

Development of 1.2L Gasoline Turbocharged MPFI Engine for Passenger Car Application

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ABSTRACT

In the emerging technology trend, there is continuous demand for increase in engine performance in terms of power & torque while providing competitive fuel efficiency. Understanding and fulfillment of complex customer requirements with affordable technology is extremely challenging. In order to meet potential conflicting needs and offer 'fun to drive' experience to customers, Tata Motors has developed first in segment turbocharged gasoline MPFI engine. Further in order to create market differentiator, multi drive modes were introduced as segment first feature. The boosted compact 1200 cc engine while developing 90 Ps power, delivers 140 N-m torque over a wide range of 1500-4000 rpm, best suited for Indian drive conditions. This performance boost is nearly 40% over and above performance of comparable NA engine without any compromise on vehicle level fuel efficiency. This paper explain the extensive development activity carried out in comprehensive manner providing good insight into technologies involved in major engine aggregates and brief on multi drive mode system. Also the engine performance results are presented towards the end of paper.

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INTRODUCTION

Tata Motors developed a four cylinder MPFI gasoline turbocharged engine with multi-drive mode for the compact car segment. The big efforts have been put into developing turbocharged engine with pleasant drivability as well as for competitive fuel economy. Consequently, with low and medium torque demand in urban driving condition, the turbocharged engine works in a more efficient speed/load region while with higher torque demand boosting helps to obtain the required performance. This new engine from Tata Motors represents a milestone in the development of gasoline engines. Its performance far surpasses that of conventional NA engines with the same capacity while at the same time offering competitive fuel economy. This paper presents the development aims and technical features of this new engine. Deep investigations were carried out during initial design and development phase by simulating the whole thermodynamic cycle, valve train simulation, engine cooling and lubrication circuit flow simulations. The effect of addition of turbocharging on different engine subsystem such as intake, exhaust, crank-train, valve train, lubrication, cooling system and corresponding challenges during development are explained in this paper. Developed 1200 cc turbocharged engine shows good characteristics in terms of performance, low-end torque, fuel economy and transient response.

DESIGN CONCEPT AND TARGET

Over the past few years Tata Motors has developed a four-cylinder gasoline turbocharged for the compact car segment. This engine currently features eight valve four cylinder with 1.2L displacement and is the first turbo charged version of gasoline engine family with multidrive mode and giving best in class performance. Major components of base engine and auxiliaries were newly developed for this application. In the following sections, detailed development of the base engine and auxiliaries are described and the performance results are presented. [Table 1](#) lists the basic specifications of the engine and [Figure 1](#) shows the appearance of the engine.

The main development targets are listed below:

- Performance boost of about 40% over and above comparable NA engine without any compromise on vehicle level fuel efficiency.
- Deriving multiple driving modes in engine
- Improved NVH performance
- Compact construction
- Better under hood thermal management.
- BS-IV compliant
- Leverage existing engine family manufacturing facilities to limit investment for new engine development

Table 1. Basic specification of engine

Parameter	1200 cc Gasoline Turbo Engine Specification
Bore x Stroke(mm)	75.0x67.5
Compression ratio	9.3:1
Max power (Ps @rpm)	90@5000
Max torque (N-m @rpm)	140@1500-4000
Cylinder block/Cy. head	Cast iron/Aluminum
Turbocharger	Water cooled
Boost control	Waste gate type
Fuel injection type	MPFI



Figure 1. Digital mock-up of the new 1200 cc MPFI turbo engine

CYLINDER HEAD AND COMBUSTION CHAMBER

The cylinder head is an all new design with two valves per cylinder configuration and with flow tuned ports & combustion chamber to extract maximum from the boosting and for good flow characteristics. The thermal inertia is also improved by optimizing the water jacket volume by 30 % for improving engine warm up rate and lower fuel consumption. The thermostat is integrated into the head for better control and to reduce the number of components. Combustion chamber in cylinder head is of hemispherical shape which proved to be highly efficient combustion chamber with minimal heat loss to the cylinder head and accommodating two large valves and these large valves are necessarily heavier than those in a multi-valve engine of similar valve area, as well as generally requiring more valve lift. The intake and exhaust valves lies on opposite sides of the chamber and necessitate a cross-flow head design. The configuration for the hemispherical chamber is to have the spark plug at the almost top/center of the dome with the valves on both sides (left & right) of the plug. There are no corners or hidden pockets so the entire air/fuel mixture is ignited. The spark plug being in the center of the sphere along with the shape of the chamber allows the explosion to quickly travel throughout the chamber. A long reach nickel-yttrium spark plug with a superior grade ceramic material selected for turbo engine

application. The fuel injector selected are of more no. of orifice (eight nos.) which provides good fuel atomization and is effective in reducing wall wetting. Spark plug and injector position in cylinder head combustion chamber and intake manifold optimized for higher combustion efficiency. Figure 2 represents combustion chamber shape. Combustion chamber volume decided based on final required compression ratio of 9.3.

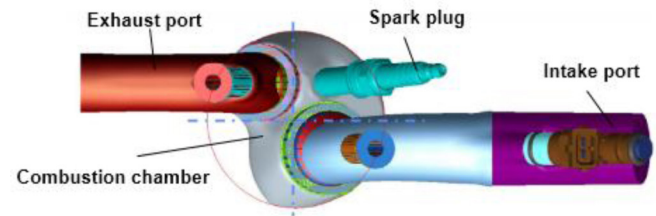


Figure 2. Combustion chamber shape

CRANKTRAIN SYSTEM

An innovative piston concept was adopted to take the higher peak firing pressures due the boosting without adding mass to the component. The piston is designed specifically for the higher thermal and mechanical load of the turbo engine with a maximum cylinder pressure of around 85 bar. The asymmetric shape of the piston skirt was optimized to reduce friction and improve the durability. The optimized piston skirt is also treated with graphite coated skirt for scuff resistance and wear rate reduction. For controlling the permitted piston temperature range piston cooling oil nozzles are installed on cylinder block for cooling. This also significantly improves piston pin lubrication. Further, the floating piston pin system assembly consisting of piston, piston pin, bushing and connecting rod were optimized for the higher gas and mass inertia forces. A highly sophisticated process of Physical Vapor Deposition (PVD) is used to apply an ultra-thin layer of chromium nitride (CrN) to the piston's top ring. The process ensures high wear resistance and a low friction coefficient. Friction between the ring and cylinder wall has been further minimized by reducing the both ring (top and second) tangential loads and second ring's width. The smaller mass and special surface treatment of the piston skirt and rings yielded additional savings in fuel consumption. Figure 3 shows piston ring assembly.

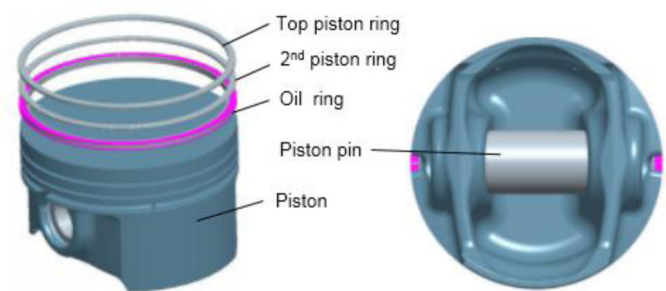


Figure 3. Piston and piston ring assembly

Connecting rod as shown in Figure 4 designed in order to withstand maximum cylinder pressure of 85 bar, with adequate fatigue safety margin. Also a press-fit bush in the small end was adopted, in order to

allow a floating piston pin. The fracture splitting method used for manufacturing connecting rods that are made of high-carbon steel, which are comparatively easy to fracture, in order to improve the accuracy, at the same time cost effectiveness.

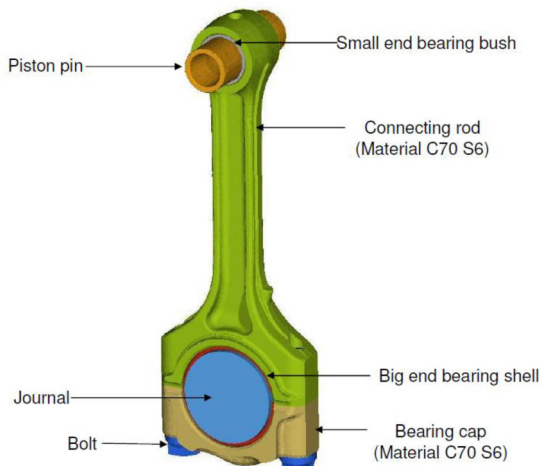


Figure 4. Fracture split connecting rod

Five bearing crankshaft is optimized and evaluated for high peak firing pressure in terms of stress fatigue factor, minimum oil film thickness and torsional vibrations amplitudes and found within limits. High inertia flywheel and vibration damper designed to reduce angular acceleration at flywheel end and improve NVH performance. Figure 4 & Figure 5 shows connecting rod and crankshaft assembly.

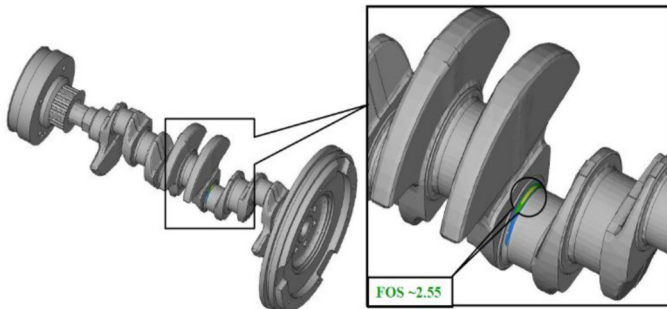


Figure 5. Crankshaft assembly

CYLINDER BLOCK

Figure 6 shows cylinder block for new engine. This is cast iron block with closed deck construction for high stiffness requirement. The weight and load optimized cylinder block concept used for this application. The design enables to utilize the existing manufacturing facilities for production with minimum changes. Because of its good acoustical characteristics additional secondary measures can be minimized. The cooling circuit within the crankcase and the entire engine was optimized using CFD calculations. A multi-layer steel gasket is used for sealing joint between cylinder head and cylinder block.



Figure 6. Cast iron Cylinder block

VALVE-TRAIN SYSTEM AND CAMSHAFT

Center pivot rocker arm overhead cam type valve train selected for this engine application as it offers low friction with roller follower mode and low engine height. It has also simple design and relatively high stiffness. Higher valve spring preload require for higher gas loads to achieve high force factor which increase cam follower contact stresses. Contact pressure between steel roller rocker follower and cam-lobe is above material limit for gray cast iron so steel cam material is used for camshaft development. Steel forging camshaft material of grade AISI 1070 with induction hardening heat treatment process exclusively developed. Sintered valve seat insert selected for high temperature and high stress application. Valve stem and roller rocker follower contact stresses are within material limits evaluated based on kinematic and dynamic simulation at max engine rpm so for this spherical rocker pad type is used.

ENGINE COOLING SYSTEM

Cooling system of new engine consist of longitudinal and transverse flow in the cylinder head for better heat transfer coefficients at high thermal loading and more uniform temperatures, integration of the water pump in cylinder block, integration of thermostat and the temperature sensor in the thermostat housing, timing-belt drive for the water pump. The water pump conveys cooling water to the inlet side of the cylinder block. The coolant flows into a gallery where it is distributed and flows around the cylinders to the exhaust side. Part of the flow is diverted to cool the turbocharger bearings to improve turbocharger reliability. Water cooling for turbocharger prevented problems associated with turbocharger heat soak after heavy running and rapid shut down. The main flow rises into the cylinder head, passes round the exhaust valves, the spark plug bosses, and finally to the inlet valves. The off-take for the heating system is on the cylinder head outlet other side. Depending how far the thermostat opens the coolant flows either to the main radiator or is short-circuited directly