Maintaining Gas Turbine Compressor Efficiency

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In Partnership with: ARAVA Technologies Limited
Presentation Outline

- Introduction
- Basic principles and compressor pressure / volume
- Compressor Performance and types of contamination
- Airfoil efficiency and contamination
- Corrosion and Erosion
- Compressor Damage - causes and preventative actions
- Why wash & cleaning methods
- Case study
- Laboratory Testing Service
- In summary
Introduction

Why is Compressor Efficiency so important?

“Up to 60% of the power produced by a Gas Turbine Engine is consumed by the compressor assembly”
Understanding the basic principles
1 - 2 Compression (Compressor)
2 - 3 Heat Addition (Combustion Chamber)
3 - 4 Expansion (Turbine)
Compressor Assembly

“Increase the pressure of the air passing through it”
Factors that contribute to a loss in Compressor Performance

- Contamination of the Airfoil Surfaces
- Corrosion of the Airfoil Surfaces
- Erosion of the Airfoil Surfaces
- Peripheral Equipment Degradation
- Distortion and Wear of the Casing and Rotor Assy
- Foreign or Domestic Object Damage
Types of Contamination

- Aerosols
- Dust
- Insects & Organic Matter
- Rust or scale from the inlet duct work
- Dissolved solids
- Oil and Hydrocarbon deposits
Contaminated Airfoils affect Efficiency

Clean Compressor:
- Airfoil Surface is clean & undisturbed
- Boundary layers are thin
- Airfoil operates at maximum efficiency

Contaminated Compressor:
- Airfoil surface is rough
- Boundary layers are thick
- Efficiency is reduced which results in:
  - An increase in the work input required to compress the flow

Does particle size matter and where does it stick?
Contamination size and distribution

Highest level of contamination observed on suction (top) surface where the boundary layer is thick and turbulent

Smaller particles stick to the pressure (bottom) surface

Particle Size Matters!

Contamination of the Airfoil Surfaces
Corrosion of the Airfoil Surfaces
Erosion of the Airfoil Surface

Ref: [2]
Location of Contamination

Deposits on the pressure (bottom) surface - dashed line indicates the ‘clean’ leading edge region.

Deposits on the suction (top) surface - the circles show the deposit induced by the presence of large recirculation due to the development of hub vortex.

Ref: 3

Contamination of the Airfoil Surfaces
Corrosion of the Airfoil Surfaces
Erosion of the Airfoil Surface
Corrosion of Airfoil Surfaces

Chemical - Industrial Environment (Sulfur or Chlorine)

Electrochemical - Galvanic reaction (moisture induced)

Both types will result in Pitting, Roughening and Material Loss = decrease in compressor efficiency
Corrosion of Airfoil Surfaces - Main contributors

- Airfoil composition and surface finish
- Atmospheric concentrations of moisture, salt and sulfur
- Maintenance Protocols
Erosion of Airfoil Surfaces

Erosion causes a change in the airfoil profile, resulting in:

- A decrease in the thickness of the airfoil
- Airfoil roughness
- Increase in tip clearance
Erosion of Airfoil Surfaces

Factors contributing to an increase in Erosion damage:

- Prolonged ingestion of Liquid or Solid Particles
- Impact Velocity and Incidence Angle
- Concentration and size of Particles
- Surface Material (coatings and resistance to impact damage)

Example from GE LM2500+

- This fouling caused in excess of 2% deterioration of isentropic compressor efficiency (power loss > 5%).
Causes of Compressor Damage

- Incorrect operation of IGVs and bleed valves
- High cycle fatigue
- Pitting due to corrosion
- Erosion and fouling of airfoils and airfoil coatings:
  - Excessive vibration
  - Surge due to fouling, erosion and airfoil roughness
Compressor Damage: Preventative Actions

- Inlet Filtration
- Routine compressor washing
- Monitoring changes in vibration
- Periodic inspection of the airfoil surfaces for pitting, erosion and coating integrity
- Functional testing of the operation and positional settings of the IGV’s and bleed valves
Inlet Filtration

- HEPA, Fine and Course
- PTFE, nano or micro glass fibre based
- Effective at removing particles >0.01 - 10 microns
- Not effective at removing aerosols that contribute to a build-up of sticky contamination
- Incorrect filter selection can be costly
- Soluble contaminants
Routine Compressor Washing

- Maintain your Compressor at maximum efficiency
- Maintain Engine Reliability and Performance

“as the compressor consumes a significant amount of the energy produced - maintaining an efficient compressor will ... ”
Why wash an engine at all?

Restore blade aerodynamics & compressor efficiency

That will contribute towards:

- Maximum available power output
- Improve fuel efficiency
- Reduce hot section deterioration
- Can provide corrosion inhibiting protection
Cleaning Methods

Off-Line (dry crank) Cleaning:
  = Power Recovery

On-Line (hot cleaning under reduced load):
  = Power Maintenance

Hand Cleaning:
  = Limited Power Recovery
Compressor Performance

On-Line Washing = Power Maintenance

Off-Line = Power Recovery

Degradation Rate with no washing

Performance decay with ONLY On-line washing

Performance recovery with ONLY Off-Line washing

Compressor Efficiency recovery with On-Line & Off-Line Washing
Using water based detergent to wash

- Eco-Friendly ✔
- Aqueous NOT Solvent based cleaners ✔
- Solvent based cleaners eventually harden internal seals ✗
- Solvent based cleaners - difficult to safely/environmentally dispose of ✗
- Unique formulated Surfactant - for increased penetration and removal of fouling ✔
- Wide range of approvals ✔
Case Study

Example from GE LM2500+

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[Brekke et. al., 2009]
Wash Sampling Analysis

- Wash samples are analysed in our fully integrated laboratory
- Tested key components of all the OEM specifications including:
  - Microscopy, Spectroscopy, Inductively Coupled Plasma
  - Comprehensive test results analysis
Wide Range of Approvals

- HAR 3A Sea King
- MK 9A Lynx
- FA-18 Super Hornet
- P3 Orion
- Blackhawk MH-90
- SAAB 340
Routine Gas Turbine Compressor Washing is the most cost effective means of maintaining an efficient compressor.

Up to 60% of the power produced by a Gas Turbine Engine is consumed by the compressor assembly.
References:

Thank you!

Shaping the future of gas turbine washing