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Development of the MaxxForce® 6 Cylinder, 4 Valves, TCIC Engine for Construction Equipment Vehicle (CEV) Application for India

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***Abstract:* - The construction equipment Vehicle (CEV) market in India has witnessed significant transformation both in terms of sales volumes as well as the demands on technology during the last decade. The tightening of emission norms, the developing road infrastructure and the entrance of global players in the market has put extraordinary focus on the right choice of engine technologies and its optimization to meet both global & local expectations at an affordable cost.**

The MaxxForce® 6 cylinder, 4 valves per cylinder, TCIC engine with advanced air management, combustion and construction features is thought to be ideal for the CEV application meeting Bharat Stage (BS) III emission norms. Adaptation of mechanical fuel injection systems has given unique feature and best balance between technology and cost. Extensive optimization on engine dynamometer and careful interfacing with the application has led to superior performance, better fuel economy and extended service life. Presented in the paper are the unique design features, optimization studies, vehicle interface and validation methodologies that are a part of the development effort. A road map for meeting future global emission norms is also presented.

INTRODUCTION:

The MaxxForce® engine platform is a state of the art heavy duty engine for the modern CEV vehicles meeting stringent emission norms in India. The task of configuring the base engine platform to suit Indian CEV market, operational demands on the vehicle, the service life requirements as well as the cost considerations underlines the need to choose the appropriate technologies that go with the engine. Brief specifications of MaxxForce6 cylinder engine models:

Table 1:

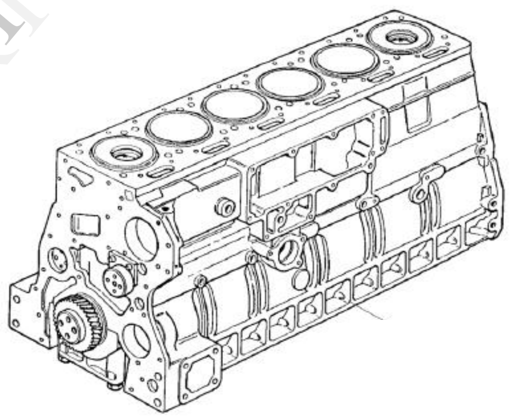
Engine Model	MaxxForce 230bhp
Emission Compliance	BSIII CEV
Configuration	6 cylinder, In line
Valve / cylinder	4
Displacement	7.2 l
Bore X Stroke	105 X 137
Combustion System	Direct Injection
Aspiration	Turbo Chager
Fuel Injection System	Bosch Rotory VE FIP
Max. Power	169.2kW@2200rpm
Peak Torque	1036Nm@1200rpm

Thechoice of mechanical fuel injection system for the first variant MaxxForce230bhp has been crucial to the definition of the engine ratings and the economic viability thereof. MaxxForce230bhp provides the necessary peak performance and fuel economy for applications like Wheel loader.

Construction:

The engine has been ruggedly built by designing the critical components for a peak firing pressure of 180 bar. The design also features state- of- the- art materials & manufacturing technologies.

Cylinder Block:



The cylinder block has been carefully designed to carry the power cylinder assembly, provide excellent stiffness with the help of a sturdy bulk head, stiff bearing caps and the incorporation of judicious ribbing structure at the bottom of the block skirt. Each cylinder head is fastened to the block by 4 x M14 high tensile bolts. The MaxxForce® platform features specially plateau honed wet liners which, along with the sturdy cylinder block structure restricts the bore distortion to a minimum and provides excellent lubrication oil consumption

Cylinder head:

The cylinder head design has been upgraded to carry 4 valves per cylinder. The individual cylinder head design provides excellent stiffness, modularity and ease of manufacturing without compromising on the engine layout compactness.

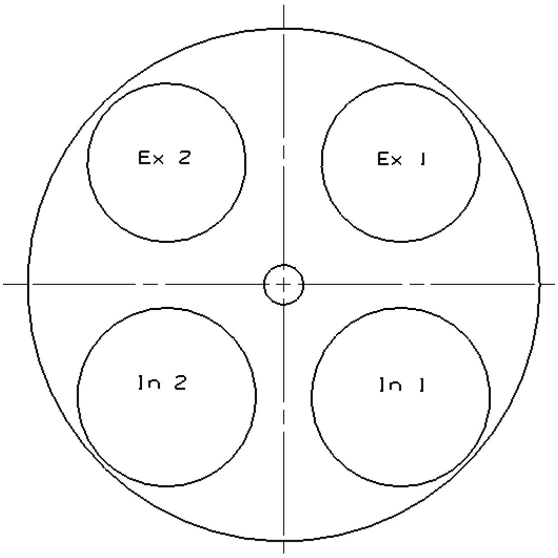


Fig 2

Inlet Area = 24.3% of cyl bore
Exhaust area= 19.2% of cyl bore

The four bolt construction provides sufficient room to configure the cross flow configuration of inlet and exhaust ports and coolant jacket reaching critical areas. The inlet port 1 is a helical design while inlet port 2 is a directed port.

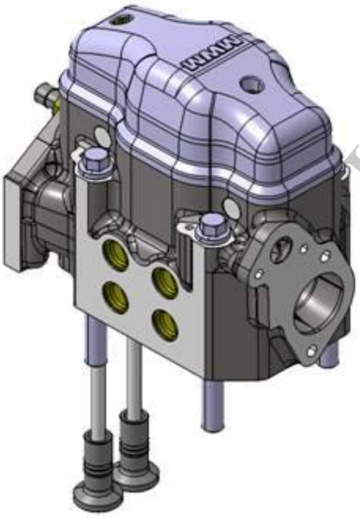


Fig 3

Valve train:

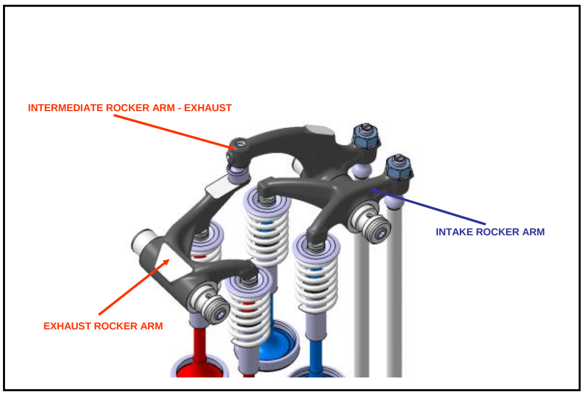


Fig 4

The valve train features an innovative arrangement of rocker arms that makes the valve actuation mechanism simpler and simplifies camshaft design. The intermediate exhaust rocker arm actuates the main exhaust rocker arm mounted on another rocker shaft which in turn provides motion to the two exhaust valves.

Connecting Rod:

The high power density of the engine puts enormous pressure on the connecting rod which has been designed to take 180 bar peak firing pressure. The fracture split at 40° design gives compact connecting rod assembly, preventing cap separation with a reasonably smaller sized bolt design.

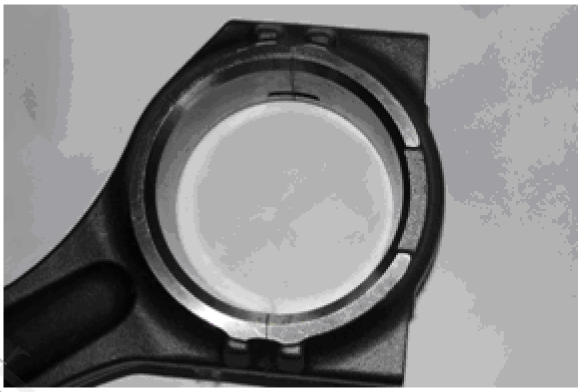


Fig 5

Gear Train:

The gear train has been designed to provide silent operation and reliable drive to essential accessories like water pump, oil pump and air compressor. The compound gear train with a double camshaft gear provides compactness and limits the engine frontal outline, making it ideal for semi forward/ cab over engine design of trucks.

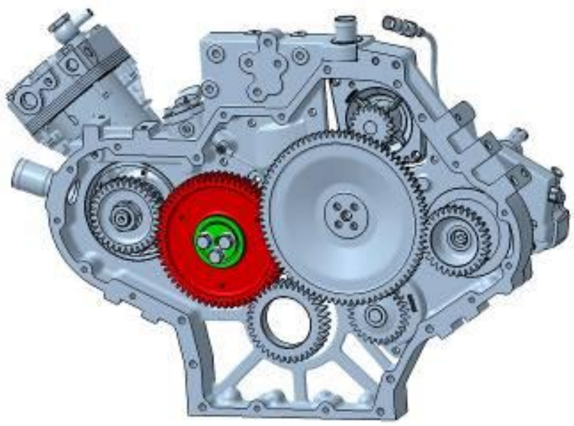


Fig 6

Combustion Optimization:

The four valve configuration provides an excellent opportunity to provide higher torque backup as well as best in class fuel efficiency. The injector – toroidal re-entrant cavity interaction was studied closely with simulation (1D & 3D) and experiments to arrive at the final design

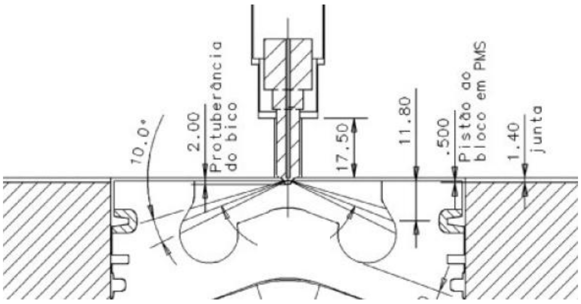


Fig 7

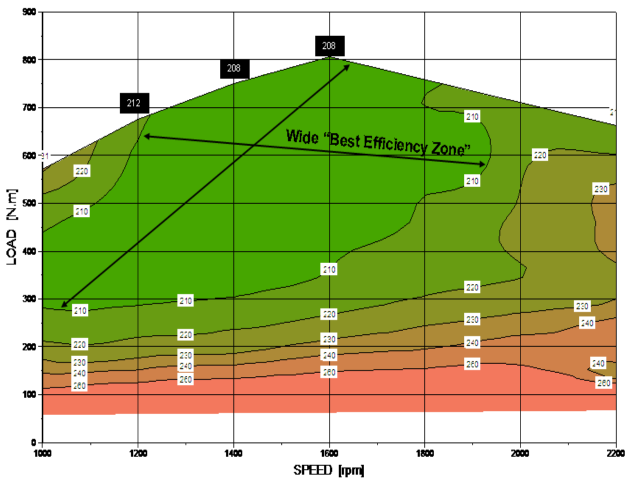


Fig 8

The iso- fuel consumption map for the MaxxForce 230bhp (169.2kW@2200rpm Mechanical) shows a wide area of “best-efficiency zone” which corresponds to the typical engine operating zone on the vehicle during highway/ semi urban duty cycle. This optimization at the lower engine speeds has provided the vehicle with @ 2.5%- 10% better fuel economy as compared to the nearest competition in different driving conditions. The emission norms for the mechanical version have been met comfortably.

Table 2

Pollutant	BSIII CEV emission Norms	Test results	Margin
	g/kW.hr	g/kW.hr	%
HC + Nox	4.0	3.65	8.75
Pm	0.20	0.141	29.5
CO	3.5	1.09	68.86

The transient driving conditions pose a challenge for the low pressure circuit (LPC) optimization. This challenge has been innovatively tackled by adapting a high flow rate reciprocating fuel feed pump on the existing gear train housing, actuated by a cam on the FIP gear and push rod. The design has helped overcome the sudden low pressure created in the LPC leading to lubrication issues in the rotary FIP. A data log of the LPC is shown in the following figure highlighting the concern area where the fuel pressure drops to negative values during transient vehicle running.

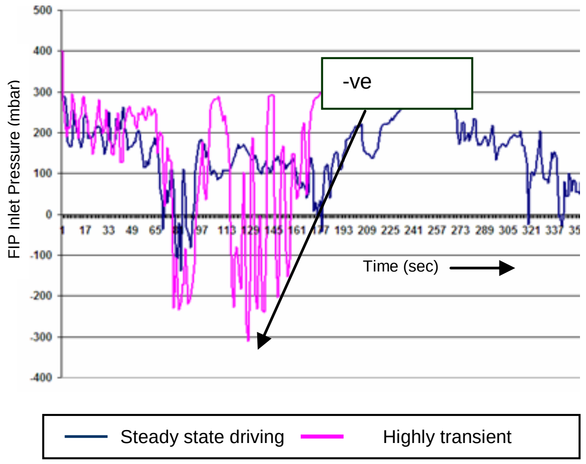


Fig 9

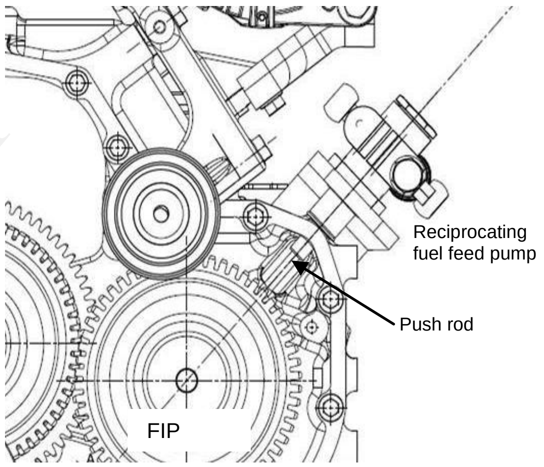


Fig 10

Validation:

The MaxxForce® 6 cylinder engine platform has been subjected to rigorous durability testing on vehicle as well as engine test beds. The objective of the exhaustive testing was to validate the localized components as well as components especially made for India. The mechanical version has undergone close to 7500 hrs of test bench testing and @ 1000 km+ of vehicle durability.

Fig 11

The tests involves a range of proprietary engine dynamometer cycles involving simulation of transient conditions, overloading, over speed, thermal shock, resonance testing, testing for FEAD components, piston mark & oil consumption tests, polycyclic durability tests. The validation also involves considerable component rig testing as well as special tests like bore distortion using Incometer®.

The engines are methodically stripped down to assess the condition of components after the tests. The components are measured for critical dimensions and compared with those at the beginning of the test giving authentic wear data which helps in arriving at discard limits and B10 life values.

Future Ready:

The MaxxForce® platform is designed to meet the future emission norms and new technology strategies are being explored to meet the future global emission norms up to 2020. The diesel engine industry has, over the years, shown favor to one or the other strategies to meet the stringent emission norms. The MaxxForce® engine is proven on various strategies and found to meet the norms comfortably. However, the focus on combustion development and reduction of "engine- out" emissions has led to a greater preference towards adapting the EGR route. A general technology evolution of the MaxxForce® engine series is illustrated in Fig 12.

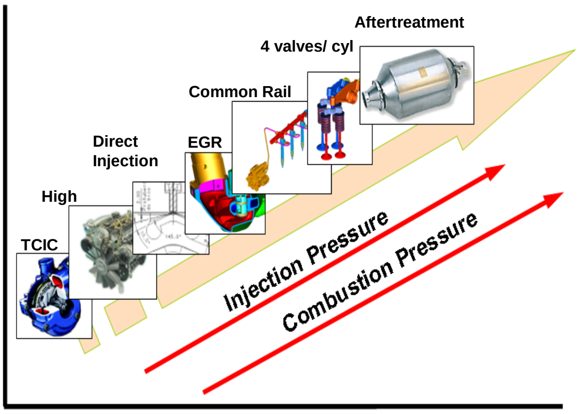


Fig 12

Alternative combustion processes like HCCI, PCCI and LTC are being explored in the laboratory for making the engine future ready.

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