Fatigue Analysis of Powertrain Components Including Gray Cast Iron

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**Agenda**

1. Durability challenges in powertrain components
2. Methods of analyzing powertrain component durability
   - Vibration fatigue
   - Safety factor analysis
   - Stress gradient approach for castings
   - Temperature’s effect on fatigue
   - Specialized methods for gray cast iron
3. Summary
Powertrain Durability Challenges

- Powertrain engineering covers a wide range of components that require differing methods for durability assessment.
Designing Around Endurance Limit

- Powertrain engineering covers a wide range of components that require differing methods for durability assessment.

Pistons, crankshafts, valve springs, etc. may be assessed using a safety factor analysis.
Safety Factors in Design: Simple to Complex

- Many parts are designed according to a safety factor.
- What is the ratio of strength to stress?
- The safety factor can be calculated many ways:

\[ \sigma_{VonMises} < \frac{1}{3} UTS \]

- Fatigue limit safety factor
- UTS-based safety factor
- Fatigue limit with mean stress safety factor
- Cumulative damage
- Stress-Life, Strain-Life, etc.
Designing Around Vibration

- Powertrain engineering covers a wide range of components that require differing methods for durability assessment.

Electronics and other under-hood mounted components are signed off with vibration tests.
Vibration Fatigue from Harmonic Stresses

- The response PSD: \( PSD_{\text{stress}}(f) = PSD_{\text{acceleration}}(f) \cdot |FRF(f)|^2 \)
- Derive the statistical cycle distribution based on work by S. O. Rice
Vibration Fatigue from Harmonic Stresses

\[ \sigma_A = [H1]^2 L1 + [H2]^2 L2 + [H1]*[H2] L12 + [H1][H2]* L21 \]

Response PSD and Statistical Cycle Distribution → SN Analysis → Fatigue Results

PSD L1 → CSD L12 → Gain Phase

FRF H1 → FRF H2

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Designing Around Heat

- Powertrain engineering covers a wide range of components that require differing methods for durability assessment.

Turbochargers and exhaust systems require thermo-mechanical fatigue analysis.
Which Temperature Dependent Fatigue Method is Best?

Start

Is stress caused by temperature

No

Isothermal fatigue

Yes

Is $T > 50\%$ of $T_{\text{melt}}$ (K)?

No

Chaboche Transient

Yes

Chaboche Transient & Creep Rupture
Designing with Castings

- Powertrain engineering covers a wide range of components that require differing methods for durability assessment.

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Engine block and other castings require specialized material modelling and fatigue algorithms
Notch Sensitivity and Fatigue of Cast Materials

\[ \frac{d\sigma}{dz} \]

\[ \sigma = \frac{K_t}{K_f} \]

Gray Iron

- Cast iron with graphite flakes for improved manufacturability and damping
- Often used in engine blocks, pump housings, and disk brake rotors
- Graphite flakes are weak and act as voids when loaded
- Leads to higher strength and stiffness in compression than tension
Fatigue of Gray Iron

- Hysteresis loop is no longer symmetric
- Shape changes in loading vs. unloading, and tension vs. compression
- Strain life methodology used with modified plasticity model and Smith Watson Topper damage parameter
- Available in nCode 12.1
9 gray irons are included in the standard nCode material database.
Summary

Methods of analyzing powertrain component durability

- Vibration fatigue
- Safety factor analysis
- Stress gradient approach for castings
- Temperature’s effect on fatigue
- Specialized methods for gray cast iron – new in nCode 12.1
Thank you!

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