2011 Automobile Maintenance Advanced Course for the Industrial Technical Instructors

TOYOTA

HYBRID PRIUS

No. : A09

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Instructor : Lin, Jen-Jiang
Hybrid Electric Vehicles

Introduction

- What is a Hybrid Electric Vehicle?
- Background
- Introduction of Hybrid Electric System
  - Advantage/Defect, Construct and Operation
- Conclusion
- References
Number of Hybrid Vehicles Sold

- **Toyota:**
  - Till the release in August of the year 2003, the global sales volume of Hybrid Vehicles has been exceeding 140,000 units, it occupies a share of 90% in the global market.

- **Honda:**
  - Till 2002, the sales volume of Insight in US has accumulated to an amount of 10,730 units, it amounts to more than 1/3 of Prius sold in US.

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Global Sales Volume of Toyota Hybrid

**Global Shares: 90%**

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<td>Crown w/ mild hybrid system</td>
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<td>1,574</td>
<td>520</td>
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<td>12</td>
<td>15</td>
<td>9</td>
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<td>Total by year/month</td>
<td>332</td>
<td>17,656</td>
<td>15,255</td>
<td>19,026</td>
<td>36,928</td>
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<td>Cumulative total</td>
<td>332</td>
<td>17,988</td>
<td>33,243</td>
<td>52,269</td>
<td>89,197</td>
<td>102,967</td>
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What is a Hybrid Electric Vehicle?

- Hybrid System:
  - A system that is constructed by integrating two (or above) types of dynamic sources with different features is called the Hybrid System.

- Hybrid Vehicles
  - A hybrid vehicle is a vehicle that adopts hybrid system as the dynamics, abbreviated as HV.

Hybrid Electric Vehicles

- Hybrid Electric Vehicles
  - The hybrid dynamic system usually adopted in a vehicle means a system that integrates the usage of two types of dynamic sources, one is internal combustion engine that uses fuel (Gasoline, Diesel, CNG engine, ..) and the other is electrical motor (DC, AC) that uses battery power.

  - A vehicle that adopts the above-mentioned hybrid electric system as the dynamics source is called a Hybrid Electric Vehicle, abbreviated HEV.

  - The generally-meant hybrid electric vehicle is exactly HEV.
Fundamental Background

- **HEV Releases**
  - **TOYOTA**
    - THS, THS-II
    - THS-C (C=CVT)
      - ESTIMA (i.e., HV-M4) August, 2001
    - THS-M (M= Mild) — 42V Electric System
      - CROWN
  - **HONDA IMA**
    - INSIGHT: November, 1999
    - HONDA CIVIC: December, 2001
  - **NISSAN NEO HS**
    - TINO: April, 2000

The Developing Background of Hybrid Electric Vehicles

- **Energy Exhaustion**
  - Reservation Issue of Petroleum

- **Air Pollution**
  - Environmental Protection Regulations

- **Global Warming**
  - CO$_2$ Emission
Emissions Legislation

Source: Honda, 1999

A Solid Goal of Reducing Vehicle CO₂ Emissions Volume set by Japan
Countermeasure of the Vehicle Plant

- TOYOTA Countermeasure to Reduce CO₂ Emissions Volume

**Electric Vehicle Types**

- **PEV (Pure Electric Vehicle)**
  - Also named BEV (Battery Electric Vehicle,)

- **HEV (Hybrid Electric Vehicle)**
  - HEV: Internal (External) Combustion + Electric Power

- **FCEV (Fuel Cell Electric Vehicle, FCEV)**
  - The final goal of Electric Vehicle
  - FCEV → FCHV
Goal of Developing Electric Vehicle

- An electric vehicle should have the following advantages:

1) Cleanness
2) High efficiency
3) Energy diversity

The Advantage/Disadvantage of a Pure Electric Vehicle

- Advantage
  - Using electric power, therefore, no waste gas emissions while in driving; causing no air pollution (Reducing environmental pollution)
  - Driven by drive motor, it will not produce the vibration and noise caused by vehicle engine (Reducing environmental pollution)
  - Different from the vehicle that uses an engine; it could retrieve the energy while decelerating (Energy Saving)
  - Gasoline, diesel oil and the likes cold only be produced from petroleum; however, electric power cold be produced from all kinds of energy sources other than the petroleum (Energy Source Diversity)
The Advantage/Disadvantage of a Pure Electric Vehicle

- **Disadvantages:**
  - Short PEV endurance, less passenger load capacity; so with limited applications
  - High battery price, vehicle price higher
  - Charging is time-consuming and tedious
  - Insufficient charging facility
  - Long FCEV fuel battery start-up charging time
    - Onboard Reformer: about 30min
    - Direct hydrogen: 3~5min

The Advantage/Disadvantage of a Hybrid Electric Vehicle

- **Advantage**
  - Effective in fuel-consumption saving and is able to reduce the air pollution
  - No problem regarding the endurance of the vehicle
  - Required battery capacity is smaller than that of an electric vehicle; storage battery could be made small in size and light in weight (it weights about 1/5~1/10 of an electric vehicle), the management of charging status is easier and the price cheaper.
  - Without the issues regarding charging consumption time and insufficient facilities.
  - Like an electric vehicle, the energy could be retrieved when decelerating
  - Possessing the pause function of engine idle running
The Advantage/Disadvantage of a Hybrid Electric Vehicle

- **Disadvantage**
  - Complicated construct for a hybrid electric vehicle and difficult in maintenance
  - Its price is higher than that of a gasoline vehicle
  - Comparing an electric vehicle, the waste-gas emission issue still exists.

Types of Hybrid Electric Systems

1. **Serial Hybrid System**
   - Using engine to drive the generator for operation, then driving the wheels by using the generator-produced power to supply to the motor; at the same time, storage battery could be charged. The reason it is called serial is because that there is only a single route of transmission for the dynamics by which the wheels are driven.

2. **Parallel Hybrid System**
   - The parallel driving dynamics could be acquired from the dynamic sources of the paralleled engine and motor; it could be operated alone or together at the same time depending on the driving conditions, the two compliment each other. Of course, while using engine to drive the vehicle for running, it is in the mean time allowable using the engine to drive the motor for power generating (generator function) to charge the storage battery.
Serial Hybrid System

Parallel Hybrid System

Single-Axis Allocation

Double-Axis Allocation

Separate Allocation
# Hybrid Electric System nomenclatures and models of Japan Major Makers

<table>
<thead>
<tr>
<th>Maker Brand</th>
<th>Hybrid Electric System Name</th>
<th>Model</th>
<th>Major Equipped Vehicle</th>
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<tbody>
<tr>
<td>TOYOTA</td>
<td>THS</td>
<td>Parallel Double-Axis Allocation</td>
<td>PRIUS, PRIUS II</td>
</tr>
<tr>
<td></td>
<td>THS-C</td>
<td>Parallel Separate Allocation</td>
<td>ESTIMA</td>
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<tr>
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<td>THS-M</td>
<td>Parallel Double-Axis Allocation</td>
<td>CROWN</td>
</tr>
<tr>
<td>NISSAN</td>
<td>NEO-HS</td>
<td>Parallel Double-Axis Allocation</td>
<td>TINO</td>
</tr>
<tr>
<td>HONDA</td>
<td>IMA</td>
<td>Parallel Single-Axis Allocation</td>
<td>INSIGHT, CIVIC</td>
</tr>
<tr>
<td>MITSUBISHI</td>
<td>GDI-HEV</td>
<td>Parallel Double-Axis Allocation</td>
<td>SUW ADVANCE</td>
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<td>DIHATSU</td>
<td>EV-H</td>
<td>Parallel Double-Axis Allocation</td>
<td>MOVE</td>
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<tr>
<td>SUBURU</td>
<td>SHPS</td>
<td>Parallel Double-Axis Allocation</td>
<td>ELTEN CUSTOM</td>
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## Construct of a Hybrid Electric Vehicle

- **Engine**
- **Gear Box Unit**
- **Decelerator**
- **Motor**
- **Converter**
- **Generator**
- **Electric Transmission**
- **Converter**
- **High-voltage Storage Battery**
- **Dynamics Separating Mechanism**

*Toyota Prius (THS)*
Dynamics Device---THS

Engine
Decelerating Mechanism
Motor
Dynamics Separating Mechanism
Generator

Prius

Dynamics Device ---IMA

Thin Combustion Engine
Motor Body
Gear Box
Engine Fuel-Saving Technology

- Countermeasure adopted regarding the Engine
  - Adopting Low-Fuel-Consumption Engine
    - Atkinson Cycle Gasoline Engine: Toyota
    - Thin Combustion Engine: Honda
    - GDI Engine: Mitsubishi
  - Reducing Engine Exhaustion Volume
    - TOYOTA PRIUS : 1.5L
    - HONDA INSIGHT : 1.1L
    - MITSUBISHI SUW ADVANCE : 1.5L
  - Idling stop function: It is also named as Auto Stop & Go (ASG)

Atkinson Cycle and Otto Cycle

Otto Cycle

Atkinson Cycle

Intake Stroke  Compression Stroke  Ignition Stroke  Exhaustion Stroke

Intake Stroke  Not Compressed Yet  Compression Stroke  Ignition Stroke  Exhaustion Stroke
Advantage/Disadvantage of Atkinson Cycle

- **Advantage:**
  - Combustion Vibration is avoidable
  - Reducing the pump pressure loss
  - Less exhaustion loss, high thermal efficiency and fuel-saving

- **Disadvantage:**
  - When operating in low speed, efficiency will be pretty worse
  - When in high-speed operation, it is hard to produce high horse power.

Atkinson Cycle Applications on Hybrid Electric Vehicles

- **Operation in Low Speed**
  - Stopping engine operation, using motor to drive the vehicle

- **When High Output Horsepower is required**
  - The highest revolution speed is limited at 4000rpm
  - Using motor to supplement the insufficiency of engine horsepower
Why GDI Engine has not been widely accepted by Hybrid Electric Vehicle

1. Under same exhaustion volume, engine fuel-saving is no better than that of Atkinson Cycle
2. Dynamics insufficiency could be supplemented by Motor
3. GDI Engine costs more
4. It is required to have GDI engine technology of small exhaustion volume

Rem: Mitsubishi Motor has already developed a GDI engine of 1.1L exhaustion.

High Voltage Storage Battery

- Rated Voltage
  - TOYOTA PRIUS (THS): 288V → 273.6V
  - TOYOTA PRIUS-II (THS-II): 201.6V
  - HONDA INSIGHT (IMA): 144V

- Models
  1. Lead-sealed Battery: Bus, Electric
  2. Nickel Hydrogen Battery: THS
     - Cylindrical Type
     - Corner-Post Type
  3. Lithium Battery: NEO-HS
High Voltage Storage Battery
--Nickel Hydrogen Battery

- Sub-battery Assembly

Cylindrical Type
Corner-Post Type

7.2V

---Lithium Battery

- Sub-battery Assembly
Motor (1)

- Functions
  - Key function
    - Driving Motor (Driving the Vehicle)
    - Generator (Regenerative Brake)
  - Sub-functions: it depends on the system
    - Start-up Motor (Start-up Engine)
      - HONDA IMA

Motor (2)

- Models:
  1. Permanent Magnet AC Synchronous Motor
    - AC Servo Motor:
      - TOYOTA PRIUS (THS)
      - NISSAN TINO (HEO-HS)
    - DC Brushless Motor: Suitable for small power
      - HONDA INSIGHT (IMA)
      - Electric Motorbike: Tse-Mon(策盟), Kimco
  2. AC Sensing Motor: EVs or FCEVs
  3. DC Motor: Electric Bicycle
Generator

- **Function:**
  - **Key Function:** Generator
  - **Sub-function:** Start-up Motor (It depends on the system)
    - TOYOTA PRIUS (THS)
    - NISSAN TINO (HEO-HS)

- **Model Types:** Same as the Motor

- **Remarks:**
  - Whether it will be equipped with a generator shall depend on the hybrid electric system

Electric Power-Conversion Device

- **Rectifier:** AC to DC
- **Inverter:**
  - Specific-defined Inverter: Changing DC into AC power source and providing the motor with required power-conversion device, i.e., DC-AC Converter
  - Broadly-defined Inverter: AC-DC-AC Converter
- **Transformer:** AC to AC (f : not changed)
- **Cycloconverter:** AC to AC (f : Changeable)
- **DC-DC Converter**
- **Chopper:** Driver for DC Servo Motor
Inverter (1)

- Function: Motor Driver
- Construct:
  - Internal basic construct circuit of an inverter
  - Different from an industrial frequency-changer, a vehicle-based inverter does not contain motor controller

Rectifier or DC Power

Current Controller

PWM Inverter

Motor

Base (Gate) Pole Drive Signal

Motor Controller

Inverter (2)

Motor-specific Bridge Circuit

Voltage Detection Circuit

Signal Processing

Circuit Protection Function Processing

Hybrid ECU (Motor ECU)

High-Voltage Storage Battery

Ignition Signal

Grounding

Charging-specific Bridge Circuit

Current Sensor

Motor

Generator

P19
DC-DC Converter

Dynamics Separating Mechanism

- Definition:
  - A mechanism that connects the separate engine dynamics and motor dynamics
  - Some models possess the function of allocating the engine and motor dynamics outputs

- Application Situations:
  - Applied only on the parallel hybrid electric system of double-axis allocation model

- Model:
  - EM clutch: NEO–HS, THS-M, GDI-HEV
  - Planet Gear Mechanism: THS
    - Possessing the function of allocating dynamics loading
Planet Gear
Dynamics Separating Mechanism

Actions of Planet Gear
Dynamics Separating Mechanism

- **Engine Stop**
- **Start**
- **Acceleration**
- **Start up**
- **Cruise**
Computer Controlled System (1)

![Diagram of computer-controlled system]

Computer Controlled System (2)

- **Control Computer**
  - Hybrid Electric ECU:
    - Control Center; integrating the functioning of all ECUs
  - Engine ECU: EFI
  - Motor ECU: Motor, Generator
  - Storage Battery ECU: Charging Storage Battery
  - Clutch Control ECU (if necessary)
  - Brake ECU
Computer Controlled System (3)

- Signal Input Sensor
  - Gear Position Sensor
  - Air-Saving Gate Sensor
  - Current Sensor
  - Storage Battery Temperature Sensor
  - EFI System Sensor

Computer Controlled System (4)

- Signal Output: Activator
  - Engine: Electronic Control Air-Saving Gate
  - Motor: Driven by Inverter
  - Generator (if equipped)
  - EM Clutch (if equipped)
  - Brake Oil Pressure Regulator

 fluid
Battery ECU Functions

1. Status of Charging (SOC) Detection
2. Maintenance of the High-Voltage Battery Performance
   - Uniform Charging for
   - Temperature Management
3. Detection of Battery
   - Battery Abnormality Detection
   - Leakage Detection
   - Voltage Abnormality Detection
   - Storage Battery Temperature
   - Storage Battery Current
Maintenance of High-Voltage Circuit

Operation Modes of the Hybrid Electric System

- Driving Mode
- Regenerative Brake Mode
- Auto Stop / Start Mode
Driving Mode

Five Basic Driving Modes

1. Battery Mode
2. Serial Mode
3. Engine Mode
4. Parallel Mode
5. Serial-Parallel Mode

Battery Mode

Motor Driver
AC: Inverter
DC: Chopper

High-Voltage Battery
Motor Driver
Motor

Engine
Serial Mode

Engine Mode
Parallel Mode

Serial-Parallel Mode
Regenerative Brake Mode (1)

- **Electric Brake:**
  - Regarding the motor revolving speed control, the motor speed could be reduced by controlling the electric power; in this way, it is called Electrical Braking.
  - When using electric braking, the motor will be operated as in a generator mode, it will convert the inertia kinetics stored in motor or in the load into electrical energy.

Regenerative Brake Mode (2)

- The handling method of the electrical energy produced while applying electrical braking:
  - Consuming it by using resistor; it is called Dynamic Braking or Generating Braking.
  - After proper converting of the electrical energy, it could be provided to other system for further application.
  - Retrieving and storing; e.g., storing to the secondary battery or in a large-scale capacitor (super-capacitor).
Regenerative Brake Mode (3)

- Regenerative Braking:
  - That using the above-mentioned second and third methods to process the electric braking electrical energy are the so-called Regenerative Braking.
  - Because the energy-storage capacity of the secondary battery has great impact on the navigation endurance of an electric vehicle, in addition to the huge driving inertia force possessed by the vehicle, so, regenerative braking method is adopted in electric vehicle in order to retrieve part of braking energy when the vehicle is decelerating and braked and convert the energy into electrical energy for recycling.
Auto Stop and Go (ASG) Mode (1)

1. Automatic Engine Idling Stop
   - Operation Timing:
     - When the vehicle stops
     - When vehicle speed becomes lower than certain speed (For double-axis parallel type and the motor itself could drive the vehicle), e.g., TOYOTA THS : 40km/h
   - Advantage: Saving fuel consumption; reducing waste-gas exhaustion
   - Effects: Concerning the fuel consumption; MPI: 15% off, GDI: 10% off

2. Engine Restart
   - Operation Timing: It will depend on the driving mode concerning Hybrid Electric System ECU
     - When a vehicle starts
     - When the vehicle speed exceeds a certain speed (For double-axis parallel type and the motor itself could drive the vehicle)

Auto Stop and Go (ASG) Mode (2)

- Motor ECU will depend on the hybrid dynamic ECU signal to control the inverter to transform the generator (or motor) function into start-up motor to start the motor.

3. Situation under which the ASG mode will not work (Engine keeps running)
   (1). When the high-voltage storage battery needs charging
   (2). When air-conditioner compressor needs to run
     - Adopting constant-temperature air-conditioning system
     - Blower is opened at FULL position
   (3). Engine cooling water temperature rises to a level that requires cooling cycle
   (4). Engine is still in warming period
The Operation of Hybrid Electric System (1)

- System starts up
  - Same way as a regular vehicle starts

- Engine starts up
  - The control system will depend on the necessity to start the engine (e.g., when engine needs to be warmed up or charged)
    - To be started up by motor: HONDA IMA
    - To be started up by generator: THS, NEO-HS

The Operation of Hybrid Electric System (2)

- When it starts to run
- When driving in low speed

Rem: The system operation of HONDA IMA is mainly by engine, motor power is used as an auxiliary solution.
The Operation of Hybrid Electric System (4)

- Regular Driving

The Operation of Hybrid Electric System (3)

- Driving under high loading
The Operation of Hybrid Electric System (5)

- When it decelerates and brakes

![Diagram of hybrid electric system]

The Operation of Hybrid Electric System (6)

- When the vehicle stops:
  - Automatic Engine Idling Stop

  Rem : For the following situations, the engine will keep operating
  - When the hi-voltage storage battery needs charging
  - When the air-conditioner compressor needs to operate; the air-conditioner blower is set to FULL position
  - Engine Cooling Water Temperature rises to the level that needs cooling cycle.
  - Engine is still in the vehicle warming period
The Operation of Hybrid Electric System (7)

- When the high-voltage storage battery is charging

The energy that runs hybrid cars

Source: Toyota
Hybrid system variations

- Honda IMA
- Toyota Crown with mild hybrid system
- Toyota Prius
- Toyota Estima Hybrid
- Electric power drive
- Motor assist
- Regenerative braking
- Idling stop

Performance Achieved

- Fuel Consumption: Japan 10-15 MODE Testing Methods
  - TOYOTA PRIUS: 28km/L (CVT)
  - HONDA INSIGHT: 35km/L (MT Vehicle)
  - NISSAN TINO: 23km/L (CVT)

- Waste Gas Exhaustion
  - CO₂ volume is about one half of that of a traditional vehicle. And, the exhaustion volumes of CO, HC and NOx are about one tenth of standard formulated in Japan regulations.
THS Assembly

THS Powertrain

- Engine
- Decelerating Mechanism
- Motor
- Generator
- Dynamics Separating Mechanism

Prius
ATKINSON CYCLE

High expansion ratio conceptual diagram

Cylinder pressure (P)

Expansion stroke

Exhaust loss comparison

Compression stroke

Compression starting point

Cylinder volume (V)

High expansion ratio cycle pumping loss

Conventional cycle pumping loss

High expansion ratio cycle

Conventional cycle

Planet Gear

Dynamics Separating Mechanism
THS Brake Control System

Block Diagram of THS Operation Control
Overall Drive Forces Control of the THS Vehicles

Application Performance of the THS Fuel Energy
Conclusion

- Hybrid Electric Vehicle:
  - Demands of Environmental Protection
    - The sales volume of low pollution vehicles will have to reach up to above a certain ratio of the overall sales volumes.
    - The Hybrid Electric Vehicle could effectively save energy source and reduce the exhaustion volume of CO$_2$, CO, HC and NO$_x$ (one half of the same-class vehicles); it could solve the environmental pollution problems imposed on earth.
  - Admission Impact of WTO: The vehicle is required to reduce energy consumption.
- Sales Price Issue
- The diversity of Hybrid Electric System
  - The combination of different dynamic systems
  - The diversity of system operation (or the diversification of element functions), e.g.,
    - The switching of electrical engineering operation (Motor $\leftrightarrow$ Generator)
    - The combination of different dynamic systems —Owing to the maturity of electric power conversion, it changes the original model of the DC 12V electric power system of a vehicle, it leads to an electric power system revolution.
  - The goal of saving energy has not been changed; under the different function-specified demands, all types of models have been proposed.
Second generation Prius

2nd generation Prius

2nd generation hybrid system THS II

Developing Goal of THS-II

Objective:
Compatibility of Environmental & Power Performance

DRIVE POWER
- 1.5 times higher output than previous model
- Air-cooled, 3-cylinder high-efficiency gasoline engine
- New hybrid transmission (Higher-efficiency power control device)

ELECTRIC POWER
- High-efficiency motor
- High-power density motor
- High-voltage electric system with voltage boost circuit

THS II
- Energy optimization management
- Torque-on-demand control
- Regenerative-brake control

CONTROL

ENVIRONMENT
- World's best fuel economy
- Ultra-low emissions

POWER
- Outstanding acceleration at start and when overtaking
- Powerful and seamless response
## THS Specifications

<table>
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<tr>
<th>Item</th>
<th>THS II</th>
<th>THS (improved)</th>
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<tr>
<td><strong>Engine</strong></td>
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<tr>
<td>Type</td>
<td>1.5 L gasoline (high-expansion ratio cycle)</td>
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<tr>
<td>Maximum output in kW (Ps)/rpm</td>
<td>57 (78)/5,000</td>
<td>53 (72)/4,500</td>
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<tr>
<td>Maximum torque in N·m (kg·m)/rpm</td>
<td>115 (11.7)/4,200</td>
<td>115 (11.7)/4,200</td>
</tr>
<tr>
<td><strong>Motor</strong></td>
<td></td>
<td></td>
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<tr>
<td>Type</td>
<td>Synchronous AC motor</td>
<td>←</td>
</tr>
<tr>
<td>Maximum output in kW (Ps)/rpm</td>
<td>50 (68)/1,200-1,540</td>
<td>33 (45)/1,040-1,600</td>
</tr>
<tr>
<td>Maximum torque in N·m (kg·m)/rpm</td>
<td>400(40.8)/20-1,200</td>
<td>350(35.7)/0-400</td>
</tr>
<tr>
<td><strong>System</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum output in kW (Ps)/vehicle speed km/h</td>
<td>82(113)/85 or higher</td>
<td>74 (101)/120 or higher</td>
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<tr>
<td>Output at 85km/h in kW (Ps)</td>
<td>82 (113)</td>
<td>65 (88)</td>
</tr>
<tr>
<td>Maximum torque in N·m (kg·m)/vehicle speed km/h</td>
<td>478(48.7)/22 or lower</td>
<td>421 (42.9)/11 or lower</td>
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<tr>
<td>Torque at 22km/h in N·m (kg·m)</td>
<td>478 (48.7)</td>
<td>378 (38.5)</td>
</tr>
<tr>
<td><strong>Battery</strong></td>
<td>Type Nickel-metal hydride</td>
<td>←</td>
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## Power-train of THS, THS II

![Power-train of THS, THS II](image_url)
Supply Approach of High-Voltage Electricity

Secondary Battery
2nd generation hybrid system THS II

Hybrid Synergy Drive

Combining "environmental performance" with "exciting driving"
Drive system output improvement

Output performance of the 2nd generation Prius

Innovations in running performance

Standing start and overtaking acceleration performance
Split Mechanism

The Actions of a Planet Gear Dynamics Separating Mechanism

- Engine Stop
- Start & charging at stop
- Start up
- Cruise
The Construct of THS-II Brake System

Regenerative Brake

Improved regenerative braking

THS

Brake pedal depression

Regenerative braking

Braking power

THS II

Brake pedal depression

Regenerative braking

Braking power

Hydraulic braking

Hydraulic braking

ECB effect

Expanded regenerative range
System Operation Modes

Control Block Diagram of THS II Operation
Overall Drive Force Control of THS II

1. Driving power performance
   - Driving power
   - Battery → Motor
   - Generator → Motor
   - Direct drive from engine
   - Running resistance

2. THS II drive power (conceptual diagram)
   - Engine
   - Battery
   - Motor drive power

3. Motor Traction Control

4. Wheel-speed behavior at start-up on a snowy road
   - Accelerator depression
   - Drive-wheel speed without control (slippage)
   - Drive-wheel speed with control
   - Vehicle speed

Time (seconds)
System Output Comparison

- **Output:**
  - 50kW
  - 33kW

- **Torque:**
  - 400N·m
  - 550N·m

Vehicle speed (km/h):

100 rpm (TMC data)

Drive shaft output (kW):

Vehicle speed (km/h):

0 40 80 120

Acceleration Performance

- **Acceleration:**
  - Sensation 50km
  - Good fuel economy

- **Elapsed time:**
  - 0-100km/h acceleration
  - 2.4s automatic transmission

- **Corolla (1.3):**
  - Good responsiveness

- **Corolla (1.5):**
  - Fuel efficiency

- **Allion (1.8):**
  - Tradeoff between performance and fuel economy in conventional vehicles

- **Camry (2.4L):**
  - Mark II (2.4L)

- **Jaguar 10.5 fuel cycle:**

- **Performance:**
  - Good acceleration

Acceleration Performance (TMC data):

- 0-100km/h
- Acceleration from start
- THS Prius (1.5)

- Elapsed time:
  - 10 (seconds)
  - 15 (seconds)

- **Corolla (1.3):**
  - 4 (seconds)

- **Corolla (1.5):**
  - 6 (seconds)
Overall Energy Efficiency

**Overall Efficiency**

<table>
<thead>
<tr>
<th>Overall efficiency (%)</th>
<th>0</th>
<th>10</th>
<th>20</th>
<th>30</th>
<th>40</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fuel efficiency</strong> (%)(well-to-tank)</td>
<td><strong>Vehicle efficiency</strong> (%)(tank-to-wheel)</td>
<td><strong>Overall efficiency</strong> (%)</td>
<td><strong>(well-to-wheel)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Regent gasoline car</td>
<td>88</td>
<td>16</td>
<td>14%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prius (before improvement)</td>
<td>88</td>
<td>32</td>
<td>28%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prius (after improvement)</td>
<td>28</td>
<td>25%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prius with THS II</td>
<td>37</td>
<td>32%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Toyota FCHV</td>
<td>50</td>
<td>29%</td>
<td></td>
<td></td>
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<tr>
<td>FCHV (target)</td>
<td>70</td>
<td>60</td>
<td>42%</td>
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</tr>
</tbody>
</table>

**Conclusion**

- **Electric Vehicle (EV):** The breakthrough of battery technology
- **FCEV:** The future developing goal of a vehicle
  - If using hydrogen as fuel:
    - Hydrogen: One needs to solve the safety issue of storage
    - LH₂: Issue of production cost
  - If using methanol, gasoline, etc. as fuels:
    - One needs to reduce the fuel reset-up time
    - Post-processing issue of CO: Cost increases
    - Production of CO₂: Dilution Issue
    - Heat management issue
References

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15. Che, hsiung hsien, "Practice of Electrically-driven Devices", Chi-Shue Publisher, 1978