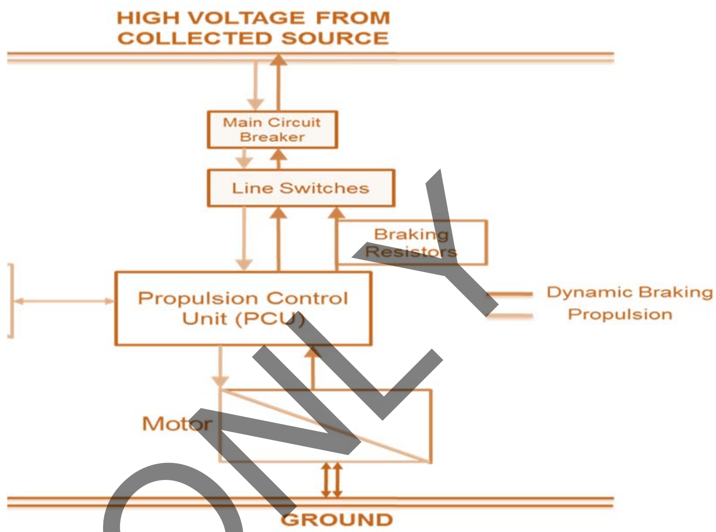
Introduction and Overview to Propulsion and Dynamic Braking Systems



Course 103






PARTICIPANT GUIDE

RAIL CAR TRAINING CONSORTIUM

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MODULE 1

GENERAL PRINCIPLES AND TERMINOLOGY

Outline

1-1 Safety Review
1-2 Overview to Rail Car Propulsion System
1-3 DC and AC Motors
1-4 Overview to Rail Car Dynamic Braking System
1-5 Summary

Purpose and Objectives

The purpose of this module is to provide participants with an overview of the principles of maintenance of rail car propulsion and dynamic braking systems.

Following the completion of this module, the participant should be able to complete the objectives with an accuracy of 75% or greater:

- Recall safety procedures when working on rail car including:
  - Lockout tagout (LOTO)
  - Proper use of PPE
- Identify hazards specific to work around propulsion and dynamic braking
- Explain basic theory of operation of a rail car's propulsion system
- Explain basic theory of operation of a rail car's dynamic braking system
- Describe principles of motor theory
- Compare AC and DC motors with respect to rail cars
- Recall the theory of grounding circuits with respect to rail cars

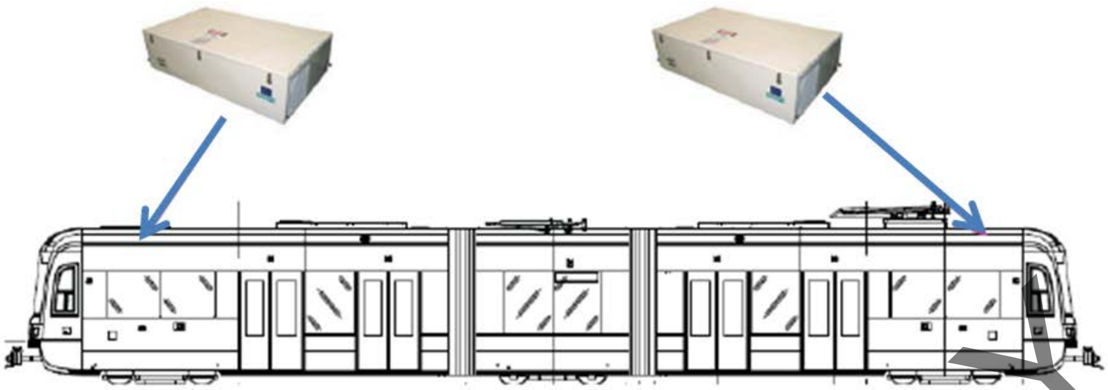

Figure 1.9 Propulsion Containers Located on top of Rail Vehicle –courtesy SDMTS

For propulsion containers located under the rail vehicle, such as illustrated in Figure 1.10, these are accessed either from inside a pit in the repair shop or when the vehicle is hoisted on lifts (Figure 1.11).

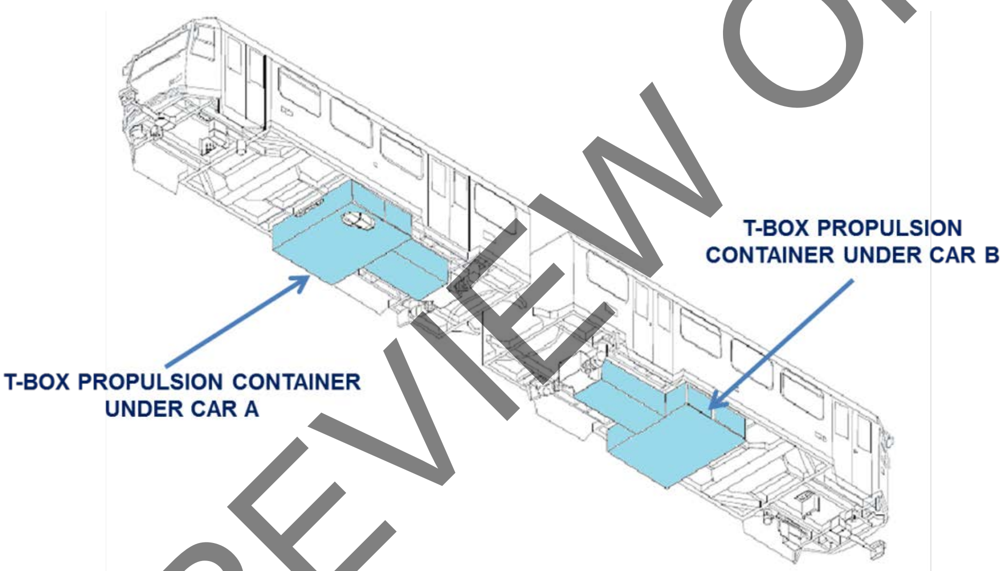

Figure 1.10 T-Box Propulsion Containers on A and B Cars –courtesy Denver RTD

Learning Application 1.2

With guidance from your instructor, write down the ways in which you will access the propulsion containers on the rail cars in your maintenance facility.

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Figure 1.11 LA Metro Rail Car on Hoists –from whitingcorp.com

Pit areas are confined spaces which present special challenges including proper ventilation, lighting, and access. OSHA defines confined spaces as those spaces "while they are not necessarily designed for people, they are large enough for workers to enter and perform certain jobs. A confined space also has limited or restricted means for entry or exit and is not designed for continuous occupancy. Confined spaces include, but are not limited to, tanks, vessels, vaults, pits, manholes, tunnels, equipment housings, etc."

While working under rail vehicles maintainers must be aware of conditions such as adequate lighting, protruding equipment, room for head space, pinch points, and others. It is necessary for rail car maintainers to observe all agency safety rules and procedures including the prevention of vehicle movement before working on the rail car's propulsion system. In addition, make sure there is continuous protection until all maintenance is complete and all personnel are clear.

One key to safety during rail car maintenance is communication. Effective communication ensures that all employees know where their fellow employees are located and what they're doing. While some companies may issue radios to employees who work around trains, many use standard hand and vocal signals. Some agencies use blue flags or blue lights affixed to the rail vehicles to indicate that personnel are working on the vehicles.

Learning Application 1.3

What are some of the other important safety considerations with work around rail car propulsion systems? Discuss with your instructor and others in your classroom.

1-3 DYNAMIC BRAKING

Many transit rail cars use three types of braking: dynamic, friction, and track. **Dynamic braking** is the use of the electric traction motors which act as **generators** when decelerating or slowing down the train. The motion of the wheels causes the motors to rotate which generates electrical energy and it is the traction motors that converts this energy into electrical current. In the final phase of deceleration, dynamic braking fades out and **friction braking** begins to take over progressively and proportionally. This is called **blended service braking** and its purpose is to ensure a smooth and even deceleration rate.

Friction braking is a common braking system used by trains and it acts by dissipating the kinetic energy of the moving train and converting the energy to heat. The heat arises from the friction between the brake pad and the brake disc or between block and wheel tire during braking. The most common type of brake used by trains, it acts by dissipating the kinetic energy of the moving train by converting the energy into heat. There is an entire course in this series devoted to friction brakes.

Track brakes, one is shown in Figure 1.14, are brakes that are applied directly on to the tracks. These electromagnetic track brakes are often installed light rail vehicles to support the braking function. Track brakes are positioned inside the truck near the wheels where space is tight.

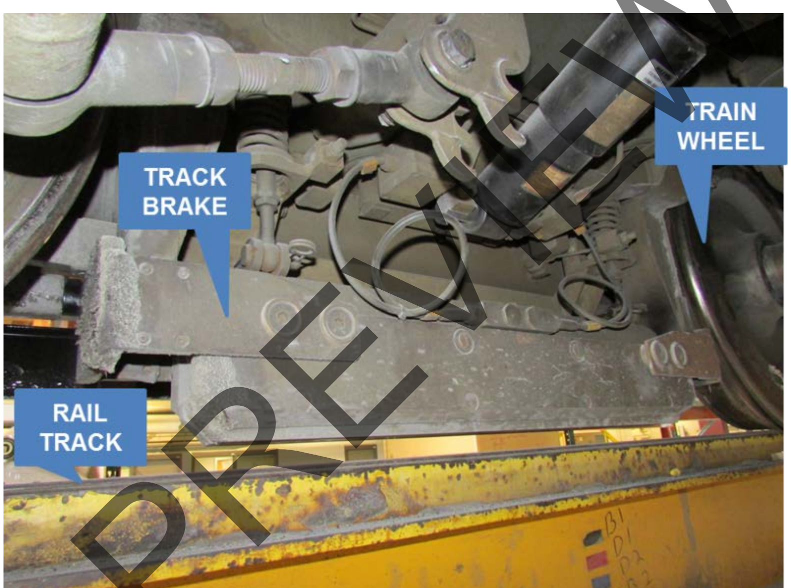

Figure 1.14 Track Brake on LRV in Denver RTD Maintenance Facility

Traction motors are also connected to **banks of braking resistors**. In Figure 1.15 these are shown on top of a rail car in the maintenance shop. If the generated electrical power is dissipated as heat in the resistors, it is termed **rheostatic**. If the generated electrical power is returned to the high voltage power source, it is termed **regenerative**. In either case, the wheels are slowed by the kinetic resistance of generation.

1-4 DC AND AC MOTORS

A motor is an electrical machine which converts electrical energy into mechanical energy. On the rail vehicle, DC and AC motors serve the same function but they are powered and controlled differently. One obvious difference is the source of power. DC motors are powered from direct current while AC motors are powered from alternating current. Other differences are in their construction. DC motors are constructed with brushes and a commutator. AC motors do not use brushes. Another basic difference is speed control. The speed of a DC motor is controlled by varying the armature windings' current while the speed of the AC motor is controlled by varying the frequency.

Traditionally, traction motors driving a train were DC electric and consisted of a case containing a fixed electrical part, the stator, and a moving electrical part, the rotor or armature. Inside of the motor are the two principal electrical components: the armature and field windings. The armature is the rotating part and is also known as the rotor. The stator is the stationary part of an electric motor and its role is to create a magnetic field for the armature to interact with and thereby rotate. The stator can comprise either permanent magnets, or electromagnets formed by a conducting coil.

As the rotor turns, it turns a pinion which, in turn, drives a gearwheel as illustrated in Figure 1.16. The stator and the rotor of a DC motor are electrically connected via fixed, carbon brushes that remain in contact with the commutator, an extension of the armature.

Figure 1.17 shows DC motor with major components labeled.

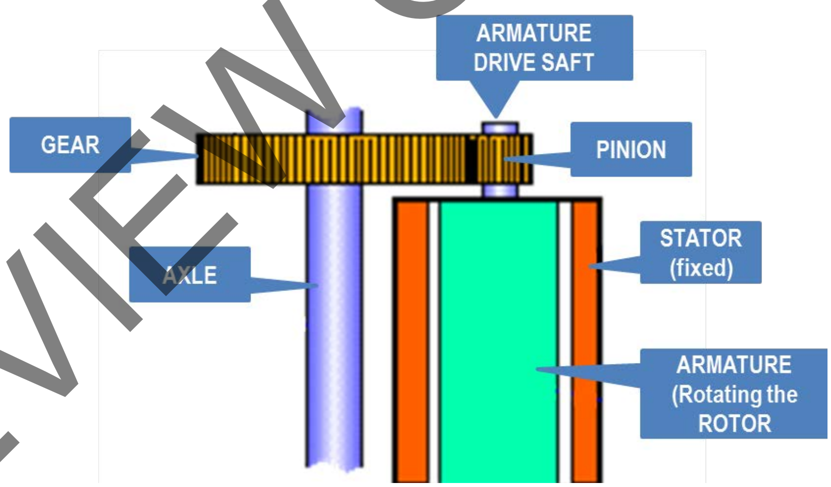

Figure 1.16 DC Motor Driving Rail Car Axle Through Pinion and Gearwheel

1-5 VARIATION IN TRANSIT RAIL PROPULSION SYSTEMS

In this series of courses on propulsion systems, the participant will soon learn that not only do propulsion systems vary by propulsion power (AC or DC), they also vary by design and layout according to the original equipment manufacturers (OEMs), by rail vehicle type (heavy or light rail), and other criteria. See Figure 1.19 and Figure 1.20 for examples of configuration and location of mail propulsion equipment of light rail and heavy rail vehicles in use at two Consortium properties.

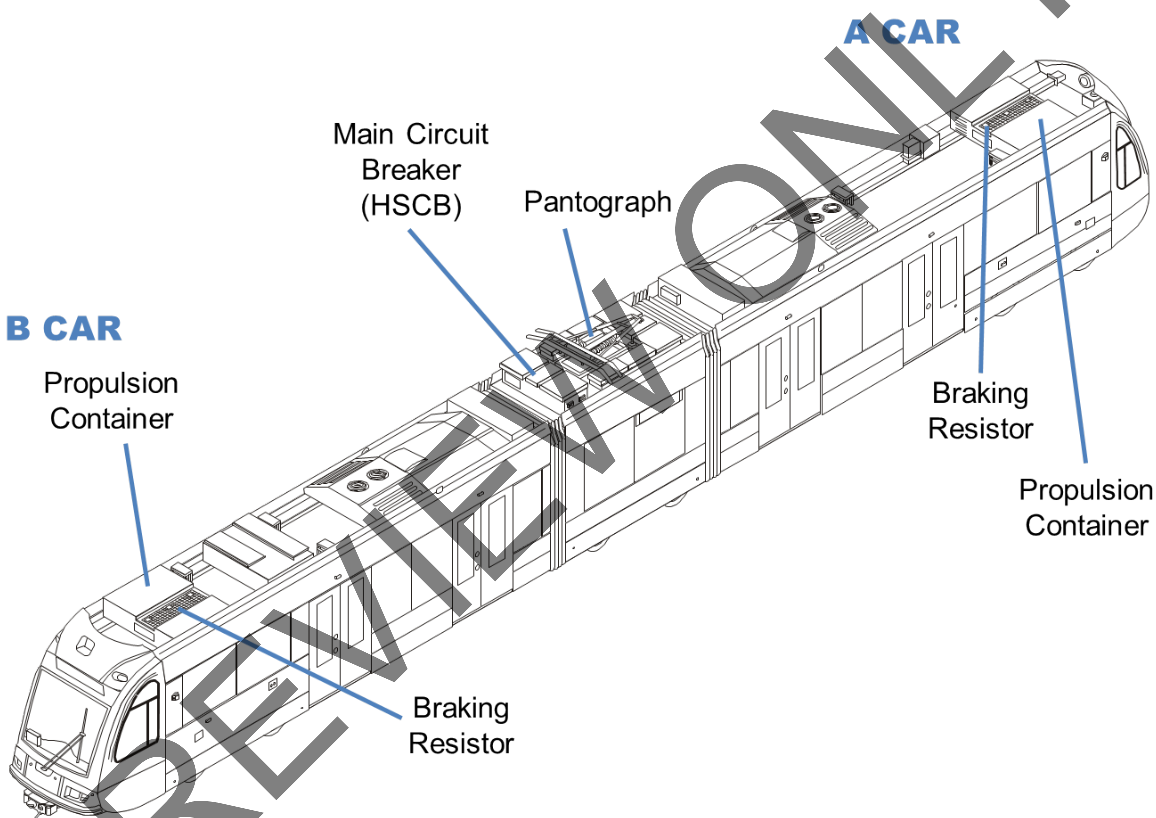

Figure 1.19 Location of Main Propulsion Equipment on Siemens© Light Rail Vehicle –courtesy CATS

MODULE 2

Principles of Operation of AC Propulsion

Outline

2-1 Overview of AC Propulsion

2-2 Switching and Filtering

2-3 Dynamic Braking

2-4 Power Inversion

2-5 AC Motors

2-6 AC Propulsion Circuit

2-7 Summary

Purpose and Objectives

The purpose of this module is to provide participants with an overview to the major components of an AC propulsion system on rail cars used in major U.S. transportation agencies.

Following the completion of this module, the participant should be able to complete the objectives with an accuracy of 75% or greater:

- Explain the five functional areas of the AC propulsion system:
  - Switching
  - Filtering
  - Dynamic Braking
  - Power Inversion
  - Motors
- Identify major components within each of the five functional areas of an AC propulsion system
- Describe principles of induction motor theory

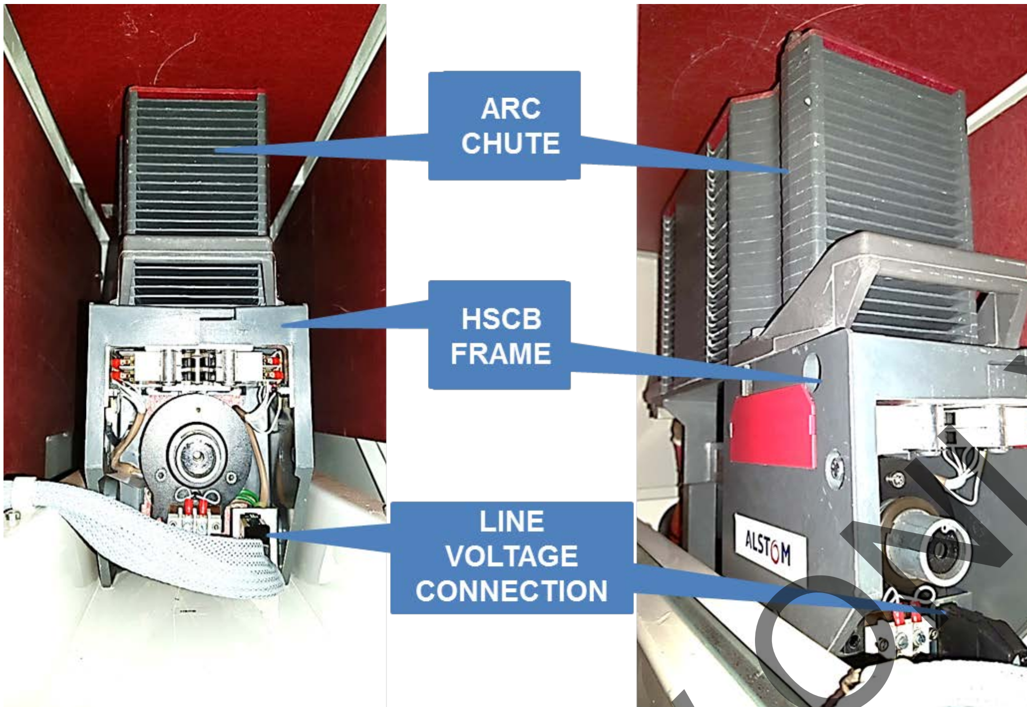

Figure 2.3 Front and Side Views of HSCB –courtesy PATCO

Line Input

The **line input** area of the rail car's propulsion container is comprised of a series of switches and circuits which conditions and filters the high voltage power before it is distributed for use by the rail car's propulsion system in particular the traction motors. The line input consists of a line contactor; the pre-charging circuit; and the line reactor. The **pre-charging circuit** consists of the pre-charge contactor and pre-charge resistors and its function is to slowly charge the DC link capacitor up to required voltage with the pre-charge resistors. See Figure 2.4.

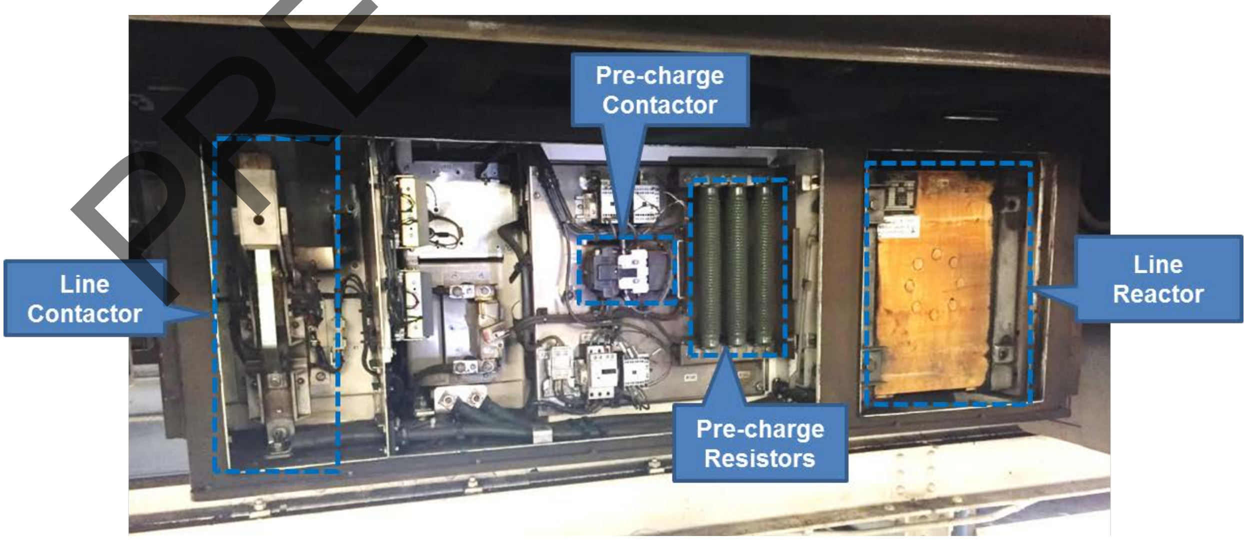

Figure 2.4 Line Contactor and Pre-charge Resistor –courtesy MBTA

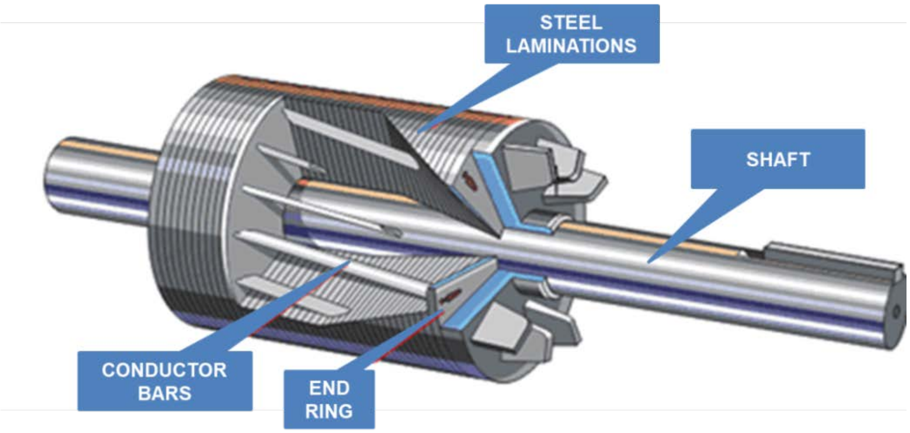

Figure 2.16 Rotor Components –courtesy CATS

So how does this rotating magnetic field make the motor move? The rotor, suspended inside the magnetic field, is an electrical conductor. The magnetic field is constantly changing as it rotates and, according to laws of electromagnetism[4], the magnetic field induces an electric current inside the rotor. The induced current produces its own magnetic field and tries to stop the rotating magnetic field by rotating as well. It's like the rotor is trying to catch up with the rotating magnetic field in an effort to eliminate the difference in motion between them! In fact, there must be a difference between rotor speed and field speed in order for voltage to be induced.

The difference between the rotor speed and the stator speed is known as **slip**. Slip is necessary to produce torque. Depending on your agency's course requirements, participants may be expected to follow this course with more in-depth training on AC motor theory.

Learning Application 2.3

With help from your instructor, write down specifications of the AC traction motors of a rail car on which you will perform inspection and maintenance. Examples shown in *italics* are of the Siemens SD160 LRV, Denver RTD.

CHARACTERISTIC	SPECIFICATION
General	*6-pole, 3-phase asynchronous motor*
Self-Ventilated	*External fan 0.29 m 3/5 at 1000 rpm*
Rotor Diameter	*297 mm (11.69 in.)*
Stator Hole Diameter	*300 mm (11.81 in.)*
Length of Core Assembly	*320 mm (12.60 in.)*

[4] The participant may search online for Faraday's Law for more in-depth description on the laws of electromagnetism the

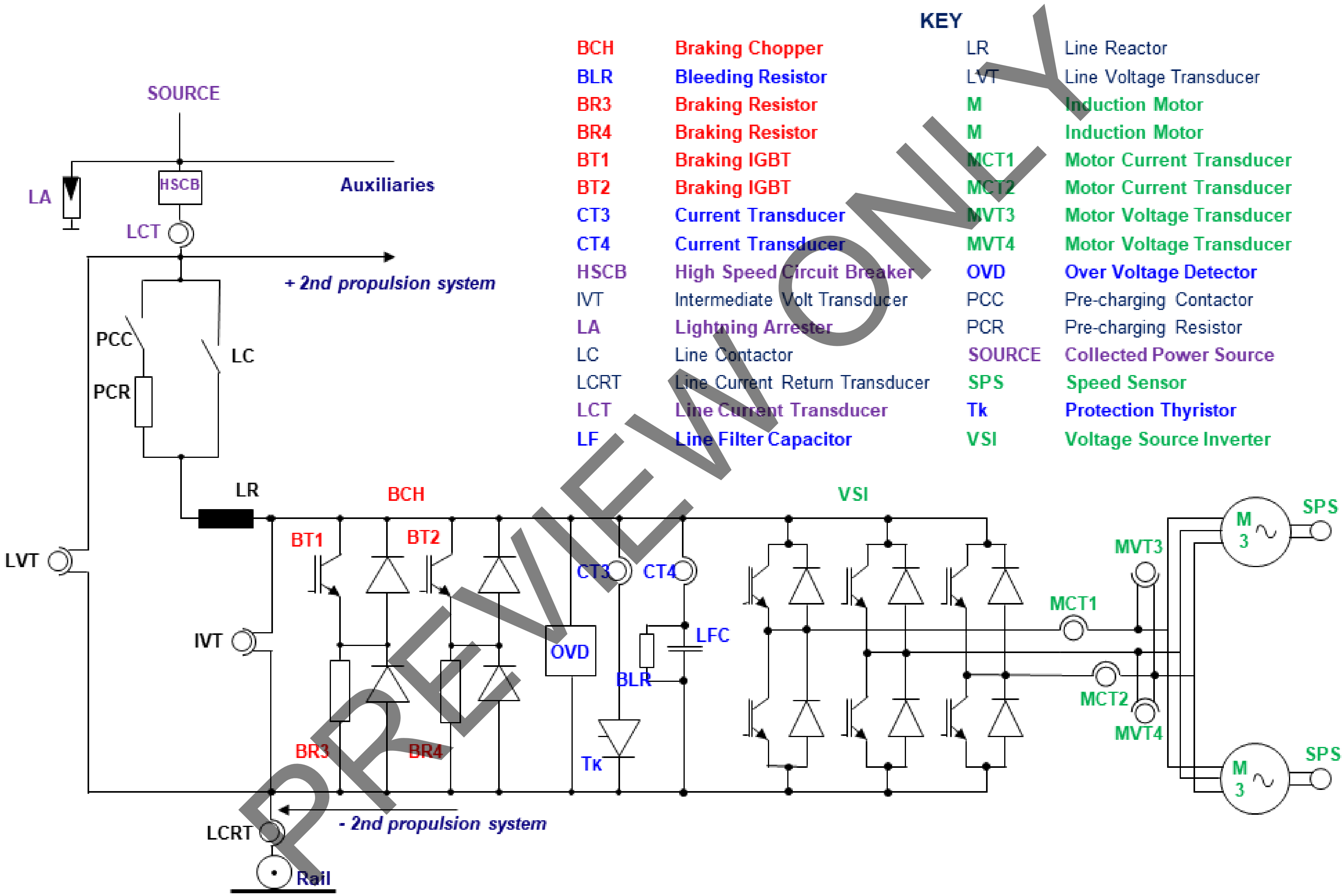

Figure 2.17 Main Circuit Example of AC Propulsion System with Major Components –courtesy Denver RTD

MODULE 3

Principles of Operation of DC Propulsion

Outline

Purpose and Objectives

The purpose of this module is to provide participants with an overview of the principles of maintenance of rail car propulsion and dynamic braking systems.

Following the completion of this module, the participant should be able to complete the objectives with an accuracy of 75% or greater:

- Explain the four functional areas of the DC propulsion system:
  - Switching
  - Filtering
  - Traction Control and Dynamic Braking
  - Motors
- Identify major components within each of the four functional areas of a DC propulsion system
- Explain the theory of operation of a DC motor
- Identify types of DC motors specifically Series, Shunt, Compound

3-2 SWITCHING AND FILTERING

Within the rail car's propulsion system, switching and filtering equipment control the connection to the supply voltage and provide some circuit protection in the event of a short circuit or similar failure. High voltage power collection, whether through a pantograph, third rail, or other systems, needs to be channeled to the rail car's propulsion system and filtered in order to smooth out the high voltage before it enters the inverter.

Switching and filtering devices serve as security devices that allow and cut off power to the main circuitry. For example, should a large amount of electrical current travel along the main circuitry due to a failure of a devices or similar problem, the high-speed circuit breaker will immediately cut off the power to protect the control devices (such as inverters) from potential damage that could occur if exposed to such electrical surges. When these breakers cut off the power, they also internally handle arcing to reduce the risk of electrocution for rail car maintainers.

Fuses and high speed circuit breakers provide system and cabling protection. Manual transfer switches to isolate systems and provide shop power connection are also part of the system. Low-voltage-operated transfer contactors are used to provide AC power source connections.

Some major components within the switching and filtering functional areas include:

- High Speed Circuit Breaker (HSCB)
- Line Contactor
- Pre-charge Resistor
- Pre-charge Contactor
- Line reactor
- Filter capacitor

While the rail car is in the shop for maintenance, power must be removed from its high voltage source. Mention must be made here of the **knife switch** mechanism installed on the rail car which enables supplemental or shop power needs to be available for various tests on the propulsion system.

Figure 3.2 shows a knife switch box on a rail car with third rail as the power source. This box is configured with a blade and handle which can be switched to three positions: run, third rail, and shop. When switched to the RUN jaws, the third rail is connected to the main fuse through the RUN and THIRD RAIL jaws in order to supply power to the car's main circuits. The auxiliary circuits are supplied through the THIRD RAIL jaw. In the SHOP POWER position while connected with an electrical plug, shop power is available to operate auxiliaries. This knife switch box is designed so the cover can only be closed when the knife switch is in the closed or RUN position.

In Module 1, the participant learned that the purpose of a rail vehicle's propulsion system is to interpret trainline commands, translate them into car motion at the required acceleration and braking rates in the proper direction of travel, and provide protection if abnormal conditions occur, such as propulsion overload, overvoltage, or short-to-ground situations. In the DC propulsion system, the DC traction motors are controlled either by **cam controllers** or by **chopper circuits**. Cam-controlled train propulsion systems are less modern than chopper circuits and some transit agencies have retrofitted their cam-controlled cars with IGBT chopper circuits.

Cam Controllers

A cam controller is a type of motor controller that uses a camshaft to make and break electrical contacts in response to the main controller operated by the train operator.

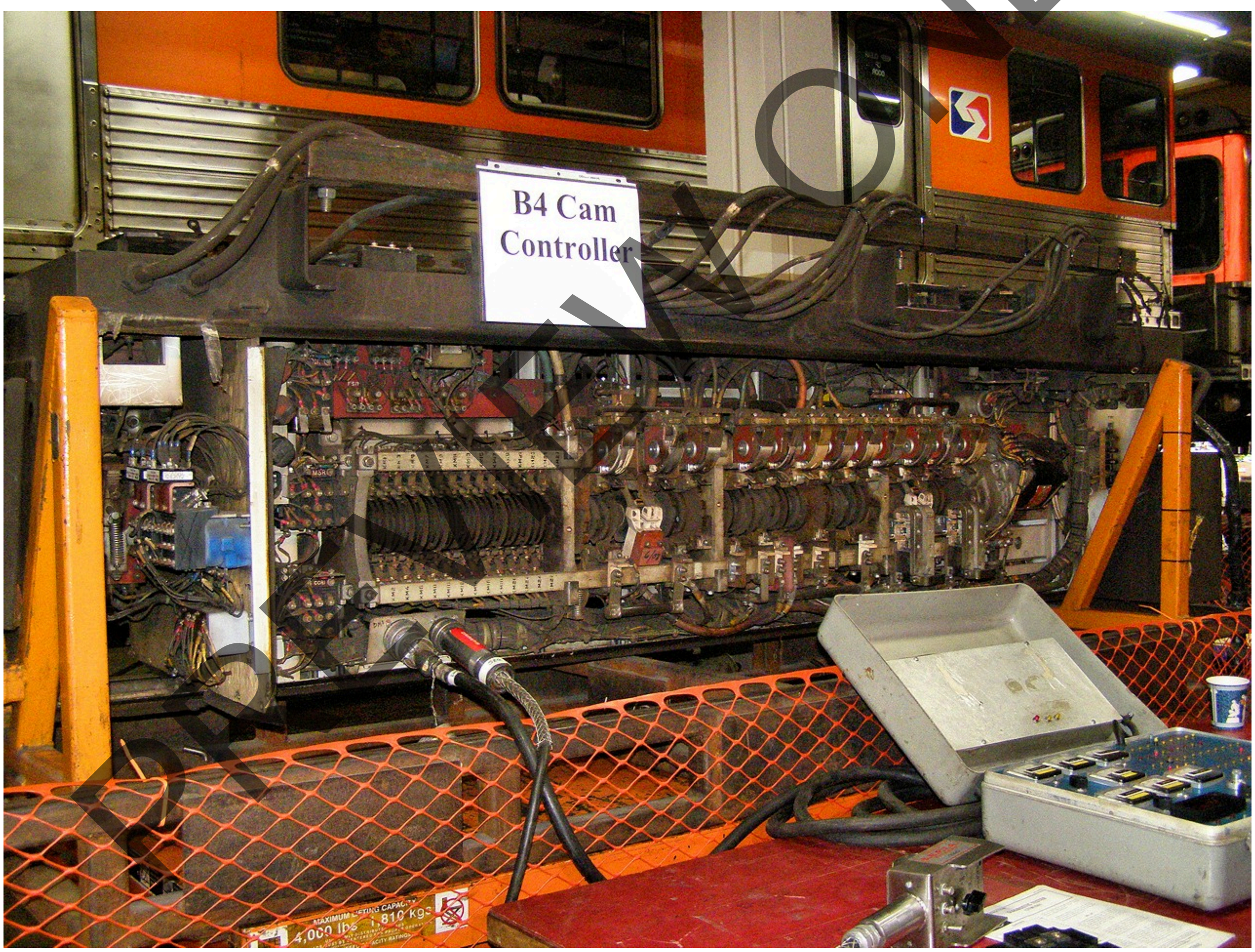

Figure 3.13 Cam Controller on SEPTA's Broad Street Subway Car –courtesy Jersey Mike's Rail Adventures blog http://prr4ever.blogspot.com/2010/09/

A cam controller uses a **servo motor** to position cams to operate the contactors within the propulsion power circuit. A servo motor (also written as one word, **servomotor**) is described as a "rotary actuator or linear actuator that allows the precise control of angular or liner position, velocity, and acceleration. It consists of a suitable motor coupled to a sensor for position feedback."[5]

Cam-controlled propulsion technology is at least thirty years old. As such, several transit rail car agencies have either retrofitted their cam-controlled rail cars with newer IGBT chopper control or else replaced these cars entirely. A well-known industry case study is that of SEPTA's Broad Street Subway Propulsion Control Box Retrofit. If the participant is interested in deeper research on this project, is at the end of this course in Appendix 1.

SEPTA's Broad Street Subway Propulsion Box Control Retrofit

Chopper Circuit

A **DC chopper** is a static device used in the DC propulsion system to convert fixed DC input voltage to variable DC output voltage that will be directly available for use by the DC motors. Basically, a chopper is an electric switch. A **chopper circuit** refers to the choppers and other devices, such as GTOs, that are used together for motor power control.

A DC propulsion system may have several chopper modules all sharing a common DC bus filter capacitor and housed in a **chopper assembly**. The chopper assembly may consist of:

- Armature chopper module
- Field chopper module
- Brake chopper module

Figure 3.14 shows the location of these chopper modules on an LRV with DC propulsion.

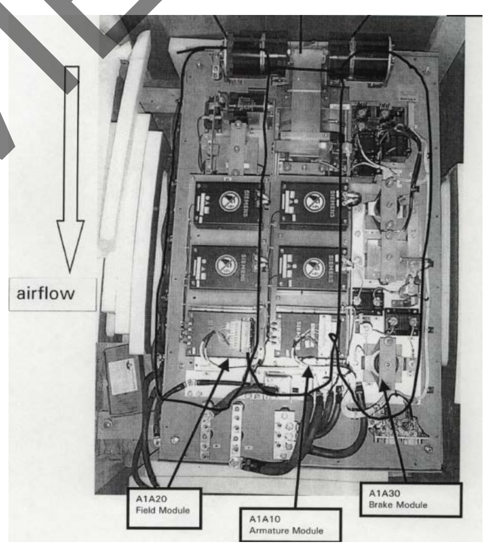

Figure 3.14 PLACEHOLDER for Photo from Juston 5-31-2017

[5] Source https://en.wikipedia.org/wiki/Servomotor

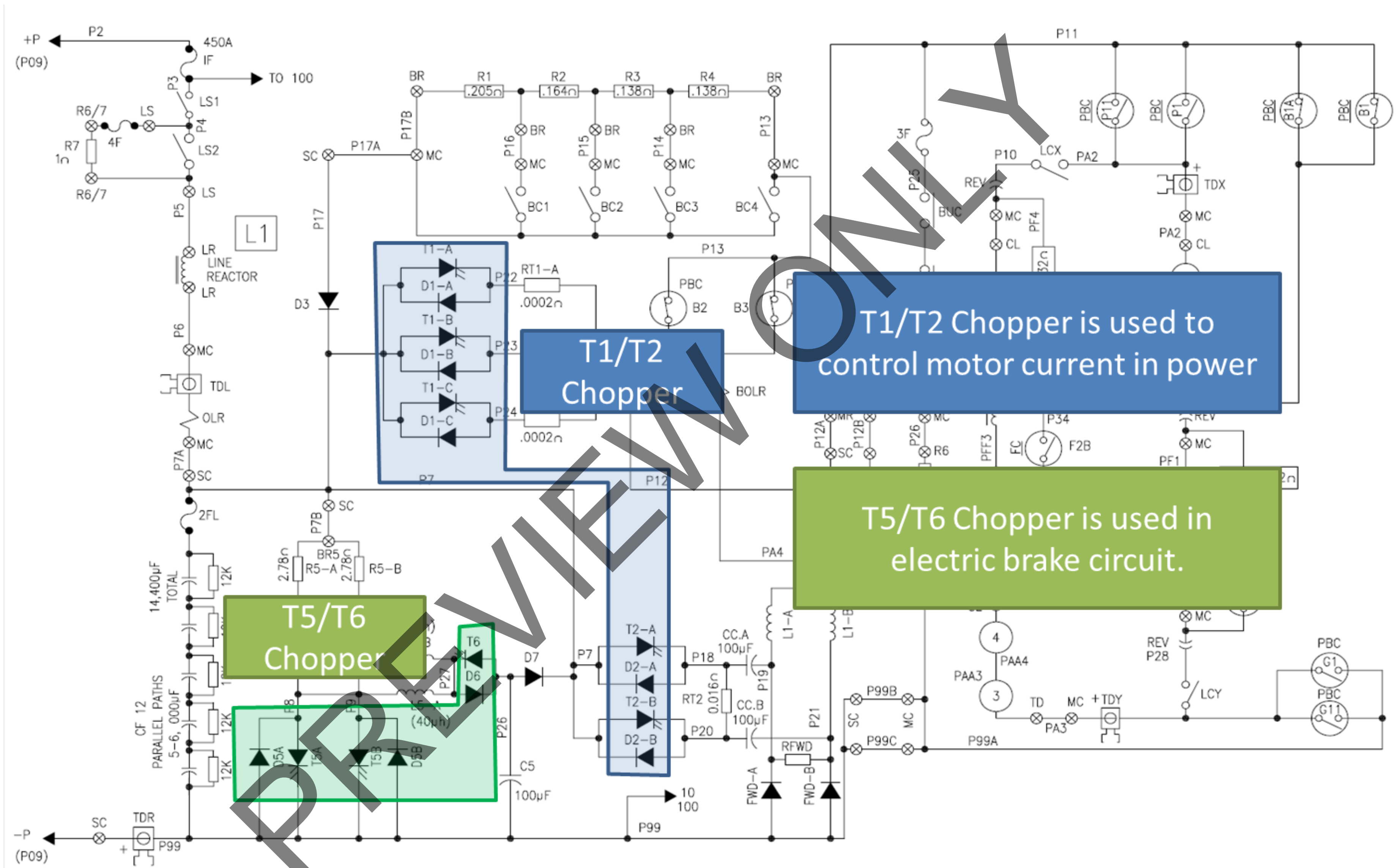

Figure 3.16 Chopper Circuits for C-Car Train –courtesy BART

Case Study 3.4: Configuration Brake Resistors LRVs Niagara Frontier Transportation Authority (NFTA)

The Braking Resistor assemblies are units which contain Type MA-20 resistor tubes. The resistor assembly consists of 43 active plus two dummy tubes. These tubes are grouped into a number of resistance banks which are located on the vehicle roof, as shown in Figure 3.18.

Each of the tubes in the assemblies is 4-9/16 inches in diameter and approximately 20 inches in length. The resistance element is made from a chromium-iron-aluminum alloy resistance material, edge-wound to form a helix. This edge winding permits the maximum amount of resistance material surface to be exposed to the cooling air.

All resistor terminals are directly welded to the resistance helix. The terminals provide holes for bolting external connect ions. The helix is held in position by three U-snaped steel supports spaced 120 degrees apart. Ribbon porcelain insulators and an asbestos cushion fit into the opening of the U-shaped supports.

The porcelain insulates each helix from its supports and keeps adjacent turns separated. A steel disc and hook are welded to the support channels and are used to mount the resistor in an assembly frame. An enlarged opening of the hook allows for expansion and contraction due to heating of the resistor helix.

Braking Resistors Rl, R2, and R3 are utilized during the dynamic braking mode. They are put into series with the traction motors by the Braking Contactors BCl, BC2, and BC3. This switching has three stages, progressing from maximum resistance to minimum resistance, depending on the vehicle speed.

Resistor R5, an MA type resistor, is a voltage regulating resistor which works with thyristor T5 to prevent the system voltage from exceeding a predetermined value.

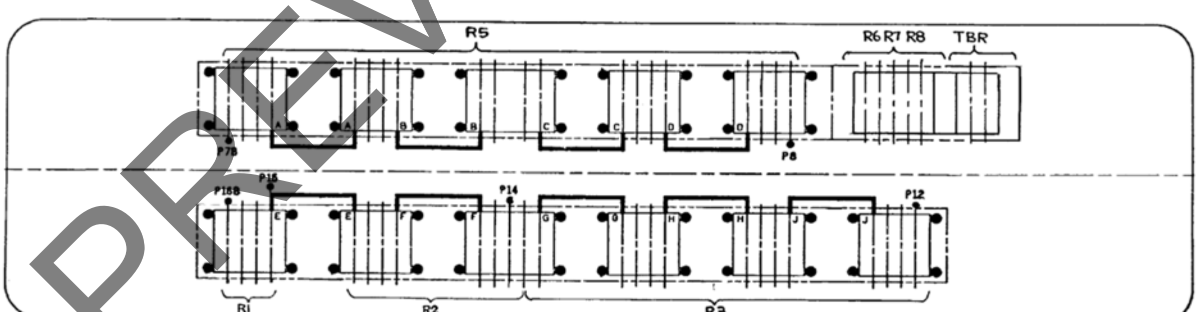

Figure 3.18 Location of Resistors –courtesy NFTA

Reverser

The reverser controls the direction that the traction motors are spinning in by changing the direction of current flow to the motor field windings – it reverses the connections of the field windings with respect to the armatures. The propulsion logic only permits the position of the reverser to be changed when the car is stopped.

The reverser, shown in Figure 3.19, consists of cylindrical copper segments for the main contacts, heavy spring fingers for contacting the drum, a set of interlock contacts, and air cylinders for rotating the drum from one position to the other. The rotation of the drum is accomplished by two opposing air cylinders. When air is admitted into one cylinder or the other, the rod is moved and its motion is translated into drum rotation by means of the lever. The magnetic valves are used for controlling the air to the cylinders.

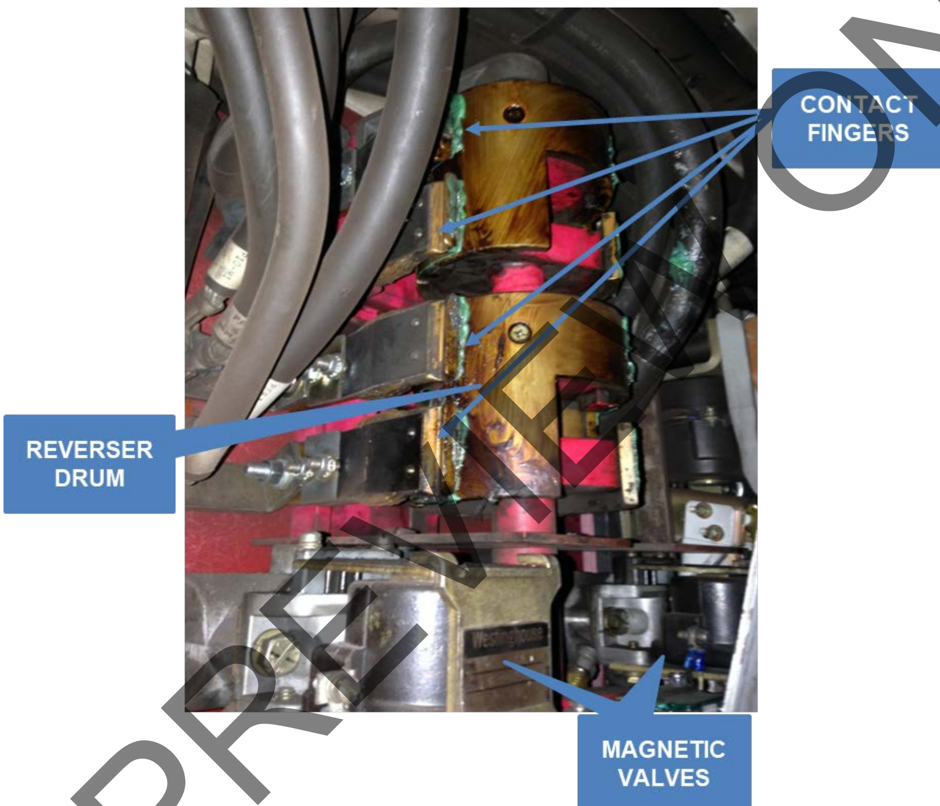

Figure 3.19 Reverser on C-Car –courtesy BART

Learning Application 3.4

With help from your instructor, compare the DC motor type described in Case Study 3.5 to the ones installed on the rail vehicles you are expected to maintain in your agency.

Characteristic	**Siemens SD100 LRV**	**Your Agency**
Voltage	750 VDC	
Speed	1805 RPM (continuous)	
Maximum Rotational Speed	3500 RPM	
Cooling	Self-ventilated	
Air Intake	Commutator end	
Air Outlet	Fan end	
Rotor diameter	345 mm	
Number of rotor slots	46	
Winding	Flat – wound copper	
Commutator diameter	280 mm (new) 265 mm (minimum permissible)	
Number of brush boxes	4 mounted jointly on brush-rocker ring	
Number of brushes	12	
Minimum brush length	30 mm	

3-5 SUMMARY

This module discussed three areas of DC propulsion: switching and filtering; traction control and dynamic braking; and motors. While general applications were covered in this module, the participant learned that propulsion systems are configured differently across rail agencies varying by manufacturer and type of rail vehicle.

MODULE 4

Principles of Operation of Dynamic Braking

Outline

5-1 Overview
5-2 Dynamic Braking
5-3 Regenerative Braking
5-4 Resistive Braking
5-5 Other Types of Braking Systems
5-6 Summary

Purpose and Objectives

The purpose of this module is to provide participants with an overview of the principles of dynamic braking as part of the rail vehicle's propulsion system.

Following the completion of this module, the participant should be able to complete the objectives with an accuracy of 75% or greater:

- Describe the theory of motor as a generator
- Explain regenerative braking
- Explain resistive braking
- Explain dynamic braking
- Summarize other types of braking systems on a rail car to include:
    - friction braking
    - hydraulic or pneumatic disk brakes
    - track brakes
    - blended braking

Key Terms

- Rheostatic Braking
- Blended Braking
- Regenerative Braking
- Brake Circuit

mph mark, only friction braking decelerates the car. At 1 mph, the friction brakes adjust the braking rate to ensure a smooth and safe deceleration until the car comes to a complete halt.

The concept of how blended braking works is shown in Figure 4.1.

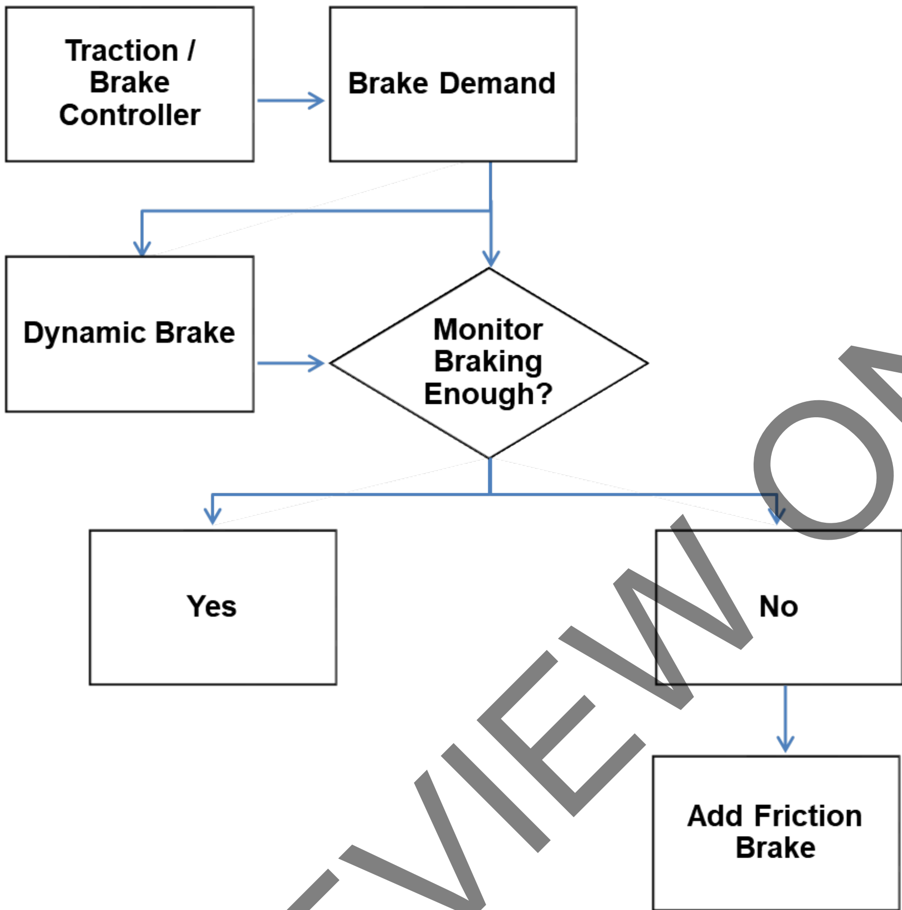

Figure 4.1 Schematic of Basic Brake Control Blending System. Source: www.railway-technical.com

MODULE 5

Tools and Materials

Outline

6-1 Overview
6-2 Tools
6-3 Materials
6-4 Specialized Tools
6-5 Summary

Purpose and Objectives

The purpose of this module is to provide participants with an overview to some of the tools and materials the technician may use while working on the rail vehicle's propulsion system.

Following the completion of this module, the participant should be able to complete the objectives with an accuracy of 75% or greater:

- Identify following tools and supplies used when working around the propulsion and dynamic braking systems:
  - bench test equipment (electric & hydraulic)
  - Portable Test Equipment (PTE)
  - Signal generator to test sensors
  - Digital multimeter
  - Re-pin connectors- cutting, crimping, generally found in toolkit
  - Acetylene torch (not welding) for braising connections for motor
  - Oscilloscopes
  - Anti-static bags
  - Torque wrenches
  - Hand tools - basic tools, wrenches, sprockets
  - Crimping tools
  - Soldering tools
  - Heat shrink guns
  - Strap wrench, cannon plug pliers

Key Terms

- Bench Test Equipment (BTE)
- Portable Test Equipment (PTE)
- Oscilloscope
- Volt-ohm-meter (VOM)

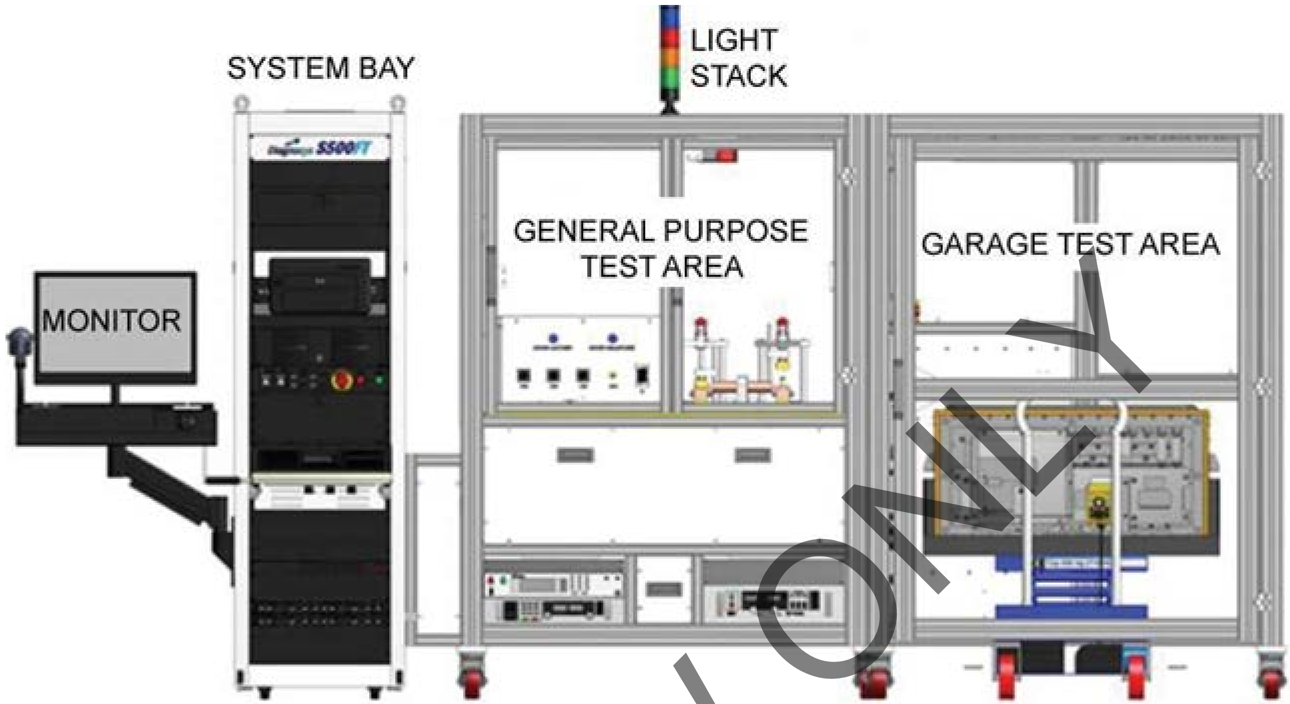

Figure 5.2 Bench Test Equipment Main Components –PATCO

The Bench Test Unit supplements other devices in order to narrow down reported faults to their location. Bench testing has been used most commonly with removing items from the vehicle in order to test them independently. Or, to swap out entire devices or modules for testing, but not on the vehicle.

Portable Test Unit (PTU)

Also referred to as Portable Test Equipment (PTE), these are portable computerized equipment that diagnose, test, and report faults on the operation of the rail car units such as APS and propulsion systems. PTU communication is facilitated by the control boards which are built in to the propulsion system and are connected to communication ports in the operator's cab or directly on to the control board on the propulsion unit.

There are three components to PTU systems: the test unit computer, communications cable, and software. Each agency's PTU system is either proprietary to that agency or is developed by the railcar propulsion system's OEM.