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Development of an Intelligent Thermal Management System for BYD DM-i Hybrid Engine

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Abstract

BYD recently introduced its new DM-i (Dual Mode-Intelligent) plug-in hybrid architecture with a new dedicated 1.5NA (Naturally Aspirated) high-efficiency engine, which can reach a peak of 43% brake thermal efficiency. With this architecture, the vehicle is mainly driven by motors and engine only starts when required. This requires that once started, the engine can reach its best working temperature as quick as possible. To achieve this target, a new intelligent thermal management system was designed. This system adopted an advanced split cooling strategy to control the flow ratio between cylinder block and head, which was realized by the combination of one electronic thermostat and one wax thermostat. An electronic water pump was used to actively control the coolant flow rate. Together with the intelligent control of thermal needs under all working conditions, the new thermal management system realized the following benefits: faster engine warm-up, better fuel economy and lower pollutant emissions. 1D (One Dimensional) simulation was used to optimize the flow ratio between cylinder block and head. By analyzing the flow distribution, temperature level and pressure drop of each component in the HT (High Temperature) loop and LT (Low Temperature) loop, the cooling performance of this new thermal management system was evaluated and optimized. 3D (Three Dimensional) simulation was used to optimize the flow channel design. Finally, the performance of the thermal management cooling system was validated on the engine test bench and the coolant temperature was calibrated for the whole engine map.

Introduction

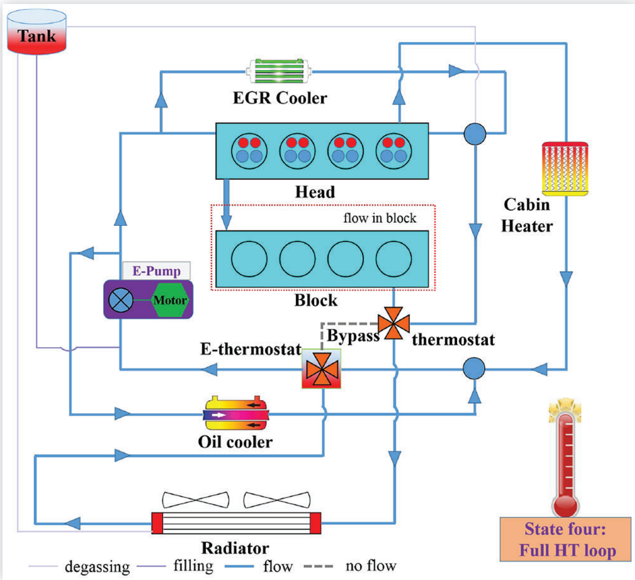
The intelligent engine thermal management system is able to decouple the cooling system operation with engine speed. The traditional mechanical driven parts are replaced by electrical ones, such as electronic water pump, electronic thermostat and electronic fan, etc., so that the cooling performance can be precisely controlled with the optimized control strategy. The performance of the thermal management system is critical to realize good fuel economy and reduced emissions. A good engine thermal management system should be able to realize the following functions [1]:

1. Keep the engine working at the optimal temperature, reduce knock tendency and improve fuel economy.
2. Reduce the engine parasitic loss, shorten the warm-up time and reduce emissions.
3. Keep the optimal oil temperature to reduce engine friction and wear, increase the engine service interval and durability.

Lots of researches have been done in the last few decades on the intelligent engine thermal management system. Cipollone et al. [2] used 1D simulation to study the effect of double cooling circuits at different temperatures on engine performance. Results showed that the engine warm-up time can be reduced by 30% with 4%~5% benefit in fuel consumption. Castiglione et al. [3] proposed a Robust Model Predictive Control (MPC) methodology for quick engine warm up, which reduced 60% the coolant flow with the help of electronic water pump. Results showed that compared to the traditional cooling system, it took 180 seconds less for the cylinder wall to be warmed up to 120°C. Cortona et al. [4] designed and simulated the performance of two cooling system setup, one with an electronic water pump and a wax thermostat, another one with an electronic water pump and an electronic thermostat. Results were validated with bench test data. It was shown that the combination of electronic water pump and electronic thermostat can precisely control the coolant temperature, reduce the water pump energy consumption and achieve quick engine warm up. Choukroun et al. [5] developed an intelligent thermal management system consisting of an electronic water pump, an electronic thermostat and an electronic fan. The performance was checked by simulation and validated by wind tunnel test results. It was shown that this concept allowed a reduced warm-up time by 50% and 2%~3% fuel consumption on the NEDC cycle.

BYD introduced a new DM-i plug-in hybrid architecture recently, aiming to have an fuel consumption lower than 4.0 L/100 km. In order to meet the requirement, a new 1.5L DHE (Dedicated Hybrid Engine) was developed. The compression

FIGURE 19 The external circulation.



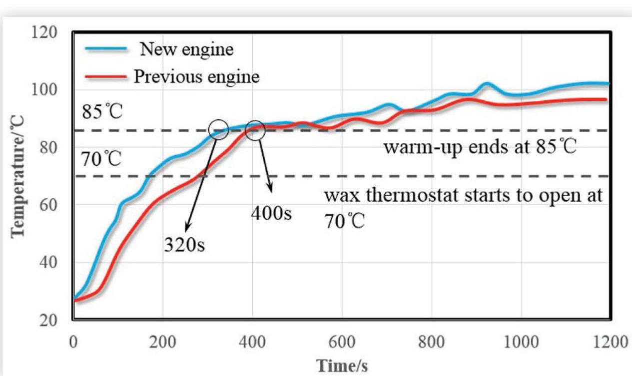
State Four: HT Loop

As shown in Figure 19, when the coolant temperature rises to 95°C, the electronic thermostat will open. In this state, the electronic thermostat and WP are used to accurately control the coolant flow rate so that the coolant can be always kept at the optimal temperature as calibrated.

At low loads, the coolant temperature is higher than 95°Cso the electronic thermostat opens naturally without additional heating. The electronic water pump runs at low speed to reduce its power consumption. While for the high load area, when the coolant temperature is below 95°C, the electronic thermostat turns on heating mode to keep the engine runs in HT loop.

Figure 20 shows the comparison of this intelligent thermal management system when applied to DM-i plug-in hybrid architecture and that of the previous generation with a wax thermostat and a mechanical water pump. The warm-up time is shortened by 20% while fuel consumption in the charge-sustaining WLTC cycle can be reduced by 1.3%.

FIGURE 20 The warm-up time comparison.



Conclusions

1. A new thermal management system was developed for BYD DM-i 1.5L DHE, including: split cooling of cylinder block and head, electronic WP, electronic thermostat and wax thermostat. Combined with intelligent control strategy, the thermal management performance was greatly improved.
2. 1D and 3D coupled simulation was adopted during the design process. 3D CFD provided the pressure drop, heat transfer coefficient for the 1D simulation and 1D simulation in turn provided flow rate boundary condition for the 3D simulation. The coupling of the 1D and 3D simulation improved simulation accuracy.
3. Simulation results were validated with thermal test bench data. Results showed good agreement within 10% difference. These results showed good accuracy of the 1D and 3D coupling simulation and it can be used to guide the thermal management system concept development with good confidence. The simulation model can also be used for future system upgrading to save cost and development time.
4. Coolant temperature map was calibrated, and four working states were realized. The vehicle's warm-up time was shortened by 20%, and the charge-sustaining fuel consumption in WLTC cycle can be reduced by 1.3%.

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Definitions/Abbreviations

DM-i - Dual Mode-Intelligent
HT - High Temperature
LT - Low Temperature
1D - One Dimensional
3D - Three Dimensional
DHE - Dedicated Hybrid Engine
TMM - Thermal Management Module
BTE - Brake Thermal Efficiency
OEM - Original Equipment Manufacturer
WP - Water Pump
WJ - Water Jacket
IEM - Integrated Exhaust Manifold
HTC - Heat Transfer Coefficient
WOT - Wide Open Throttle
EGR - Exhaust Gas Recirculation
BSFC - Brake Specific Fuel Consumption
ECU - Engine Control Unit