CHAPTER 20
Regenerative Braking Systems

OBJECTIVES
• Explain the principles involved in regenerative braking.
• State the types of regenerative braking systems.
• Discuss the parts and components involved in regenerative braking.

PRINCIPLES OF REGENERATIVE BRAKING
• Inertia, Force, and Mass
• Frequently Asked Question
  ▪ What Is the Difference Between Mass and Weight?
• Reclaiming Energy in a Hybrid
• Transferring Torque Back to the Motor
• Principles Involved
FIGURE 20.1  This Honda Insight hybrid electric vehicle is constructed mostly of aluminum to save weight.

FIGURE 20.2  A Toyota Prius hybrid electric vehicle. This sedan weighs more and therefore has greater kinetic energy than a smaller, lighter vehicle.

TYPES OF REGENERATIVE BRAKING SYSTEMS

• Series regeneration
  ▪ Electrohydraulic brake (EHB) system
• Frequently Asked Question
  ▪ Are the Friction Brakes Used During Regenerative Braking?
• Parallel regeneration
FIGURE 20.3 The electronic brake control unit (EBU) is shown on the left (passenger side) and the brake hydraulic unit is shown on the right (driver’s side) on this Ford Escape system.

FIGURE 20.4 A typical brake curve showing the speed on the left and the percentage of regenerative braking along the bottom. Notice that the base brakes are being used more when the vehicle speed is low.

BATTERY CHARGING DURING REGENERATION

- Background
  - Kinetic energy can be converted into electrical energy with a generator
- Frequently Asked Question
  - How Does the Computer Change a Motor to a Generator So Quickly?
FIGURE 20.5 The frequency \( f \) applied to the stator windings of an AC synchronous motor can be varied to create either forward torque \( T \) or regenerative braking. If the frequency is changed from point 1 to point 2 as shown on the chart, the torque is changed from motoring (powering the vehicle) to generating and this change can be made almost instantly by the controller.

BATTERY CHARGING DURING REGENERATION

- **Parts and Operation**
  - A conventional DC motor has wire windings on the armature that act as electromagnets
  - Permanent magnets

- **Frequently Asked Question**
  - What Do Regenerative Brakes Look Like?
  - Limitations of Regenerative Brakes

REGENERATIVE BRAKING SYSTEMS

- **Dash Display**
- **Regenerative Brake Components**
  - Brake pedal position (BPP)
- **Tech Tip**
  - “B” Means Braking
HOW THE REGENERATION SYSTEM WORKS

- Regeneration and conventional brakes controlled by one brake pedal
- Regeneration also occurs only when the throttle has been fully lifted
- Frequently Asked Question
  - Can an On-Vehicle Brake Lathe be Used on a Hybrid Electric Vehicle?

HOW THE REGENERATION SYSTEM WORKS

- Note: One of the major concerns with hybrid vehicles is:
  - Rust and corrosion on the brake rotors and drums.
  - This occurs on hybrids because the base brakes are usually only used at low vehicle speeds
  - Electric Motor Becomes a Generator

FIGURE 20.9 The ABS ECU on a Toyota Prius uses the brake switch and pressure sensor inputs to control the regenerative braking system. The circuit includes a voltage signal from the sensor, the regulated 5V supply to it, the input from the brake light switch (12 V when the brakes are on), and the ground connection.
DECELERATION RATES

- Comfortable deceleration is about 8.5 ft/sec² (3 m/s²)
- Loose items in the vehicle will “fly” above 11 ft/sec² (3.5 m/s²)
- Maximum deceleration rates for most vehicles and light trucks range from:
  - 16 to 32 ft/sec² (5 to 10 m/s²).

ENGINE DESIGN RELATED TO REGENERATIVE BRAKING

- A variation of the VTEC valve actuation system to close all of the valves in:
  - Three cylinders in both the V-6 and the inline four cylinder engines during deceleration
  - This traps some exhaust in the cylinders and because no air enters the pistons
FIGURE 20.11  This Honda valve train photo shows the small spring used to absorb the motion of the rocker arm when the cam is switched to a lobe that has zero lift. This action causes the valves to remain closed thereby reducing engine braking, which increases the amount of energy that can be captured by the regenerative braking system when the vehicle is slowing. The powertrain control module controls this valve action in response to inputs from the throttle position (TP) sensor and vehicle speed information.

SERVICING REGENERATIVE BRAKING SYSTEMS

- Unique Master Cylinders
- Ford Escape Precautions
  - Caution: Preventing physical harm or causing vehicle damage when serving braking system
- Frequently Asked Question
  - When Does Regenerative Braking Not Work?

FIGURE 20.12  A master cylinder from a Toyota Highlander hybrid electric vehicle.
FIGURE 20.13 When working on the brakes on a Ford Escape or Mercury Mariner hybrid vehicle, disconnect the black electrical connector on the ABS hydraulic control unit located on the passenger side under the hood.

SUMMARY

• All moving objects that have mass (weight) have kinetic energy.
• The regenerative braking system captures most of the kinetic energy from the moving vehicle and returns this energy to high-voltage batteries to be used later to help propel the vehicle.
• The two types of regenerative braking include parallel and series.

SUMMARY

• Brushless DC and AC induction motors are used in hybrid electric vehicles to help propel the vehicle and to generate electrical energy back to the batteries during braking.
• Most hybrid electric vehicles use an electrohydraulic braking system that includes pressure sensors to detect the pressures in the system.
SUMMARY

- The controller is used to control the motors and turn them into a generator as needed to provide regenerative braking.