2021-01-1241 Published 21 Sep 2021

Development of 43% Brake Thermal Efficiency Gasoline Engine for BYD DM-i Plug-in Hybrid

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Citation: Yang, D., lu, G., Gong, Z., Qiu, A. et al., "Development of 43% Brake Thermal Efficiency Gasoline Engine for BYD DM-i Plug-in Hybrid," SAE Technical Paper 2021-01-1241, 2021, doi:10.4271/2021-01-1241.

Abstract

BYD recently developed a brand new 1.5 Naturally Aspirated(NA) engine dedicated to its Dual Mode-intelligent(DM-i) plug-in hybrid architecture. This engine can reach a peak of 43% brake thermal efficiency. Combined with Electric Hybrid System(EHS), the full architecture can achieve low fuel consumption at various vehicle speeds, while maintaining fast accelerations. To reach such high thermal efficiency, the technological choice consisted in the association of: high compression ratio of 15.5, long stroke, Atkinson cycle, high tumble port, cooled EGR and high energy ignition. High compression ratio led to the increase of knock and pre-ignition tendency, which was suppressed by EGR and piston cooling jets. A lot of work was also done on the software side to optimize knock and pre-ignition control. The thermal management was completely redesigned. The use of electronic water pump, associated with two thermostats (one electronic and one traditional wax type) made it possible to implement split cooling and gradient control of coolant temperature map. Associated with intelligent control of thermal needs under all working conditions, the benefits were: faster engine warm-up, improved fuel economy and emissions reduction. To push the thermal efficiency even higher, friction was reduced to its minimum through different measures: 0W-20 oil, low tension piston ring, piston DLC coating, two-stage variable displacement oil pump and electrification of the accessories. With the combination of these technologies, and further optimization, the new dedicated 1.5NA high-efficiency engine achieved top level thermal efficiency in its class. Applying this engine to the DM-i plug-in hybrid architecture, the vehicle can achieve a charge-sustaining fuel consumption of 3.8 L per 100 kilometers in the WLTC cycle.

Introduction

The increasing number of vehicles has brought great challenges to the world's global energy consumption, environmental impact and many other fields. China promised to reach its peak of carbon emissions by 2035 and then achieve carbon neutrality by 2060[1]. This implies a complete reconfiguration of automotive industry to meet these new objectives of energy consumption and pollutant emissions. Hybrid vehicles are part of the solution to reduce the heavy dependence of traditional fuel vehicles on fossil energy and excessive emission pollutants. They also have the advantage of not having the range anxiety experienced with pure electric vehicles. Therefore, hybrid vehicles (with different degrees of hybridization) will dominate the market as the most ideal powertrain in the future.

In recent years, the global sales of hybrid vehicles was gradually increasing, and its proportion in passenger cars was also getting higher and higher, as shown in Figure 1. In 2020,

FIGURE 1 Global sales of passenger cars and hybrid vehicles.

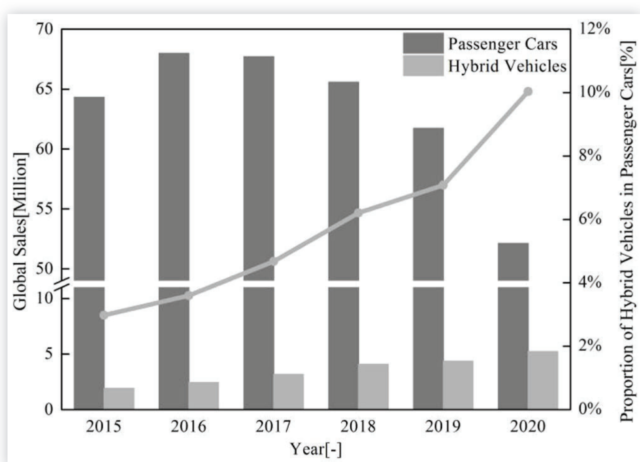
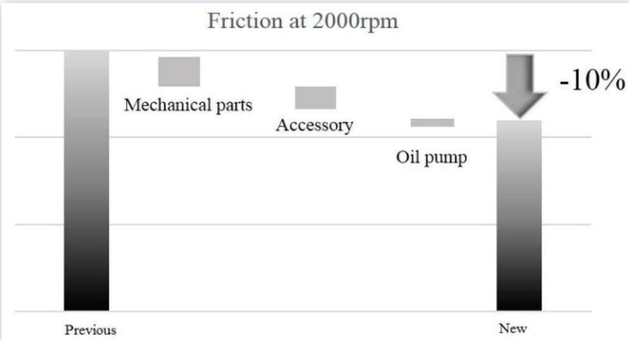


FIGURE 24 Comparison of engine friction.



mechanical vacuum pump, mechanical air-conditioning compressor and traditional belt like alternator were eliminated and replaced by electronic water pump, electronic vacuum and electric air-conditioning compressor. The engine start was realized by ISG motor. All these made it possible to design a complete gear train free of accessories and effectively reduce power losses. In terms of lubrication system, a two-stage variable displacement oil pump was used and the oil pressure can be reduced at low engine speed or low load. What's more, 0W-20 low viscosity oil was used, which also had obvious effect on reducing the friction of moving parts. As shown in Figure 24, Compared to the previous generation, the friction of this new engine was reduced by 10%.

Optimization of Lightweight and NVH

DM-i plug-in hybrid architecture has put forward higher requirement for engine lightweight. Cast aluminum was used for cylinder block, PA66-GF30 was used for intake manifold and cylinder head cover, the component weights were greatly reduce. IEM not only reduced exhaust temperature, but also reduced the engine weight. With CAE strength simulation, the sizes of crankshaft main journals, connecting rod journals and piston pins were optimized and reduced. As shown in Figure 25, by optimizing key components, the new engine weight reduced by 11%.

FIGURE 25 Comparison of engine weight.

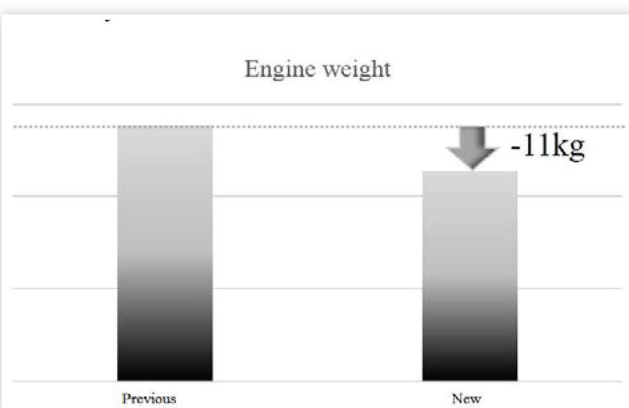
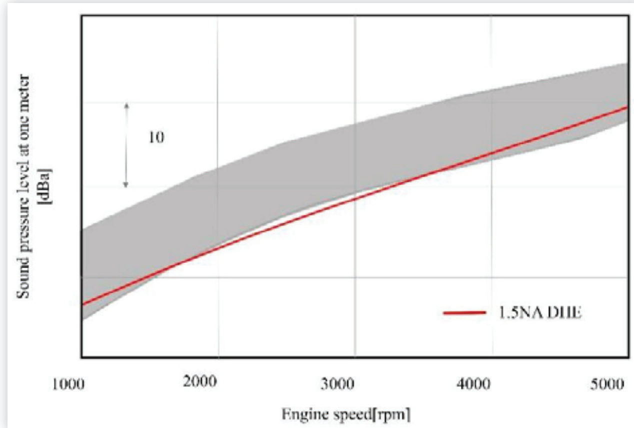


FIGURE 26 Comparison of engine noise.



In addition, many optimizations were also done for NVH. Oil pan was optimized with stiffener structure to improve its modal and reduce radiated sound power. The wall thickness of intake manifold was optimized and an extra bolt was added to fix intake manifold on cylinder head, which greatly reduced noise and vibration. Advanced toothed silent chain was used to reduce friction and chain meshing noise. With the above works and further optimization, engine noise was well controlled, this new engine achieved top level noise in its class, as shown in Figure 26.

Conclusions

In this recently developed 1.5NA DHE, ultra-high compression ratio of 15.5 was enabled with long stroke/bore ratio and deep Atkinson cycle. The use of high tumble port and cooled EGR not only improved combustion speed, but also reduced engine knock tendency. With the advanced combustion system, refined intelligent thermal management system and reduced friction, this engine can reach a peak of 43% brake thermal efficiency with a wide economic zone.

Combined with efficient EHS, DM-i hybrid architecture can achieve low fuel consumption at various vehicle speeds. Compared to a conventional ICE vehicle of the same class, this vehicle can reduce fuel consumption by 25%, achieving a charge-sustaining fuel consumption of 3.8 L per 100 kilometers in the WLTC cycle. This would have a significant positive impact on CO_2 and emission reduction in the automotive field.

References

1. http://www.xinhuanet.com/energy/2021-03/1.
2. Zhu, D., Pritchard, E., Dadam, S.R., Kumar, V. et al., "Optimization of Rule-based Energy Management Strategies for Hybrid Vehicles using Dynamic Programming," *Combustion Engines* 184, no. 1 (2021): 3-10, doi:10.19206/CE-131967.

3. Takahashi, D., Nakata, K., Yoshihara, Y., and Omura, T., "Combustion Development to Realize High Thermal Efficiency Engines," *SAE Int. J. Engines* 9, no. 3 (2016): 1486-1493. https://doi.org/10.4271/2016-01-0693.
4. Ikeya, K., Takazawa, M., Yamada, T., Park, S. et al., "Thermal Efficiency Enhancement of a Gasoline Engine," *SAE Int. J. Engines* 8, no. 4 (2015): 1579-1586. https://doi.org/10.4271/2015-01-1263.
5. Hakariya, M., Toda, T., and Sakai, M., "The New Toyota Inline 4-Cylinder 2.5L Gasoline Engine," SAE Technical Paper 2017-01-1021 (2017), https://doi.org/10.4271/2017-01-1021.
6. Dadam, S., Jentz, R., Lenzen, T., and Meissner, H., "Diagnostic Evaluation of Exhaust Gas Recirculation (EGR) System on Gasoline Electric Hybrid Vehicle," SAE Technical Paper 2020-01-0902 (2020), https://doi.org/10.4271/2020-01-0902.

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Definitions/Abbreviations

BMEP - Brake Mean Effective Pressure
BSFC - Brake Specific Fuel Consumption
CA - Crank Angle
CFD - Computational Fluid Dynamics
DCT. - Dual Clutch Transmission
DLC - Diamond-Like Carbon
DM-i - Dual Mode-intelligent
DOE - Design of Experiment
ECU - Engine Control Unit
EGR - Exhaust Gas Recirculation
EHS - Electric Hybrid System
FMEP - Friction Mean Effective Pressure
GPF - Gasoline Particulate Filter
IEM - Integrated Exhaust Manifold
ISG - Integrated Starter Generator
NA - Naturally Aspirated
NVH - Noise, Vibration and Harshness
PN - Particulate Number
WLTC - World Light Vehicle Test Cycle
WOT - Wide Open Throttle