, it is known in the art that contaminants can be removed from the internal components of a gas turbine engine by ingesting, into the engine inlet at idle speed, substances generally characterized as liquid solvents. However, liquid solvents, because of their dispersive characteristics, chemically attach not only the contaminants but also other portions of the engine which are made of the same material as the contaminants. Hence, where contamination of the vanes and blades has resulted from material erosion of other engine components, the ingestion of liquid solvents into the engine has not proven to be an acceptable method of removing the contaminants.

Another known method of removing contaminants from the internal components of a gas turbine engine utilizes solid particle abrasives which are ingested into the engine at idle speeds. The abrasive particles impinge upon the contaminated surfaces dislodging the contaminants. However, materials used in the prior art as abrasives have proven to be unsatisfactory. More particularly, these abrasives have been found to be overly abrasive such that they not only dislodge the contaminants but also destroy the surface smoothness of the blade or vane. Furthermore, it is generally accepted that while most of the abrasive material will be ejected from the engine through the exhaust some of the abrasive will remain in the engine. Prior art abrasives have either been noncombustible in which case the particles clog cooling holes of the turbine components and restrict needed cooling air flow or the abrasives are combustible but leave residue deposits which also clog turbine component cooling holes.

The present invention seeks to overcome these problems by providing a method of removing contaminants from the surface of a metallic article, wherein abrasive particles are caused to impinge upon the contaminated surface and to remove the contaminants therefrom, the abrasive particles comprising a material which, when heated, reacts with oxygen to form predominantly gaseous products of reaction. Advantageously, the abrasive particles are formed from coke.

After the abrasive particles have been used to decontaminate the contaminated surface they may be subjected to heating in the presence of oxygen. The particles form predominately gaseous products of reaction and leave minimal residue. This feature renders the invention of particular utility in connection with the decontamination of the internal components of an air-breathing machine, for example a gas compressor associated therewith, wherein there is a hot section of the machine downstream from the location of the components to be decontaminated and in which hot section the particles may be combusted.

According to another aspect of the invention therefore, there is provided a method of removing contaminants from the internal metallic components of a gas turbine engine having, disposed in a serial flow relationship in a fluid flow passage in said engine, an air inlet for admitting air to said engine, a rotatable compressor, a combustor, a rotatable turbine, and a hot gas exhaust, said method comprising entraining abrasive particles in a stream of air flowing in said passage upstream of said contaminated components, said particles being comprised of coke whereby the particles react with oxygen to form predominately gaseous products of reaction when heated; and directing said stream of air and said entrained parricles in impingement on said contaminated components thereby removing the contaminants therefrom. We have found that abrasive particles formed from a material having a carbon content of at least 70% by weight and particularly in the form of coke is especially suitable for carrying out the invention. A more preferred carbon content is in the range of 75% to 98% by weight and more especially above 80% by weight. Desirably, the particles have an erosivity within the range of 0.004 grams to 0.15 grams and have had at least some volatile material removed therefrom. According to a further aspect of the invention there is provided a method of removing contaminants from the internal components of a compressor associated with a gas turbine engine said method comprising the steps of providing abrasive particles comprised of a material having a carbon content of at least 70% by weight, erosivity within the range of 0.004 grams to 0.15 grams and which has undergone a distillation-type process wherein at least some volatile matter has been removed therefrom, whereby the particles react with oxygen to form predominantly gaseous products of reaction when heated; and directing said particles in impingement upon said contaminated internal components of said engine to thereby remove said contaminants therefrom.

Still further aspects of the invention are set out in the appended claims.

The invention will now be described in greater detail, but by way of example only, with reference to the accompanying drawing, which is a schematic cross-sectional drawing of a gas turbine engine in which the method of the present invention is utilized.

Referring now to the Figure, a schematic view depicting an air-breathing gas turbine engine is shown generally at 30 for the purpose of illustrating an application of the novel method comprising the present invention. Engine 30 is comprised of inlet 32, fan 34, booster 36, compressor 38, combustor 40, high pressure turbine 42, low pressure turbine 44 and exhaust 46 arranged in a serial flow relationship. Fan 34 is surrounded by circumferentially and axially extending fan shroud 48 while booster 36, compressor 38, combustor 40, high pressure turbine 42, low pressure turbine 44 and exhaust 46 are enclosed in circumferentially and axially extending engine cowl 50. Fan shroud 48 is disposed so as to overlap the upstream end of engine cowl 50 forming, in cooperation therewith, an annular by-pass duct 54 through which air propelled by fan 34 is exhausted. An annular flowpath 56 is provided radially inward of by-pass duct 54 and extends the axial length of engine 30. Booster 36, compressor 38, combustor 40, high pressure turbine 42, low pressure turbine 44 and exhaust 46 are each disposed sequentially within flowpath 56.

Fan 34 and booster 36 are driven by low pressure turbine 44 through shaft 58 which extends forward from the aft-located low pressure turbine. Compressor 38 is powered by high pressure turbine 42 through hollow drive shaft 60 disposed coaxially and concentrically with drive shaft 58. Ambient air drawn into inlet 32 is propelled aftward by fan 34. A portion of the air is propelled through by-pass duct 54 to provide the majority of the thrust generated by engine 30. The remaining air enters annular flowpath 56 where it is initially pressurized by booster 36, further pressurized by compressor 38 an and mixed with fuel and burned in combustor 40. The hot gases resulting from the combustion process are expelled from the combustor 40 through high pressure turbine 42 which extracts kinetic energy from the hot gases. Energy extracted by the high pressure turbine is utilized to drive the compressor 38. The hot gases of combustion are then received by the low pressure turbine whereby additional energy is extracted for powering fan 34 and booster 36. The hot gases are thence expelled from the engine through exhaust 46 whereby the kinetic energy remaining therein provides further thrust generation by engine 30.

Compressor 38 is comprised of a series of stages disposed axially adjacent with respect to each other. Each stage is comprised of a plurality of circumferentially disposed stationary stator vanes 62 affixed to the compressor housing positioned axially adjacent to a plurality of circumferentially disposed rotating rotor blades 64 rigidly connected to rotating drive shaft 60. Stator vanes 62 and rotor blades 64 have precisely defined airfoil surface configurations or shapes which impart kinetic energy to the airflow through the compressor. Airfoil surface shape is critical in achieving optimal pressurization of the air. If the airfoil surface shape is not aerodynamically efficient, the air flowing over the airfoil surfaces will not be accelerated nor pressurized to the degree necessary for optimum compressor efficiency. In service, contaminants, which either enter the engine from the environment or are present as products of erosion from engine components, can adhere to the compressor stator vanes 62 and rotor blades 64. These contaminants alter the aerodynamic characteristics of the airfoil surfaces and result in reduced compressor efficiency.

To remove contaminants from the airfoil surfaces of the vanes 62 and blades 64, kinetic energy is imparted to solid abrasive particles and directing the particles in impingement onto the contaminated surface whereby the contaminants are dislodged. Referring again to the Figure, a jet nozzle 68 is disposed in near proximity to engine inlet 32 and discharges abrasive particles 66 into the airstream flowing through inlet 32 while the engine is operating under idle conditions. Particles 68 are entrained in the airstream and are propelled by fan 34 in the aft direction. While some of the abrasive particles are ejected from the engine through by-pass duct 54, the remaining particles enter flow passage 56. As the airstream flows in the aft direction, the particles 66 entrained therein impinge directly upon the vanes and blades in successive stages of the compressor 38 dislodging contaminants adhered thereto. It should be noted that the velocity of the air flowing through passage 56 is quite substantial such that particles 66 striking the airfoil surfaces have substantial kinetic energy. While some kinetic energy will be lost by the particles as a result of the collision with the airfoil surface and as a result of performing net work in dislodging the contaminants, the moving airstream will quickly restore some, if not all, of the kinetic energy prior to collision of the particles 66 with the next successively adjacent downstream airfoil. Hence, the abrasive particles are effective to remove contaminants not only from the airfoils disposed at the upstream end of the compressor but also those disposed at the downstream end.

Abrasives known in the prior art have not proven to be suitable for use in the removal fo contaminants associated with air-breathing gas turbine engines. The prior art abrasives are too hard resulting in pitting, scoring and other distortion of the airfoil surfaces. Furthermore, some of these abrasives burn in the hot sections of the engine and leave a residue which clogs cooling passages and otherwise interferes with the proper operation of the engine while others, which are noncombustible, lodge in the cooling holes of the turbine components of the engine and restrict needed cooling air flow.

The novel method of the present invention includes the use of materials which overcome these shortcomings. The present invention contemplates the use of abrasive particles comprised of a material which, if subjected to the temperature in the hot sections of the engine for a sufficient residence time, will oxidize and produce a product of reaction which is predominantly gaseous, rather than solid, leaving little or no undesirable residue. Consequently, the cooling holes of the turbine components of the engine remain free of residue and the necessary cooling operation can occur without impairment.

It has been discovered that materials comprised substantially of carbon will, when oxidized in the presence of sufficient oxygen, produce substantially a gaseous poduct, namely carbon dioxide, without producing a residue sufficient to clog the cooling holes of the turbine components. Materials comprised of carbon in amount above 70% by weight and preferably in the range of 75% to 98% by weight will not, if oxidized, leave residues in amounts sufficient to interfere with the operation of the internal component of a gas turbine engine. Furthermore, these materaials exhibit abrasive qualities particularly well adaptable for removal of contaminants from the internal components of gas turbine engines. Specifically, these materials exhibit erosivity levels within the range of 0.004 grams to 0.15 grams, as measured in a manner hereinafter to be described, and are suitable abrasives for use in the subject method.

Another feature of these types of carbon materials which prescribes their use is their fracture characteristics. Upon impact with the vanes and blades of the compressor some of the kinetic energy held by the carbon particles is dissipated through fracture of the particle. Furthermore, the carbon particle will fracture into a plurality of jagged pieces, each of which possess generally the same abrasive surface roughness characteristics as its parent. Since the abrasive characteristics of the particle are retained in each piece, removal of contamination from downstream vanes and blades is enhanced.

The aforementioned erosivity is a measurement of the abrasivity of the particles measured under carefully controlled conditions. Specifically, erosivity is the amount of material, expressed in grams, eroded from a titanium plate by impingement of a stream of abrasive particles thereon. The controlled conditions under which erosivity is measured are as follows. The abrasive particles are ejected from a .188 inch diameter nozzle which is pressurized by air at 40 p.s.i. and disposed at an angle of 15° with a target plate made of a titanium based alloy consisting, nominally by weight, of 6 Al, 2 Sn, 4 Zr, 2 Mo, with a balance essentially Ti, commercially known as Ti-6-2-4-2. The nozzle is disposed a distance of 4 inches from the plate as measured along the 15° angle. The target plate is 2 inches in length, 1 inch in width and .080 inches thick. The abrasive particles are ejected from the nozzle in impingement on the 2 square inch target surface for a period of 75 seconds. The difference between the weight of the target plate before and after impingement by the abrasive is defined as erosivity and is expressed in grams. The greater the weight difference (erosivity) the greater the abrasive characteristics of the abrasive.

By-product coke produced from distillation of coal or petroleum has been found to be a particularly suitable carbon material for use as an abrasive for application in the subject method. Typically, by-product coke will be comprised of approximately 80% to 95% carbon and less than 8% volatile matter and preferably within the range of 1% to 6% volatile matter. Volatile matter is those products which evolve in the presence of heat applied during decomposition of material. By way of example, in the carbonization of coal, the complex coal substance, in the presence of heat, is broken down causing the evolution of condensible tars and oils (volatile products) and leaving coke. The percent of volatiles remaining in the coke will depend upon the degree of carbonization of the coal, that is to say, the temperature applied to the coal. The greater the carbonization of the coal, the less volatile matter remaining in the coke and hence the less volatile material available to contaminate the internal components of the gas turbine engine when the coke is oxidized therein. The erosivity of by-product coke is approximately .044 grams as measured in accordance with the procedure previously described. Coke crushed to a particle size such that it will pass through a Size 6 Sieve on the U.S. Standard Screen Scale has been particularly effective for cleaning the internal components of a gas turbine engine.

Coke particles 66 ingested into the engine inlet 32 are entrained in the air flow stream and impinge upon the stator vanes 62 and rotor blades 64 of the first stage of the compressor 38. As a result of the collision, contamination is removed from the airfoils and the coke particles 66 fracture into similarly abrasive smaller pieces which then are carried by the air flow stream into impingement upon the blades 64 and vanes 62 of the next downstream stage of the compressor 38 removing contaminants therefrom. This sequence occurs at each successive downstream stage whereby all the blades 64 and vanes 62 of the compressor 38 are decontaminated.

The major portion of the coke particles 66 emerging from the compressor 38 is carried by the flowing air stream through the hot section of engine 30, sequentially comprised of combustor 40, high pressure turbine 42, low pressure turbine 44, and out of the engine 30 through the exhaust 46. The majority of the coke particles 66 will not burn in the hot section since the stream of air flows through the engine at a high velocity and therefore the residence time of the coke particles 66 in this section is insufficient for oxidation to occur. Some of the coke particles 66, however, will remain in the hot section of the engine 30 being deposited in various portions of the hot section as, by way of example, in cooling passages of the blades and vanes of turbines 42 and 44. Coke particles 66 remaining in the hot section of engine 30 are exposed to the high temperatures in the hot section and, in a short time, will accumulate a sufficient residence period in the hot section for oxidation of the particles to occur. The coke particles 66 will then completely oxidize producing, as a predominant product of reaction, carbon dioxide gas which is immediately carried out of the engine 30 by the air flow stream. The solid residue, if any, remaining will not be sufficient to interfere with cooling of the turbines 42 and 44 or with the operation of other components of engine 30.

By combining selected quantities of carbon particles of a number of specific mesh sizes, polishing the vanes and blades can be accomplished in addition to removal of the contaminants. The larger particles having larger mass and hence more momentum serve to dislodge the contaminants from the surface of the airfoil. The smaller fine particles serve to lightly smooth and polish the surface of the airfoil. Polishing alone may be accomplished only by ingesting particles in the smaller mesh ranges.

The method set forth in the claims is useful in removing any undesirable materials or condition from the surface of an article. Hence, it is understood that the word "contaminants" as used in the appended claims includes any material or condition which is undesirably disposed on or at the surface of the article.

WHAT WE CLAIM IS:

1. A method of removing contaminants from the surface of a metallic article, wherein abrasive particles are caused to impinge upon the contaminated surface and to remove the contaminants therefrom, the abrasive particles comprising a material which, when heated, reacts with oxygen to form predominantly gaseous products of reaction.

2. A method of removing contaminants from the surface of a metallic article, wherein abrasive particles are caused to impinge upon the contaminated surface and to remove the contaminants therefrom, the abrasive particles being particles of coke whereby the particles react with oxygen to form predominately gaseous products of reaction when heated.

3. A method of removing contaminants from the surfaces of internal components of a compressor associated with a gas turbine engine, wherein abrasive particles are directed into impingement upon the contaminated internal components of the compressor and remove the contaminants therefrom, the abrasive particles comprising a material which, when heated, react with oxygen to form predominately gaseous products of reaction.

4. A method as set forth in any preceding claim, wherein the particles are entrained in a fluid flow stream which is directed into the contaminated surface or surfaces to cause the particles to impinge thereon.

5. A method of removing contaminants from the internal metallic components of an air breathing machine having an air flow path adapted to provide for the passage of air through said machine with said contaminated internal metallic components disposed within said flow path, said method comprising entrained abrasive particles in a stream of air in said flow path upstream of said contaminated internal metallic components, said particles being comprised of coke whereby the particles react with oxygen to form predominately gaseous products of reaction when heated; and directing said stream of air and entrained particles in impingement upon said contaminated internal metallic components, thereby removing the contaminants therefrom.

6. A method of removing contaminants from the internal metallic components of a gas turbine engine having, disposed in a serial flow relationship in a fluid flow passage in said engine, an air inlet for admitting air to said engine, a rotatable compressor, a combustor, a rotatable turbine, and a hot gas exhaust, said method comprising entraining abrasive particles in a stream of air flowing in said passage upstream of said contaminated components, said particles being comprised of coke whereby the particles react with oxygen to form predominately gaseous products of reaction when heated; and directing said stream of air and said entrained particles in impingement on said contaminated components thereby removing the contaminants therefrom.

7. A method as set forth in Claim 6, wherein the particles are introduced into said gas turbine engine through said inlet.

8. A method as set forth in Claim 6 or Claim 7, wherein the stream of air and said entrained particles are directed to impinge upon contaminated blades and vanes associated with

the compressor.

9. A method as set forth in any of Claims 6 to 8, wherein the abrasive material reacts with oxygen to form predominately gaseous products of reaction when exposed to the heat generated in a hot section of said engine while said particles are therein.

10. A method as set forth in any preceding claim, wherein the abrasive particles have an erosivity within the range of 0.004 grams to 0.15 grams.

11. A method as set forth in any preceding claim, wherein the particles have a carbon content of at least 70% by weight.

12. A method of removing contaminants from the internal components of a compressor associated with a gas turbine engine, wherein abrasive particles are caused to impinge on the contaminated internal components, the abrasive particles having a erosivity within the range of 0.004 grams to 0.15 grams and a carbon content of at least 70% by weight, whereby the particles react with oxygen to form predominantly gaseous products of reaction when treated.

13. A method as set forth in any preceding claim, wherein the material from which the particles are formed has undergone a distillation-type process wherein at least some volatile matter has been removed therefrom.

14. A method of removing contaminants from the internal components of a compressor associated with a gas turbine engine said method comprising the steps of providing abrasive particles comprised of a material having a carbon content of at least 70% by weight, erosivity within the range of 0.004 grams to 0.15 grams and which has undergone a distillation-type process wherein at least some volatile matter has been removed therefrom, whereby the particles react with oxygen to form predominantly gaseous products of reaction when heated; and directing said of particles in impingement upon said contaminated internal components of said engine to thereby remove said contaminants therefrom.

15. A method as set forth in any of claims 13 to 15, wherein the particles are directed onto the contaminated surface by entraining the particles in the fluid flow stream which is directed onto the surfaces.

16. A method as set forth in any preceding claim, wherein the particles have a volatile matter contant of less than 8% by weight.

17. A method as set forth in any preceding claims, wherein the particles have a volatile matter content within the range of 1% to 6% by weight.

18. A method as claimed in any preceding claim, wherein the particles have a carbon content within the range of 75% to 98% by weight.

19. A method as claimed in any preceding claim, wherein the size of at least some of said particles is sufficiently small to permit passage thereof through a size 6 sieve in the U.S. standard screen scale.

20. A method as set forth in any preceding claim, wherein said particles are comprised of by-product coke produced during the distillation of petroleum products.

21. A method as set forth in any of claims 1 to 19, wherein the said particles are comprised of by-product coke produced during the distillation of coal.

22. A method as set forth in any of claims 1 to 19, wherein the said particles are comprised of by-product coke produced by carbonisation of coal.

23. A method substantially as hereinbefore described with reference to the accompanying drawings.

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1563581 COMPLETE SPECIFICATION

1 SHEET *This drawing is a reproduction of the Original on a reduced scale*