EVALUATION OF POWERTRAIN START ABILITY DURING ENGINE COLD START AT LOW BAROMETRIC CONDITIONS

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AGENDA

INTRODUCTION  Page 3

DYNAMIC METHOD – MODEL SET-UP  Page 7

RESULTS  Page 12

CONCLUSIONS  Page 19
INTRODUCTION
PROBLEM DEFINITION

Small cylinder displacement
Extremely low ambient temperature and pressure
Low firing frequency
More restrictive NVH requirements

Limited amount of indicated torque during engine cold start attempt
High friction torque
More challenging crankshaft speed build up

Downsized engines can show very long cranking times or, in the worst case, they are not capable of accelerating above cranking speed (unassisted start not possible)
STATIC METHOD – SIMPLE APPROACH

- Indicated Torque calculated by means of GT-Suite engine model in “Speed Mode”
- Torque Balance evaluated at several constant cranking speed: 100, 150, 200, 250, 300, 350 rpm

\[
\text{Indicated Tq} > \text{Engine Friction Tq} + \text{Trans Friction Tq} \implies \text{Positive Brake Torque}
\]

\[
\text{Indicated Tq} < \text{Engine Friction Tq} + \text{Trans Friction Tq} \implies \text{Negative Brake Torque}
\]
DYNAMIC METHOD – ADVANCED APPROACH

- Use detailed GT-Suite engine model in “Load Mode”
- Consider Starter behavior (torque vs. speed characteristic)
- Consider Engine and Transmission Friction
- Consider Flywheel behavior and characteristic of the crank-slider mechanism
DYNAMIC METHOD – MODEL SET-UP
Dual Mass Flywheel introduces additional complexity in the engine start-up process, due to interaction of its dynamic behavior with the crankshaft speed build-up.
Starter output torque fluctuates during an engine cycle, providing more torque when the crankshaft decelerates and vice-versa.
**DYNAMIC METHOD – MODEL SET-UP**

**“3 TERMS” EMPIRICAL ENGINE FRICTION MODEL**

**Cold FMEP vs. Engine Speed**

From experimental measurements

**FMEP multiplier vs. Temp.**

Reference FMEP measurement temperature

FMEP multiplier vs. Ambient/Oil temperature applied to reference FMEP

**Additional FMEP multiplier:**

to cover friction reduction over time @
constant cranking speed due to local oil
temperature increase (shear stresses)

Based on experimental measurements
ADDITIONAL ASSUMPTIONS

- Empirical Combustion Model based on cold engine in-cylinder measurements
- Fuel fully evaporated
- Global Lambda based on engine calibration
- Imposed combustion efficiency (based on cold engine measurements) assumed to cover all issues with fueling, evaporation, mixture preparation and combustion
- Low speed cylinder leakage modeled
RESULTS
RESULTS – MODEL CORRELATION

Model results vs. experimental measurements
Both transient crankshaft speed profile over time and time to start are well captured in simulation

Measurements set-up:
- Engine: 3cyl 1.0 TC
- Vehicle: Opel Adam
- Transmission: 6 gears MT
- Flywheel: DMF
- 3 different sets of boundary conditions resulting in 3 different start behaviors: long, average and fast (wide time-to-start range covered)
RESULTS – MODEL CAPABILITY

Sensitivity Study: Impact of different ambient and oil temperature levels
The dynamic approach can capture the impact on time to start of different ambient and oil temperature levels

**Ambient/Oil Temperature Impact**

- Engine: 3cyl 1.0 TC
- Vehicle: Opel Adam
- Transmission: 6 gears MT
- Flywheel: DMF
- Same ambient pressure level
- 3 different ambient/oil temperature levels
RESULTS – MODEL CAPABILITY

Sensitivity Study: Altitude Impact (low barometric conditions)
The dynamic approach can capture the impact on time to start of different barometric conditions.

- Engine: 3cyl 1.0 TC
- Vehicle: Opel Adam
- Transmission: 6 gears MT
- Flywheel: DMF
- Same ambient/oil temperature level
- 3 different altitude levels

Altitude Impact
RESULTS – MODEL CAPABILITY

Sensitivity Study: Impact of different starter characteristics
The dynamic approach can capture the impact on time to start of different starter torque characteristics over rotational speed

Starter Characteristic Impact

- Engine: 3cyl 1.0 TC
- Vehicle: Opel Adam
- Transmission: 6 gears MT
- Flywheel: DMF
- Same ambient conditions
- 3 different Starters
RESULTS – MODEL CAPABILITY

Sensitivity Study: Impact of different hydraulic VCP Parking Position Strategies
The dynamic approach can capture the impact on time to start of different engine subsystem setups and/or calibrations

VCP Parking Position Impact

- Engine: 3cyl 1.0 TC
- Vehicle: Opel Adam
- Transmission: 6 gears MT
- Flywheel: DMF
- Same ambient conditions
- 3 different VCP parking position strategies
RESULTS – MODEL CAPABILITY

Sensitivity Study: Impact of different Flywheel Concepts
The dynamic approach can capture the impact on time to start of different mechanical device layouts

Flywheel Impact

- Engine: 3cyl 1.0 TC
- Vehicle: Opel Adam
- Transmission: 6 gears MT
- Same ambient conditions
- Flywheel: SMF vs. DMF
CONCLUSIONS
CONCLUSIONS

- The dynamic method takes into account the contribution of the starter, in terms of positive torque delivery
- Friction reduction over cranking time due to local oil temperature increase (shear stress) can be taken into account (empirical model)
- Good correlation between experimental measurements and simulation results has been achieved
- Both transient crankshaft speed and time-to-start can be well captured
- Impact of different starter characteristics can be evaluated
- Impact of engine size and number of cylinders into the selection of the best starter matching in terms of time-to-start optimization can be estimated
- Impact of damping effect on the crankshaft acceleration of dual mass flywheel (DMF) can be taken into account
- Impact of engine parameters such as hydraulic variable cam phasers parking timings during engine cranking can be quantified
THANK YOU FOR YOUR ATTENTION! 
QUESTIONS?