Holistic Design of a cam phaser

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Motivation

Complex systems, such as combustion engines, should be viewed as wholes, not as a collection of parts.

Following this approach the motivation for this examination is to analyze the hydraulic cam phaser in an engine environment with it’s influences in this complex system.
Structure

1. Introduction
   - Design and Function of a Hydraulic Cam Phaser
   - Task Definition for 1D Simulation GT-Suite

2. Configuration of the Simulation Model in GT-Suite
   - Overall Model
   - Oil Pump
   - Oil Circuit
   - Valvetrain
   - Cam Phaser

3. Calibration of the Simulation Model
   - Cam Phaser
   - Valvetrain
   - Oil Pump

4. Selected Results and Method of Analysis
   - Evaluation Method (3D Map)
   - Control Accuracy

5. Conclusion
1. Introduction

- Design and Function of a Hydraulic Cam Phaser
- Task Definition for 1D Simulation GT-Suite
1. Introduction

Design and Function of a Hydraulic Cam Phaser

Cylinder head of a 4-cylinder gasoline engine with two cam phasers

Cam phaser inlet
1. Introduction

Design and Function of a Hydraulic Cam Phaser

Electromagnetic valve actuator
Sprocket
Vane piston
Camshaft
Position valve with piston
Lock pin

Valve lift [mm]

Crankangle

Inlet

Outlet
Design and Function of a Hydraulic Cam Phaser

1. Introduction

Electromagnetic valve actuator

Sprocket

Vane piston

Camshaft

Position valve with piston

Lock pin
1. Introduction

Challenges and Chances & Tasks for 1D-Simulation

Challenges for hydraulic cam phasers
- Phase rate \([°\text{Crank/ sec}]↑\)
- Phase range \([°\text{Crank}]↑\)
- Control readiness \([\text{s}]↓\)
- Control accuracy \([°\text{Crank}]↑\)
- Fail Safe
- Volumetric Oil flow losses \([\text{l/min}]↓\)
- Operational under oil pressure limitations

Task definition for 1D Simulation GT-Suite
- Which phase rates \([°\text{Crank/s}]\) can be achieved dependent on the operating point of the engine?
- Which (physical) control accuracy can be achieved dependent on the operating point of the engine?
- How much time is needed after engine start until cam phaser is ready?
- How high is the pressure drop due to phasing?
- Does the Camphaser lock and unlock as intended?

➢ Concept review and optimization
➢ Reduction of testing effort
2. Configuration of the Simulation Model in GT-Suite

- Overall Model
- Cam Phaser
- Oil Circuit
- Valvetrain
2. Configuration of the Simulation Model in GT-Suite

Holistic Cam Phaser Simulation

**Input**
- Engine State
  - Crank-Speed
  - Oil-Temperature
  - Load
  - ...

**Output**
- Engine State
  - Map of phase rate
  - Control accuracy
  - Shifting readiness
  - ...

**Variable Valvetrain**
- flatter lobe / steeper lobe
- High Pressure Pump operating point
- ...

**Cam phaser**
- Phaser Design
- ...

**Oil circuit**
- Pressure stage of the Oil pump
- Piston cooling
- Oil properties (e.g. Gas fraction)
- ...

**Post Processing**
- Map generation
- Interpolation
2. Configuration of the Simulation Model in GT-Suite

GT Map – Overall Model

cranktrain

oil pump

oil circuit

valvetrain

cam phaser
GT Map – Oil Pump

The geometry of the conveying chamber and the inlets and outlets are measured in CAD.
2. Configuration of the Simulation Model in GT-Suite

GT Map - Oil Circuit

→ Simplified oil circuit. Never the less the volumes and pressure drops have to correspond the real oil circuit.

control line to oil pump

map $\Delta p = f(Q, T, \text{Rho})$ of oil/water heat exchanger

from oil pump

map $\Delta p, Q = f(n, T)$ of the remaining engine

map $\Delta p, Q = f(n, T)$ of the second cam phaser (or detailed camphaser if needed)
2. Configuration of the Simulation Model in GT-Suite

**GT Map – Valvetrain**

The valvetrain was simplified in order to improve computing speed. The influence of these simplifications on the torque at the cam phaser are very small. As stand alone model in quasi-dynamic mode the computing speed is < 10 sec./Period.
2. Configuration of the Simulation Model in GT-Suite

GT Map – Cam Phaser

lock pin

vane piston

central valve
3. Model Calibration

- Cam Phaser
- Valvetrain
- Oil Pump
3. Model Calibration

Calibration of Hydraulic Properties via CFD

- Flow rate
- Pressure drop
3. Model Calibration

Phase Rate of Cam Phaser

Operating point: 1000 RPM; 90°C oil temperature
3. Model Calibration

Calibration of Valvetrain Model
Alternating Torque – Low RPM

Graph showing comparison of GT instantaneous plot data and Engine test bench data at 500 rpm.
3. Model Calibration

Calibration of Valvetrain Model
Alternating Torque – Medium RPM

![Graph showing calibration data]

- GT Instantaneous plot data 3000rpm
- Engine test bench data 3000 rpm

Angle [deg]
3. Model Calibration

Calibration of Valvetrain Model

Mean Torque

deviation less then 10% for all operating points

Crank speed [rpm]
Comparison of the Results with Measurements on the Reduced Test Stand.

Time Constant for Free=>Dissolved Air

\[ T_{f->d} = 5 \text{ s} \]

The air is entirely free.

Good consistency of the calculated pressure curve with the measured pressure curve.
4. Selected Results and Method of Analysis

- Evaluation Method (3D map)
- Control Accuracy
4. Selected Results and Method of Analysis

Determination of a Phase Rate Map as a Function of the Motor Constraints

Full Factorial DOE
(Variation of speed, temperature and load)

Performance Calculation for discrete operating points

Interpolation and visualization
4. Selected Results and Method of Analysis

Camphaser Performance Map

early intake closing

late intake closing

Camtronic - steeper lobe

Camtronic - flatter lobe
Control Accuracy During Controlled Operation

Definition of control accuracy:

- Phase angle at crank speed 750 rpm
- Time [s]

Variation of Oil Temp.

- 30°C
- 60°C
- 90°C
- 120°C
- engineering target

4. Selected Results and Method of Analysis
5. Conclusion
Conclusion

• Reliable performance predictions, even with complex correlations, can be achieved with GT-Suite 1D modeling.

• Optimization of the component design in the engine environment.

• Significant reduction of test bench time and testing costs via 1D Simulation.

• Increase the stage of maturation before prototype is built.

• Standard process in MB design verification.

Thank you for your attention. Questions?