A New High Efficiency Modular Engine Family –
On the road to 45% Thermal Efficiency

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CONTENTS

1. New Engine Family
2. Improving Efficiency For Future Needs
3. Miller Engine Research
4. Summary
1.1 A Brand New Changan Engine Family

Features

- Turbo GDI downsizing
- High Efficiency combustion
- Very low friction
- Thermal Management

First Launch Engine

- 4 cyl. 1.4l Turbo-GDI

Future Options

- 3 & 4 cylinder variants
- 3 bores sizes
- Advanced combustion
- Electrification & Variability

- The first variant from the new Engine family will shortly be launched
- The family is designed on Modular principles to allow efficient development of further variants to meet future needs.
1.2 Core Family technology

- New technology has been integrated to enhance Turbo-GDI system function in all key areas of engine operation.
1.3 Modular Designed Family

- Through a Modular design, with standardised interfaces, it is possible to define new engine variants with minimal new key parts needed.
- This benefits cost, manufacturing flexibility & efficient development.
1.4 World Class Attributes of the First Variant

- The new engine family matches the global benchmarks for all key attributes
2.1 State-of-the-art Efficiency of Production Engines

- The highest efficiency for ICEs in production is a 36,900 litre ship engine at 51 ~ 52% (fuel dependent)
- The highest efficiency passenger car engines are 42% - gasoline & 44% - diesel
2.2 Importance of Cylinder Displacement

- Cylinder displacement is a critical parameter in the achievement of high thermal efficiency.
- For an equal overall design, Surface/Volume ratio primarily defines the achievable peak efficiency due to heat loss to the coolant.
- Relevant to this, Changan accepts an effective penalty of 1.8% efficiency relative to best-in-class Toyota 2.5l Atkinson engine by using a 1.6l 4 cyl. engine in our research.
2.3 Peak Efficiency Road Map

- The new engine family provides a good foundation for accelerated improvement in the future
- The efficiency road map will be realised by added technology & continuous improvement of the base engine components
Our down-sizing strategy to-date has modestly improved peak efficiency but has greatly expanded the area of “good efficiency” (33% BTE, 256 gm/kW.hr)

For future engines designed for highly electrified vehicles, we are adding focus on improving peak efficiency, i.e., both peak efficiency and further expanding the area of “good efficiency”
3.1 Key Technology - Miller Cycle

- Patented by Ralph Miller in 1957. Uses an extra valve mechanism to release some induction volume to the exhaust manifold, to have increased expansion ratio relative to compression ratio.
- Raised geometric compression ratio is possible due to the lost effective compression ratio due to the released volume of charge.
- Modern engines “mimic” this mechanism by varying valve timing.

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3.2 Late IVC or Early IVC

Miller Cycle can be realised either with Late IVC or Early IVC
- Early - under-fill the cylinder by closing valve during intake stroke
- Late - fill cylinder, then push some charge back into intake

The benefits/detriments of the two approaches are very balanced with mild strengths/weaknesses

At this time Changan is taking the EIVC solution based on current needs
3.3 Needed design changes for Miller

1) Cylinder head  Revised combustion chamber featuring valve masking
2) Inlet camshaft  Modified period (& lift) for Miller effect
3) Inlet valve spring  To match cam profile
4) Piston  Revised crown shape (Compression ratio)
5) Turbocharger  Re-matching to combustion characteristics

- Very few parts need changing for a Miller variant
- All parts have common interfaces with existing parts for efficient development and manufacturing
- Other parts may be upgraded for all variants as part of the ongoing development of the engine family
3.4 Peak Thermal Efficiency achieved today

- To maintain the performance of the 1.4l T-GDI engine, the research engine was “up-sized” to 1.6l. This required 2 additional parts to be changed; Crankshaft & Conn Rod.

- 40.5% PTE has been achieved using Miller Cycle combined with cooled EGR; 0.3% above the “state of the art” displacement line. In excess of 33% TE is achieved above 3 bar BMEP.

- Use of cooled EGR & 2 cylinder de-activation strategy (up to 4 bar) would permit “equal to diesel” efficiency at all loads up to 14 bar BMEP.
3.5 Part Load results – Combustion (without cylinder de-activation)

- At low BMEP the Miller engine has lower pumping losses. The burn rate is slower due to the adverse cylinder turbulence despite the valve masking.
- At mid~high BMEP’s the burn rate is better due to the improved combustion phasing, whilst the raised manifold pressure requires increased turbocharger work.
- The BSFC (or TE) improvement achieved is the result of the balance of these 2 factors.
### 3.6 Full Load results of EIVC Miller

- The 1.6l Miller engine achieves the same performance as the NE14TG-AA – 13% lower specific performance.
- The 1.6l Miller engine has superior low speed torque (<1500 RPM), both in Nm and BMEP despite using Lambda 1 scavenging for RDE.
- The higher speed fuel efficiency of the Miller engine is dramatically better (up to 25%), partially due to maintaining Lambda 1 operation up to 4000 RPM rather than the 2500 RPM of NE14TG-AA.
Increased displacement, enhanced cooling & reduced friction provide a strong base for two new technologies, Water Injection & Variable Valve Actuation.

This we believe will approach 45% PTE and allow more than 80% of the map to be above 33% efficiency for Conventional vehicles and 100% of the map above 33% for Hybrid vehicles.

Beyond 45% it seems likely lean operation will be needed.
4.1 Summary

- Changan has designed and developed a new Modular engine family that will shortly enter into the market.

- The 1\textsuperscript{st} Launched variant meets the global standards for a Turbo GDI engine in all attributes, with a Peak Thermal Efficiency of 36\% and over 80 kW/litre.

- Work is advanced on Miller variants that can achieve up to 40\% Peak Thermal Efficiency, combined with over 70 kW/litre.

- A road map is in place using the architecture of the modular engine to increase its Peak Thermal Efficiency towards 45\% and more than 80\% of the map to be above 33\% efficiency.

- The modular engine family will allow Changan to meet future customer and legislation needs, whether for Conventional, Hybrid or Plug-in Hybrid vehicles.