Modeling of Clutch Housing and Facing Temperature for Estimating Clutch Life of a Manual Transmission Vehicle

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**Introduction & Motivation**

**Poor clutch life** is a major issue for some vehicle models.

**Clutch overheating** is the primary cause for clutch failure. The reasons include:

- Vehicle Overloading
- Heavy Traffic
- Riding of Clutch Pedal
- Incorrect Gear Selection
- Poor Low end torque
Impact of Clutch Temperature:

- Safe Zone
- High Clutch Wear

- Temp
- Friction
- Slip
- Torque Transfer

- Clutch Failure
- Disc Wear
Impact of Clutch Temperature:

The wear rate sharply increases when $T > 200 \, ^\circ C$.

The critical temperature of friction materials is about 400 $^\circ C$.

When $T > 400 \, ^\circ C$ the clutch disc will be permanently damaged.

Objective & Scope of the Study

**Objective:**

- Estimate temperature rise on clutch facing & clutch housing.
- Optimize Clutch Design at an early stage of Product Development in conjunction with **supplier provided data** (facing temperature vs wear ratio) for different clutch materials.

**Tools Used:**

- 1D Thermal Simulation by using GT-Suite and Matlab/Simulink
- MathWorks
Theory Behind the Simulation Model

Transmitting torque from the engine (T) - Resistance Torque ($\tau_{drv}$) = Drive Torque + Clutch Slip

Convection
- Housing Dissipates Some Heat to Ambient

Dissipated Energy
- Heats Up Air Within Clutch Housing

Thermal Energy
- Heats Up Frictional Components
- Heat Energy Generated

Torque Loss
- Engine
- GB
- Clutch Housing
- T High
- T Low
- CSC (T Avg)

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Theory Behind the Simulation Model

Step (1): The torque that a clutch can transfer from an engine is obtained by the equation below:

\[ T \cdot \text{FOS} = N_f \cdot R_m \cdot \mu \cdot F_a \]

- \( T \) = Transmitting torque from the engine
- \( \text{FOS} \) = Factor of safety is 1.3
- \( N_f \) = Number of sliding surfaces
  - \((\text{Single clutch}=2; \text{Twin clutch}=4)\)
- \( R_m \) = Clutch mean or effective radius
- \( \mu \) = Friction coefficient of the clutch linings
- \( F_a \) = Clamping load

LuGre Friction Model

This friction model is based on the idea of intermeshing bristles that transmit the friction load between contacting bodies. The bristle model captures micro slip and also the drop in friction as the sliding speed is increased.

Clamp Load – The load exerted by the diaphragm to clamp the clutch disc between pressure plate & flywheel
Theory Behind the Simulation Model

Step (2): Resistance torque generated by the driveline & vehicle during vehicle launch is obtained by:

\[
\tau_{drv} = \left( I_{\text{trans}1} + \frac{I_{\text{trans}2}}{R_t^2} + \frac{I_{\text{dsh}}}{R_t^2} + \frac{I_{\text{axl}}}{R_d^2 R_t^2} + \frac{M_{\text{veh}} r_{\text{whl}}^2}{R_d^2 R_t^2} \right) \frac{d\omega_{drv}}{dt} + \left( \frac{F_{\text{aer}} + F_{\text{rol}} + F_{\text{grad}}}{R_d R_t} \right) r_{\text{whl}}
\]

- \( \tau_{drv} \) = Resistance torque
- \( I_{\text{trans}} \) = Transmission inertia
- \( I_{\text{dsh}} \) = Driveshaft inertia
- \( I_{\text{axl}} \) = Axle inertia
- \( M_{\text{veh}} \) = Vehicle mass
- \( r_{\text{whl}} \) = Wheel dynamic rolling radius

\( d\omega_{drv} \) = Angular speed of input shaft

\( R_t \) = Transmission ratio

\( R_d \) = Final drive ratio

\( F_{\text{aer}} \) = Aerodynamic resistance force

\( F_{\text{rol}} \) = Rolling resistance force

\( F_{\text{grad}} \) = Gradient resistance force
**Step (3): Clutch energy is calculated by using the below equation**

\[
E = \int_{t_i}^{t_c} \Delta T_t \cdot \Delta \omega_t \cdot dt
\]

- **E** = Clutch energy; **ti** = Initial temperature
- **tc** = Critical temperature; **\Delta T_t** = Torque range
- **\Delta \omega_t** = Angular speed bet’n engine & gearbox
- **D** = Outer diameter of clutch; **d** = Inner diameter of clutch

**Power** = \( \frac{E}{t} \)

**Step (4): Clutch temperature is calc. by using thermal conductance**

- **Thermal Conductance** = \( \frac{W}{m^2 \cdot K} \)
- **Area** = \( \frac{\pi (D^2 - d^2)}{4 \cdot N_f} \)
Step (5): Clutch wear is calculated by using the below equation:

\[ \text{Total volume worn off (mm}^3\text{)} = \text{Friction energy dissipation (MJ)} \times \text{Wear rate (mm}^3\text{/MJ)} \]
Step (6): Clutch useful volume is calculated by using below equation

\[
\text{Clutch useful volume (mm}^3\text{)} = \text{Clutch area (mm}^2\text{)} \cdot \text{Clutch useful thickness (mm)}
\]

Step (7): Finally, Clutch life is obtained by using below equation

\[
\text{No of cycles} = \frac{\text{Clutch useful volume}}{\text{Total volume worn off}}
\]

\[
\text{Clutch life (km)} = \text{Drive cycle distance (km)} \cdot \text{No of cycles}
\]
Input Data Requirements

- **Vehicle**
  - Vehicle Weight
  - Tyre Size
  - Coast Down

- **Powertrain**
  - Engine Performance Maps
  - Engine & Driveline Inertias
  - Driveline Ratios
  - Driveline Efficiency

- **Clutch**
  - Clutch Disc & Clutch Housing
    - Mass
    - Surface Area
    - Material
  - Clutch Sizes
  - Friction Coefficients
  - Heat Transfer Coefficients

- **Driver & Climate**
  - Drive Cycle
  - Road Grade
  - Ambient Temperature
Drive cycle data (~27 km) was collected in Chennai city during peak traffic.

~ 30 repeated launches in 1200 sec was observed (~1.2 km), which means every 40 sec/launch occurs.
Clutch Thermal Simulation Model
Clutch Thermal Simulation Model

- **Clutch**
  - Thermal Mass representing the Clutch Plates for Temperature calculation based on Friction Heat Rejection.

- **Housing**
  - Thermal Mass representing the Clutch Housing

- **Ambient**
  - Ambient Temperature

- **Convection**
  - Energy_Loss+FrictionHeat
  - Rec_Dissip-1
  - Clutch_to_Housing-1
  - Air-1

- **Conduction**
  - Lookup_Wear_Rate-1
  - Temperature-1
  - Test-1
Simulation Model
Passenger Vehicle (SUV) was used for testing.

The thermocouple was inserted in Clutch housing & temperature was measured.

Test data collection was started once the air within the clutch housing reached 80 deg. C.
Vehicle/Engine Speed Comparisons

The simulation method is forward looking model

Good correlation is observed for vehicle and engine speeds
Clutch Temperature Simulation Results

- Simulation model predicts both clutch facing and housing temperatures
- Out of which the **clutch housing temperature** can be measured easily during testing
Simulation Vs Test Results

- Clutch temperature simulation model shows an excellent correlation (> 90%) with the test results.
Sensitivity Analysis Results

**Final Drive Ratio (FDR)**

- Better FE
- Better High Speed NVH
- Better In-Gear Elasticity

**Vehicle Weight**

- Better Clutch Life
- Better Launch NVH
- Better In-Gear Acceleration
- Better Gradeability

**Road Grade**

**Tyre Size**

Right Trade-Off
Clutch Life Estimation (Example)

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cumulative Wear (mm³)</td>
<td>170</td>
</tr>
<tr>
<td>Clutch Useful Volume (mm³)</td>
<td>43982</td>
</tr>
<tr>
<td><strong>Number of Cycles</strong></td>
<td>258</td>
</tr>
<tr>
<td>Cycle Distance (km)</td>
<td>0.71</td>
</tr>
<tr>
<td><strong>Total Distance (km)</strong></td>
<td>183</td>
</tr>
</tbody>
</table>
Applications

Different Facing Material

Optimize the Target Performance based on Benchmark

Optimize the Clutch Design
Conclusion

- **Clutch overheating** is the primary cause for clutch failure.

- By using **1-D thermal modeling**, clutch facing & housing temperature are simulated.

- Simulation results show an **excellent correlation (> 90%)** with the test data.

- FDR has a huge impact on Clutch wear, FE, Drivability & NVH. Hence, doing a **right trade-off** is very critical at an early design stage.
References


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Thank you for your attention!