Manufacturing Process Precision Effects on Life Cycle Impacts of Automotive Drivetrain

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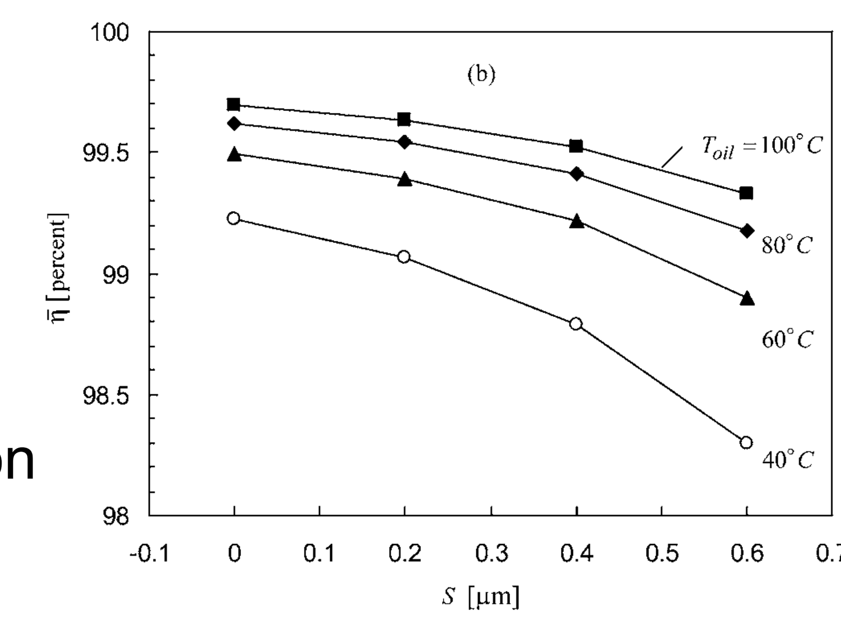
Motivation

- Manufacturers have become increasingly responsible for the environmental impact of their products throughout all life cycle stages
- Manufacturing decisions can have a direct effect on product use (e.g. operational efficiency, service life)
- Therefore, it is important to evaluate effect of manufacturing decision on life cycle environmental impacts
- Products with environmental impacts dominated by their use phase may be especially affected by manufacturing decisions

Introduction

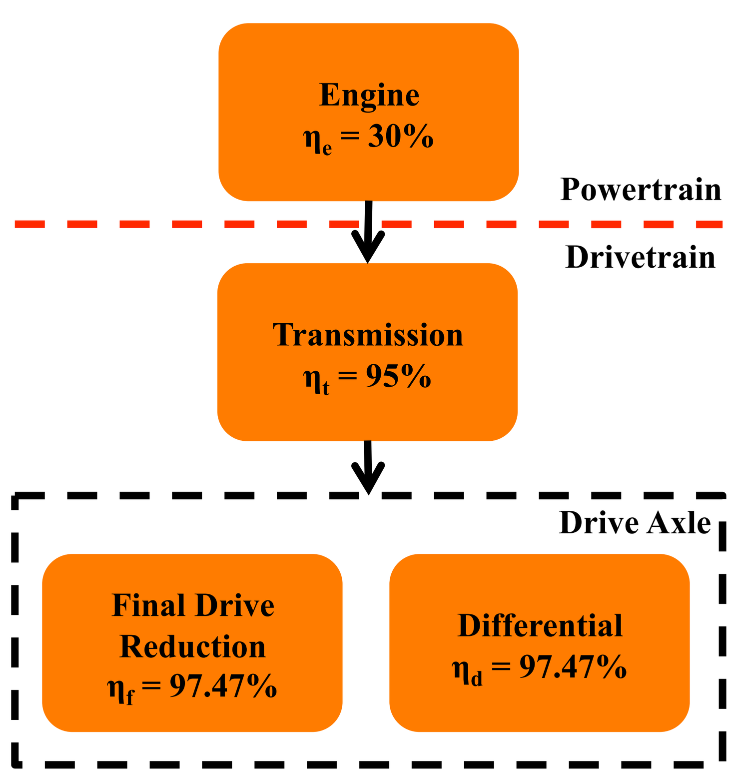
- Efficiency of gear systems strongly influenced by manufacturing process:
  - Surface roughness of mating surfaces
  - Assembly errors (e.g. shaft misalignments)
  - Form errors
- Objective was to study impact of increased manufacturing precision through higher surface finish of final drive reduction on life cycle environmental impacts of an automotive drivetrain



Relationship between gear mesh efficiency, η, and RMS surface roughness, S, for different inlet lubrication temperatures, T_{oil}, for a gear set modeled after an automotive final drive reduction (Xu, et al. 2007).

General Vehicle Model

- Vehicle based on Honda Civic:
  - Vehicle mass, M = 1193kg
  - Frontal area, A_r = 2m^2
  - Drag, C_d = 0.30
  - Rolling resistance, C_{rr} = 0.013
- Functional load:
  - 1.2 passengers each weighing 71.2kg and carrying 7kg of luggage
  - Fuel tank assumed 55% filled (13gal tank)
- Functional life 130000km



Simplified powertrain and drivetrain

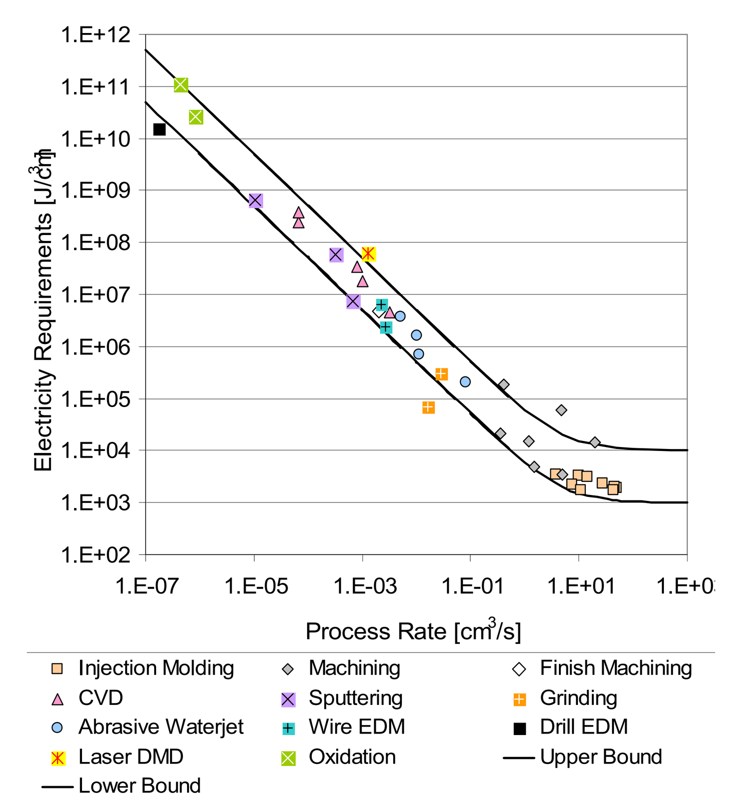
Manufacturing Phase Analysis

- Empirical surface roughness relationship for grinding (from Malkin & Guo 2008):

$$Q_{w2} = Q_{w1}\left(\frac{R_{a2}}{R_{a1}}\right)^{1/x}$$

R_a average height surface roughness
Q_w volumetric removal rate
x experimentally defined constant

- Representative process:
  - Process rate ~10^{-2}cm^3/s
  - Specific energy ~200000J/cm^3
- Volume of modeled gear pair
  - Surface area ~21055mm^2
  - DOC = 1mm
- Michigan energy mix



Specific energy requirements of various manufacturing processes varied by process rate (Gutowski, et al. 2006)

Use Phase Analysis

- Change in fuel consumption dependent on change in power that must be delivered by fuel:

$$\Delta P_{fuel} = \frac{P_{tractive}}{\eta_e\eta_t\eta_d}\left(\frac{1}{\eta_{f2}} - \frac{1}{\eta_{f1}}\right)$$

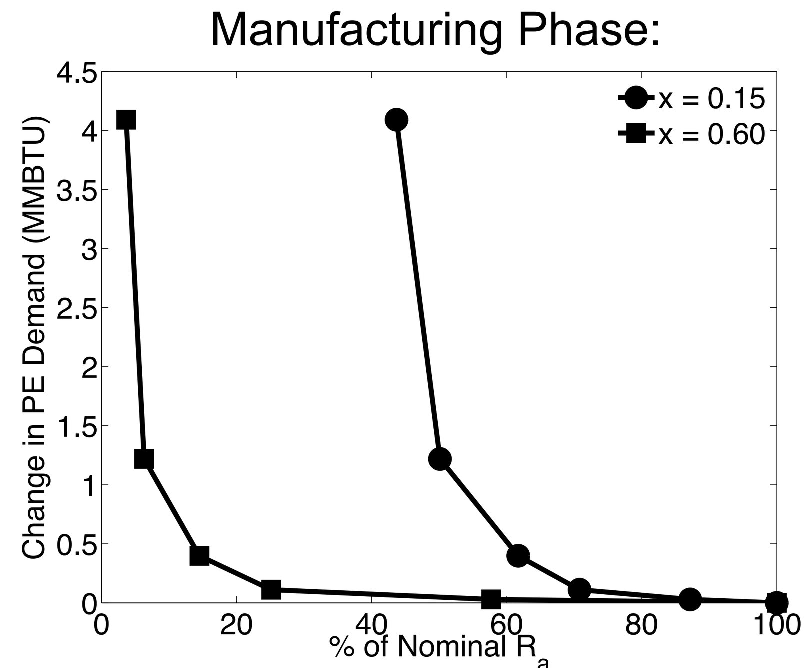
$$P_{tractive} = v\left(ma + mg\sin\theta + mgC_{rr} + \frac{1}{2}\rho_{air}v^2A_rC_d\right)$$

Where:
v velocity of vehicle
m total mass of vehicle and load
a commanded acceleration of vehicle
g acceleration due to gravity
θ road grade
ρ_{air} = 1.225kg/m^3 at 15°C and 101.32kPa

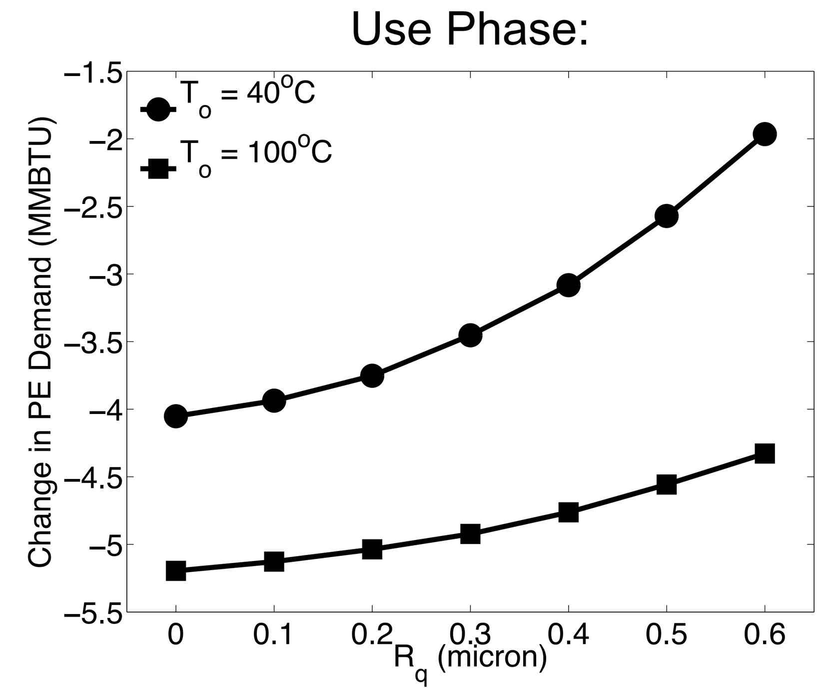
  - Neglects power for accessories and idling powertrain
- U.S. EPA FTP-75 used as standard driving cycle
  - Deceleration events removed from calculations
- Fuel was regular, unleaded gasoline
  - Engine assumed to fully combust fuel

Results

Manufacturing Phase:



Use Phase:



- Comparing both results indicates that improving manufacturing precision of the final drive reduction can provide a substantial reduction in life cycle impacts
- Since final drive reduction is one of several gears in automobile, impact of manufacturing precision on use phase could be much greater
- Increased precision may also increase service life, which would further reduce life cycle impact of automotive drivetrain

Conclusion

- Relationship exists between the manufacturing process precision of a product and its environmental impacts over its entire life cycle
- In the case of automotive drivetrain components, increased process precision can reduce life cycle environmental impacts
- Manufacturing process precision should be improved if resources required for improvement are less than potential benefit of improvement

Future Work

- Refinement of data and analysis
- Explore causal effects
- Extend to other manufacturing considerations and environmental impacts
- Extend to other products
- Extend traditional LCA methodology to evaluate the impact of process precision and other manufacturing considerations on the functional performance of a product during use

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