ELECTRIC POWER RESEARCH INSTITUTE

Guideline for Coating of the Compressor Section of Combustion Turbines in Power Generation Applications

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REPORT SUMMARY

For more than a decade, EPRI has been developing gas turbine hot section component repair and coating guidelines to assist utilities in the refurbishment of these critical and expensive parts. Utilities and repair vendors have used these guidelines to perform repairs on buckets (blades), turbine nozzles (vanes), combustion liners, and combustor transitions. The present guideline has been developed at the request of power producers to address the compressor section of the turbine.

Background

During the early 1990s, EPRI was instrumental in developing repair and coating guidelines for several gas turbine engines. Repair vendors and utilities assisted in the development of the first set of guidelines, which included the General Electric MS7001 Model B and early versions of the Westinghouse Model W501. Newer, more advanced machines have found their way into domestic and international fleets throughout the 1990s and into the 2000s, including General Electric MS6001 Model B, MS7001 Model E/EA, MS7001 Model F/FA, MS9001 Model E, and Siemens-Westinghouse Models W501 D4/D5 and W50lF. Similar refurbishment criteria are needed for the newer machines. The EPRI program is ongoing and is now focused on developing repair and coating guidelines to meet this need. Updated and new volumes of this report will be issued periodically as the guidelines are completed for each machine.

Objectives

- To assemble repair and coating guidelines that utilities can use for the refurbishment of hot section components, including buckets (blades), nozzles (vanes), combustion liners, combustor transitions, and compressor components
- To cover the minimum requirements for weld repair, heat treatment, damage and dimensional inspections, and quality assurance for gas turbine hot section components

Approach

Each of the repair guidelines have been assembled in a standard format that includes scope, definitions, applicable documents, general requirements, technical requirements, processing requirements, and quality requirements. The present guideline has been assembled to review: the history of compressor coatings, the types of coatings employed, the benefits of those coatings, details of aluminum-ceramic coating processing, anti-fouling and erosion resistant aluminum-ceramic variations, and discuss current applications.

Results

A comprehensive, multiple-volume set of repair and coating guidelines is being developed for utilities to employ for hot and cooler section component repairs. The set comprises the following:

Volume 1: GE MS7001 Model B

Volume 2: GE MS6001 Model B

Volume 3: GE MS7001 Model F/FA

Volume 4: GE MS7001 Model E/EA

Volume 5: Westinghouse Models W501 A through D

Volume 6: Westinghouse 501F

Volume 7: Coatings

Volume 8: GE MS9001 Model E

Volume 9: Siemens V84.2

Volume 10: Compressor Guidelines

The entire multiple-volume set is now available for utilities and independent power producers to employ for hot section component repairs.

EPRI Perspective

Gas turbine owners/operators are encouraged to use these guidelines for compressor section component repair and refurbishment. This review provides detailed information on processing of aluminum-ceramic compressor coatings and for processing of anti-fouling and erosion-resistant aluminum ceramic coating variations. With this information, power producers will be able to work with coating vendors to specific processing conditions for today's advanced compressor sections.

Keywords

Combustion turbines
Combustion turbine O&M
Combustion turbine repair
Compressor
Compressor coatings

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1
BRIEF HISTORY OF COMPRESSOR COATINGS

The dimensional and mechanical integrity of the compressor airfoils of a power generation gas turbine play a critical role in the performance and availability of the system as a whole. Due to a variety of mechanisms serving to deteriorate the surface condition of these airfoils, significant losses in compressor efficiency can rapidly occur as a result of increased aerodynamic drag. Efficiency losses exceeding 3% are not unusual or unexpected. If left unchecked, these damage mechanisms can ultimately compromise mechanical strength, which can then potentially lead to catastrophic failure. Industry-wide estimates indicate that catastrophic compressor blade failures account for approximately 20% of the total damage occurring in industrial gas turbines. This is not necessarily surprising, given that the failure of a single rotating compressor blade can result in substantial subsequent or downstream damage.

The primary mechanisms causing compressor airfoil surface deterioration are corrosion/oxidation, wear/erosion and roughness/fouling. Given the relatively corrosive/erosive operating environment of a modern industrial gas turbine compressor section, and the predominant usage of simple 12-chromium stainless steels as materials of construction for the airfoils, it became clear in the early stages of gas turbine design evolution that the use of coatings could maximize component life and compressor efficiency.

In the 1950's, the first compressor coating to see widespread use was a diffused nickel cadmium (Ni-Cd) system applied by electroplating. Ni-Cd plating remained the most popular compressor coating system up until the end of the 1970's. To apply the coating, a layer of nickel is first electrolytically deposited followed by a layer of cadmium. The cadmium is then subsequently diffused into the nickel by thermal exposure. Given its favorable performance and the relatively low cost of application, the system remained in widespread use until environmental concerns arose in the 1980's. These concerns eventually translated into Occupational Safety and Health Administration (OSHA) and Environmental Protection Agency (EPA) regulations involving heavy metals such as cadmium, which essentially ended the use of Ni-Cd systems in the early 1990's.

In the 1960's, two alternative coating systems were developed and implemented, primarily in aviation gas turbines: low temperature pack aluminides and metallic-ceramic coatings. Pack aluminides found wide usage in the 1960's on military turbine compressor vanes, stators and blades. In the pack aluminide system, parts are processed in batches where aluminum is diffused into the steel surface by thermal exposure to an aluminum bearing powder, or "pack." This step may be followed by a conversion coating step to seal the coating and improve surface finish. Advantages of the system are good erosion resistance as well as corrosion protection. However, due to the superiority in performance of the metallic-ceramic systems, current usage of low temperature pack aluminides on industrial gas turbines is limited to specific compressor components in Pratt & Whitney manufactured units.

The metallic-ceramic systems, which also entered service in the 1960's, consist of an initial layer of well bonded glass-like inorganic polymer embedded typically with aluminum particles, or “pigmentation.” Prior to the mid-1970’s, this system was employed as a stand-alone coating. In the 1970’s, “topcoat” systems were developed to improve surface finish and seal the underlying “basecoat.” Currently, virtually all of the more advanced metallic-ceramics used today utilize a barrier layer topcoat for enhanced corrosion/erosion performance and surface finish improvement.

Due to proven performance over the years in a wide variety of operating environments, the metallic-ceramic systems have become the coatings of choice for new build by original equipment manufacturers (OEM’s), as well as the coatings of choice for industrial gas turbine overhaul shops during maintenance activities. Many variations of the metallic-ceramic system have been developed and implemented in order to meet the demands of specific variations in compressor operating environment. Due to either environmental considerations or inferior performance, the other two compressor coating systems, which saw widespread usage in the last 50 years (Ni-Cd plating and low temperature pack aluminides), have significantly fallen out of favor amongst OEM’s and overhaul shops alike.

In Section 2, this guideline will discuss the various types of compressor coatings which have been used and are currently in use. However, due to the current prevalence of metallic-ceramic systems relative to all other systems, Section 4 of this guideline will only outline processing of the metallic-ceramic systems.

2
TYPES OF COMPRESSOR COATINGS

2.1 Nickel-Cadmium Plating

2.1.1 System Characteristics

The system consists of a layer of nickel electrolytically deposited on the steel substrate by a conventional plating process, followed by electroplating of a layer of cadmium on top of the nickel. The underlying nickel provides a hard, relatively erosion resistant base layer and serves as an interdiffusion zone for the outer cadmium layer. The nickel also acts as a barrier between the cadmium and steel base material. This is an important characteristic, since cadmium is known to cause liquid metal embrittlement of high strength steels. There have been documented cases in gas turbine compressor sections of the relatively low melting cadmium causing catastrophic failures due to an insufficient barrier layer of nickel. However, it is the galvanically active cadmium that provides the corrosion resistance of the system. It is a sacrificial layer in that it is designed to corrode preferentially over the underlying or exposed substrate.

2.1.2 System Processing

Nickel plating is similar to other plating processes in that it employs soluble metal anodes. It requires the passage of direct current between two electrodes immersed in a conductive, aqueous solution of nickel salts. The flow of direct current causes one of the electrodes (the anode) to dissolve and the other electrode (the cathode) to become covered with nickel. The nickel in solution is present in the form of divalent positively charged ions (Ni^{++}). When current flows, the positively charged ions react with two electrons ($2e^-$) and are converted to metallic nickel (Ni^0) at the cathode surface. The reverse occurs at the anode, where metallic nickel is dissolved to form divalent positively charged ions, which enter the solution. The nickel ions discharged at the cathode are replenished by those formed at the anode.

Of the two most common plating baths commercially used (the Watts and nickel sulfamate solutions), the nickel sulfamate process is generally used to plate compressor airfoils. Processing variables include design and positioning of anodes relative to parts being plated, current density and plating bath chemistry and temperature.

Cadmium plating also utilizes anodes, either in the form of balls to maximize surface area or conforming anodes for complex geometries. Plating solutions are typically cyanide baths, generally formed by dissolving cadmium oxide in a sodium cyanide solution.

Plating times and current densities are designed to result in a nickel plating thickness in the range of 0.005-0.006 inch. Cadmium thickness targets are 0.001-0.002 inch, resulting in a total plate thickness of 0.006-0.008 inch.

After completion of both plating steps, parts are thermally treated at approximately 630 °F, which causes inter-diffusion of the nickel and cadmium layers.

2.1.3 System Performance

Nickel-cadmium plating systems exhibit very good corrosion resistance in pH neutral salt spray environments. As mentioned previously, the cadmium layer provides the sacrificial corrosion protection, and the harder, underlying nickel layer offers good erosion resistance. However, due to the sacrificial role of the cadmium, significant roughening of this outer layer due to corrosion occurs, and attendant aerodynamic performance losses become inevitable.

2.2 Low Temperature Pack Aluminide Coatings

2.2.1 System Characteristics

Low temperature pack aluminides are characterized as diffusion coatings in that the resultant surface layer is formed substantially by transformation of the base material by inward diffusion of aluminum. They are thus very similar to high temperature pack aluminides used on turbine hot section parts. On compressor hardware, the system represents a relatively thin, hard layer of base metal significantly enriched in aluminum.

2.2.2 System Processing

Parts are coated in batches using the pack cementation process. This process involves surrounding the parts in suitable containers with a powder, or "pack," consisting of the following constituents:

- Aluminum – in the form of a pure metal powder
- Filler – in the form of an inert ceramic material, such as aluminum oxide, to prevent sintering of the mix during thermal processing
- Activator – typically a volatile halide which serves as a chemical reactant in the aluminum transfer process

Parts embedded in the pack mix are heated to temperatures in the range of 900 °F, resulting in the formation of volatile aluminum halides which react with the steel compressor components. The net result is significant inward diffusion of aluminum.

2.2.3 System Performance

Low temperature pack aluminides are relatively hard, and thus provide good particulate erosion resistance. Although good in oxidation resistance at elevated temperatures, they are inferior in corrosion resistance to nickel cadmium plating and metallic-ceramic systems.

2.3 Aluminum Ceramic Systems

2.3.1 System Characteristics

Aluminum ceramic coatings consist of a layer of well bonded glass-like inorganic polymer matrix with aluminum particles, or "pigmentation," dispersed throughout. The as-cured coatings are not electrically conductive, and contain about 70% by weight aluminum. After curing, the coating is typically burnished (mechanically cold-worked) by dry blasting at low pressure using a variety of abrasive media. The burnishing process does not remove material, but causes the coating to become conductive and thus galvanically active. The greater galvanic activity of the coating relative to the steel base material ensures the coating will become sacrificial in a corrosive environment.

2.3.2 System Processing

See Section 4 of this guideline.

2.3.3 System Performance

In terms of galvanic activity, the aluminum ceramic systems are slightly less active than cadmium plating and slightly more active than aluminum base materials. The system thus provides very good corrosion resistance, good high temperature resistance and reasonable resistance to particulate erosion. However, the coating even as-burnished can be relatively rough (approximately 55 microinches AA at a 0.010 cutoff), which can negatively affect aerodynamic performance of the compressor.

2.4 Aluminum Ceramic Basecoats with Smooth Topcoats

2.4.1 System Characteristics

Topcoats applied over aluminum ceramic basecoats act as a sealer, or barrier coating, over the underlying sacrificial basecoat. The barrier topcoat, utilizing compatible chromate/phosphate chemistry, fills surface porosity and improves smoothness, and resists environmental attack since it is relatively impervious to corrosion by sulfate or chloride residues. Thus, overall system performance in terms of corrosion resistance is greatly enhanced, and an aerodynamically efficient surface is established and maintained due to the dramatically improved surface finish.

Some typical published system properties are as follows:

Thickness…………………	0.0005 – 0.003 inches
Galvanic Potential………..	-0.730-0.760 volts (vs. calomel electrode in 5% NaCl at 20 °F
Tensile Bond Strength……	> 8,000 psi (ASTM C633)

2.4.2 System Processing

See Section 4 of this guideline.

2.4.3 System Performance

Aluminum ceramic systems with smooth topcoat sealants represent the current "state-of-the-art" in terms of compressor coating performance, and for this reason, Section 4 (Processing) of this guideline will focus exclusively on these systems.

2.4.3.1 Corrosion Resistance – as a sealed sacrificial coating, top-coated aluminum ceramic systems exhibit superior corrosion resistance to Ni-Cd plating, diffusion aluminide and non-sealed aluminum ceramic systems. In salt fog exposure testing per ASTM B117, mild steel coated with sealed aluminum ceramics will not exhibit initiation of red rust in 2500 hours of exposure. The high effectiveness of the topcoat sealing layer also allows the coating to maintain a smooth surface finish when exposed to corrosive species.

2.4.3.2 Erosion Resistance – relatively speaking, aluminum ceramic systems are not as erosion resistant as many metallic or ceramic coating systems specifically designed for erosion resistance, primarily due to inherently lower coating hardness. With effective compressor inlet filtration in place, aluminum ceramic systems perform well in terms of providing beneficial corrosion resistance and maintenance of smooth aerodynamic surfaces. However, in applications where either particulate or water droplet erosion are an issue, variations to the standard top-coated system have been developed to provide improved resistance to erosion (see Section 2.6 of this guideline).

Typical published test values for erosion rate on sealed aluminum ceramic systems are 100-500 liters/0.001 inch of coating, as tested per ASTM D968.

2.4.3.3 Surface Finish Improvements – over the years, numerous studies have been published in the technical literature that clearly substantiate the performance benefits of smooth surface finishes on compressor rotating and stationary airfoils. The greater compressor efficiency resulting from smooth and aerodynamically efficient airfoils manifests itself as significant improvements in unit output and heat rate. Characterization of performance enhancements which can be realized through improvements in compressor airfoil surface finish is provided in Section 3.4 of this guideline.

Other compressor coating systems, as well as aluminum ceramic coatings without topcoat sealants, will typically exhibit as-processed surface finishes in the range of 30-60 micro-inches AA. Due to the "self leveling" ability of the liquid coating as well as advances in topcoat technology, sealed aluminum ceramic coatings are capable of achieving surface finishes in the range of 10-20 micro-inches AA.

2.5 Anti-Fouling Coatings

2.5.1 Operating Environments Prone to Fouling

In general, industrial gas turbine compressors are much less prone to fouling than axial or centrifugal compressors used in the chemical process industry. However, when applied in industrial environments with certain airborne contaminants, or with units prone by design to oil leakage from forward bearing compartments, fouling can significantly deteriorate compressor performance as ingested organic materials adhere and/or polymerize on airfoil surfaces.

2.5.2 Key Characteristics for Resisting Fouling

Fouling occurs predominantly by organic materials impinging and adhering to airfoil surface irregularities. Thus, coatings which effectively combat fouling will either possess:

- Very smooth surface finishes, or
- Slick, "non-stick" surfaces as provided by materials such as polytetrafluoroethylene (PTFE, or "Teflon").

2.5.3 Typical Anti-Fouling Compressor Coatings

2.5.3.1 Smooth Coatings – as previously discussed in Section 2.4, aluminum ceramic systems sealed with smooth topcoats produce very aerodynamically smooth surfaces, and thus can effectively resist fouling by not allowing adherence of fouling chemical species on airfoil surfaces. Sealed aluminum ceramics have shown excellent resistance to fouling in hydrocarbon compressors, an application much more prone to fouling than gas turbine compressors.

2.5.3.2 PTFE Bearing Coatings – coating systems have been developed and implemented by companies such as Sermatech International (Sermatech's "SermaLon" coating) where the outer barrier layer of the coating is modified with the addition of PTFE, creating a smooth "non-stick" surface which sheds potentially fouling airborne contaminants. The SermaLon system is a three layer coating, consisting of an outer PTFE-bearing barrier layer, a middle "inhibitive" layer, and an inner aluminum ceramic sacrificial layer for corrosion resistance. The PTFE bearing systems have also shown outstanding resistance to fouling in aggressive hydrocarbon compressor applications. However, due to the PTFE fluorocarbon addition, temperature capability of this system is limited to a maximum of approximately 500 °F. Thus, where coatings such as SermaLon have been applied in gas turbine compressors, the application has been restricted to the forward 5-6 compressor stages.

2.6 Erosion Resistant Coatings

2.6.1 Key Characteristics for Resisting Erosion

In general, materials can be categorized as exhibiting either ductile or brittle behavior in terms of erosion resistance. For ductile materials, optimum erosion resistance occurs at high impingement angles, as impact energy is absorbed through plastic deformation. At lower or shallower angles, particularly with sharp particles, material removal takes place by "plowing" and micro-cutting mechanisms, resulting in material loss and higher wear. For brittle materials, resistance to erosion and wear relies on particles ricocheting from their harder surfaces. As such, brittle materials resist erosion best at low impact angles. At higher impingement angles, these hard materials have limited ability to absorb energy through plastic deformation, and thus crack, with cracks eventually linking and resulting in material removal.

For compressor blades operating in industrial gas turbines with reasonable inlet filtration, the predominant mechanism of material removal is low angle erosion. This is clearly evident from typical wear patterns exhibited in relatively erosive environments, where metal loss is typically observed either just aft of leading edges, or in the radially outboard regions of the trailing edges. Thus, virtually all compressor coatings applied with the intention of improving erosion resistance possess high hardness in order to resist material loss at low impingement angles.

2.6.2 Typical Erosion Resistant Compressor Coatings

2.6.2.1 Hard Top-coated Aluminum Ceramics – this system consists of a base or bond coat of corrosion resistant aluminum ceramic material, which is then top-coated on erosion prone areas of the component with a hard aluminum oxide layer. The alumina layer is typically applied by an air plasma spray process to a thickness of 0.002-0.004 inches. Thus, the entire blade can be base coated for corrosion resistance, and the regions prone to erosion then subsequently coated with alumina.

2.6.2.2 Titanium Nitride Coatings – similar to systems used in the cutting tool industry, hard titanium nitride coatings can be applied to compressor blades through chemical vapor deposition (CVD) or physical vapor deposition (PVD) processes. Relatively thin, hard layers can be developed which have the advantage of representing minimal changes in blade weight and profile.

2.6.3 Considerations for Applying Erosion Resistant Coatings

There are many coating materials/systems available which have successfully been used for wear and erosion resistance in applications other than gas turbine compressor airfoils. However, the vast majority of the materials/systems are inappropriate for application in a modern gas turbine compressor due to the following considerations.

2.6.3.1 Weight – for obvious reasons, any coating system which adds appreciable weight to a relatively thin compressor blade cannot be used.

2.6.3.2 Profile and Smoothness – erosion resistant coating systems cannot substantially change the aerodynamic profile of the blade, nor represent such an increase in surface roughness that aerodynamic efficiency is adversely affected.

2.6.3.3 Corrosion Resistance – although an improvement in particulate or water droplet erosion may be achieved, an appropriate coating system must possess sufficient corrosion resistance to remain intact through the intended service interval. Therefore, in selection of an appropriate erosion resistant coating for a given application, the coating chemistry must also be suitable for withstanding the various corrosive species or media which may be encountered. In general, simply increasing coating thickness will not ensure the intended performance.

2.6.3.4 Fatigue Properties – the hard erosion resistant coating must not result in a fatigue debit due to a greater risk of surface crack initiation, nor significantly change the blade resonant frequencies.

For these reasons, it is only the systems listed in Section 2.6.2 which have seen widespread use in gas turbine compressor applications.

3
BENEFITS OF COMPRESSOR COATINGS

3.1 Corrosion Resistance

3.1.1 The Operating Environment

The predominant materials of construction for blades and vanes in modern industrial gas turbines (IGT's) are 12% chromium stainless steels. Nominal composition (intended alloying elements) of the most commonly used alloys in this family of materials is as follows:

	Nominal 400 Series Stainless Steel Alloy Composition, weight %				
Element	**403/410**	**422**	**Greek Ascoloy**	**410Cb**	**Custom 450**
Carbon	0.135	0.225	0.175	0.135	0.05 max.
Chromium	12.00	12.50	13.00	12.00	15.00
Nickel	---	0.75	2.00	---	6.00
Tungsten	---	1.00	3.00	---	---
Columbium	---	---	---	0.15	8 x C% min.
Silicon	---	0.40	---	---	---
Molybdenum	---	1.00	---	---	0.75
Vanadium	---	0.22	---	---	---
Copper	---		---	---	1.50

These "400 series" martensitic stainless steels provide the best trade-off of properties, manufacturability and cost for this compressor blade/vane application, and have been used successfully for many years by all major OEM's. However, the operating environment of a gas turbine compressor can be extremely harsh in terms the presence of aggressive corrodents and the potential for aqueous corrosion, and although these alloys are termed "stainless" steels, the use of coatings to mitigate corrosion damage is certainly necessary.

At the inlet of the compressor, the air is essentially at ambient temperature and pressure, and general atmospheric humidity will typically "wet" the first several stages of the compressor. In addition, it is extremely common for modern IGT's to be fitted with inlet fogging systems for power augmentation. As a result, these forward stages are continuously exposed to a "wet" environment and the potential for aqueous corrosion. In addition, when the machine is shut down, moisture can condense on the latter compressor stage surfaces as well.

Due to the huge quantities of air ingested by gas turbine compressors, deposition of atmospheric contaminants on gas-washed surfaces can readily occur, regardless of the quality of inlet filtration utilized. Most commonly, neutral chloride salts such as NaCl, when dissolved in water, can form a neutral electrolyte capable of significant corrosion damage. Other species typical of airborne pollutants, such as oxides of sulfur and nitrogen, or airborne ammonia, can accumulate on compressor surfaces, and in the presence of moisture, form acidic ammonium sulfate or ammonium nitrate salts. This lower pH electrolyte has the potential for generating considerably greater corrosion damage, typically in the form of pitting. Airborne contaminants can often deposit on airfoil surfaces in a "dry" state, accumulate on compressor airfoil surfaces, and when the unit is shut down, can absorb moisture from the air. When these deposits first dissolve in the absorbed water, the ion concentration is very high, and thus the solution can be very corrosive. Units that run in cyclic or peaking service thus have the potential to suffer significantly greater corrosion damage than units running continuously.

In summary, for the same gas turbine model, the degree of corrosion observed over time will depend on several factors:

- The proximity of the gas turbine inlet to salt laden environments
- The concentration of pollutants in the air
- The chemical species of pollutants in the air
- The efficiency of inlet filtration
- The level of moisture to which the compressor is exposed
- The duty cycle of the machine

3.1.2 The Corrosion Process

Corrosion of metallic materials is a natural process where the metal often returns to a chemical state, or compound, in which it is found in nature. Metals are typically found in their "natural" state as chemical compounds rich in oxygen or sulfur. Corrosion is an oxidation process, generally in an aqueous environment, where chemically:

$$M + H_2O \rightarrow MO + H_2$$

and M = the oxidizing metal. Aqueous corrosion is greatly accelerated by the presence of ions in the aqueous solution. Therefore, the rate of corrosion of a metallic surface is a function of:

- the length of time the surface remains wet
- the acidity or alkalinity of the solution on the surface (extremes of pH are generally more corrosive than neutral solutions)
- the specific nature or type of ions in solution

3.1.3 Corrosion Resistant Coating Types and Benefits

Corrosion resistant coatings used on metallic materials typically fall into two categories: barrier coatings or sacrificial coatings. Barrier coatings seek to stop or inhibit corrosion by acting as a physical barrier between the metal and the corrosive environment. Barrier coatings are typically comprised chemically of materials that are relatively impervious to corrosion. These coatings work well as long as the coating remains intact.

Sacrificial coatings are designed to corrode preferentially relative to the metallic substrate or base material. From a galvanic standpoint, they are thus always more galvanically active than the material they are designed to protect. In other words, the coating will possess a higher negative potential in the galvanic series than the material it will protect, and will thus act as a "sacrificial anode." A significant advantage of sacrificial coatings over barrier coatings is that they do not rely on remaining intact to maintain corrosion protection.

The primary benefit of corrosion resistant compressor coatings is to prevent or inhibit metal wastage from airfoil surfaces due to corrosion. Corrosion, if left unabated, can result in:

- significant performance losses as airfoil surfaces are roughened or "fouled" by the corrosion process
- loss of mechanical integrity as metal is lost from crucial surfaces
- fatigue failures due to stress concentrations resulting from pitting corrosion or frequency changes caused by general wastage

For IGT's operating primarily in base load service, it is common to have only the forward 5-7 stages of the compressor coated, since these stages operate at a temperature regime below the boiling point of water (surfaces can thus be "wetted"). For peaking service machines, where condensation during times of shutdown can wet all surfaces, it is often prudent for the IGT owner/operator to coat all compressor stages to prevent corrosion damage.

3.2 Erosion Resistance

3.2.1 The Operating Environment and Erosion Mechanisms

In most modern IGT's, the use of high efficiency inlet air filtration systems mitigates any significant damage due to solid particle erosion. However, it is not uncommon as air intake components and hardware upstream of the compressor inlet deteriorate or corrode over time, thus liberating hard particles, for the forward compressor rotating stages to experience metal loss due to erosion, predominantly on the airfoil leading edges.

The most common source of erosion damage in advanced technology IGT's currently in service is from the use of inlet air fogging systems employed for power augmentation. Much has been written in the technical literature regarding this equipment in terms of the control of water droplet size to mitigate compressor damage. If water droplets of a sufficiently large enough diameter are generated, or system design and placement allows the agglomeration of optimum size droplets into larger, potentially damaging droplets, substantial damage can occur to forward rotating compressor airfoils.

The mechanisms of metal loss through erosion have been previously discussed in Section 2.6.1 of this guideline.

3.2.2 Benefits of Erosion Resistant Compressor Coatings

Erosion damage to IGT compressor airfoils can have much the same effect or consequences as the damage caused by corrosion, as listed in the bullet items of Section 3.1.3. Erosion resistant coatings are generally utilized on the forward rotating airfoil stages, but can be applied throughout the compressor in applications prone to erosion damage. These hard coatings can effectively inhibit or eliminate metal loss due to low angle erosion phenomenon, and thus extend the operating life of these compressor airfoils.

3.3 Anti-Fouling

3.3.1 The "Fouling" Environment and Its Impact

As in the case of erosion, the use of high efficiency inlet air filtration can significantly mitigate the risk of compressor fouling. However, airborne organic contaminants can find their way into the compressor air stream, and can form tenacious deposits due to the polymerization process, particularly in applications where the ambient air quality is low, such as in heavily industrialized areas. In addition, materials "domestic" to the IGT can find their way into the compressor section, such as bearing oil or other lubricants, and deposit on airfoil surfaces.

The primary impact of fouling of compressor airfoil surfaces is the resultant loss in aerodynamic performance, which translates into a loss in compressor efficiency. A drop in compressor efficiency will always result in an overall loss of unit output and an increase in heat rate. Often, due to the chemical nature of the fouling deposits and their strong adherence to airfoil surfaces, compressor wash procedures can be highly ineffective in removing them, and thus have little impact in improving compressor performance.

3.3.2 The Benefit of Anti-fouling Compressor Coatings

The obvious benefit of anti-fouling coatings is to prevent the buildup of fouling deposits on compressor airfoil surfaces, and thus maintain compressor efficiency. The mechanisms by which these coatings are capable of resisting organic deposit adherence are discussed in length in Section 2.5 of this guideline. In addition, the importance and benefits of establishing and maintaining smooth, aerodynamically efficient compressor airfoil surfaces are addressed in the following Section (Section 3.4).

3.4 Aerodynamic Benefits from Improved Surface Finish

3.4.1 Performance Losses from Rough Surfaces

The performance of axial compressors relies upon relatively smooth airfoil surfaces to maintain laminar flow and thus optimum aerodynamic airfoil efficiency. It is a well established phenomenon that as the roughness of compressor airfoil surfaces increases, compressor efficiency decreases. Over time in service, surface roughness increases due to a number of different "fouling" mechanisms:

- corrosion products form on airfoils
- particles of varying compositions and species impact and adhere to airfoils
- salts condense on airfoils

As the airfoil surfaces become rougher over time in service, the loss of compressor efficiency is clearly measurable as an increase in compressor outlet temperature, a decrease in power output for the same firing temperature and an increase in unit heat rate. It is not uncommon for losses in isentropic compressor efficiency to exceed 3% from fouling of airfoil surfaces.

Compressor washing either on- or off-line can be effective in removing water soluble deposits from fouled surfaces, and mild abrasives (e.g., pecan hulls) introduced into the compressor can often successfully remove non-soluble deposits. However, surfaces roughened by tenacious deposits or corrosion will generally have a tendency to foul more quickly than a “new and smooth” surface.

The financial impact of compressor fouling can be quite dramatic. For a base loaded gas turbine in combined cycle operating at a 13:1 compression ratio and a turbine rotor inlet temperature of 1127 °C, a 1% loss in compressor efficiency results in a 0.70% decrease in overall cycle efficiency and a 1.43% decrease in power output. Thus for a 100 MW base load combined cycle plant paying $8/MMBtu and receiving $50/MW-hr, this 1% loss in compressor efficiency represents an increase of over $300,000 per year in fuel costs and almost $600,000 in lost revenue due to power losses.

3.4.2 Surface Finish Optimization Through Coating of Compressor Airfoils

Aluminum ceramic basecoats with smooth topcoats, when applied to compressor airfoils, can optimize surface finish prior to installation and during service through the following mechanisms:

- Minimize surface roughness of new and service run airfoils due to the smoothing or “self-leveling” phenomenon from the liquid phase application process
- Inhibit the buildup of corrosion products in service
- Minimize the buildup of airborne contaminants ingested in the compressor due to the nature of the smooth ceramic surface relative to an uncoated metallic surface
- Provide a surface more readily cleaned by standard compressor washing procedures

Top-coated aluminum ceramic coatings are sprayed onto airfoils during application as a liquid, typically using multiple spray passes or coats, with drying allowed to occur between coats. The liquid coating has a tendency to fill surface irregularities on the new or service run airfoil during the coating process and substantially improve surface finish. It is not uncommon for the coating application to improve surface finish of a service run airfoil from approximately 60-80 µin Ra to a coated finish of 30-40 µin.

Corrosion resistant coatings such as sealed aluminum ceramics can also be effective in inhibiting the buildup of surface corrosion products, and thus maintain smooth, aerodynamically efficient surfaces in service.

Aluminum ceramic coatings with smooth sealing topcoats can also act to minimize the adherence of organic or other airborne particles entrained in the compressor airflow on airfoil surfaces. Relative to bare metallic surfaces or surfaces with metallic coatings, the metallic-ceramic coated surface will foul more slowly due to the lower tendency of airborne contaminants to stick to the ceramic surface. This non-metallic surface is also more easily cleaned during standard water wash procedures. These characteristics of the aluminum ceramic system serve to maintain smooth surfaces during operation.

3.4.3 Typical Compressor Performance Improvements through Compressor Coating

A number of recent examples of IGT performance improvement through compressor coating have been reported in the literature or conference proceedings:

Example 1

Example 1 provides performance data before and after a major outage on a General Electric Frame 6 gas turbine. During the major outage, a number of modifications were made to the machine, as follows:

- First stage bucket replacement of different design
- Second stage bucket replacement of different design
- Inner barrel brush seal installation
- Firing temperature increase of 8 °F.
- Inlet guide vane angle medication.
- Top-coated aluminum ceramic coating of all compressor airfoil rotating and stationary stages

Overall performance improvement after the major outage was reported to be a 14.22% increase in output and a 6.10% decrease in heat rate, attributable to all cleaning and modifications made during the outage. Assignment of portions of this performance improvement was made to the various modifications and cleaning operations accomplished during the outage. After this, a 5.2 % increase in output was assigned to the addition of compressor coating.

It is obviously difficult to measure accurately the improvement in performance attributable to one change made during an outage, particularly one where a number of design modifications are made. The “stack-up” of variability or error in assignment of values to modifications can represent a large potential error in the reported effect of any one change. Thus, a cautionary note must be attached to reporting performance improvements calculated in this manner.

Example 2

In 1998, another example was reported where two Siemens-Westinghouse W501F gas turbines underwent outages at the same time. The units were "sister" units of the same design vintage installed at the same power plant. Identical maintenance activities during the outages were performed on the two machines, with the exception that the rotating and stationary compressor airfoils were coated with a smooth top-coated aluminum ceramic system on one machine, and not on the other.

Output and heat rate improvements were measured on both machines after the outage due to typical outage activities, such as cleaning and clearance optimization. However, the unit with compressor coating showed a greater degree of improvement. Thus, performance improvements attributable to compressor coating were:

- Increase in compressor efficiency - 0.64%
- Decrease in heat rate - 0.58%
- Increase in output - 1.26%

This side-by-side comparison establishes a relatively accurate example of performance improvement which can be attributed to surface finish optimization provided by smooth compressor coatings. In this instance, the owner of the equipment estimated a payback from compressor coating of less than six (6) months.

4

PROCESSING OF ALUMINUM-CERAMIC COMPRESSOR COATINGS

4.1 General Processing Methods

4.1.1 Typical Technical Requirements

The following technical requirements should be met for all aluminum ceramic compressor coatings:

4.1.1.1 Chemical Composition:

Composition of aluminum ceramic coatings is generally proprietary to the coating supplier. However, in general:

Aluminum content: >/= 70 weight %

Balance: Dichromate and phosphate compounds, which form a glass-like inorganic polymer matrix

4.1.1.2 Thickness: 0.0005-0.003 inches (0.012-0.073 millimeters)

4.1.1.3 Surface Roughness:

< 10 µinch Ra at 0.010 inch cutoff (0.25 µm @ 0.25 mm)

< 25 µinch Ra at 0.030 inch cutoff (0.63 µm @ 0.75 mm)

4.1.1.4 Salt Spray Corrosion Resistance (ASTM B117):

> 2500 hours without red rust (0.002 thick coating on 1010 steel, scribed)

4.1.1.5 Erosion Resistance (ASTM D968):

>300 liters/mil

4.1.1.6 Tensile Bond Strength (ASTM C633):

> 8,000 psi (strain rate 0.1 inch/min.)

4.1.1.7 Galvanic Potential:

-0.730 – 0.760 volts (vs. calomel electrode in 5% NaCl at 20 °C)

4.1.2 Typical Processing Requirements

4.1.2.1 Receive material and check for shipping damage. Verify quantity and record serial numbers, if parts are serialized.

4.1.2.2 Clean as necessary to remove any loose dirt or debris through brushing or light abrasive blasting.

4.1.2.3 Visually inspect for the presence of defects, dents, cracks, surface imperfections or other deleterious conditions.

4.1.2.4 Thermally degrease parts at 600-700 °F (315-370 °C).

4.1.2.5 Grit blast areas to be coated with 90 grit aluminum oxide blast media.

4.1.2.6 Mask "no coat" areas with hard tooling or tape.

4.1.2.7 Using a high-volume, low-pressure (HVLP) spray gun in a controlled environment room, apply base coat material with smooth, even coating passes. Allow to air dry between passes.

4.1.2.8 Using an appropriate nondestructive thickness measuring device (Fischer-scope), inspect for required thickness. If required thickness is not achieved, additional coats shall be applied until thickness requirement is met.

4.1.2.9 Visually inspect coating for runs, sags, contamination, bare spots or other imperfections.

4.1.2.10 Cure coating. Thermal cycle used for curing is dependent on specific coating chemistry. However, typical cycle utilized is 600-700 °F (315-370 °C) for 30-60 minutes in air.

4.1.2.11 Burnish coating to develop desired electrical conductivity. Although various burnishing methods can be utilized, burnishing is typically achieved by glass bead blasting.

4.1.2.12 Visually inspect coating for runs, sags, contamination, bare spots or other imperfections.

4.1.2.13 Measure conductivity of coating and record results.

4.1.2.14 Thermally degrease parts at 600-700 °F (315-370 °C).

4.1.2.15 Using a high-volume, low-pressure (HVLP) spray gun in a controlled environment room, apply top coat sealant material with smooth, even coating passes. Allow to air dry between passes.

4.1.2.16 Visually inspect coating for runs, sags, contamination, bare spots or other imperfections.

4.1.2.17 Cure coating. Thermal cycle used for curing is dependent on specific coating chemistry. However, typical cycle utilized is 600-700 °F (315-370 °C) for 30-60 minutes in air.

4.1.2.18 Using an appropriate nondestructive thickness measuring device (Fischer-scope), inspect for required thickness.

4.1.2.19 Visually inspect coating for runs, sags, contamination, bare spots or other imperfections.

4.1.2.20 Using an appropriate profilometer, inspect coated part for surface finish and record.

4.1.2.21 Package and ship parts in suitable containers that will prevent component contact and damage under rigorous handling conditions.

4.2 Critical Process Steps

4.2.1 Surface Preparation

As is the case with any coating application, metallic surfaces to be coated must be extremely clean and dry prior to application. After thermal degrease and grit blast preparation, parts should be handled with clean white gloves to avoid contamination. Care should be taken in masking, using either hard tooling or tape, to ensure an accurate transition between "coat" and "no coat" areas.

4.2.2 Spray Environment and Technique

For application of aluminium ceramic coatings, it is extremely important that spraying take place in an environmentally controlled booth, where temperature and humidity can be closely controlled and monitored. A lack of proper control of temperature and humidity will adversely affect the quality of the coating. Relative humidity is generally held within 30-50%, and temperature within 70-85 °F (21-29 °C).

Quality and consistency of the applied coating is highly dependent on the skill of the sprayer. Proper spray techniques require significant operator training, such that smooth, even coatings with consistent thickness are developed.

4.2.3 Burnishing

After base coat application and curing, mechanical cold-working is required to develop the desired electrical conductivity of the coating. Although a variety of methods can be successfully applied, burnishing is typically accomplished by dry aluminium oxide or glass bead blasting. As in the case of spraying, significant operator skill is required to achieve a properly burnished surface without damaging the coating.

4.3 Surface Finish Measurements

Characterization of surface finish, or "texture," is described in detail in ANSI/ASME B46.1. Surface finish is typically defined in terms of average roughness, or "Ra," and expressed in units of micro-inches (μin.) or microns (μm).

The variation in a surface is often described in terms of short range and long range. The term "roughness" typically embraces the short range variation, and "waviness" the long range. With respect to surface finish measurement protocol, a "cutoff" length is defined to differentiate between measurement of roughness and waviness.

In measuring roughness of IGT compressor airfoil surfaces, a cutoff of 0.030 inch is typically specified, which gives an accurate depiction of the finish of large, flat airfoil surfaces. However, shorter cutoffs are routinely specified for smaller, more highly curved airfoils, such as 0.010 inch, and will generally result in much lower Ra values than the longer 0.030 inch cutoff measurements. It is thus extremely important when assessing surface finish Ra values to know the units being reported and the cutoff value used.

4.4 Typical Quality Requirements

4.4.1 Coating Shop Qualification

4.4.1.1 Vendor Audits - Prior to placing a coating order of any sort with a specific vendor, the vendor's facilities, quality control system and general operation shall be audited by Purchaser for capability to adequately apply the desired coating. Approval shall be granted for a period specified by Purchaser, but may be removed by Purchaser for inadequate vendor performance.

4.4.1.2 First Article Inspection - At Purchaser's option, the vendor shall be required to prepare a first article for approval prior to the acceptance of a process plan or any changes to the plan. The supplier will be required to process sample material through the entire process for non-destructive and destructive examination, by Purchaser, for compliance with the requirements of Section 4.1.1. Approval of vendor's process will be based on the results of this inspection and the Vendor Audit (4.4.1.1).

4.4.1.3 Personnel Qualifications - Inspection personnel shall be qualified to ASNT Recommend Practice No. SNT-TC-1A Level II or III where applicable. Personnel with Level I qualifications shall work under the direct supervision of a Level II or Level III inspector.

4.4.2 Documentation & Certification

4.4.2.1 Quality Control Tests - In-process and final Quality Control inspections shall be performed, as identified in Section 4.1.2. Results of all required testing shall be recorded by serial number, if parts are serialized.

4.4.2.2 Processing Records - Processing records shall be maintained in sufficient detail to indicate compliance with this guideline and to allow traceability by lot.

4.4.2.3 Certificate of Compliance - All processing and quality control records shall be reviewed by the vendor to verify compliance with this guideline and the purchase order. Any deviations shall be reported immediately to the purchaser and may be cause for rejection. A document certifying that all aspects of this specification and the purchase order have been met, shall be signed by the responsible vendor representative and shall be presented to the purchaser upon completion of the order. This document shall include:

- Purchase Order Number
- Purchase Specification Number
- Purchaser Drawing Number
- Serial Numbers and Final Disposition
- A copy of all documents approving vendor requested deviation from this guideline, if applicable

4.4.2.4 Records – All process control cards and quality control inspection results shall be maintained on file by the vendor for a period of five (5) years. This information shall be made available to the purchaser upon request.

4.4.3 Access

The purchaser shall be allowed reasonable access to inspect components at all times during the coating process.

4.5 On-site vs. Shop Application – Technical and Economic Considerations

Maintenance plans for most industrial gas turbines (IGT's) allow access to the compressor section of the machine only during major outages, with typical schedules dictating major outages every 48,000 equivalent operating hours (EOH). Since IGT operators rarely have spare sets of rotating and stationary compressor airfoils in inventory, it is thus necessary to apply (or strip and re-apply) coatings to compressor airfoils during the major outage timeframe.

Some companies have developed the ability to perform coating at the turbine site rather than completely removing all airfoils and then transporting them to a shop. The primary benefits of performing coating at the turbine site are the avoidance of the necessity to remove stationary compressor airfoils from their casings or blade rings and to un-stack the rotor, and the avoidance of transporting these expensive assets to a shop. However, a number of technical and economic considerations become relevant, as follows:

4.5.1 Technical Considerations

4.5.1.1 Site Access – the turbine site must be able to accommodate room for the large ovens and rotor rotating equipment required to properly cure the coating after spray application. In addition, the site must be able to supply the requisite power, water and compressed air for coating operations.

4.5.1.2 Surface Preparation – airfoils to be coated must be prepared by abrasive blasting with appropriate media and compressed air. For the rotor, which can be lifted out of the lower half casings, and the upper half casings containing stationary airfoils, blasting and coating can take place away from the machine. However, in the case of the lower half stationary blading, extreme care must be taken such that all blast and coating media is removed and does not become lodged or entrapped in air extractions or other critical areas.

4.5.1.3 Spray Access – "in situ" airfoil spacing and length (span) can make spray access problematic, and thus make it difficult to achieve complete and uniform coating coverage.

4.5.1.4 Compressor Design – unit design can greatly impact the efficiency of on-site coating operations. For instance, in the case of 3-bearing rotors, the compressor rotor can be lifted out and coated separately from the turbine rotor. For a 2-bearing machine, this is not possible, and the entire rotor will be involved in coating operations. Thus, no work can typically be performed on the turbine rotor during these activities. For General Electric (GE) style rotors, compressor rotor wheel web regions cannot be coated in the "stacked" condition, and care must be taken to not entrap material between wheels. Also, GE style rotors require un-stacking for compressor blade removal, so great care to preclude blade damage must be taken.

4.5.1.5 Coating Quality – in general, assurance of coating quality is easier in a shop environment, where surface preparation and spray environment can be closely controlled.

4.5.2 Economic Considerations

4.5.2.1 Outage Duration – to properly complete all surface preparation, coating application, inspections and clean-up, the on-site coating company must be allowed access to the compressor section of the machine typically for 5-7 days. Thus, on-site application of compressor coating will invariably extend the major outage interval. The exact number of days the outage is extended will depend on several variables, such as outage staffing and schedule, and compressor design. For an 80 MW base loaded machine selling power at $0.05 per kW-hr, this equates to $96,000 per day of lost revenue for every day of outage extension.

Logistically, in general, for a turbine site not located close to a qualified coating shop, and particularly where customs clearance considerations come into play, it is more timely for compressor coating operations to be performed on site. For a turbine site near a qualified shop, outage planning can often be accomplished such that removal and shipping of hardware to the coating shop will have little or no impact on outage duration.

5
PROCESSING OF ANTI-FOULING AND EROSION RESISTANT ALUMINUM CERAMIC VARIATIONS

5.1 Anti-fouling Coatings

As outlined in Section 2.5 of this guideline, aluminium ceramic compressor coatings can be modified to include topcoats which are specifically designed to resist fouling, particularly by airborne organic materials, and also to resist relatively acidic environments. The outer coating layer provides a very smooth, “slick” surface, frequently by containing materials such as polytetrafluoroethylene (PTFE, or “Teflon”).

A general outline of PTFE-bearing anti-fouling coating processing is as follows:

1. Thermally degrease parts at 600-700 °F.
2. Abrasive blast surfaces to be coated.
3. Mask as required.
4. Apply aluminium ceramic base coat.
5. Cure at 600-700 °F.
6. Burnish coating to develop desired electrical conductivity.
7. Apply an intermediate coating layer. This layer will typically contain PTFE and a metallic content as well. Thus, the intermediate layer provides corrosion resistance and a chemically favorable surface for bonding of the outer layer.
8. Cure intermediate layer at 300-400 °F.
9. Apply the PTFE-bearing outer coating layer.
10. Cure outer layer at 300-400 °F.
11. Final inspect and certify coating.

5.2 Erosion Resistant Coatings

As discussed in Section 2.6 of this guideline, hard topcoats such as aluminum oxide can be applied on top of unsealed aluminum ceramic base coats to provide significantly improved erosion resistance. A general processing outline would thus be:

1. Thermally degrease parts at 600-700 °F.
2. Abrasive blast surfaces to be coated.
3. Mask as required.
4. Apply aluminium ceramic base coat.
5. Cure at 600-700 °F.
6. Burnish coating to develop desired electrical conductivity.

7. Mask as required.
8. Apply an aluminum oxide outer layer by the air plasma spray (APS) process.
9. Remove masking.
10. Finish the aluminum oxide layer to improve surface roughness, typically by manual sanding.
11. Inspect and certify coating.

6
CURRENT APPLICATIONS

6.1 Compressor Rotating and Stationary Blading

Top-coated aluminum ceramic materials currently form the "state-of-the-art" with respect to IGT compressor section coatings. Virtually all major original equipment manufacturers (OEM's) coat the first 5-7 compressor stages, or "wet" stages, of rotating and stationary airfoils at new unit build. However, experience has shown that coating all stages of compressor airfoils has significant benefit with respect to performance and corrosion resistance.

Within the last 10-12 years, Alstom and General Electric began utilizing an alternate stainless steel called Custom 450 (C-450) for manufacture of airfoils in the forward section of the compressor. This material has comparable strength to standard compressor airfoil materials (such as 403/410 stainless steels), but better corrosion resistance. Thus, these OEM's do not coat C-450 airfoils in the new condition. Service experience to date has shown:

- In some operating environments, the C-450 material has exhibited significant pitting corrosion in the uncoated condition, such that the addition of a corrosion resistant coating could be desirable.
- Severe localized corrosion, or "worm-hole" pitting corrosion, has been observed on **coated** C-450 material in laboratory environments, clearly indicating very unique and potentially dangerous behaviour of this material when coated and operating in corrosive environments.

Until the above mentioned phenomenon is more clearly understood, and a coating developed and substantiated for use on this material, service operation of C-450 airfoils in the coated condition is **NOT** recommended.

6.2 Compressor/Turbine Wheels and Disks

6.2.1 Compressor Wheels

To minimize corrosion in service, particularly with units in peaking service, it has been found to be advantageous to apply aluminium ceramic coatings to the web and rim sections of compressors wheels and disks. For welded or "shrunk-on" rotor construction, such as Alstom and certain Siemens Power Generation (former Westinghouse-style) designs, disassembly of the rotor is obviously not practical. However, for Westinghouse-style designs, access to the wheel web regions outboard of the diaphragm seal lands is reasonably good in the assembled state of the rotor for coating application.

For GE compressor rotor designs, it is necessary to completely un-stack the rotor to coat the web and bore regions. However, experience has indicated this practice to be of substantial value, as rotors in peaking service have been found to trap corrosion products inboard of wheel rabbet fits, which can then cause rotor imbalance.

For Siemens “V” series rotors, rotor un-stacking occurs at virtually every hot gas path (HGP) and major outage such that access to wheel web and bore regions for coating is not an issue. Coating on surfaces inboard of the “Hirth” coupling fit has also been found to be of significant benefit in combating corrosion.

6.2.2 Turbine Disks

Extreme pitting corrosion has frequently been observed on the steel turbine disks of older IGT’s in peaking service, which occurs during periods of inactivity or shutdown. Severe cases of material wastage in the dovetail serration fits have been known to result in extensive looseness, or “rock,” of the buckets/blades. Bucket/blade rock can lead to liberation of seal pins during start-up or turning gear operation.

Typically in conjunction with wheel restoration procedures to eliminate excessive bucket/blade rock, turbine disks have been commonly coated with aluminium ceramic systems to preclude further corrosion and material loss. Turbine disk operating metal temperatures are generally well within the capabilities of most aluminium ceramic systems. This approach has proven to be successful in combating further disk corrosion. Given that many IGT’s are currently being transitioned from base load to intermediate or even peaking duty cycles, coating of disks with aluminium ceramic systems should be considered regardless of whether dovetail serration thermal spray restoration procedures are required.

6.3 Compressor Inlets/Bellmouths

Coating of compressor inlets/bellmouths with aluminium ceramic systems is certainly a consideration in order to minimize corrosion and maintain smooth aerodynamically efficient surfaces. However, sheer size of these components mandates on-site coating, which becomes problematic with respect to applying aluminium ceramic systems, primarily due to the curing requirement. Also, this region of the compressor obviously is subjected to relatively low (essentially ambient) temperatures. For these reasons, simple 2-part epoxy coating systems have found greater acceptance for coating inlets/bellmouths.

6.4 Burner Components

Components which make up combustor burner assemblies are commonly prone to corrosion given their exposure to the elements and typically simple steel construction. Several burner components have benefited from the application of a simple aluminium ceramic coating. One example is the gas distribution and swirler assemblies for the Siemens V84.2 gas turbine.

7
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A
APPENDIX A

List of Compressor Coating Companies And Coating Trade Names

1. AAR Power Services
   148 Industrial Park Drive
   Frankfort, NY 13340
   www.aarcorp.com/aircraft/power_services.html

   Coating Trade Names:

   - Chemcoat – sealed aluminum ceramic

2. General Electric Energy
   4200 Wildwood Parkway
   Atlanta, GA 30339
   www.gepower.com

   Coating Trade Names:

   - GECC-1 – sealed aluminum ceramic

3. Liburdi Turbine Services, Inc.
   400 Highway 6 North
   Dundas, Ontario
   L9H 7K4 Canada
   www.liburdi.com/liburditurbine

   Coating Trade Names:

   - Reactive Ion Coating (RIC) – erosion resistant
   - LCC – corrosion resistant

4. Sermatech International
1566 Medical Drive
3rd Floor, Suite 300
Pottstown, PA 19464
www.sermatech.com

Coating Trade Names:

- Sermetel W – aluminum ceramic
- Sermetel 5380DP – sealed aluminum ceramic
- Sermalon – smooth anti-fouling (Teflon bearing)
- SermaWear – erosion resistant

5. Turbine Resources Unlimited, Inc.
P.O. Box 430, 1056 Route 20 East
West Winfield, NY 13491
www.calltru.com

Coating Trade Names:

- TRU Seal 3000 – sealed aluminum ceramic
- TRU Flow 2000 – smooth anti-fouling (Teflon bearing)

6. TurboCare
Winston-Salem Facility
3050 Westinghouse Road
Rural Hall, NC 27045
www.turbocare.com

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