THERMAL EFFICIENCY ENHANCEMENT OF GASOLINE ENGINE

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Honda R&D Co., Ltd. Japan
3. How to Achieve Brake Thermal Efficiency 45% <SAE_PAPER 2015-01-1263>

4. Conclusion
Intended Direction of This Research

Brake Thermal Efficiency (%) vs Torque (Nm)

- Cylinder Deactivation Engine
- Downsizing, Boosting, Engine
- NA Engine

@ 2000rpm
Intended Direction of This Research

Aim of This Research:
Improvement of Maximum Brake Thermal Efficiency

Target Value: 45%

Under Following Condition
- 91 Research Octane Number Gasoline
- Stochiometric Air/Fuel (A/F) Ratio
- Engine for Passenger Car

Cylinder Deactivation Engine

DN Engine

Downsizing  Boosting  Engine

@ 2000rpm
Brake Thermal Efficiency (%)

Target Value: 45%

\[ \eta = 1 - \left( \frac{1}{\text{CR}} \right) \]

\( \eta \) : Thermal Efficiency
\( \text{CR} \) : Compression Ratio
\( \kappa \) : Specific Heat Ratio

High EGR Rate
High Compression Ratio

Improving Anti-knock Performance

High EGR Rate
- High Turbulent Kinetic Energy, Combustion chamber shape
- High Energy Ignition

High Compression Ratio
- High Stroke-Bore Ratio, Gasoline Direct Injection
- Low Effective Compression Ratio

Torque (Nm)
How to Achieve Target Thermal Efficiency

Estimated Efficiency by Past Test Result and 1D Simulation

- Compression ratio (CR) : 17 or over
- Ignition timing : MBT
- EGR rate : 30% or more
- Boost pressure : 200 kPa or more

*FMEP: Mass-production L4 engine
*Ignition timing: MBT
## Test System: Single-cylinder Engine

### Engine specifications

<table>
<thead>
<tr>
<th>Specification</th>
<th>Details</th>
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<tbody>
<tr>
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**Inlet Valve Open@1mm -10deg ATDC (Fixed)**

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*Figure showing lift versus crank angle (CA) with data points marked.*
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Stroke was changed by

- Crankshaft
- Connecting Rod
- Cylinder Sleeve
Countermeasure of High Compression Ratio
1 Stroke-Bore (S/B) ratio

2000 rpm, IMEP 520 kPa, MBT, Port injection

*Thermal efficiency calculation FMEP, PMEP
: Equivalent to L4 engine

Slow burning occurred by narrow area of combustion chamber

Improvement of Limitation of Higher Compression Ratio

Slow burning

S/B 1.5 (626cc)

S/B 1.2 (499cc)

S/B 1.5
Influence of S/B to thermal efficiency

- 2000rpm, IMEP 720kPa, MBT, EGR rate 20%
- Compression Ratio = 13.5
- *Thermal efficiency calculation FMEP, PMEP: Equivalent to L4 engine

Graph showing the influence of S/B on brake thermal efficiency, cooling loss, and FMEP+PMEP against S/B ratio.
Countermeasure of High Compression Ratio
2 Effective Compression Ratio (Late Intake Valve Close)

2000rpm, EGR rate 20%, S/B 1.5

Efficiency Improvement

Anti-knocking Performance Improvement

Theoretical Thermal Efficiency Equivalent to CR 16.5

CR 17.0 (CRe 12.4) Late IVC
CR 13.5 Standard IVC
CR 17.0 Standard IVC

Late IVC
Standard IVC = 580 deg
Late IVC = 614 deg

MBT (%) 360 370 380 390 400

Late IVC + ε 17

Otto cycle

Equivalent to CR 16.5 Otto cycle

Equation

\[
\text{Efficiency Improvement} = \frac{\text{Late IVC}}{\text{Standard IVC}} 
\]

\[
\text{Anti-knocking Performance Improvement} = \frac{\text{Late IVC} + \varepsilon 17}{\text{Late IVC}} 
\]

\[
\text{Theoretical Thermal Efficiency} = \frac{\text{Late IVC + \varepsilon 17}}{\text{Late IVC}} 
\]
Countermeasure for High EGR Ratio
1 Flame Kernel Formation

Space Near Spark Plug Gap

- $V_1 > 2\%$ of Combustion Chamber Volume at TDC

2000 rpm IMEP 810 kPa

EGR rate of co-variation of IMEP 5\% (%)

V: Combustion chamber volume at TDC
V1: Volume of virtual sphere centering on Ignition-plug electrode with inflating to touch surface of piston or cylinder head
Countermeasure for High EGR Ratio
1 Flame Kernel Formation

High Energy Ignition

- Ignition Energy Extends EGR Limit
- Ignition Energy Set to 450 mJ
  - Wear of Spark Plug
  - Power consumption

2000 rpm, IMEP 520 kPa, EGR Rate=20%, $\varepsilon = 9.5$

![Standard Ignition](image1)

![High Energy Ignition](image2)

![Graph](graph)

- EGR rate of co-variation of IMEP 5% (%)
- Ignition energy (mJ) 0 to 1200
Countermeasure for High EGR Rate

2 High Turbulent Intensity - 3D Simulation Result

- High Turbulent Intensity
- 3D Simulation Result

- Formation of High Tumble Flow
- Holding Tumble Flow
- Increase Turbulent Kinetic Energy (TKE)
- Combustion

- Higher Tumble Ratio Worsens Flow Coefficient
- >> Higher Boosting Efficiency Requirement

- Piston Shape for Keep Tumble Flow

- Ignition point
- Vortex center

(a) Flat piston
(b) Bowl-shaped piston
Countermeasure for High EGR Rate

2 High Turbulent Intensity - 3D Simulation Result

Same Tumble Ratio, TKE Varied

High TKE:<Stable>
Small Change In Center Axis of Tumble Flow

Low TKE:<Unstable>
Large Change In Center Axis of Tumble Flow

Stable Center Axis of Tumble Flow Make Higher TKE
Countermeasure for High EGR Rate
2 High Turbulent Intensity - 3D Simulation Result

TKE@BTDC30deg (m²/s²)

Tumble ratio (-)

Unstable

Stable

Unstable

Flow Blance [-]

Center Axis of Tumble Flow

IN

EXH

40.5mm Half of Bore Dia.

Toward Center of Cylinder

Toward Outer of Cylinder

Velocity Distribution

MIN

MAX

SAE INTERNATIONAL
**Brake Thermal Efficiency Achieved: Single Cylinder Engine**

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<td>1.5</td>
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<tr>
<td>Displacement volume (cm³)</td>
<td>626</td>
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<tr>
<td>Compression ratio</td>
<td>17.0</td>
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<tr>
<td>Effective compression ratio</td>
<td>12.4</td>
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<tr>
<td>Intake port</td>
<td>Tumble port</td>
</tr>
<tr>
<td>Piston shape</td>
<td>Bowl shape</td>
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<td>Ignition energy</td>
<td>450 mJ</td>
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*Thermal efficiency calculation FMEP, PMEP: Equivalent to L4 engine*

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**Diagram:**

- **Achieved efficiency:** 45% at 2000 rpm
- **EGR rate (%):**
  - 200 rpm: 10%
  - 400 rpm: 20%
  - 600 rpm: 30%
  - 800 rpm: 35%
  - 1000 rpm: 25%

**Mass-production engine 2.0L NA**

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*SAE INTERNATIONAL*
Engine System Design

- High Compression Ratio
  - High S/B Ratio
  - Late Intake Valve Close

- High EGR Rate
  - High Turbulent Intensity
  - High Energy Ignition

- Maximum Power = 2.5L NA Engine

- Anti-knocking Performance
  - LPL-EGR
  - Gasoline Direct Injection

- Engine Size
  - Installation in Vehicle
  - A/F Ratio varies

- High Efficient and Wide Range Boosting System

- Response of EGR
- Cooler Performance
- Countermeasure for Condensation Water
Engine Height Setting

S/B Ratio Changes from 1.2 to 1.5
• Block Height Increase 40 mm

Factors Affecting Block Height
• S/B Ratio
• Cylinder Offset
• Bore Diameter

Eliminate Cylinder Offset to Give Priority to Efficiency-improving Benefit of S/B Ratio
A/F Ratio Varies

2000 rpm, IMEP 520 kPa, EGR 0%

Cylinder No.

#1
#2
#3
#4

A/F Ratio

13 14 15 16

Leaner

Miller Cycle Cause A/F Varies
A/F Ratio Varies / Countermeasure

- Improving A/F Varies
- Small Volume

Intake Pipes Assembled in Firing Order

Same Effect on Less Intake Volume

Extension of Intake Pipe
Examination of Boosting System Specifications

High EGR Rate and High Expansion Ratio
> Lower Exhaust Gas Enthalpy

Turbine
Small Exhaust Energy

High-efficiency T/C

Large Intake Energy

Miller Cycle and High EGR Rate
> High Boost Pressure Is Required

Miller Cycle, High EGR Rate

Boost Pressure (kPa)

D/S ENG EVO
This ENG EVO

NA
EGR20%

ηe45%
EGR35%

Down Sizing

AIR
EGR
Examination of Boosting System Specifications

Single T/C Is Insufficient Engine Operation Point

- Combined Boosting System Is Required
  - T/C for Maximum Efficiency Point
  - T/C for Maximum Power Output Point

1D Simulation Result

- Target

- Single T/C
- Combined T/C

Break thermal efficiency @ 2000rpm (%)

BMEP @ 5000rpm (bar)

Pressure Ratio (-)

Air Mass Flow Rate (kg/s)

49 47 45 43 41

8 10 12 14

4 6 8 10 12 14 16 18
OUTLINE

3. How to Achieve Brake Thermal Efficiency 45%<SAE_PAPER 2015-01-1263>

4. Conclusion
Specifications of 45% Brake Thermal Efficiency on Single Cylinder Engine

Higher Compression Ratio : Compression Ratio 17
  • Late Intake Valve Close--- Effective Compression Ratio 12.4
  • Long Stroke --- Stroke-Bore Ratio 1.5

Higher EGR Rate : EGR Rate 35%
  • Ensuring Space around Ignition Point --- 2% Volume of TDC’s Combustion Chamber Volume
  • High Energy Ignition --- 450mJ
  • High Turbulent Kinetic Energy --- High Tumble Ratio Port, Keeping Tumble Flow Shape of Combustion Chamber

Multi Engine Application

Increased Engine Height Due to High Stroke-Bore Ratio
  • 0 Cylinder Offset to Restrict Engine Height Increase to 10mm

Countermeasure for A/F varies caused by Late Intake Valve Close
  • Firing Order Arranged Intake Manifold

High Efficiency and Wide range Boosting System is Needed
  • Combined T/C
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