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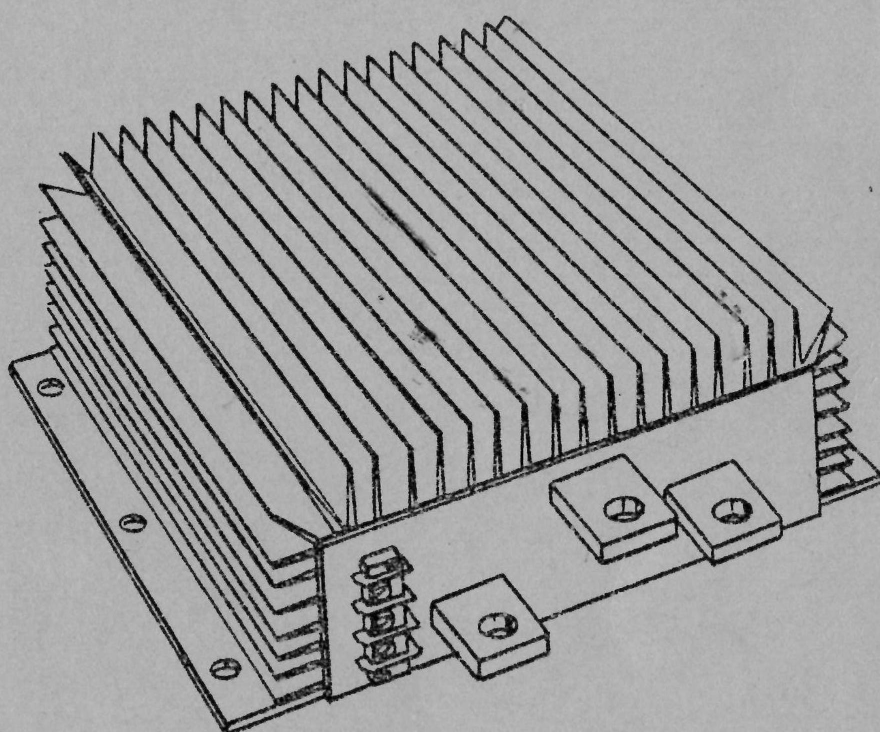
INSTALLATION MANUAL

for the

PMC-21, 25



transistorized speed controller
for on-road electric vehicles

PMC-21

PMC-25

ON-ROAD ELECTRIC VEHICLE CONTROLLER

INSTALLATION MANUAL

PMC ENERGY SYSTEMS, INC.

version 1.1

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INTRODUCTION

Within the last few years transistor technology has evolved to the point where a low cost, high performance electric vehicle controller is now possible. The PMC-21 and PMC-25 on-road electric vehicle controllers combine the highest state-of-the-art transistor technology with PMC's time-proven pulse-width control circuitry. The result is a rugged, reliable, and cost-effective on-road EV controller.

The PMC transistorized controller is designed to replace battery switching and SCR controllers in on-road electric vehicles. It provides the user with many benefits, the most important of which are smooth, accurate control of speed and torque, and increased range per battery charge. The PMC breaks new ground in EV control. Properly installed and used, it will make your vehicle come alive with new capabilities and ease of handling.

This installation manual has been written to assist in the proper installation of the PMC controller into an on-road vehicle. With these instructions, the controller installation and vehicle testing should be a straightforward task. Every attempt has been made to answer questions that may arise during installation. If problems arise that cannot be solved with the help of this manual, do not hesitate to contact the factory.

Chapter 1

GENERAL DESCRIPTION OF THE PMC CONTROLLER

1.1 TERMINOLOGY

The PMC transistorized pulse-width-modulated controllers are designed specifically to control the speed and torque of direct current motors in electric vehicle applications. The term "transistorized" is used to distinguish the controller from an "SCR" (silicon controlled rectifier) controller, and refers to the fact that the solid-state device used to modulate the power to the motor is a transistor rather than an SCR. The term "pulse-width-modulated" refers to the technique of varying the transistor "on time" (duty cycle) as a means of controlling the average voltage to the motor.

1.2 TRANSISTOR VS. SCR CONTROLLERS

Transistors and SCRs both function in the same manner in a controller, namely, by switching the battery voltage on and off in rapid succession. However, transistors offer some important advantages over SCRs which make them attractive for use in motor controllers. These advantages involve "turn-off" capabilities, "full-on" capabilities, and "switching speed".

1.2.1 TURN-OFF CAPABILITY

An SCR cannot be turned off simply by removing the gate signal. As a result, SCR controllers must contain power components which are present only to turn off the SCR at the end of each pulse. A transistor, however, is turned off simply by removing its base drive. As a result of this feature, fewer power components are required in a transistorized controller. Also, SCR controllers must be protected from a failure of the SCR to turn off (a condition known as SCR "lock-on"). Transistor controllers do not require lock-on protection because the transistor turns off immediately when its base drive is removed.

1.2.2 FULL-ON CAPABILITY

Many SCR controllers require a "bypass contactor" to go from 90% to 100% duty cycle. The "full-on" capability of transistors, however, allow transistorized controllers to go to 100% duty cycle without a bypass contactor. As a result, transistorized controllers do not normally require a bypass contactor.

1.2.3 SWITCHING SPEED

SCRs are typically slow to turn on and off. This characteristic causes heating during the switching transitions. As a result, SCR controllers are typically operated at switching frequencies below 400 Hz.. Low switching frequencies cause high motor ripple current which results in motor heating and inefficiency. Transistors, however, typically have very fast switching speeds and may be run at high switching frequencies (the PMC operates at 2000 Hz.) without excessive heating of the transistors. This results in lower motor ripple current and higher efficiency (see diagram on page 5).

1.3 TRANSISTOR VS. BATTERY SWITCHING CONTROLLERS

Battery-switching controls have been used in the past in on-road vehicles due to their low cost. However, battery-switching controls have some strong disadvantages which are overcome by the transistorized controller. The advantages of transistorized controllers over battery-switching controls involve simplicity of wiring, equal battery discharge, smooth speed control, current limiting, and current multiplication.

1.3.1 SIMPLICITY OF WIRING

Usually, battery switching controllers consist of a series of high-current switches arranged so that various voltages may be applied to the motor. There are many variations of battery switching, ranging from battery tapping to diode switching. However, all battery switching controllers have one thing in common, namely, complicated high current wiring and throttle connections. A transistorized controller, on the other hand, allows the batteries to be grouped into a single string and connected to the controller with a single contactor. The throttle connection is also simplified. The overall result is a much simpler control system.

1.3.2 EQUAL BATTERY DISCHARGE

Connecting the batteries into a single string has another advantage, namely, equal battery discharge. Some battery switching techniques cause the batteries to become discharged unequally. Complicated recharging procedures are required to regain equal charge. With a transistorized controller equal battery discharge is always assured.

1.3.3 SMOOTH SPEED CONTROL

Battery-switching controllers typically apply a series of voltage levels to the motor. This results in a succession of discrete speeds at which the vehicle can travel. A transistorized controller, however, varies the vehicle speed smoothly from zero to full. The result is total and precise control over the vehicle's speed and torque. An example of the usefulness of torque control can be seen in attempting to climb a hill. With a battery-switching controller, one throttle position may not provide enough torque to climb the hill at a reasonable speed, while the next position may attempt to accelerate the vehicle and draw excessive current. With a transistorized controller, however, the throttle may be "feathered" to a position which allows the vehicle to climb the hill at any speed that the driver desires.

1.3.4 CURRENT LIMITING

When the throttle is fully depressed in a vehicle using a battery-switching controller, full battery voltage is applied to the motor. The only thing then limiting the current from the battery to the motor is the resistance of the motor and cables, and the "back emf" of the motor. If the motor is stalled (unable to turn), the back emf is zero, and a dangerously high "stall current" will flow. With a transistorized controller, however, the maximum motor current is limited to a preset maximum value. As a result, the danger of motor burnout due to full throttle position in a stalled condition is greatly reduced. Excessive battery currents can also cause battery terminal burnoff. Use of a current limited controller helps eliminate this problem.

1.3.5 CURRENT MULTIPLICATION

One of the most intriguing aspects of the transistorized controller is the fact that, during acceleration, it allows more current to flow into the motor than flows out of the battery. This is possible because the controller acts as a D.C. transformer, i.e. it takes in high voltage (the full battery voltage) and low current, and puts out low voltage (the motor voltage can vary from zero to full) and high current. The result of the controller's D.C. transformer action is that, unlike a vehicle using a battery-switching controller, during acceleration when the motor draws high current, the battery is required to put out only a fraction of that value. This fact accounts for the increased range per battery charge which is common to vehicles using transistorized controllers.

1.4 UNIQUE FEATURES OF THE PMC CONTROLLERS

All transistor controllers are not alike. The PMC has some unique features which give it important advantages over other transistor controllers. These advantages involve electrical considerations such as tapless design, high frequency operation, thermal protection, high-pedal protection, and slow-speed controlability, and mechanical considerations such as thermal management, weathertight packaging, simple installation, and "in-field" servicability.

1.4.1 TAPLESS DESIGN

Most high voltage controllers take power from the 12 or 24 volt tap on the main battery pack in order to provide a source of base drive current. Depending on the current required, this battery tap can cause the tapped batteries to slowly become discharged relative to the rest of the pack. The PMC, however, contains a power supply which derives the base drive current from the full input voltage. This feature avoids discharged batteries and also greatly simplifies controller installation.

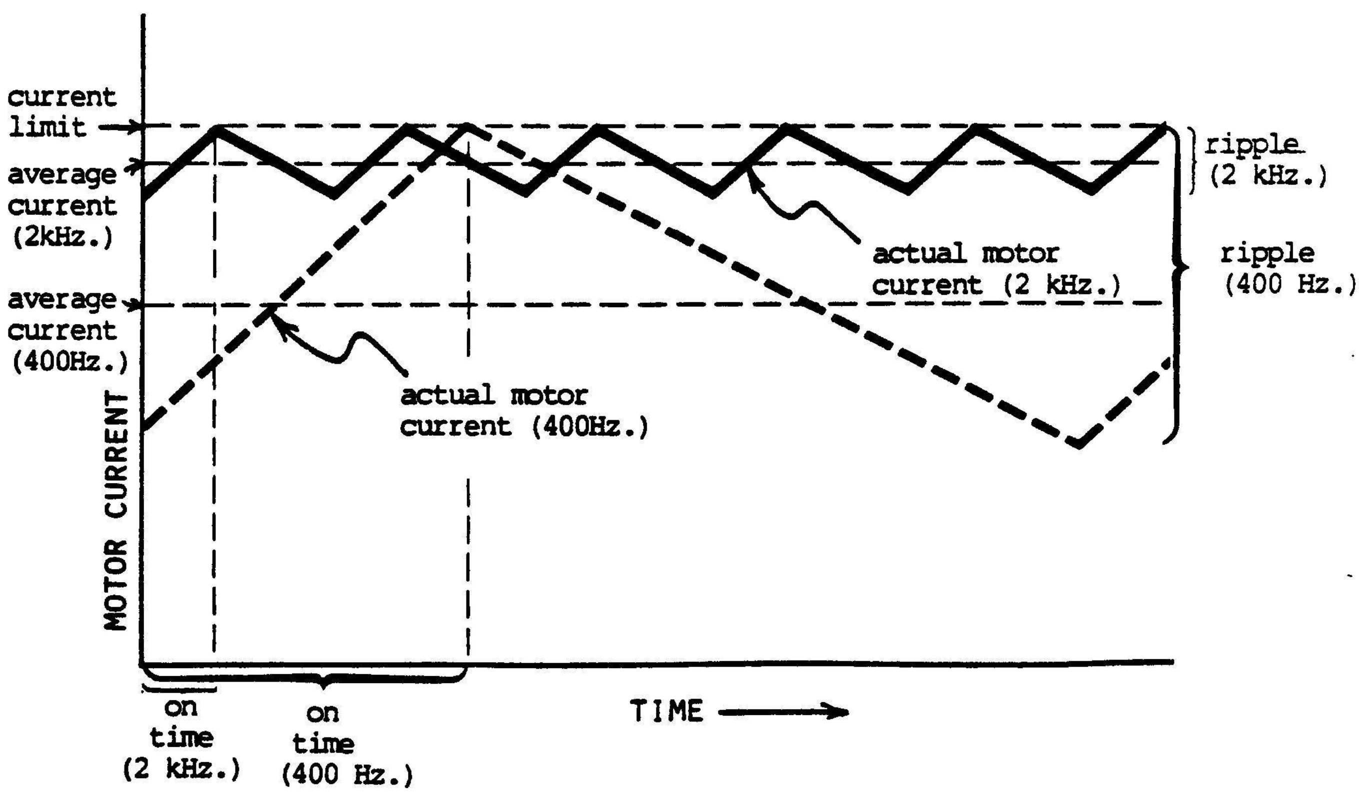
1.4.2 HIGH FREQUENCY OPERATION

Many transistorized controllers operate at a low frequency (400 Hz. or less). Low switching frequency causes high motor ripple current which results in motor heating.

There are other important disadvantages to low frequency operation. One important disadvantage is that stall current can be substantially lower than the controller current limit. This is a result of the fact that at partial duty cycle the effective current limit is not equal to the peak controller current, rather, it is equal to the peak current minus one-half the ripple. The PMC operates at 2,000 Hz.. At this high frequency the ripple is very small, and the motor stall current is very close to the controller current limit.

The diagram below shows how operating frequency affects stall current. The dashed line shows the actual motor current for a 400 Hz. controller. Note that the actual current comes very close to zero during the cycle. At lower frequencies, there is nothing to stop the actual current from actually going to zero before the next cycle begins. Note in particular that the average current is much lower than the controller current limit.

The dark line in the same diagram shows the actual current in the PMC controller operating at 2000 Hz.. Note that due to the high frequency operation, the ripple value is very small and that the average current is very close to the controller current limit.



1.4.3 THERMAL PROTECTION

The design of the PMC controller places a great deal of emphasis on thermal management. However, if the controller is undersized for the application or abused, overheating may occur. The PMC contains a temperature sensor which cuts the output current approximately in half if overheating occurs. The indication that overtemperature has occurred is an inability of the controller to deliver more than about 200 amperes to the motor in a situation where the motor would normally draw more than 200 amperes. The controller will continue to operate in the overtemperature mode and should cool due to the reduced output power. When overheating occurs, the vehicle should be parked until the controller cools to a safe operating level. If overheating occurs frequently, additional cooling should be provided (see section on controller cooling).

1.4.4 HIGH-PEDAL PROTECTION

The PMC contains special circuitry which senses a "high" (partially or fully depressed) throttle pedal during power-up of the controller (power-up occurs immediately after the main contactor closes). If a high-pedal is sensed, the circuitry disables the controller until the pedal is returned to zero. Once at zero, the circuitry resets the controller and normal operation resumes. This feature of the controller protects against a number of potentially dangerous situations. The most obvious is the case in which the operator has the throttle fully engaged when the key switch is turned on. Another situation is one in which the throttle potentiometer has been connected improperly. If the pot were to be connected backwards, and no high-pedal protection was in effect, the vehicle could go full on with the closing of the main contactor.

1.4.5 PMC CONSTRUCTION

The PMC represents a new approach to the mechanicals considerations of controller design. The power components are mounted to an aluminum plate and connected electrically via short bus bars. No solder is required for any of the power component connections. The entire assembly, including printed circuit control board, is then mounted inside a massive three-sided heatsink. The heatsink is enclosed on the remaining three sides and the three power busbars exit from one end. All heat generated by the power components is conducted to the outside of the controller and carried off from the heatsink fins.

Therefore, both thermal design and weathertight packaging requirements are satisfied at the same time by the PMC controllers's unique construction.

1.4.6 SERVICABILITY

The PMC controller was designed with servicability in mind. Transistor and SCR controllers are typically not user-servicable due to the complication of the circuitry and the difficulty of replacing and retesting power components. However, the PMC is fully field-servicable. All of the power components may be replaced using only a screwdriver. The printed circuit board mounts with three screws and plugs into an interfacing wiring harness. The printed circuit board is adjusted at the factory so that no in-field adjustments are required.

1.5 PMC SPECIFICATIONS

1.5.1 PRODUCT DESIGNATIONS

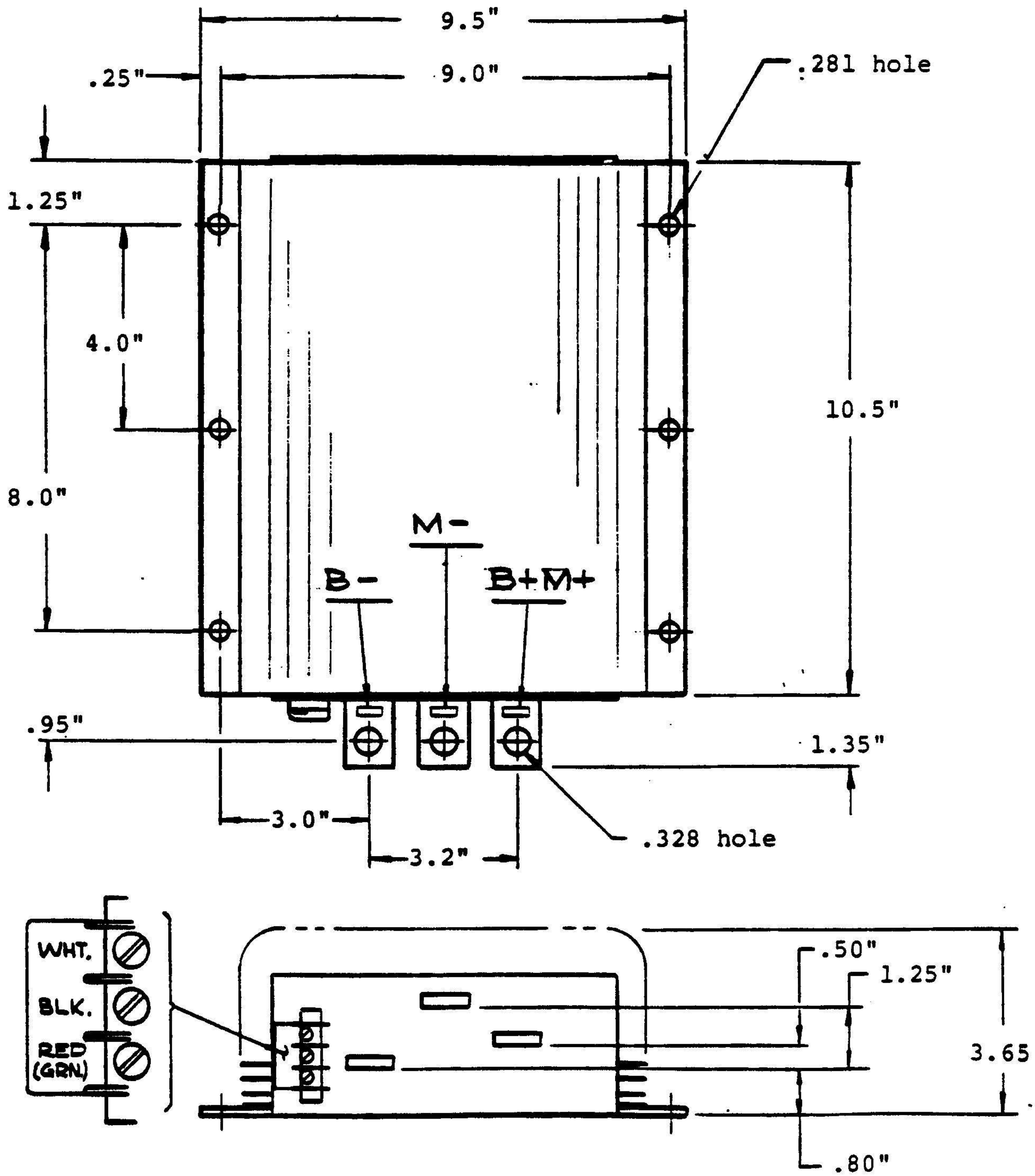
The PMC controller product line is designated as follows:

Designation	Description
PMC-3	Golf Car Controller 250 ampere 24-36 volt 10 kHz.
PMC-5	Industrial Controller 275 ampere 24-36 volt 2 kHz.
PMC-11	Industrial Controller 350 ampere 24-36 volt (suffix A) 36-48 volt (standard) 48-60 volt (suffix C) 2 kHz.

PMC-17	Industrial Controller 450 ampere 24-36 volt (suffix A) 36-60 volt (standard) 72-84 volt (suffix D) 2 kHz.
PMC-21	On-Road Vehicle Controller 400 ampere 72-96 volt 2 kHz.
PMC-25	On-Road Vehicle Controller 400 ampere 96-120 volt 2 kHz.

1.5.2 PMC-21, PMC-25 MECHANICAL SPECIFICATIONS

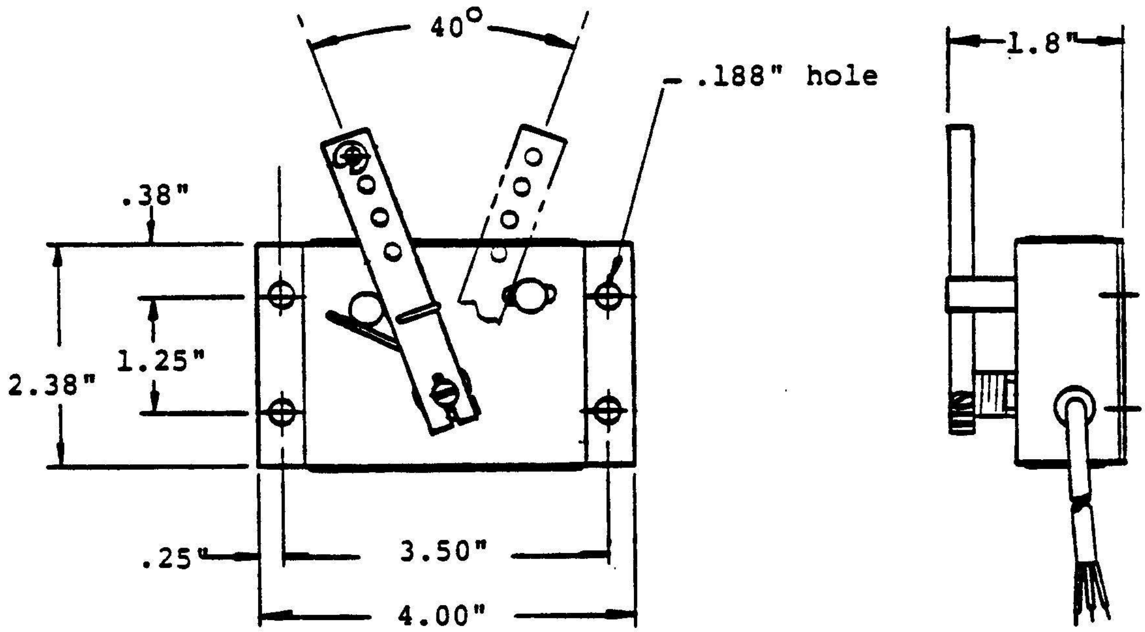
The mechanical specifications of the PMC-21 and PMC-25 controllers are identical and are shown in the diagram on the following page.



PMC-21, PMC-25 DIMENSIONS

WEIGHT: 14 lbs.

The mechanical specifications of the PB-1 potbox are as follows:



1.5.3 PMC ELECTRICAL SPECIFICATIONS

Input Voltage:	72 - 96 volts (PMC-21) 96 - 120 volts (PMC-25)	
Current Limit:	Both Models:	400 amps (adjustable)
Current Rating: (assumes cooling from vehicle airflows)	Both Models:	5 min. - 400 amps 1 hour - 300 amps
Voltage Drop:	Both Models:	at limit - 1.9v. at cruise - 1.0v.
Frequency of Operation:	Both Models:	2 kHz.
Thermal Cut-out Temp:	Both Models:	165 F.
Electrical Isolation to Heatsink:		YES
Potbox Resistance:		5 kohm

Chapter 2

VEHICLE APPLICATIONS

2.1 USE WITH SERIES, SHUNT, AND COMPOUND MOTORS

The PMC does not provide current for seperately excited fields such as those found in shunt and compound motors, and may be considered as being specifically designed for series-wound motors. However, the controller may be used with shunt and compound motors if a seperate source of field current is provided. For motors with shunt fields wound for full battery voltage, the shunt field may be connected across the entire battery pack via a contactor. In such installations a "freewheeling diode" should be installed across the field to prevent arcing across the contactor as it opens. For motors with fields wound for less than full battery voltage, or in cases where field control is desired, either a seperate transistor field controller is required, or the field may be connected to various taps off of the main battery pack.

When a series winding is not provided in the motor, such as in a pure shunt motor, an inductor must be added in series with the armature in order to provide the inductance which would normally be supplied by the series winding. High current inductors (part number IND-100) are available from your PMC dealer.

2.2 MAIN CONTACTOR

The main contactor shown in the installation diagram is necessary in order to disconnect the controller from the battery pack while the vehicle is not in use or in an emergency situation. The contactor must have a current rating equal to or greater than the normal average battery current required by the vehicle.

A solenoid used as a main contactor is subject to a different kind of stress than when used in a resistor control. When the main contactor closes, the rapid charge-up of the input capacitors (inside the controller) causes a very high inrush current to flow in the contactor. Inexpensive solenoids will often stick closed after a few such events, especially at high battery voltages. Therefore, a high quality contactor designed to open at least the nominal battery voltage must be used. Such contactors are available from suppliers such as GE, HB, Curtis Instruments, and others.

2.3 EMERGENCY DISCONNECT SWITCH

It is very important that a manual emergency disconnect switch be placed in the line between the battery and controller. If a failure or short circuit should occur, the result could be a runaway motor connected to full battery voltage. In this situation, the main contactor may be opened to shut the system down. However, if the main contactor fails to open for some reason, the emergency disconnect switch is the only means of shutting the system down. Therefore, it is very important that a manual disconnect switch be in place in all installations.

2.4 ISOLATION CONSIDERATIONS

The controller heatsink and mounting plate are electrically isolated from the high power terminals. However, if the controller has been dropped or otherwise abused, a short circuit may occur between the M- terminal and the heatsink. In such a situation, if the controller is mounted directly to the vehicle chassis, the vehicle chassis could become electrically "hot". **For this and other safety reasons, it is very important that the vehicle chassis not be connected in any way to the main battery pack.** In any event, always check for continuity between the vehicle chassis and the M- terminal.

2.5 ACCELERATOR POTENTIOMETER (POTBOX)

The three wires of the accelerator potentiometer must be connected in the following order: pot wiper (black) to middle terminal, low side of pot (white) to top terminal, and high side of pot (red or green) to bottom terminal (nearest the contoller cover plate). Incorrect connection will lead to faulty operation of the controller.

The PB-1 potbox supplied with the controller contains a 5 kohm high reliability potentiometer with return spring. The lever arm is drilled for various throw distances. The potbox must be securely mounted to the vehicle and connected to the throttle in such a way that the lever arm moves freely and undergoes its full travel.

The FP-1 footpedal potentiometer is available from your PMC dealer if it is not possible to utilize the PB-1 potbox supplied. The FP-1 is a self-contained footpedal which may be mounted directly to the floor of the vehicle. It contains a 5 kohm potentiometer and a strong return spring, and comes with a 6 ft. long connection cable.

2.6 CONTROLLER COOLING

The PMC is designed to dissipate enough heat to keep its temperature within specified limits. However, it does depend on air movement across its surface for cooling and therefore some consideration must be given to its mounting location. During operation the controller should be exposed to an airstream which moves at approximately the speed of the vehicle. If no airstream is available, an external fan will be required. A special fan shroud designed to fit over the controller and support a compact squirrel cage fan is available from your PMC dealer.

Chapter 3

INSTALLATION INSTRUCTIONS

An installation diagram and installation worksheet has been provided at the end of this manual for use in the following instructions. The installation diagram shows the proper completed installation. The installation worksheet contains all of the components connected with dotted lines. It is recommended that as the following connections are made, the connection is drawn on the worksheet.

Installation of the PMC controller into a vehicle is accomplished by means of the following steps:

- Locating and mounting the controller unit to the vehicle
- Locating and mounting the potbox or footpedal to the vehicle, and connecting the lever arm to existing throttle linkage
- Locating and mounting main contactor
- Making high current connections between battery, main contactor, motor, and controller
- Making low power connections between key switch, main contactor, and potbox
- Testing vehicle

CAUTION! BEFORE PERFORMING ANY OF THE FOLLOWING INSTALLATION PROCEDURES, DISCONNECT THE BATTERY IN AT LEAST TWO PLACES! WEAR SAFETY GLASSES AT ALL TIMES! DOUBLE CHECK BEFORE MAKING FINAL CONNECTIONS!

3.1 MOUNTING THE CONTROLLER

The controller may be located anywhere on the vehicle and may be mounted in any position. The unit should be mounted firmly using at least three of the four mounting holes. The mounting holes are drilled to accept #10 shoulder washers. For safety, the unit should be electrically isolated from the vehicle chassis.

Generally, the best mounting location will provide the following:

- good airflow across the controller
- protection from direct water spray
- minimum cable length to and from battery pack
- clear access to the controller terminals
- easy removal and reinstallation of the controller

If the vehicle has a front grill, the controller may be mounted vertically directly behind the grill opening with the power terminals pointed either sideways or downward. If batteries are under the front hood, this mounting location will also satisfy the short lead length condition and the easy access condition.

3.2 MOUNTING THE POTBOX

The potbox supplied with the controller should be mounted in such a way as to allow connection between the potbox lever arm and the existing vehicle throttle linkage. The lever arm provides a series of holes so that the pedal "throw" may be converted into the correct amount of potentiometer rotation. Once mounted, the operation of the potentiometer may be tested by measuring the resistance between the black and white wire with an ohmmeter. With the pedal not depressed, the resistance should read less than 100 ohms. As the pedal is depressed, the resistance should rise smoothly until it reaches a value of at least 4500 ohms. Inspect the return spring on the throttle pedal to be sure that it is in good condition. NOTE: The throttle pedal must have a stop at the end of its travel. If the potbox lever arm runs its full travel before the pedal stop is reached, the potbox lever may be bent.

3.3 MOUNTING THE MAIN CONTACTOR

The main contactor should be firmly mounted to the vehicle chassis near the positive battery terminal or near the B+M+ terminal on the controller. An alternate mounting technique is to bolt the main contactor terminal directly onto the B+M+ terminal of the controller.

3.4 ELECTRICAL CONNECTIONS

The electrical connections to the controller consist of two types: the high current connections and the low power connections. Care must be taken to make the connections correctly. There are six possible ways to connect the two ends of the battery pack to the three power terminals, only one of which is correct. Two of the five incorrect configurations will cause a runaway motor upon closing the main contactor, and three will cause contactor meltdown. Though unlikely, controller damage is also possible in each of the five incorrect configurations.

The three potentiometer leads must be connected correctly or faulty controller operation will result. Motor runaway is possible if one of the pot wires becomes disconnected while the controller is operating. For safe operation, potentiometer leads must be secure and well insulated.

3.5 MAKING THE HIGH CURRENT CONNECTIONS

IN THE FOLLOWING INSTRUCTIONS, REFER TO THE INSTALLATION DIAGRAM AT THE END OF THIS MANUAL. ALSO, A WORKSHEET HAS BEEN PROVIDED AT THE END OF THIS MANUAL FOR THE PURPOSE OF CHECKING OFF THE MAIN CONNECTIONS AS THEY ARE MADE.

In the following steps, use of size 0 or 00 copper welding cable and correctly sized, correctly applied crimp terminals is recommended.

A MAIN CONTACTOR TO BATTERY: Complete the connection from the positive battery pack to one end of the main contactor.

B MAIN CONTACTOR TO CONTROLLER: Make a connection from the other main contactor terminal to the M+B+ terminal on the controller. (Note: If the main contactor is mounted directly to the M+B+ controller terminal, this step is already accomplished).

C MOTOR TO CONTROLLER: Connect one end of the motor to the M- terminal on the controller.

D MOTOR TO CONTROLLER: Connect the other end of the motor to the M+B+ terminal of the controller.

E BATTERY TO CONTROLLER: Make the final connection between the negative terminal of the battery pack and the B- on the controller.

This completes the high current connections. Recheck all connections and be sure that all connections are shown on the worksheet. Do not reconnect the battery pack until all low power connections have been made.

3.6 MAKING LOW POWER CONNECTIONS

G POTBOX: Connect the three pot leads to the controller. Check to be sure that the color order is correct. Note: Be careful during this step to not touch a screwdriver between the pot terminals and either the vehicle frame or any main terminal on the controller.

H MAIN CONTACTOR COIL: Connect the main contactor coil in such a way that it is energized only when the key switch is turned on.

This completes the low power wiring. Double check all wiring.

3.7 VEHICLE TESTING

CAUTION! PLACE F/R SWITCH IN NEUTRAL AND PUT THE VEHICLE UP ON JACKS FOR THIS STEP. DO NOT LET ANYONE STAND IN FRONT OF OR BEHIND THE VEHICLE.

The following tests require use of a 100 watt, 120 volt lightbulb and a socket. A voltmeter capable of measuring full battery voltage and an ohmmeter are also required.

STEP 1: Reconnect the battery terminals and verify that full voltage appears between the positive and negative battery terminals.

STEP 2: With an ohmmeter, check to be sure that the main contactor is open. If so, close the emergency disconnect switch. Connect a voltmeter between B+ and B- on the controller and measure the voltage. It should be at or near zero. Continue to monitor this voltage as a 120 volt 100 watt lightbulb is temporarily placed across the terminals of the main contactor. The lightbulb should glow momentarily and then dim out completely. The voltage should rise to full battery voltage. The voltage should decay slowly when the lightbulb is removed. Disconnect the voltmeter.

STEP 3: Temporarily disconnect the power cable which is connected to the M- terminal of the controller. Connect one end of the lightbulb socket to this cable end, and the other end of the lightbulb socket to the M- terminal. Place the lightbulb in the socket. Wrap the end of the power cable with electrical tape to avoid an inadvertent short circuit. Turn the key switch on and depress the throttle pedal slightly. The lightbulb should begin to light and a 2 kilohertz hum should be heard. Depress the throttle further. The brightness of the lightbulb should be proportional to the throttle position. Turn the keyswitch off and reconnect the power cable to the M- terminal.

STEP 4: **Check to make sure that the wheels are off the ground.** Sit in the vehicle and put on the emergency brake. Place the vehicle in neutral and turn the key switch on. Turn the key switch off immediately if the motor runs without applying pedal.

STEP 5: Release the brake. Depress the throttle slightly and observe a 2 kilohertz tone coming from the motor. Note that the wheels rotate in the correct direction. Turn the key switch off.

STEP 6: Remove the jackstands. With the vehicle in a clear area, attempt to drive the vehicle. Drive the vehicle slowly and check for mechanical problems.

THIS COMPLETES THE VEHICLE TESTING. IF NO PROBLEMS ARE ENCOUNTERED, GO ON TO CHAPTER4: OPERATION OF VEHICLE. IF PROBLEMS ARE ENCOUNTERED, CONSULT THE FOLLOWING INSTALLATION TROUBLESHOOTING GUIDE.

3.8 INSTALLATION TROUBLESHOOTING GUIDE

NOTE: THIS GUIDE IS DESIGNED TO TROUBLESHOOT THE INSTALLATION ONLY AND IS NOT INTENDED AS A GUIDE TO SERVICING THE CONTROLLER ITSELF

PROBLEM	POSSIBLE REASON
STEP 1:	
Incorrect or zero voltage appears at terminals.	* Batteries not all connected. * Batteries incorrectly connected. * Batteries discharged.
STEP 2:	
Voltage between B+ and B- at full battery voltage.	* Main contactor not open - welded closed or energized.
Voltage between B+ and B- not zero.	* Capacitors partially charged. Discharge with resistor placed between B+ and B- terminals.
Lightbulb does not go on.	* Lightbulb bad or not connected. * Lack of continuity somewhere in circuit.
Lightbulb stays on.	* Vehicle miswired or controller faulty. Do not proceed until problem found.
STEP 3:	
Lightbulb goes on full when key switch turned on.	* Vehicle miswired or controller faulty. Do not proceed until problem found.
Lightbulb does not go on at any throttle position.	* Potentiometer not connected correctly. * Lightbulb bad or not connected. * Main contactor or emergency disconnect switch open.

STEP 4:

Vehicle runs when key turned on.	* Vehicle miswired or controller shorted. Disconnect terminal at M- and check for controller short until problem found.

STEP 5:

No 2 kilohertz tone.	* Controller in high-pedal disable - check pot resistance and pot connections. Check for free lever arm movement. * Main contactor not closed. * Motor not a complete circuit.
Wheels turn wrong direction.	* Series field connected backwards.

STEP 6:

Vehicle has no speed.	* Batteries discharged.

Chapter 4

OPERATION OF VEHICLE

This section will deal with the most common issues which relate to the operation of an on-road electric vehicle using the PMC controller. These issues involve reliable operation, the 2 kilohertz hum which is audible when driving the vehicle, battery current and motor current, power and torque, and driving tips.

4.1 RELIABLE OPERATION

Many thousands of miles of reliable operation have been accumulated on many vehicles using PMC controllers. Trouble-free operation can be acheived by paying attention to the following considerations:

a) Waterproof Controller - Be sure that the controller is never "hosed down" or allowed to become subjected to water spray. Although great care has been taken in its manufacture to protect from the harmful effects of moisture, the controller's reliability will be greatly enhanced by keeping it dry. Never mount the controller with the terminals pointing up. If there is any question about the ability of water to get inside the controller, seal around the terminals with silicone rubber.

b) Keep Controller Cool - If the overtemperature sensor cuts the output current back consistently (see section 1.4.2), more cooling is required. High temperatures cause the controller's lifetime to be shortened.

c) Tighten All Connections - A loose connection can generate enough heat to quickly burn off a battery terminal or damage a controller terminal. All high current connections must be kept clean and tright. Recheck all connections periodically. Use spring washers if possible in place of flat washers. Use aluminum joint compound such as CUAL-AID or NO-ALOX on controller terminal connections.

d) Open Main Contactor When Not In Use - When the vehicle is not in use, and especially when the vehicle's batteries are on charge, make certain that the main contactor is open. It is recommended that a "charger interlock" be built into the vehicle system so that the main contactor cannot become energized while the charger is plugged in. During charge, the batteries may build up to a very high voltage. With the contactor closed, this high voltage is applied to the controller terminals and may exceed its voltage rating, thereby causing controller damage.

4.2 THE 2KHZ. HUM

The 2 kilohertz ripple current in the motor (see diagram on page 5) causes an audible tone to be emitted of the motor laminations and housing. This "hum" is normal and in fact is very useful for telling when the controller is in the chopping mode. The hum disappears completely at 100% duty cycle (full-on). In this mode, the controller is not chopping and the batteries are essentially connected directly across the motor.

Some interference with weak AM radio stations may be noticed. FM and cassettes are usually uneffected. In the full on mode all noise and possible radio interference should cease.

4.3 BATTERY CURRENT AND MOTOR CURRENT

As explained in Section 1.3.4, during the chopping mode more current flows into the motor than out of the battery. This idea may be confusing to individuals who are used to working with battery switching techniques because for all controllers other than solid state choppers, battery current always equals motor current.

The reason that the FMC controller allows the battery current to be less than the motor current is that during operation in the chopping mode, the path for battery current is being opened and closed (inside the controller), while the path for motor current is not. When the battery current is turned off during each switching period, the motor current continues to flow via the freewheeling diode. Thus, on the average, more current will flow into the motor than out of the batteries.

The current limit rating of the controller refers to the limit of the motor current. Under heavy load (stalled or nearly stalled motor) with full throttle, the controller logic limits the duty cycle to a small value in order to limit the motor current to the rated value. Therefore, a measurement of battery current would show less current than a simulteneous measurement of the motor current (the ratio of battery current to motor current at stall depends on such things as input voltage and motor resistance). As the vehicle increases its speed, the motor's back emf increases, the duty cycle increases, and the battery current also increases. Finally, when the controller reaches 100% duty cycle, the battery current equals the motor current. From then on, as long as the controller remains in the full on mode, motor current and battery current remain equal.

4.4 POWER AND TORQUE

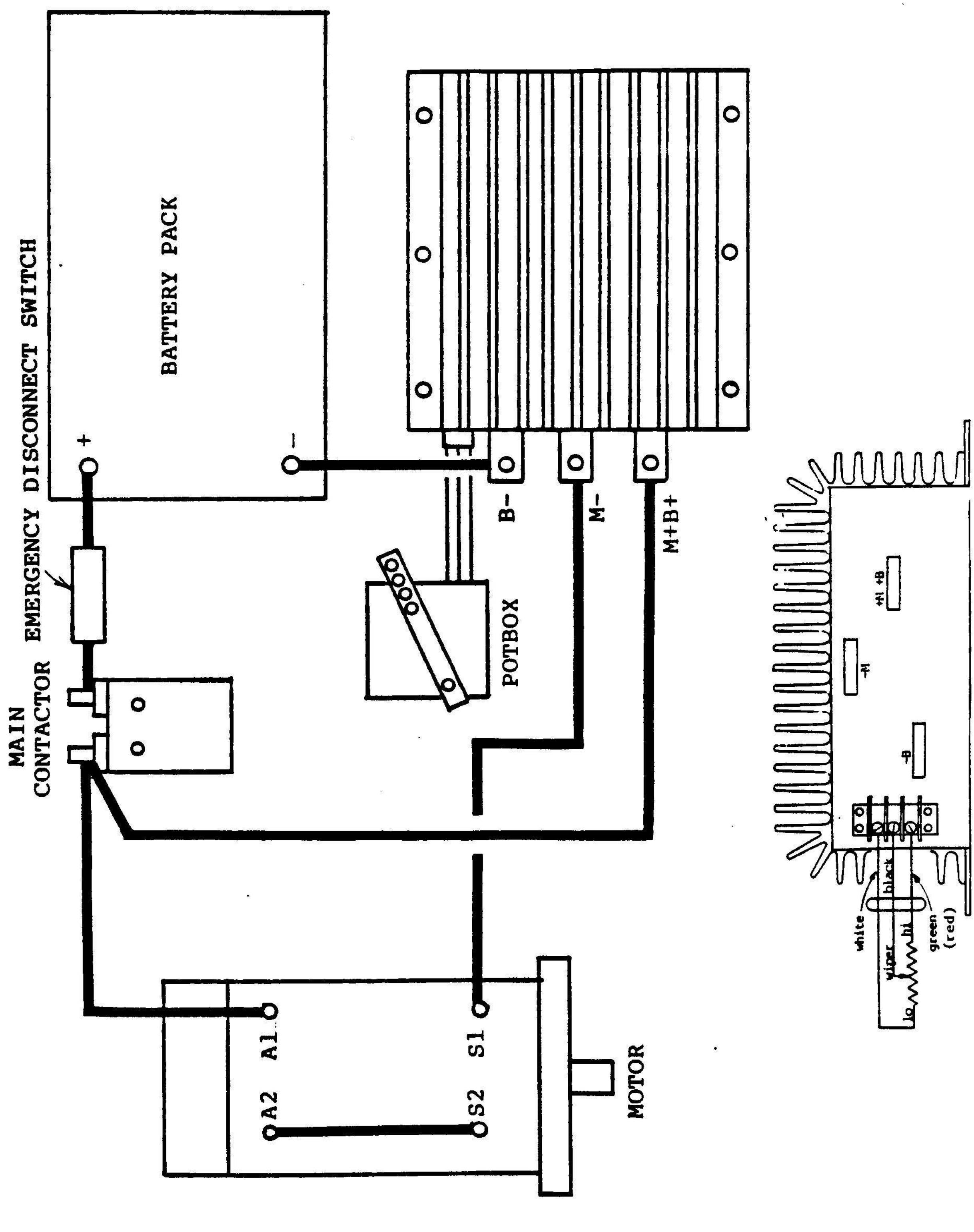
There is often a lot of confusion between power and torque since both relate closely to the ability to propel the vehicle. The difference between the two concept is best understood if one realizes that torque, or the twisting force of the motor shaft, is closely related to motor current, while horsepower, or the rate at which energy is being expended on the vehicle to sustain or change its speed, is related to both the motor torque and the motor speed. The motor speed is closely related to the voltage applied to the armature terminals. The power being used by a vehicle can be measured by multiplying motor amps times motor volts, or by multplying battery amps times battery volts. The latter calculation will be slightly larger than the former as it will include the power lost in the controller, batteries, and connections.

4.5 DRIVING TIPS

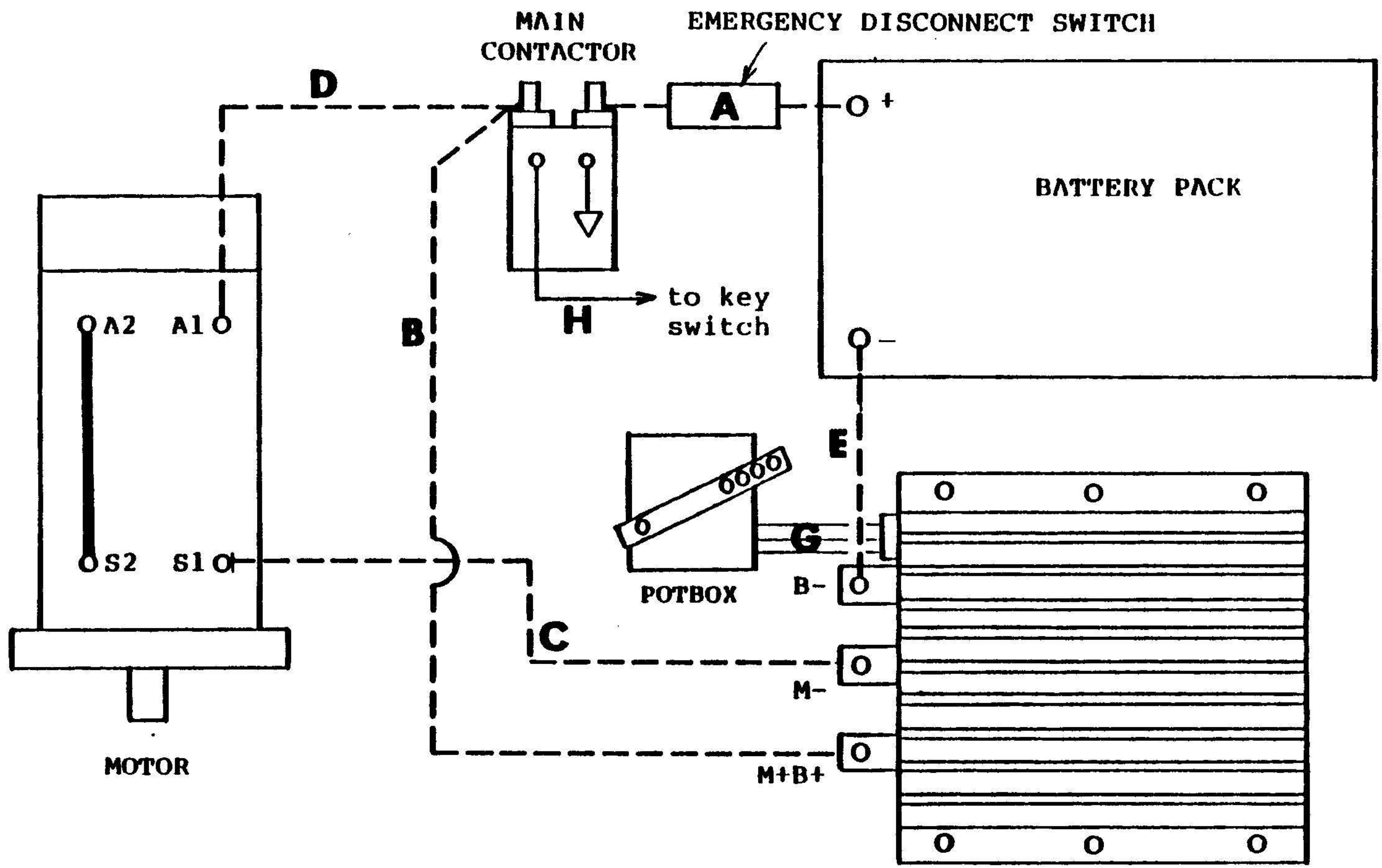
The horsepower which is required to propel a vehicle may be gotten either by supplying high motor torque at low motor speed, or low motor torque at high motor speed. This translates into either high motor amps at low motor voltage or low motor amps at high motor voltage. The latter combination is highly preferable since low motor current reduces heating in both the motor and controller.

There are two ways to trade off motor voltage for motor amps. One way is to drive using the lowest gear possible, thereby keeping motor speed high. The second way is to use as high a battery voltage as is possible. Care must be taken, however, not to exceed the rated rpm of the motor.

INSTALLATION DIAGRAM
(FOR PMC-21, 25)



INSTALLATION WORKSHEET



INSTALLATION WORKSHEET INSTRUCTIONS: DRAW IN HEAVY LINES TO REPRESENT THE CONNECTIONS AS THEY ARE ACTUALLY COMPLETED DURING THE INSTALLATION PROCESS. CHECK COMPLETED DIAGRAM AGAINST INSTALLATION DIAGRAM (PREVIOUS PAGE) TO BE SURE THAT ALL CONNECTIONS ARE CORRECT.