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Oil Circuit Optimization for Fast Turbocharger Feeding

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I. Goal of Analysis

The aim of this work is to improve the **Time To Oil at turbocharger** inlet of a diesel engine for **construction equipment** and **agriculture** applications. Below the main requirements that engine should be able to guarantee:

1. **HIGH RELIABILITY** → hard working conditions, long service intervals and cheap maintenance
2. **LOW-END TORQUE** → high hydraulic parasitic loads from idle to maximum engine speed
3. **QUICK POWER** → power output available immediately after the cranking phase

**HIGH ENGINE PERFORMANCE AND RELIABILITY CAN LIVE TOGETHER IF SUPPORTED BY ROBUST LUBRICATION SYSTEM**

The analysis done is focused on the behaviour of system during priming process in cold conditions and several improvements have been evaluated:

- **MODIFICATION OF BASELINE CIRCUIT** (oil cooler bypass)
- **NEW ARCHITECTURE** (main gallery control)
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II. 1D Model Development (1/2)

The 1D model has been developed starting from GEM3D approach, this can help for better understanding the complex network of channels and make easier the model build-up.
II. 1D Model Development (2/2)

All system’s components have been taken in account and implemented in the 1D model:

- **Ducts from oil pan to each end-users**
  → GEM3D approach

- **Oil pump**
  → performance map imposed (flow rate as function of: pressure rise, oil type and temperature, pump speed)

- **Oil cooler and filter**
  → real volume with tuned orifice

- **Pressure control valve**
  → variable orifice diameter controlled by spring valve law (no dynamics effect)

- **Bearings and bushings**
  → predictive model with real load applied (cylinder pressure rise, valvetrain load, power take off load)
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III. Steady-state Validation (1/2)

The validation of model was performed for the BASELINE architecture in steady-state condition with hot oil and different engine speeds, from idle to rated speed.

Good matching of oil pressure can be reached by:

- tuning of oil cooler and filter (pressure loss curve);
- playing with bearing clearances in the admitted range (high effect on flow rate and therefore also on the pressure);
- playing with pressure control valve tolerances (spring stiffness).
Pressure control valve starts opening over 1800 eRPM and the pump matching looks good (enough pressure at low engine speed in hot conditions).
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IV. Priming Analysis & Validation (1/2)

The worst condition for **Time To Oil** is the priming process at **low temperature** (high oil viscosity) and turbocharger is one of most critical end-users (high revolution speed).

Below the model set-up used for the priming analysis:

- Engine @ idle speed
- 10w-40 oil @ -15° C (≈ 3500 cSt)
- Dry circuit complete filled with air
- 4,2 simulation seconds / running hour
- Explicit Solver (accurate solution)
- 15 mm discretization length (plug flow)
- No thermal effects

**MOVING FROM 110° C TO -15° C THE KINEMATIC VISCOSITY IS INCREASED BY A FACTOR OF 300x FOR 10w-40 OIL**
IV. Priming Analysis & Validation (2/2)

PRIMING PROCESS FROM FULL DRY SYSTEM – 1150 eRPM – 10w40 @ -15° C

Good predictions of pressure rising after pump and **Time To Oil** at turbocharger inlet port.

Significant differences in pressure values at filter outlet and turbo inlet due to a **rough tuning** of oil cooler and filter in cold condition.
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Cheap oil circuit with one spring valve for both the functions of overpressure and control.

Control valve with feedback from pump downstream (blind system to the required main gallery pressure).

Weak performance during cold start (loss of net flow) and remote oil filter applications (loss in series).
PRIMING PROCESS FROM FULL DRY SYSTEM – 800 eRPM – 10w40 @ -15° C

\[ t=100\% \] is the timeframe in which the lowest threshold value of pressure (p. target) is reached at turbo inlet for BASELINE layout and all the priming analyses are referred to this time-scale.
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V. Oil Cooler Bypass (1/3)

Same architecture like BASELINE with an additional bypass on the oil cooler.

- Cooler bypass helps to reduce the pressure rising after pump and get more net flow through the system.

- Oil cooler bypass is a **Differential Pressure Activated** made by a spring-valve (loss of pressure).
V. Oil Cooler Bypass (2/3)

PRIMING PROCESS FROM FULL DRY SYSTEM – 800 eRPM – 10w40 @ -15°C

Oil cooler bypass shows a valuable effect in reduction of Time To Oil, up to 25% referred to BASELINE performance.

All the pressure curves, except the pump outlet (control valve not changed), are higher and shifted on left side than BASELINE.
V. Oil Cooler Bypass (3/3)

PRIMING PROCESS FROM FULL DRY SYSTEM – 800 eRPM – 10w40 @ -15°C

Oil Flow Management

High net flow

Cracking pressure of cooler bypass

High net flow through the system during the first phase of priming allows the reduction of Time To Oil at turbocharger inlet.
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V. Main Gallery Control (1/3)

New circuit architecture with an additional relief valve, oil cooler bypass and new feedback signal for controlling the oil pressure:

- Control valve feedback from main gallery (reliable signal, remote oil filter compensation).
- High net flow through the system during cold priming thanks to the high cracking pressure of relief valve (2 times higher than control).
- Expensive circuit with 2 components for managing the oil pressure (relief & control valves).

*relief valve works directly with the pressure after pump.
V. Main Gallery Control (2/3)

PRIMING PROCESS FROM FULL DRY SYSTEM – 800 eRPM – 10w40 @ -15° C

Time To Oil at turbocharger is 60% less than BASELINE layout.

The oil pressure in the system is quite high, but the relief valve avoids too high peaks during cold start.
V. Main Gallery Control (3/3)

PRIMING PROCESS FROM FULL DRY SYSTEM – 800 eRPM – 10w40 @ -15° C

In the first part of transient all the delivery flow goes through the system (blue line close to the red one in the left graph).  

Control the oil pressure from main gallery is the best strategy in order to guarantee a fast priming, specially during cold start.
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- **GT-Suite** is a powerful tool in lubrication system development/analysis: GEM3D is a great approach for understanding the geometry of complex networks and GT-ISE’s libraries offer a wide field of tools for the 1D modeling.

- Measurements in **COLD CHAMBER** are very expensive and GT-Suite has the right capabilities to ensure reliable results. The model has to be fine-tuned when the focus moves from hot to cold condition (pressure drop of filter and cooler).

- **BASELINE** circuit is not suitable for fast priming at low temperatures. The high viscosity of oil causes the early opening of main bypass with too low net flow through the circuit.

- The additional **OIL COOLER BYPASS** allows to improve the Time To Oil at turbocharger about 25% (effect starting from BASALINE layout), but this solution works very well if coupled with main gallery control (more pressure available).

- **MAIN GALLERY CONTROL** is the best solution and reduction of Time To Oil up to 60% has been foreseen. This architecture makes the circuit robust against low temperatures and remote oil filter applications, but needs 2 additional valves if compared to BASELINE (cooler bypass and relief valves).
QUESTIONS???

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