Metallurgical Failures in Gas Turbines

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Turbine failures

• What is a turbine?
• Use of gas turbines in offshore energy applications.
• Failure modes
• Why failures occur – case studies
• Conclusions
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What are Turbines?

• A turbine is a rotary mechanical device that extracts energy from flow of fluid and converts it into useful work.

• A turbine typically comprises a rotor assembly with blades attached. Moving fluid acts on the blades so that they move and impart rotational energy to the rotor.

• Almost all electricity is generated by a turbine of some type.
Gas Turbines
Gas turbines in offshore energy applications
Gas Turbines In Offshore Energy Applications

• Power Generation
  – Electrical power for the offshore installation
  – Normally at least two gas turbines

• Mechanical Drive (compressors or pumps):
  – Gas gathering
  – Gas lift
  – Export compression
Gas Turbines In Offshore Energy Applications

- Industrial gas turbines
- Aero-derivatives
- Usually supplied as a turbine package comprising
  - Air intake and filtration system
  - Fuel system
  - Bearing lubrication system
  - Starting system
  - Controls
  - Exhaust system
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<th>Company</th>
<th>% UK</th>
<th>Models UK</th>
<th>Models Worldwide</th>
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<td>Siemens-Westinghouse (Alstom, Ruston, EGT)</td>
<td>46%</td>
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<td></td>
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Offshore - Considerations

• Often working in an harsh environment:
  – Airborne salts
  – Industrial pollutants
  – In some locations fine dust

• Movement of FPSOs
  – Movement of lubricating oil
  – Flexing leading to alignment considerations
Modes of Failure

• Fatigue
• Corrosion
  – Low temperature corrosion
  – High temperature corrosion
• Erosion/wear
• Creep
Fatigue

- Fatigue is a progressive cracking mechanism caused by repeatedly applied or fluctuating stresses – termed cyclic stresses.
- Fatigue involves two stages:
  - Initiation
  - Propagation
- High cycle fatigue can occur under the influence of many hundreds of thousands or millions of stress cycles.
- The presence of notches or indents act as stress-raisers to promote fatigue.
Fatigue
Fatigue

- High cycle fatigue often occurs due to resonance of blades.

- Resonance occurs when a system experiences an external force at a frequency that causes it to oscillate at an increased amplitude.
Fatigue
Fatigue

Avoiding Fatigue Failures

• Careful design of the turbine to avoid resonant frequencies
• Investigate problems with excessive vibration
• Carry out regular inspections for stress-raising features
  • Impact notches
  • Corrosion pits
  • Erosion pits
Corrosion

Low Temperature Corrosion

High Temperature Corrosion
Low Temperature Corrosion

- Ingestion of airborne corrosive species such as airborne salts and sulphur or nitrogen oxides.
- Airborne contaminants combine with moisture in the air to form corrosive acids.

“Long Term Operating Experience with Corrosion Control in Industrial Axial Flow Compressors”, David Linden, Proceedings of the 40th Turbomachinery Symposium
September 12-15, 2011, Houston, Texas
Low Temperature Corrosion

- The inlet stages of the compressor are the most susceptible to corrosion.

- The inlet stages typically operate at sub-atmospheric pressure and the gaseous water condenses into water droplets that combine with other contaminants.

- As the air travels through the compressor the temperature and pressure increases driving liquid water back into a gaseous state.

Low Temperature Corrosion

- The corrosion of compressors is promoted by fouling, which provides a location for water droplets to form and agglomerate and for acidic conditions to be developed.
Low Temperature Corrosion

Prevention of Low Temperature Corrosion

- Use materials with greater corrosion resistance for blading.
- Use of blade coatings
- Inlet filtration
- Compressor cleaning

“Long Term Operating Experience with Corrosion Control in Industrial Axial Flow Compressors”, David Linden, Proceedings of the 40th Turbomachinery Symposium
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High Temperature Corrosion

• The turbine section of gas turbines are exposed to combustion gases at temperatures of more than 850 degrees centigrade.

• At high temperatures, metal can react with oxygen to form scales, consuming the metal. The corrosion process is termed high temperature oxidation. During start and stop of turbines the scales can fall off, allowing the underlying metal to suffer further corrosion.
High Temperature Corrosion

- If there are impurities in the combustion gases, very rapid corrosion can occur.

- Impurities can include sodium and potassium. The impurities can be present as contaminants in the fuel or from salt-laden air at coastal locations.

- The impurities combine with sulphur in the fuel to form salts (e.g., sodium sulphate $\text{Na}_2\text{SO}_4$), which cause breakdown of the oxide films that protect hot path turbine materials. This is termed **hot corrosion**
  
  - Type I - Occurs in the temperature range 815°C and 955°C.
  - Type II – Occurs in the temperature range 595°C and 815°C.
High Temperature Corrosion

Prevention of High Temperature Corrosion

- Blade coatings.
- Removal of contaminants.

“Progress in Gas Turbine Performance”, Edited by Ernesto Benini
Erosion occurs when solid or liquid particles impact against components of the gas turbine and remove small particles from the surface. Typically considered to be associated with particles greater than 10-microns in size. Causes roughening of smooth surfaces creating stress-raising features that promote fatigue cracking.
Creep

- Creep is time – dependent permanent plastic deformation, which generally occurs at high temperatures under a constant load or stress. It can cause a progressive reduction of rotor tip clearances and can ultimately lead to fracture of components.
Creep
Creep

Creep life of Waspaloy

Creep Life (Hours)

Temperature (Centigrade)
Why Do Failures Occur?

Gas turbine failure by category (number of failures)

- Maintenance faults
- Lack of maintenance
- Design Fault
- Faulty manufacture
- Faulty installation
- Misuse
- Unknown
- Others

K.D. Sinfield – IMIA Conference – September 1993
Case Study 1

Failure due to design issues
Failures due to design issues – Compressor damage due to stator blade failure
Compressor damage due to stator blade failure

Stator blade fractured by a mechanism of fatigue
Compressor damage due to stator blade failure
Compressor damage due to stator blade failure
Compressor damage due to stator blade failure
Case Study 2
Failure due to operating issues
Hot corrosion due to fuel contaminants
Hot corrosion due to fuel contaminants
Hot corrosion due to fuel contaminants
Conclusions

• Failures in gas turbines can lead to extensive damage throughout the machine.

• Even modern turbine designs can suffer failures due to some unanticipated design deficiencies.

• Improper maintenance or operation by the user can lead to component failures.