4. CONTROL SYSTEM MANUAL

4.1 Introduction & General Description

(see controls rules in section 3.3)

Please read the following section carefully. Failure to configure your control system properly could result in personal injury, damage to the control system, or damage to your machine.

In this section you will find:

- descriptions of the control system components
- configuration options
- wiring diagrams
- hook-up instructions
- rules for usage

If, after reading this section, you have problems configuring the control system, please contact U.S. FIRST for assistance. We will be happy to answer any questions you may have. See section 5.1 for information on how to contact U.S. FIRST.

The heart of the control system consists of two main units: the Transmitter, and the Receiver/Relay box. The Receiver/Relay box contains both the Receiver board and the Relay board. Most of the other control system components connect directly to one of these three boards.

The transmitter reads up to 8 proportional or switched inputs, and passes the corresponding signals to the receiver via a pair of RNET radios (or a tether). Although some of the input devices listed in the next section are intended as sensors to be used on your machine, any of them may be connected as input devices to the transmitter.

The receiver generates 8 pulse-width-modulated (PWM) control signals, which are used to control the servos, speed controllers and relay board. The speed controllers in turn provide power to the Milwaukee drill motors.

The relay board receives up to 6 channels of PWM signal from the receiver, and provides up to 6 channels of non-proportional, bi-directional (forward-off-reverse) power for the pnuematic pumps, valves and Delco seat motors. In addition, sensors mounted on your machine can be connected directly to the relay board to activate or deactivate, independently, a particular direction of a particular channel on the relay board.

4.2 Control System Components

The kit contains a wide variety of input devices:

- two CH Products three-axis proportional joysticks with trigger and thumb switches
- four Honeywell Microswitch rocker switches
- eight Honeywell Microswitch limit switches
- four CP Clare reed switches.
- two Air Logic pressure switches

The limit switches, reed switches, and pressure switches are intended for use as feedback sensors on your machines, but may also be used as part of the user interface on the transmitter end.

There is also a variety of output devices:

- two Hitec servos
- two Tekin reversing speed controllers
- two Milwaukee cordless drill motors
- four Delco seat motors
- two McCord-Winn Textron air pumps
- two Numatics pneumatic valves.

The servos and speed controllers are controlled directly by the PWM output of the receiver; the drill motors are driven by the speed controllers. All other output devices are driven the relay board, which converts PWM signals and sensor inputs to relay outputs. A summary of all control system components is shown in Table 4.1.

Attempting to drive the drill motors directly with the receive/relay box, or attempting to drive other devices with the speed controllers could damage the control system and is therefore prohibited.

If you wish to activate both speed controllers, both servos, and all 6 channels of the relay board (a total of 10 output channels), two of the channels from the receiver board must be split by using the two included servo Y connectors to create two sets of paired outputs. Alternately, some channels of the relay board may be activated solely by the feedback sensors on your machine.

Table 4.1: Control System Components

Transmitter Side	Receiver Side
Motorola RNET radio	Motorola RNET radio
Transmit box	Receiver/Relay box
9V power supply	2 Tekin speed controllers
2 Flightstick joysticks	2 Hitec servos
4 rocker switches	2 Battery boxes, each with an internal 30A circuit breaker
9 pin molded cable	4 Milwaukee 12V batteries
15 pin molded cable	2 Milwaukee drill motors plus gearheads
9 pin tether adapter	4 Delco seat motors
Black project box	2 McCord Winn air pumps
15 pin female connector	2 air valves
	8 Limit Switches
	4 Reed Switches
	2 Pressure Switches
	2 20A circuit breakers
	2 Six channel terminal strips
	9 pin ribbon cable
	#12 wire, black, red
	2 conductor #24 cable
	3 conductor #24 cable
	2 servo Y connectors
	2 servo extension cables
	Spade Connectors

4.3 Power Distribution

The two battery boxes must be wired in parallel to the terminal strips, from which the 12V power must be distributed, using #12 AWG wire where indicated in Fig. 5.1 (See also Fig. 4.5). Use red wire for +12V and black wire for GND. All boxes are clearly marked +12V and GND. Please note that you will be required to pay for replacement or repairs due to any improper wiring.

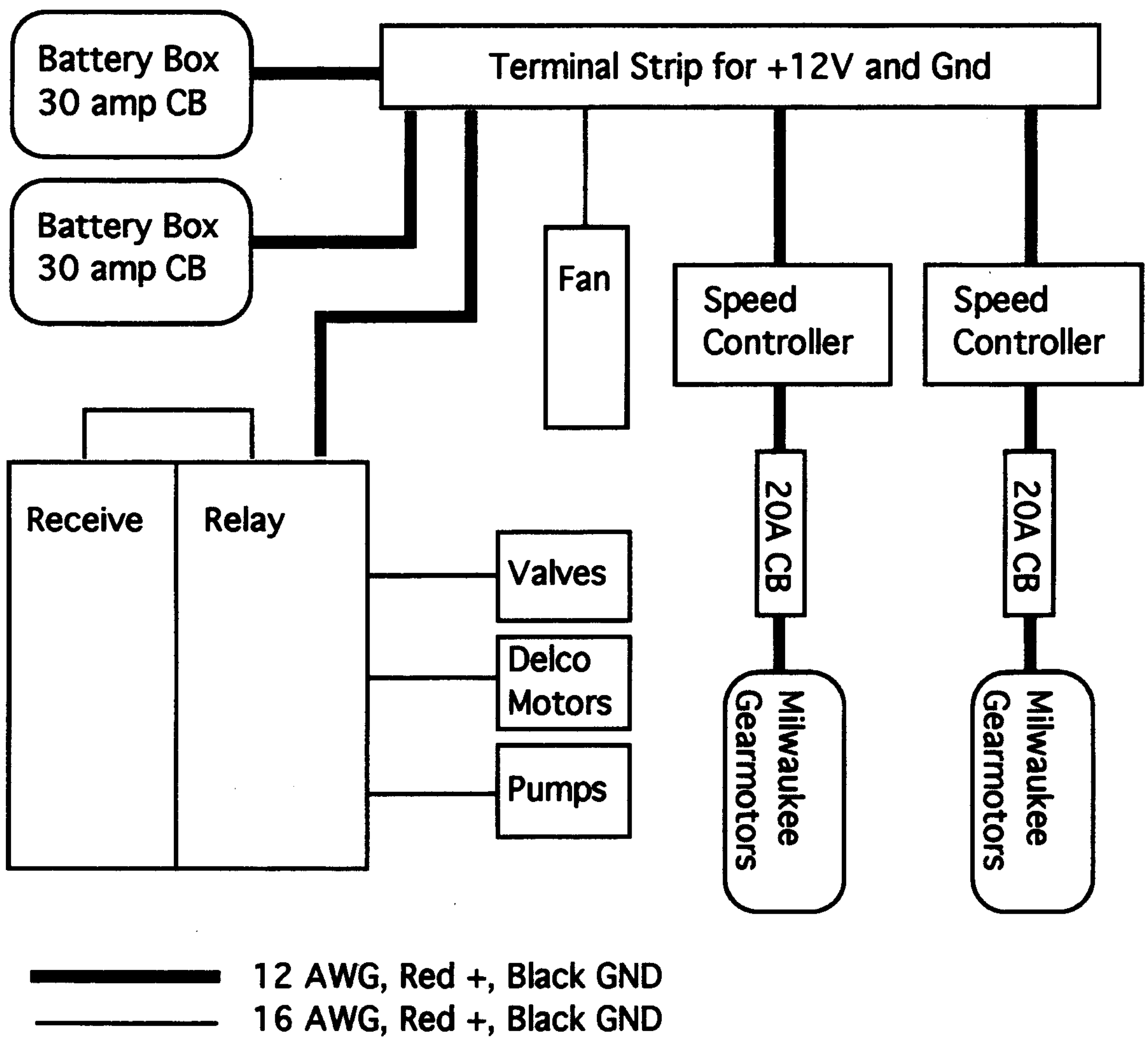

Figure 4.1 Power distribution

The wires and cables included in the kits are intended for specific uses. Table 4.2 shows the minimum wire sizes allowed for hookup of the various control system devices.

Table 4.2: Minimum Wire Size by Device Type

Device	Wire Type
Drill Motors, Battery Boxes, Speed Controllers (power & motor leads), Relay Board (power)	12 AWG Red & Black
Receiver Box (power), Delco Motors, Pumps, Valves	16 AWG, 2 Conductor
Limit Switches, Reed Switches, Pressure Switches, PWM Cables, Rocker Switches	24 AWG, 2 or 3 Conductor

The control system cables containing 3 wires or less may be shortened or lengthened as needed as long as the following conditions are met:

- Proper insulation (electrical tape, wire nuts, or shrink wrap) must be used.
- Proper wire type, as specified above, must be used.

The spade connectors in the kit may be used only for connections between multiple segments of 24 AWG wire and the switches.

4.4 Transmitter Box

The connection diagram for the Transmit Box is shown in Figure 4.2.

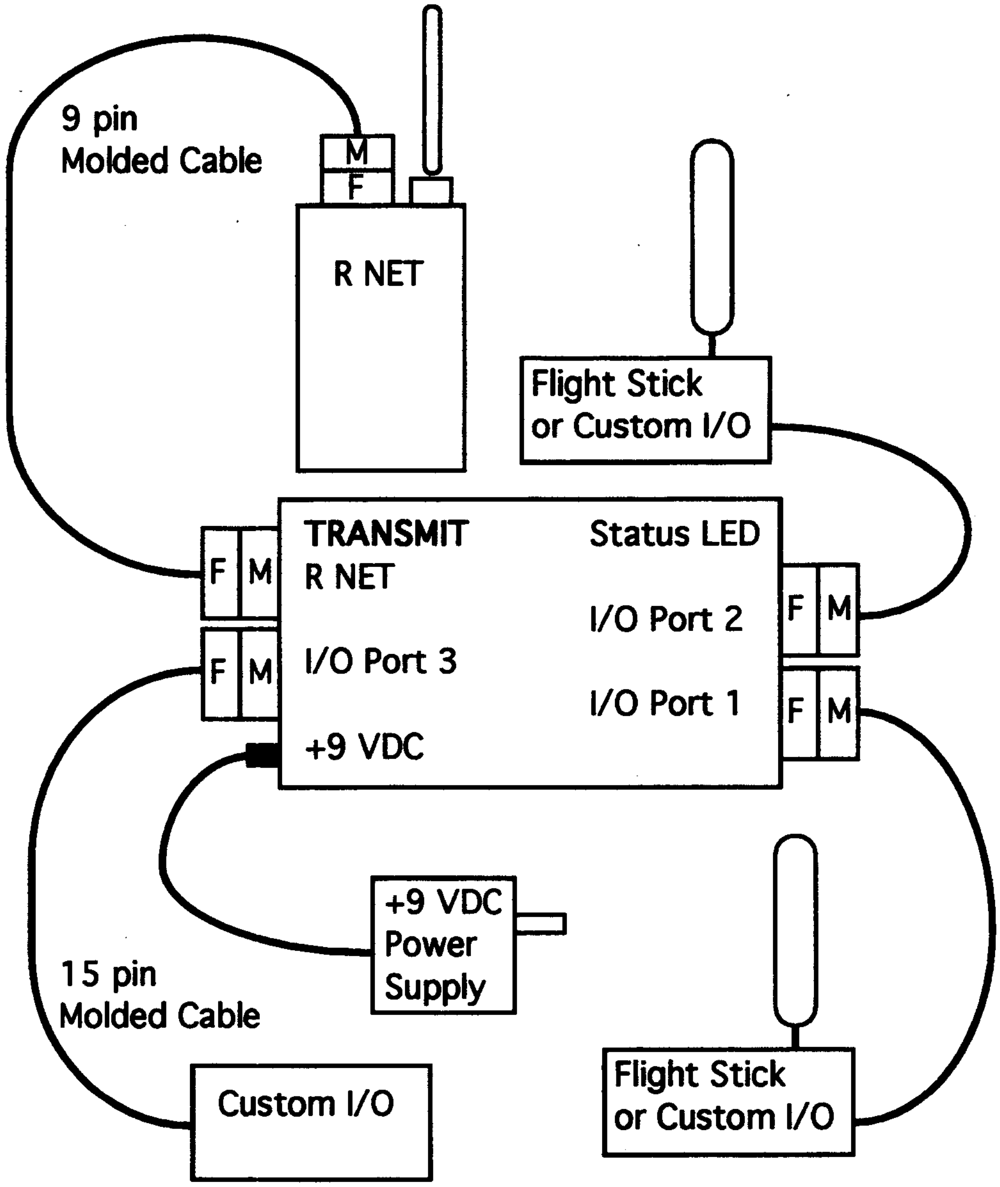

Figure 4.2 - Connection Diagram for Transmit Box

<u>**Warning**</u>

Only the 9 volt power supply included with the kit should be used to power the transmit box. If you experience any problems with the 9 volt power supply, contact U.S. FIRST for a replacement. Use of an alternate power supply could damage the transmit box or RNET and is therefore prohibited.

The RNET radio should be connected to the transmit box by the 6ft. nine-pin cable. The transmit box reads both proportional input devices (joysticks) and non-proportional input devices (switches), encodes the signals, and sends the data to the receive box via the RNET radio link or tether. There are 8 proportional input channels, and 4 non-proportional, bi-directional input channels. Table 4.3 shows the input channel pin assignments for each input port.

Table 4.3: Input Port Pin Assignments

	I/O Port 1	I/O/Port 2	I/O/ Port 3
Pin	Input Channel	Input Channel	Input Channel
1	Power	Power	Ground
2	SW3 (forward)	SW1 (forward)	SW3 (forward)
3	A5	A1	SW4 (forward)
4	Ground	Ground	A7
5	Ground	Ground	A3
6	A6	A2	SW1 (reverse)
7	SW3 (reverse)	SW1 (reverse)	SW2 (reverse)
8	Power	Power	Power
9	Power	Power	Ground
10	SW4 (forward)	SW2 (forward)	SW3 (reverse)
11	A7	A3	SW4 (reverse)
12	Ground	Ground	Ground
13	A8	A4	SW1 (forward)
14	SW4 (reverse)	SW2 (reverse)	SW2 (forward)
15	Power	Power	Power

Notes: SW1 through SW4 denote non-proportional, bi-directional switch inputs.
There are separate input lines for each switch direction.
Switch inputs should be switched to Ground.
A1 through A8 denote analog (proportional) inputs.
Analog inputs measure a variable resistance between the input line & Power.
The X & Y axes of the Flightsticks are connected to A1,A5 & A2,A6, respectively.
The momentary switches on the Flightsticks are connected to SW1 & SW3.
The throttle wheels on the Flightsticks are connected to A4 & A8.

Although there are 12 available input channels, only 8 may be used at once. This limitation exists because the receive box only provides 8 output channels. Therefore, the input devices best suited to control your machine must be selected, and the transmit box configured accordingly. A good start is to use the channels available from the Flightsticks.

Two options exist for the processing of joystick signals. The default option assigns output channel 1 to A1, which is the X-axis of the joystick connected to input port 2, and channel 2 to A2, the Y-axis of the joystick connected to input port 2. Similarly, channels 3 and 4 are assigned to the X (A5) and Y (A6) axes of the joystick connected to input port 1, respectively. The Coordinated joystick option is intended for driving a machine with a single joystick by commanding speed with the Y axis and commanding turning rate with the X axis. This option may be selected by setting DIP switches 1 and 2 located inside the transmit box. To activate Coordinated mode, set DIP switch 1 for a joystick on input port 2, and DIP switch 2 for a joystick on input port 1.

The remaining 4 output channels may be configured by setting DIP switches 5 through 8 located inside the transmit box; refer to table 4.4.

Attention: Before opening the transmit box, remember to disconnect the power supply. While the transmit box is open, be careful to avoid static discharges to the circuit board or connectors. Also, make sure not to let any foreign particles, especially metal fragments, get inside the enclosure or onto the circuit board. It is best to open the unit in a clean environment away from where your machine is being worked on. Never operate the transmitter with the cover off.

Figure 4.3 shows the location of the DIP switches on inside the transmit box. To access the DIP switches, the cover of the transmit box must be removed. To remove the cover, unscrew the four Phillips head screws on the underside of the transmit box.

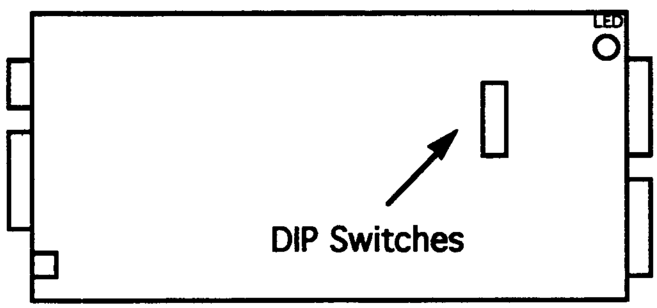

Figure 4.3: Location of DIP Switches Inside Transmit Box

Table 4.4 shows the how to map the various input channels on the transmitter to the output channels on the receiver, and the corresponding DIP switch settings.

Table 4.4: Transmit Box DIP Switch Settings

Input Configuration								DIP Switch Settings			
CH1	CH2	CH3	CH4	CH5	CH6	CH7	CH8	5	6	7	8
A1	A2	A5	A6	A4	SW1	A8	SW3	0	0	0	0
A1	A2	A5	A6	SW2	SW1	A8	SW3	1	0	0	0
A1	A2	A5	A6	A4	A3	A8	SW3	0	1	0	0
A1	A2	A5	A6	SW2	A3	A8	SW3	1	1	0	0
A1	A2	A5	A6	A4	SW1	SW4	SW3	0	0	1	0
A1	A2	A5	A6	SW2	SW1	SW4	SW3	1	0	1	0
A1	A2	A5	A6	A4	A3	SW4	SW3	0	1	1	0
A1	A2	A5	A6	SW2	A3	SW4	SW3	1	1	1	0
A1	A2	A5	A6	A4	SW1	A8	A7	0	0	0	1
A1	A2	A5	A6	SW2	SW1	A8	A7	1	0	0	1
A1	A2	A5	A6	A4	A3	A8	A7	0	1	0	1
A1	A2	A5	A6	SW2	A3	A8	A7	1	1	0	1
A1	A2	A5	A6	A4	SW1	SW4	A7	0	0	1	1
A1	A2	A5	A6	SW2	SW1	SW4	A7	1	0	1	1
A1	A2	A5	A6	A4	A3	SW4	A7	0	1	1	1
A1	A2	A5	A6	SW2	A3	SW4	A7	1	1	1	1
Note: 0 = open, 1 = closed The default configuration is all DIP switches set to open. DIP switches 3 and 4 should always be set to open.											

DIP switches 3 and 4 must always remain open. DIP switches 5 through 8 may be modified to select which input channels the transmitter will read and send to the receiver.

The default configuration of the transmit box is to read all proportional axes and switches available on the two Flightstick joysticks. This yields a total of 6 proportional channels, and 2 non-proportional, bi-directional channels.

The Flightsticks can be connected directly to input ports 1 and 2. The rocker switches, limit switches, reed switches, and pressure switches can be connected via input port 3.

The black project box included in the kit is intended to serve as both a mounting point and a wiring box for devices connected to input port 3. However, other kit materials may be used to mount these devices. For the instructions below, it is assumed that you are using the project box.

Input devices other than the joysticks should be wired to the 15 pin female soldercup connector. This connector should be mounted on the side of the project box. From there, use the 15 pin cable to connect to input port 3 on the transmit box.

4.5 Receiver/Relay Box

The receiver/relay box contains both the receive board and relay board. Each board provides unique functions, as described below.

Receive Board

The receive board decodes the transmitted data and converts it to pulse width modulated (PWM) signals. There are eight output channels available.

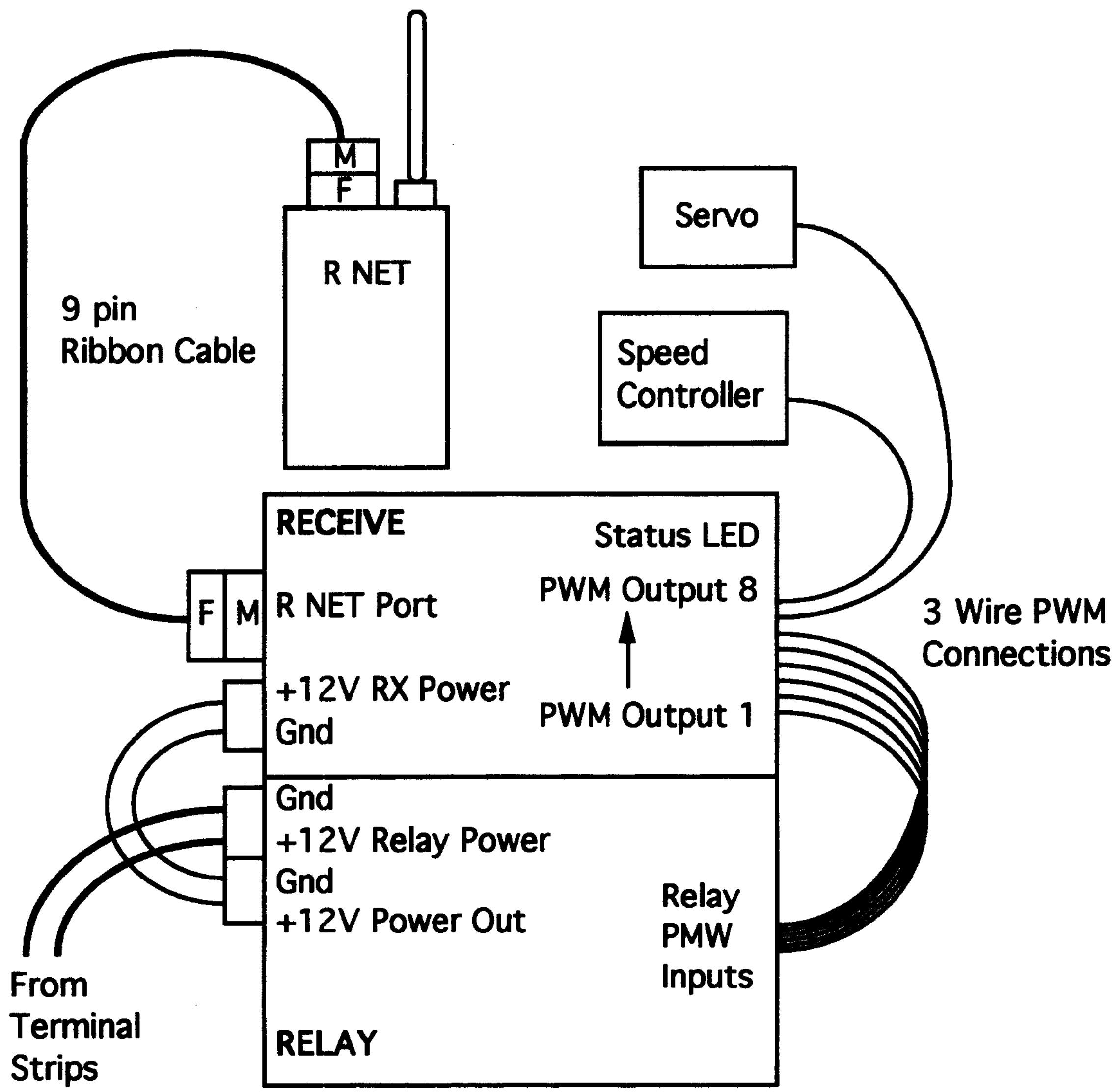

Figure 4.4: Receive/Relay Box Connections

The RNet is connected to the receive board by the nine pin ribbon cable. Avoid bundling it with the battery or motor wires. Shielding is not necessary and has caused problems in the past. Locate the RNET so the antenna is not shielded by metal objects. At the contest you will be required to return your RNET pair and will be using units dedicated to the contest fields. For this reason make your RNET accessible so it can be installed and removed quickly during the competition. The hook and loop fastener is installed on the RNET in the same location that it will be installed at the contest. However, we recommend a secondary means of attachment because the RNETs have broken loose in the past.

The PWM outputs connect to the three wire PWM cables from the servos, speed controllers, and relay board only. Except the servos, they do not drive any motors directly. These are signal wires only.

To connect the transmitter to the receiver using the tether adapter, connect one end of the tether adapter to the RNET port on the transmitter box. Connect the other end of the tether adapter to the male end of the 6 foot, 9 pin molded cable. Connect the molded cable in series with the ribbon cable. Connect the other end of the ribbon cable to the RNET port on the receiver box. Figure 4.5 illustrates this concept.

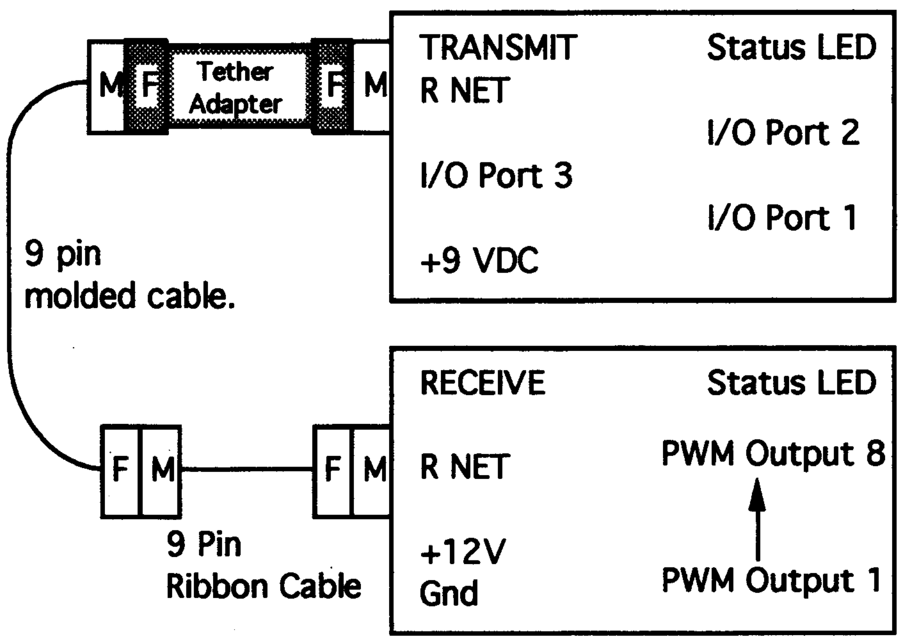

Figure 4.5: Use of the Tether Adapter

Relay Board

The relay board decodes the PWM signals and switch inputs and activates or deactivates the relay outputs accordingly. The relay outputs will drive the McCord Winn air pumps, Numatics air valves, and Delco seat motors. At least one PWM input needs to be connected to the receive box for it to operate at all. Table 4.5 correlates the relay outputs with PWM and sensor inputs.

The PWM inputs connect to the PWM outputs on the receive box.

The sensor inputs on Input Port 1 and Input Port 2 are asserted when they are connected to RTN. Table 4.6 describes the pin assignments on these ports. Use the 2 conductor jacketed cable and the 15 pin female connectors to make the connection between the switch inputs and the switches.

Do not connect power or any other signals to these switches or switch inputs. Be careful to observe the polarity of the power inputs when wiring the control system. You will be required to pay for replacement or repair of devices damaged due to improper wiring.

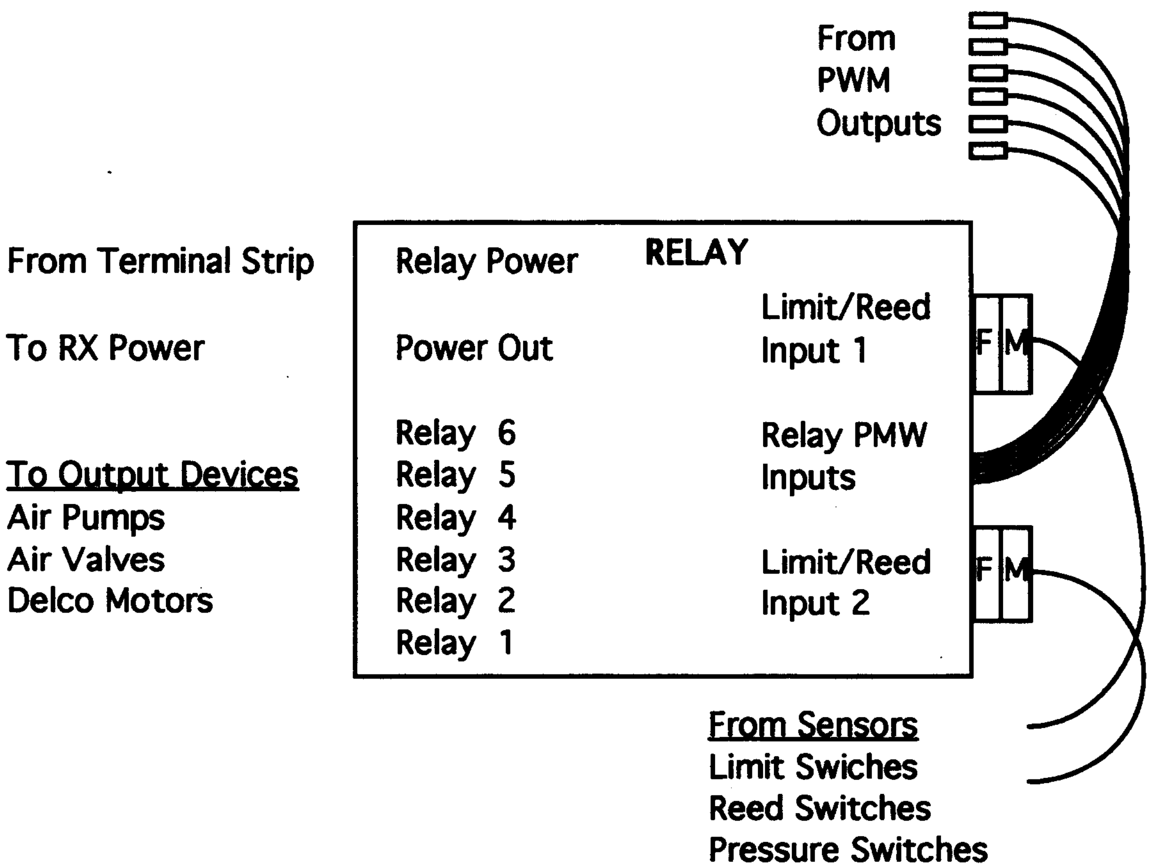

Figure 4.6: Relay board connections

Table 4.5: Relay Board Truth Table

PWM input	GOFWD	STOPFWD	GOREV	STOPREV	OUTPUT
Forward					Forward
Forward		X			Off
Off					Off
Off	X				Forward
Off			X		Reverse
Reverse					Reverse
Reverse				X	Off
Note: X is asserted All other input combinations will be decoded as Off.					

Table 4.6: Input Port 1 and Input Port 2 Pin Assignments

P1 pin #	Switch Contact		P2 pin #	Switch Contact
1	GOFWD1		1	GOFWD4
2	GOREV1		2	GOREV4
3	RTN		3	RTN
4	STOPFWD2		4	STOPFWD5
5	STOPREV2		5	STOPREV5
6	GOFWD3		6	GOFWD6
7	GOREV3		7	GOREV6
8	RTN		8	RTN
9	STOPFWD1		9	STOPFWD4
10	STOPREV1		10	STOPREV4
11	GOFWD2		11	GOFWD5
12	GOREV2		12	GOREV5
13	RTN		13	RTN
14	STOPFWD3		14	STOPFWD6
15	STOPREV3		15	STOPREV6

Example

Stop channel 1 from moving forward when a switch is asserted and initiate channel 3 reverse when a different switch is asserted. Figure 4.7 shows the proper wiring for this condition. Note that switches are shown in the non-asserted condition.

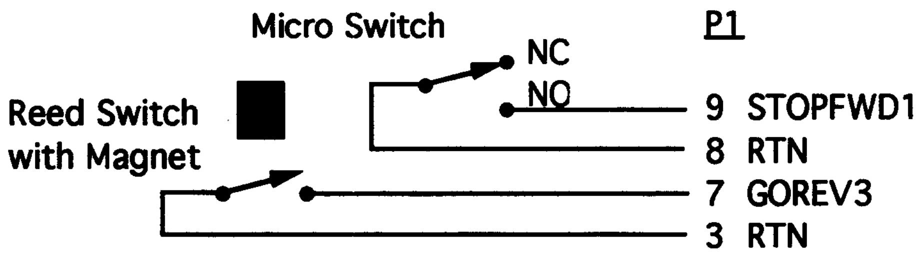

Figure 4.7: Example sensor wiring.

For example, a motor connected to the relay board powers a mechanism with a limited range of travel. By mounting a limit switch in such a position that it is triggered when the mechanism reaches one of the ends of travel, the limit switch can disable the motor from trying to travel further in that direction without preventing it from moving back in the other direction. This can prevent binding or damage to the mechanism, and can save energy by preventing the motor from operating in a stall condition.

PWM Cables

Some of the PWM cables in the kits have Hitec/JR style connectors while others have Futaba J-style connectors. The Hitec/JR style cables have yellow, red, and black wires, while the Futaba style cables have white, red, and black wires. The PWM connectors should be plugged into the receiver box with the black wire on the bottom, and the yellow or white wire on top. In order to use the Futaba style connectors, you may need to shave off the external tab to gain a proper fit. See the figure below for details.

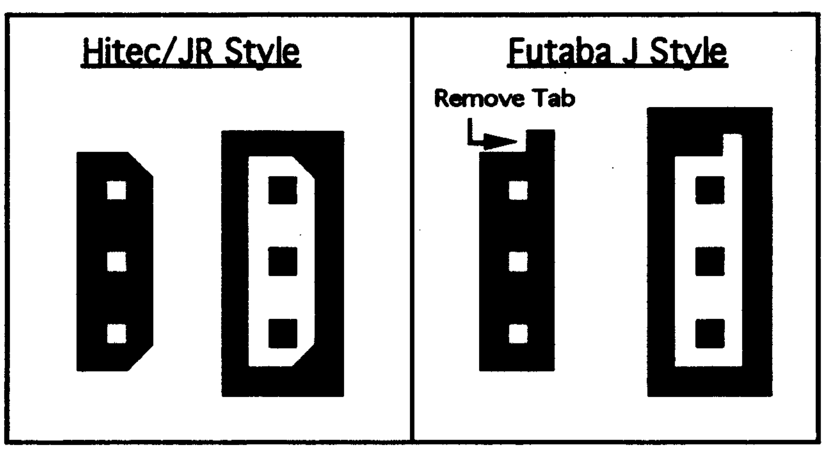

Figure 4.8 : Hitec and Futaba-Style PWM Connectors

4.6 Output Devices

Milwaukee Gearmotors and Tekin Speed Controllers

Refer to the Tekin REBEL Owner's Manual for connection of the speed controller to the battery and motor. Two capacitors, included with each speed controller, must be installed on each drill motor as described in the Owner's Manual. We have provided a screw and solder lug on each motor for this purpose, because soldering to the motor housing is difficult. Please secure the motor wires carefully to avoid breaking the capacitor leads.

One 20A circuit breaker must be installed in series with each drill motor to protect both the drill and the speed controller. Do not disable the circuit breaker by connecting its terminals together. Please insulate the terminals of this circuit breaker separately, as in Figure 4.9, so inspectors at the competition can verify correct installation. If the circuit breaker trips during use, you should use a higher gear reduction ratio. The circuit breaker usually resets in less than one second.

If the speed controller shuts off due to overheating during use, you may need to use a higher gear reduction ratio, or you may be running it continuously in reverse. The speed controller runs hotter in reverse than it does in forward. The speed controller usually takes 30 seconds or more to reset. An optional 12V muffin fan has been included in the kit primarily for added protection against overheating of speed controllers and/or drill motors. You should install this fan to direct cooling air over the power components that run the hottest. You may provide power to the fan from the 12V power distribution terminal blocks directly. Note that the fan is not reversible.

The drill motors and gearboxes snap together for convenient handling during assembly of a drill; this motor-gearbox sub-assembly cannot support normal loads by itself. The gearshift lever on the gearbox and the gears actuated by it cannot withstand large gear-shifting forces, especially while operating. All parts to assemble the complete gearshift mechanism, including a gearshift button, three springs, and gearshift link are provided in the Drill Bag in the kit. We recommend that you use the plastic drill shell to support the motor, gearbox and shift mechanism, and provide ample speed reduction between the drill and its load. See Figure 4.10 for proper installation of the gearshift button, springs and link.

The drill components were designed for drilling small holes and driving small screws, not for propelling a 120 pound machine or launching huge balls several feet into the air. Please remember this when designing and operating your machine. Align mechanical power transmission components accurately. If you couple the spindle to another shaft, support the shaft with two bearings and use a suitable flexible coupling. If you mount a gear, pulley, or sprocket to the gearbox spindle, use the largest pitch diameter possible to minimize side loads resulting from transmitting torque. Note the tradeoff between side loads and available gear ratio. A small pulley on the spindle allows a good gear ratio, but results in excessive side loads. Consider seriously the possible need for two stages of speed reduction between the drill and its load. If the drill shows signs of overloading, such as clutch disengagement, improve your design. When you get out on the playing field, failures will be far more likely than they were during practice.

Figure 4.11 shows performance curves for one drill motor installed in the drill shell with its gearbox, powered from one battery through a speed controller at full forward "throttle," and battery voltage as a function of battery current.

Delco Seat Motors

The Delco seat motors contain one worm gear reduction stage and a positive temperature coefficient (PTC) thermistor for overload protection. As the motor becomes warm from use, the resistance of the PTC device increases, thereby reducing the motor current and output torque. Operation at or near stall continuously will reduce the output torque to near zero until the motor has been allowed to cool. To prevent overheating, take care to couple the output shaft in a manner that does not impose large side loads, use an appropriate gear ratio, and minimize the internal friction of the mechanism driven. Figure 4.12 shows dimensions and operating characteristics of the Delco seat motors.

Mechanical Power Transmission

One of the most common problems teams have experienced in past competitions is mechanical power transmission failure. Typical torques at the final stage of your propulsion power transmission assembly are large enough to cause serious problems for most conventional means of fixing gears, pulleys or sprockets to shafts. Set screws almost always fail. Pins offer better torque transmission, but can cost you valuable time if one breaks. Be careful not to use a pin so large that it occupies so much if the original shaft cross-section that the shaft breaks. Consider carefully the use of good clamping type couplings, even though they may be expensive. We have included two 3/8 in. bore Trantorque collet type couplings in the kit, and recommend that you use them on the drill spindles. Although the Trantorque is intended for use on a smooth shaft, it has been used successfully on the threaded spindle. You should bore the component to be mounted a few thousandths of an inch smaller than the recommended 0.750 in. to compensate for the spindle diameter, which is slightly under 0.375 in. Be careful to avoid interference with other machine parts when installing the Trantorque coupling (see Figure 4.13).

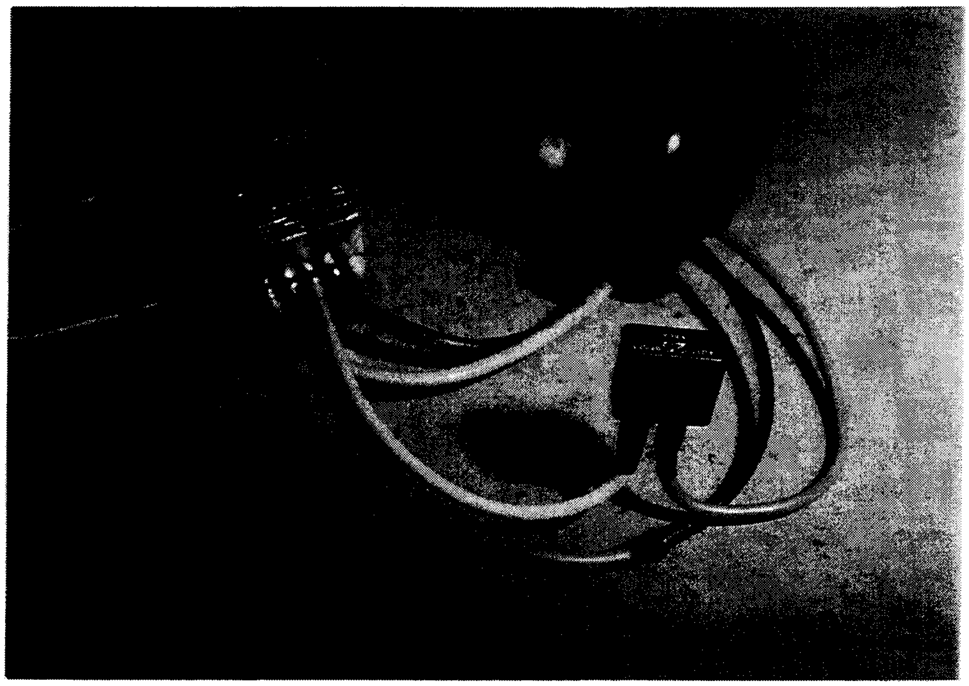

Figure 4.9: Installation of 20A circuit breaker.

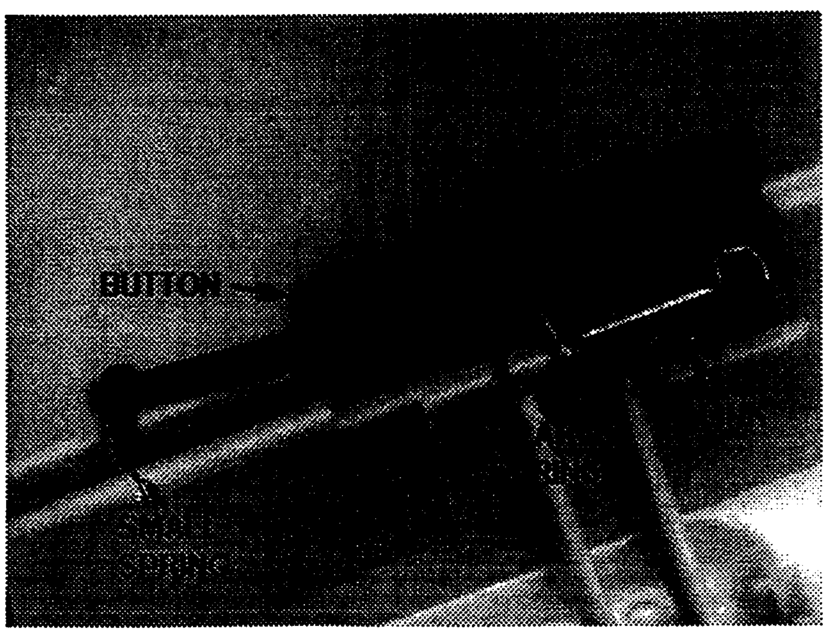

Figure 4.10 : Installation of the gearshift button, 3 springs and gearshift link in drill shell.

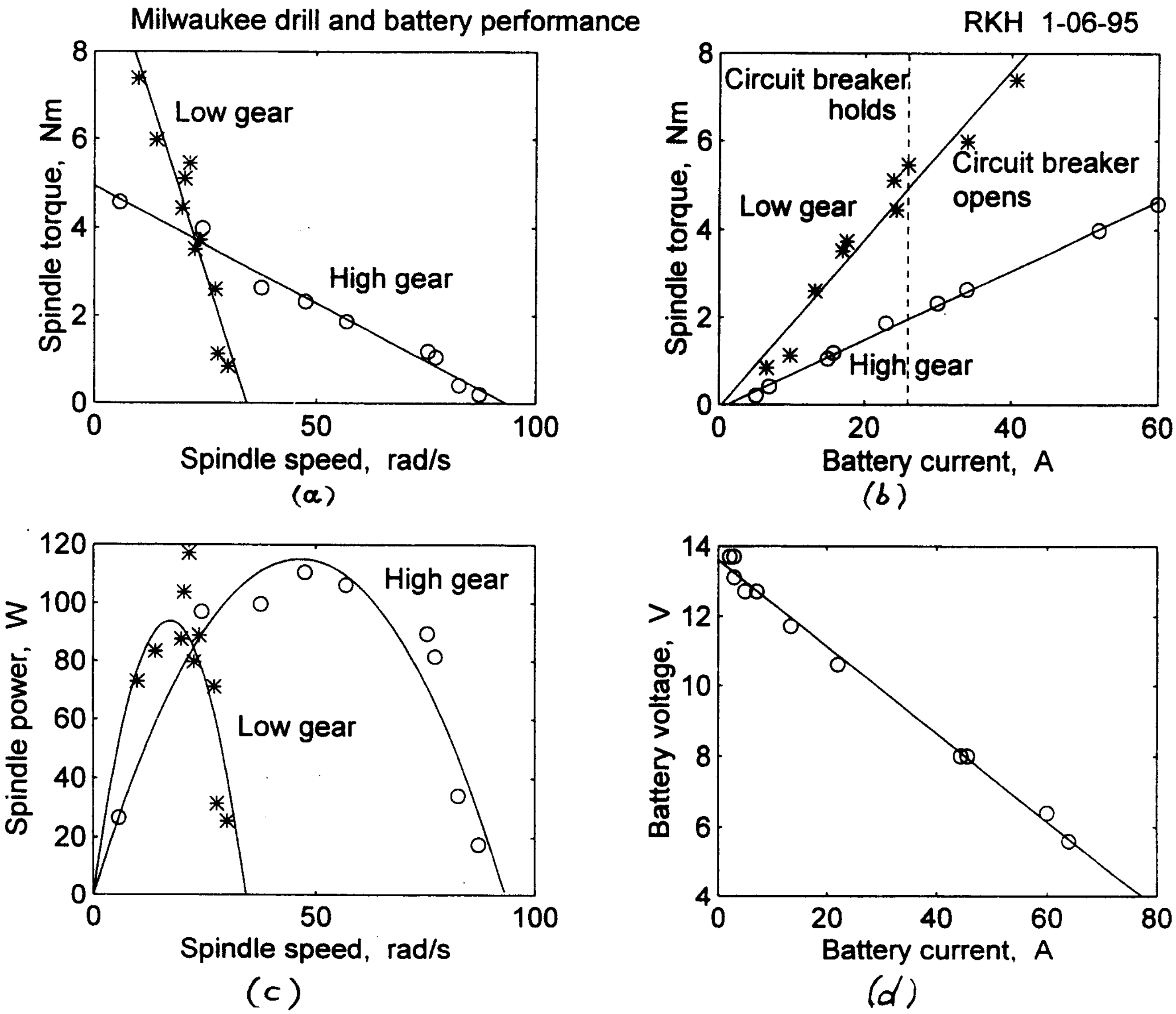

Figure 4.11: Performance curves for one drill motor with its gearbox, powered by one battery through a speed controller. (a) Torque vs. speed, (b) Torque vs. current, (c) Output power vs. speed, (d) Battery voltage vs. battery current.

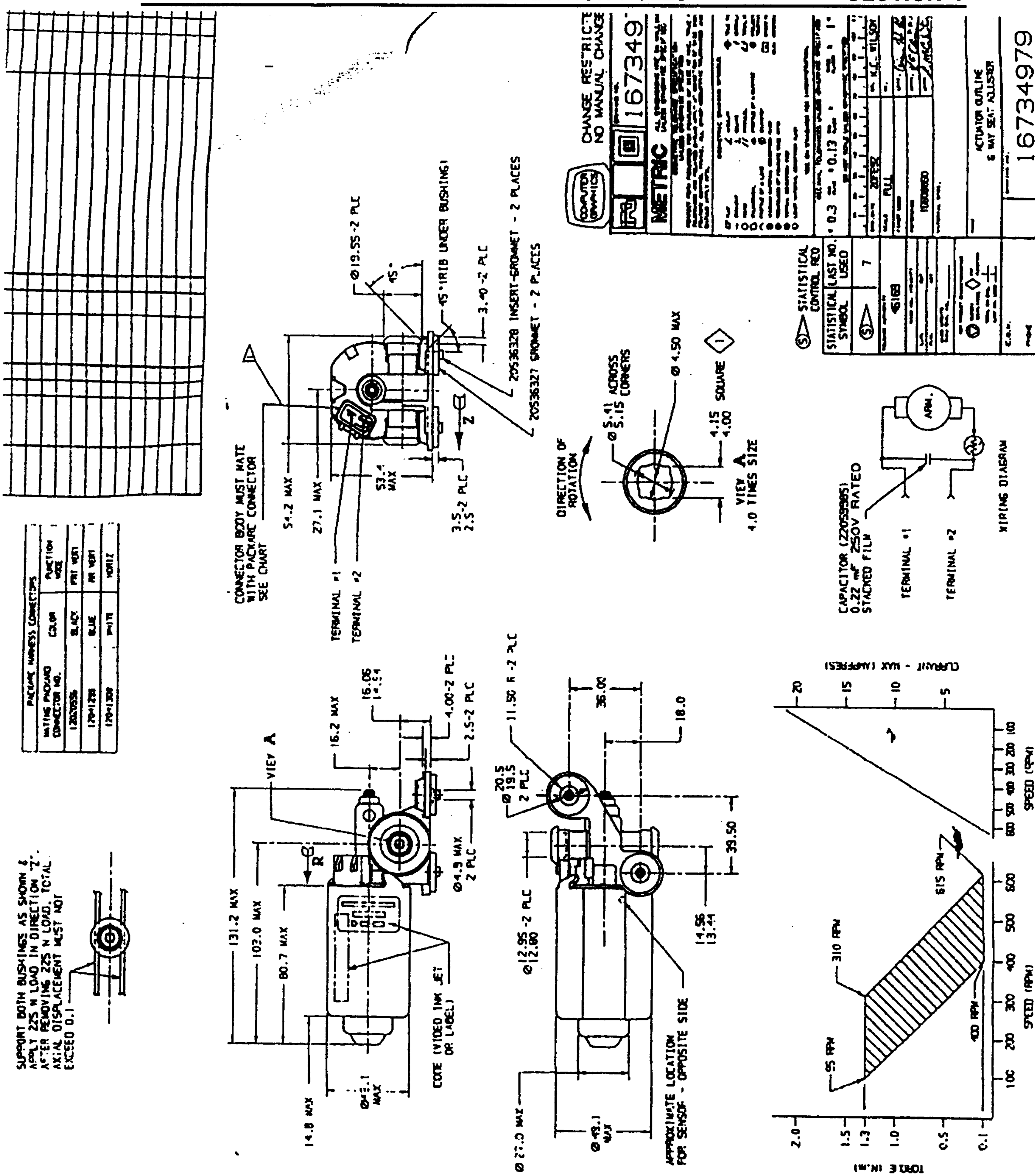

Figure 4.12: Dimensions and operating characteristics of the Delco seat motors.

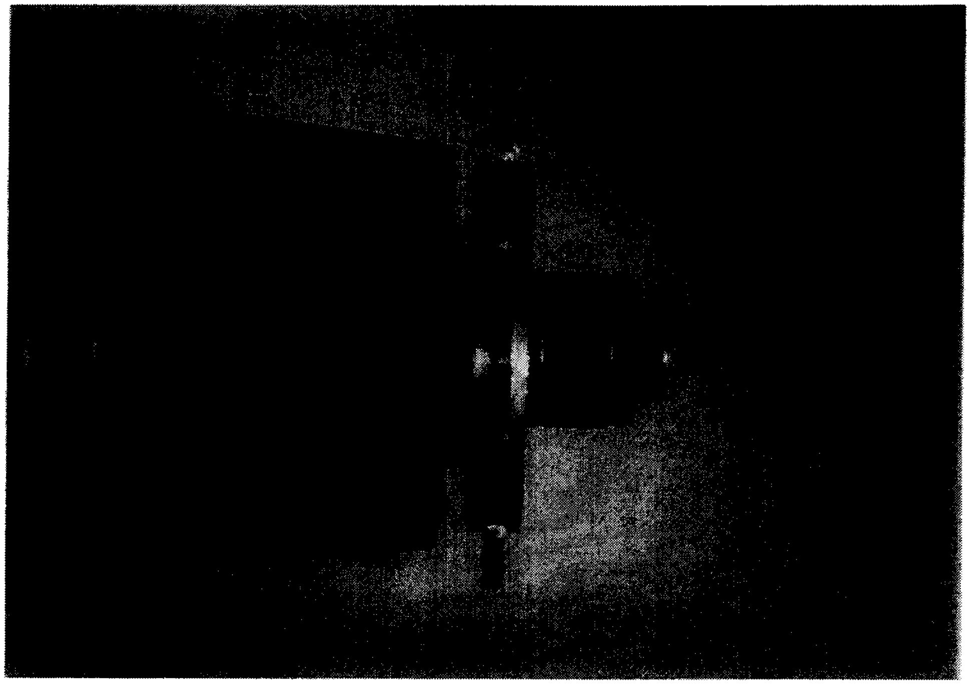

Figure 4.13: Sprocket mounted to drill spindle using Trantorque coupling

Numatics Air Valve

The double acting solenoid valve has two solenoids. Exciting either solenoid pulls the valve into its corresponding state. Wiring the valve with two diodes per Fig 4.14 will allow you to use the relay board outputs to control it in both states with only one channel.

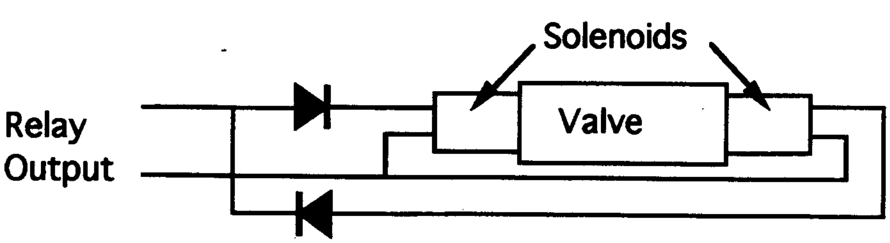

Figure 4.14

4.7 Batteries & Chargers

The battery chargers use a temperature sensor to terminate charging. A warm battery must be allowed to cool before the charger will begin charging. Please do not attempt to cool a battery by immersing it in ice, water, or snow. A battery that has been left out in cold weather must be allowed to reach room temperature before charging. Failure to do so will cause serious damage to the battery, which may leak toxic liquid as a result.

Be careful to avoid shorting the batteries. Short-circuit current exceeds 100A and can cause fire, serious injury, and leakage of toxic materials. If you have a battery that you know to be damaged, please do not put it in the trash. Turn it in to us and tell us that it is damaged, so we can recycle it properly.

Freshly charged batteries will be provided at the competition for teams who have not had time to charge a pair fully for their next match. The best strategy when working in the pit is to trade one set of batteries at the U.S. FIRST charging station for a fresh set a few minutes prior to your next match and "top them off" with your own charger. Use the other set for testing in the pit.

Two batteries with an average load of 10A each will run for at least five minutes. Figure 5.11 shows the voltage of one fully charged battery as a function of discharge current.

Do not alter the battery boxes. You may mount battery boxes to your machine using 1/4"-20 screws, which will fit tightly into the holes on the bottom of the battery box.