Fatigue Simulation for Differential Casing of Farm Tractor through FEMFAT-Max

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Company Background

- M & M: Founded in 1945, a US $15.9 billion multinational group with more than 155,000 employees in over 100 countries.

- India's premier Utility Vehicle (UV) and Farm Equipment company.

- Mahindra is the top-selling tractor brand in the world by volume.
Agenda

- Differential – An Overview
- Analysis Flow
- Finite Element Stress Analysis
- Damage Simulation
- Conclusion
- Acknowledgements
Differential – An Overview

Differential transmits power from drive shaft to the wheels while allowing wheels to rotate at different speeds in turns.

Tractor Differential
Differential – An Overview

Differential Case

- Serves as a housing for various gears and other components that drive the rear axle.

- Undergoes large stress/strain fluctuations within one complete revolution, even under constant driving torque.

- One of the weakest components in the rear axle assembly. Hence it is necessary to accurately predict the strength and durability of differential case at an early stage of design.

Differential case with various gears, pin and bearings
**Analysis Flow**

**Loading History**

<table>
<thead>
<tr>
<th>Torque</th>
<th>No. of cycles</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>N1</td>
</tr>
<tr>
<td>T2</td>
<td>N2</td>
</tr>
<tr>
<td>T3</td>
<td>N3</td>
</tr>
</tbody>
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**Stresses for one complete rotation of Differential Case**

- Torque, T1
- Torque, T2
- Torque, T3

**Damage FEMFAT - Max**

- Scale factor
- Reference Torque, T2

**Cumulative Damage**

- Torque, T1
- Torque, T2
- Torque, T3
Analysis Flow in FEMFAT- Channel MAX

Load cases for stress analysis

Channel history for one complete revolution

Stress history for the actual duty cycle

Orientation of differential case

Load Factor

Equivalent stress

Damage prediction using FEMFAT Channel Max
Finite Element Stress Analysis

FE Model of Differential Assembly

- Differential Case
- Ring Gear (Dummy)
- Bevel Mounting Pin
Load Cases – Forward Gear Condition

Load Case 1 (0°)

Load Case 2 (45°)

Load Case 3 (90°)

Load Case 4 (135°)

Load Case 5 (180°)

Load Case 6 (225°)

Load Case 7 (270°)

Load Case 8 (315°)

Load Cases during One Complete Revolution of the Differential Case
Loads & Boundary conditions for Differential Casing

Apply Tangential Force, Radial Force & Axial Force on the Ring Gear

Bearing Constraints

Bevel Gear Mounting Area Fully Constrained

Bearing Constraints
Variation of Differential Case Stresses - Forward Gear Condition

Von-Misses Stress

Angle: $0^\circ$  
Angle: $45^\circ$  
Angle: $90^\circ$  
Angle: $135^\circ$  
Angle: $180^\circ$  
Angle: $225^\circ$  
Angle: $270^\circ$  
Angle: $315^\circ$
Displacement Plot

Displacement Plot - Forward Gear Condition at an Angle 0°

Variation of Displacement during one complete rotation of Differential Case
Damage Simulation

Total damage calculation from duty cycle:

\[ D = (d_{L1} \times N_{L1}) + (d_{L2} \times N_{L2}) + (d_{L3} \times N_{L3}) + (d_{L4} \times N_{L4}) +
\]
\[ + (d_{H1} \times N_{H1}) + (d_{H2} \times N_{H2}) + (d_{H3} \times N_{H3}) + (d_{H4} \times N_{H4}) +
\]
\[ + (d_{R1} \times N_{R1}) + (d_{R2} \times N_{R2}) \]

- \( D \) = Total Damage
- \( d_{L1}, d_{L2}, d_{L3}, \text{and} \ d_{L4} \) = Damage for 1 block of L1, L2, L3 and L4 gears, respectively
- \( N_{L1}, N_{L2}, N_{L3}, \text{and} \ N_{L4} \) = No. of blocks of L1, L2, L3 and L4 gears, respectively
- \( d_{H1}, d_{H2}, d_{H3}, \text{and} \ d_{H4} \) = Damage for 1 block of H1, H2, H3 and H4 gears, respectively
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- \( d_{R1}, d_{R2} \) = Damage for 1 block of R1 and R2 gears, respectively
- \( N_{R1}, N_{R2} \) = No. of blocks of R1 and R2 gears, respectively

Assume Tractor has 8 forward gears (L1, L2, L3, L4, H1, H2, H3, & H4) and 2 reverse gears (R1 & R2).
Channel Definition in FEMFAT - Max

Load History File

- One rotation

Channel History

8 Load cases considered for each gear
Fatigue Analysis Results

Equivalent Stress History Vs Applied Cycles

Cycles shown for 0.61 of max load (for illustration only)
Damage Contour Plot of Differential Casing

Forward gear

Reverse gear

High Damage Contour Plot

Low Damage Contour Plot

Max. Damage
Conclusion

- Duty cycle based fatigue life prediction method has been presented for differential case under various torque condition.

- The method considers the cyclic variation of differential case stresses during one complete rotation.

- Significant reduction in CAE time and cost due to utilization of stress scaling (load factor) option in FEMFAT-Channel max.

- Damage predictions that are accurate (reduce failures, warranty claims, etc.)