IMPACT OF ENGINE OPERATION ON GAS TURBINE COMPONENT DURABILITY USING DUCTILITY EXHAUSTION

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A CULTURE OF CUSTOMER CARE

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INTRODUCTION

• Reliable operation of gas turbines is key to our customers needs

• Reliability covers a range of potential issues, however material degradation from creep and fatigue presents the most serious of risk

• Industrial gas turbines experience both cyclic loading (variability in operation) and constant loading (extended periods of operation) which leads to both fatigue and creep damage

• The interaction between creep and fatigue can lead to additional damage, which should be considered

• Operational flexibility is important to customers, it is imperative that we understand these interactions in more detail in order to provide better tools for asset management
• What is ductility?
  – Total available strain including plasticity and creep

  – Differences in failure mode occur due to loading rate
DUCTILITY EXHAUSTION AND SUPERALLOYS

• Ductility is Strain Rate Dependent
  − At high strain rates, damage is driven by dislocations
  − At low strain rates, damage is driven by diffusion

![Diagram showing rate dependent ductility](image)
DUCTILITY EXHAUSTION AND SUPERALLOYS

• Ductility Behavior
  – At high strain rates, ductility is high
  – At low strain rates, ductility is low
DUCTILITY EXHAUSTION AND SUPERALLOYS

• Rate Dependent Ductility in Superalloys
  - Comparing ductility between a typical Superalloy and 316H stainless steel, shows the Superalloy has a higher ductility at lower strain rates, resulting in improved creep resistant
  - This introduces challenges for testing, as lower rate tests tend to require significantly more time

• Using Ductility to Calculate Damage
  - Hot section component experience a range of loads
    • Transient loads during start up and shutdown
    • Constant loads during extended periods of operation
  - The stress-strain response to the load cycle can be used to find the varying strain rates

\[
\frac{\Delta \varepsilon}{\Delta t} = \dot{\varepsilon}
\]
DUCTILITY EXHAUSTION AND SUPERALLOYS

• Using Ductility to Calculate Damage
  
  - Strain rate can be used to find the available ductility at that rate
  
  - Damage can then be determined from the incremental strain and the available ductility

\[
\lambda = \int_0^t \frac{\dot{\varepsilon}}{\varepsilon_f(\varepsilon, T)} dt
\]
OPERATIONAL STRESSES IN GAS TURBINE COMPONENTS

- Hot section components experience two principal load conditions
  - Mechanical loads; resulting in primary stresses ($\sigma_p$)
  - Thermal loads; resulting in secondary stresses ($\sigma_s$)

- Rotating components, such as disks, are typically dominated by primary stress (speed)

- Static components, such as nozzles, are typically dominated by secondary stresses (temperature)
OPERATIONAL STRESSES IN GAS TURBINE COMPONENTS

- Primary stresses ($\sigma_p$) give rise to forward creep
  - Increasing strain under constant load

- Secondary stresses ($\sigma_s$) give rise to stress relaxation
  - Also due to creep, but at constant displacement

- Both primary and secondary stresses can give rise to plasticity, resulting in redistribution of stress and strain
THE INTERACTION BETWEEN CREEP AND FATIGUE

- It is the combination of both primary and secondary stresses which leads to interactions between creep and fatigue.

- The potential for interaction is driven by redistribution and relaxation as the peak stresses shakedown.

- The interaction can cause perturbations in stress which can lead to increased damage.
THE INTERACTION BETWEEN CREEP AND FATIGUE

• Interaction occurs when creep is perturbed by a cyclic load

• Relaxation and redistribution occur during dwells in the load cycle, resulting in a stress drop

• At the end of the dwell, the stress unloads resulting in a stress which now exceeds yield at the end of the cycle

• There is insufficient energy to cause plasticity at both ends of the cycle, therefore, the stress is “pinned” at yield

• Upon reloading, the elastic stress range is applied perturbing the peak stress leading to further relaxation and damage
APPLICATION TO GAS TURBINE OPERATION

• This Interaction can also occur between different load cycles

• Variation in both the elastic stress ranges and stresses at the start and end of the cycle, can lead to perturbations

• This exaggerates the non linear accumulation of damage over the operation period
SUMMARY

• An approach has been presented which can predict damage from creep and fatigue interaction using ductility exhaustion.

• Superalloys exhibit rate dependent ductility, which supports a ductility exhaustion approach.

• Interaction between creep and fatigue damage mechanisms can lead to additional damage.

• Damage accumulation from creep and fatigue is non-linear and path dependent.
IMPLICATIONS FOR ASSET MANAGEMENT

• Our common goal is to maximize reliability, availability and operational flexibility

• The continued development of technology is key to achieving this goal

• To support this we must achieve data driven Equipment Heath Management

• Equipment Health Management is no longer just about hours and cycles, its about real time damage modeling
Thank you