

CHAPTER THREE

Special Features

IN THIS CHAPTER

- Motor Braking
 - Regeneration Solutions
 - Sharing the Power Bus: V Bus+ and V Bus-
 - Current Foldback (*I^T Limit*)
 - Front Panel Test Points
 - Resolver Alignment
-

MOTOR BRAKING (FAULT RELAY±)

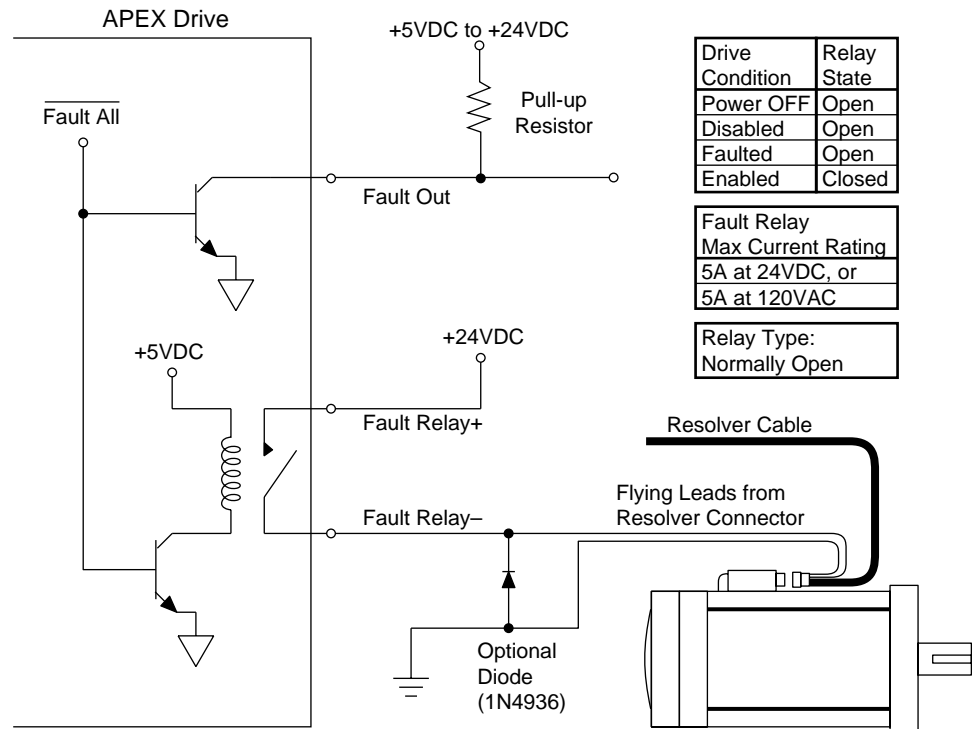
If the APEX Drive faults, for any reason, the drive will be disabled and the motor will freewheel. If a freewheeling load is unacceptable, use the fault relay terminals, **Fault Relay+** and **Fault Relay-**, to control a motor brake.

The fault relay inside the APEX Drive is *normally open*. This means that when the drive is faulted or disabled, or when the power is off, the relay will be open. When the APEX Drive is enabled, it energizes the relay coil, and holds the relay closed. The relay is rated for 5 amps at 24VDC or 120VAC.

Most motor brakes have a coil that, when energized, will release the brake. To control a brake with the fault relay terminals:

- ① Connect the power source for the brake to one of the fault relay terminals.
- ② Connect the other fault relay terminal to the brake.
- ③ If you use a DC power source, you may need to connect a diode across the brake coil to reduce voltage spikes when the brake is engaged or disengaged. A 1N4936 diode, or equivalent, should be sufficient.

EXAMPLE 1: APEX and NeoMetric motors are available from Compumotor with an optional mechanical brake. Call Compumotor's Customer Service Department (800-722-2282) for more information. The next drawing shows how to connect the brake to the fault relay terminals.

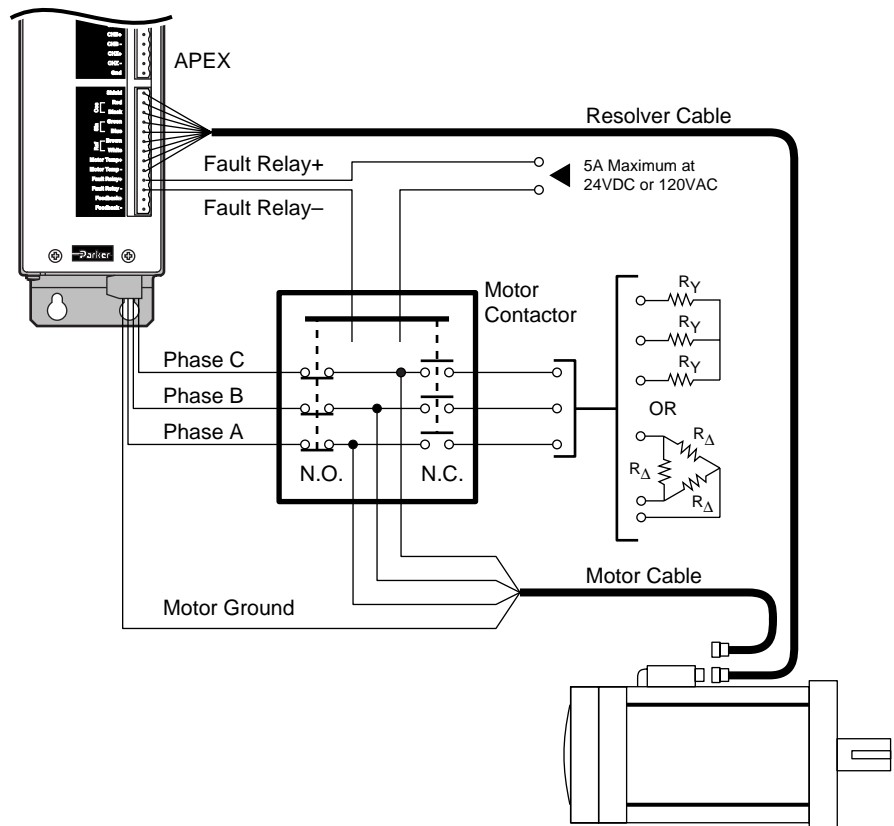


Fault Relay with Mechanical Brake

24VDC is applied, through the fault relay terminals, to one of the flying leads on the motor's resolver connector. The other lead is connected to ground. An optional diode is shown installed between the two leads. The diode's polarity is correct as shown.

The drawing also shows that the fault output and the fault relay are controlled by the same internal signal. Any fault condition that triggers the fault output will also cause the fault relay to turn off (relay will be opened).

EXAMPLE 2: The next drawing illustrates how to connect auxiliary resistors to control motor braking. The drawing shows that during normal operations, the motor contactor is energized and provides a direct connection between the motor and drive. The motor contactor (*N.O.* = normally open with power removed; *N.C.* = normally closed with power removed) is controlled by the fault relay terminals on the APEX Drive's resolver connector. If the drive faults or if the line voltage is disconnected, the contactor connects the motor braking resistors across the motor.



Motor Braking with Resistors

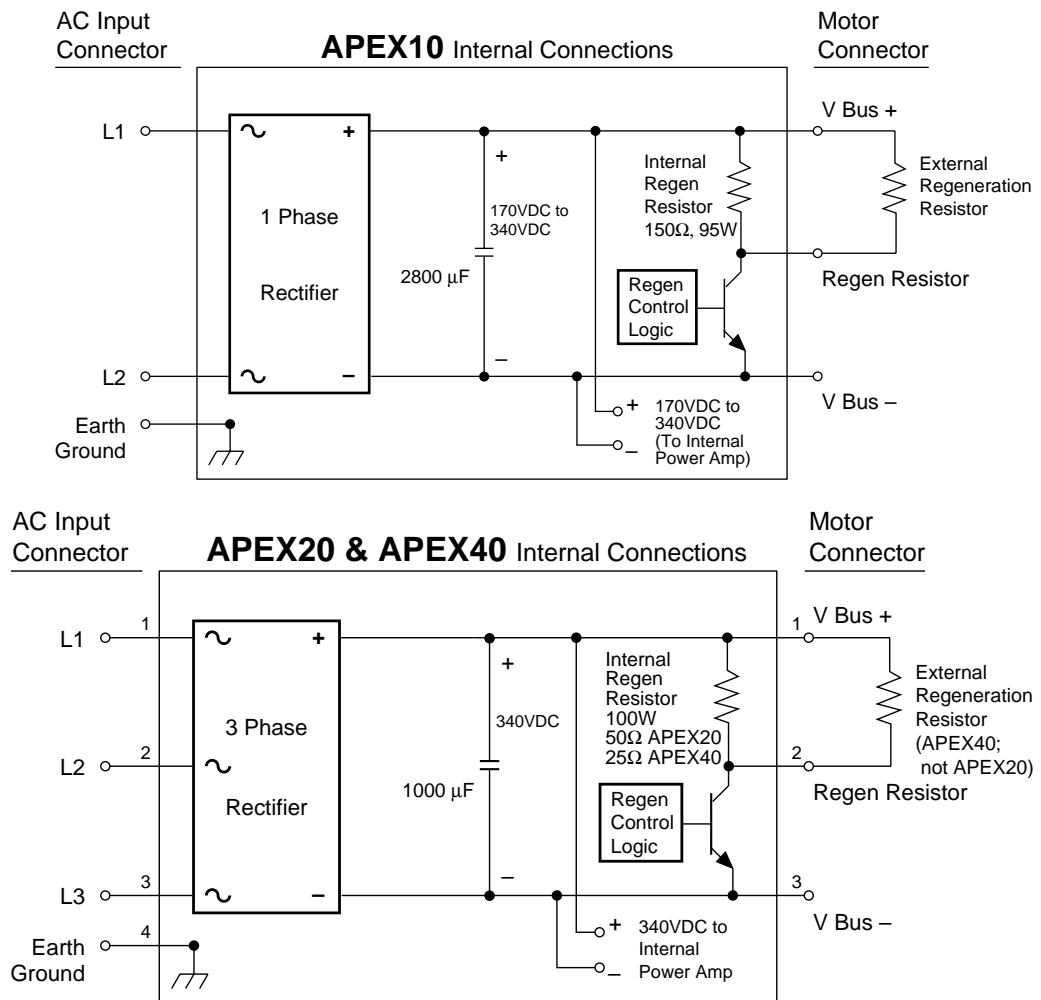
The braking resistors can be sized by analyzing specific applications. If the total load inertia is less than five times the rotor inertia, non-inductive 200 watt power resistors can be used as the braking resistors. For a wye configuration, use 5 ohms or more ($R_Y = 5\Omega$). For a delta configuration, use 15 ohms or more ($R_D = 15\Omega$). If quicker stopping is required, the braking resistor values can be lowered, but you must increase their power ratings.

REGENERATION AND THE APEX DRIVE

The APEX Drive can dissipate regenerated energy in its internal *regeneration resistor*. If an APEX system regenerates more energy than the internal resistor can dissipate, you can connect an external resistor between two terminals labeled **V Bus+** and **Regen Resistor**, located on the motor connector. The external resistor will double the dissipation capabilities of the APEX10 and APEX40. To increase the APEX20's dissipation capabilities, you can add a resistor network, as explained later in this chapter.

The APEX Drive's regeneration circuit works automatically—there are no adjustments to make. The circuit monitors the voltage on the power bus. If regenerated energy from the motor causes the bus voltage to rise above a threshold value, the circuit closes a switch, thus connecting the regeneration resistor between the positive and negative sides of the power bus, **V Bus+** and **V Bus-**. The energy is then dissipated in the resistor. During the regeneration event, the red LED labeled **Regen Active**, located on the APEX Drive's front panel, will be illuminated.

The next drawing shows a schematic that includes the internal regeneration resistor, terminals for an external regeneration resistor, and the DC power bus.



Regeneration Circuit

FAULTS CAUSED BY EXCESSIVE REGENERATION

The APEX Drive's protection circuitry monitors regeneration activity, and can trigger one of two fault conditions if excess regeneration occurs. The drive's internal IGBT power switch is the component that determines the limits. Exceeding the regeneration resistor's *continuous* power rating will cause a **Regen Fault**. Exceeding the resistor's *peak* power rating will cause an **Overvoltage Fault**. Either of these faults will shut down the drive, to

Important specifications for the regeneration circuit are:

	Nominal Operating Voltage: (based on AC input)	Regen Resistor Turns ON:	Overvoltage Fault Turns ON:
APEX10	170VDC-340VDC	390VDC	420VDC
APEX20	360VDC	390VDC	420VDC
APEX40	340VDC	390VDC	420VDC

Dissipation ratings for the internal regeneration resistor are:

	Continuous Power Dissipation Rating	Peak Power Dissipation Rating
APEX10	95 watts	1KW
APEX20	100 watts	3KW
APEX40	100 watts	6KW

safeguard the system.

Details regarding the regeneration fault and overvoltage fault are explained below.

REGENERATION FAULT

A regeneration fault indicates that the *continuous* power dissipation capabilities of the regeneration resistor have been exceeded.

The resistor's temperature is determined by the *average* power dissipation over time and is affected by such things as the length of time the resistor is on, how much power it dissipates, and the length of time it is off. When regeneration occurs, the temperature will increase during deceleration and during a repetitive move profile. The temperature will decrease after regeneration stops—when the motor is accelerating, moving at constant velocity, or at rest.

If the average power dissipated in the resistor is less than the continuous rating in the table above, the temperature will stay below damaging levels. If the average power dissipated is greater than the continuous rating, the temperature may rise to a level that can permanently damage the resistor; however, the regeneration fault circuit will shut down the drive before temperatures reach this level. The purpose of the regeneration fault is to protect the regeneration resistor from damage due to high temperatures.

You can clear the regeneration fault by cycling power or sending a reset signal to the APEX Drive's reset input. To cycle power, turn off AC power to **Control L1/Control L2**, then turn the power back on. However, if the resistor has not had adequate time to cool, and the conditions leading to the regeneration fault persist, **you may damage the regeneration resistor by cycling power repeatedly**. Information about continuous power dissipation in the regeneration resistor is lost when power is cycled.

CAUTION

Repeatedly cycling power or resetting the drive to clear regeneration faults may damage the regeneration resistor.

OVERVOLTAGE FAULT

An overvoltage fault indicates that the *peak* power dissipation capabilities of the regeneration resistor have been exceeded.

Regeneration causes the voltage on the DC power bus to rise. The regeneration resistor will turn on when the bus voltage reaches 390VDC. Peak power dissipation occurs at the moment the resistor turns on. The peak power value is determined by the size of the resistor, in ohms, and the voltage across it:

$$\text{APEX10 Peak Power} = \frac{V^2}{R} = \frac{(390\text{VDC})^2}{150\Omega} \approx 1000\text{W} \quad (1\text{ KW})$$

$$\text{APEX20 Peak Power} = \frac{V^2}{R} = \frac{(390\text{VDC})^2}{50\Omega} \approx 3000\text{W} \quad (3\text{ KW})$$

$$\text{APEX40 Peak Power} = \frac{V^2}{R} = \frac{(390\text{VDC})^2}{25\Omega} \approx 6000\text{W} \quad (6\text{ KW})$$

As soon as the resistor turns on, regenerated power begins to be dissipated in the resistor, and, in most applications, bus voltage drops. When the voltage falls below 375VDC, the resistor turns off. If the motor is still producing regenerated power, the bus voltage will rise again, the resistor will turn on at 390VDC, and the cycle will repeat over and over until the motor no longer produces enough power to turn on the regeneration resistor.

However, some applications can regenerate more than the peak power shown in the above three equations. Too much peak power can overwhelm the regeneration circuit—the bus voltage will continue to rise, even while the resistor is on. To protect the system from excessive voltages, an overvoltage circuit monitors the bus voltage, and triggers the overvoltage fault if the voltage exceeds 420VDC.

An overvoltage fault will shut down the drive. The red LED labeled **Over Voltage**, located on the APEX Drive's front panel, will be illuminated. You can clear the fault by sending a reset signal to the APEX Drive's reset input, or by cycling power.

WHEN DO YOU NEED AN EXTERNAL REGENERATION RESISTOR?

The APEX Drive's regeneration control circuit was designed to automatically deal with regenerated power from almost all applications. Occasionally, however, an application situation arises in which regeneration will cause more power dissipation than the internal resistor can safely tolerate. If you have an APEX10 or APEX40 Drive, you can connect an external regeneration resistor to double the power that the system can dissipate.

If you have an APEX20 Drive, you cannot simply add an external resistor. The drive's internal power switch is already at its maximum rated current; adding an external resistor would increase the current, and damage the drive. You can, however, build your own external resistor network in place of the internal circuit. Use the procedures in this section to determine your system's needs. Then, if you need more continuous dissipation capability, see *Building Your Own Regeneration Circuit* in the next section.

To determine whether or not you need an external resistor, you can use one of two methods:

- Empirical Method
- Calculation Method

EMPIRICAL METHOD

The empirical method uses a trial procedure to determine whether excess regeneration will cause a regeneration or overvoltage fault. Operate your system (or a prototype of your system) and observe the results of regeneration. When your system decelerates, the **Regen Active** LED will be illuminated whenever regeneration turns the internal resistor on.

If the system's regeneration levels are too high, eventually either a regeneration fault or an overvoltage fault will shut down the APEX Drive. (Be sure to let your system run for a long enough time to see if the regeneration fault will be triggered.) At this point, you have two options:

- Modify the system's move profile
- Install an external regeneration resistor

By changing the move profile—less torque, slower velocities, or a longer time between moves, for example—you may be able to reduce the regeneration to a lower level, so that the fault no longer occurs.

By installing an external resistor, you can double the regeneration circuit's power dissipation capabilities. With the resistor installed, the circuit's specifications become:

	Continuous Power Dissipation Rating	Peak Power Dissipation Rating
APEX10	100 watts	2 KW
APEX20	N/A	N/A
APEX40	180 watts	12KW

After you alter the move profile, or install the external resistor, run the system again to verify that regeneration no longer causes a fault.

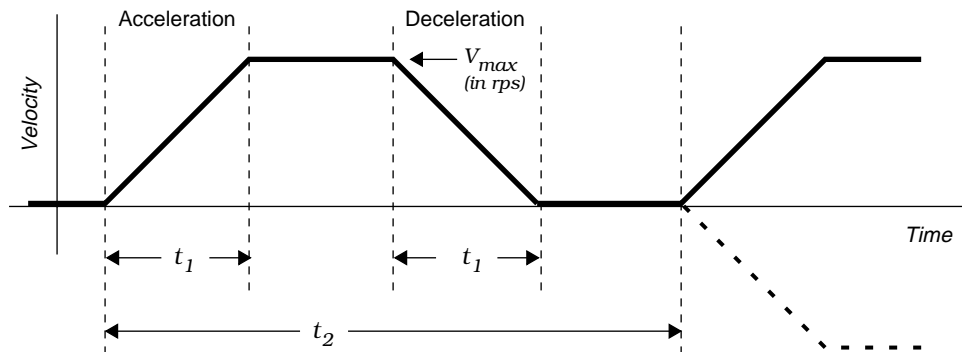
CALCULATION METHOD

You can use the calculation method to predict peak power dissipation and average power dissipation. If peak power or average power exceed the ratings given above for the internal resistor only, you should install an external regeneration resistor.

A NOTE ABOUT UNITS: We want a solution for power that is expressed in *watts*. To be consistent, we will use SI (metric) units in the following equations. If you want to use other units, apply conversion factors in the appropriate places.

CALCULATING PEAK POWER

A typical trapezoidal move profile is shown below.



Move Profile for Regeneration Calculations

Regeneration only occurs during the deceleration portion of the move. At any moment during deceleration, the amount of power regeneration is equal to the shaft power:

$$P_{shaft} = \omega T = 2\pi v T$$

where

T = torque, in newton meters (Nm)

ω = shaft velocity, in radians per second

v = shaft velocity, in revolutions per second (rps)

Peak power regeneration occurs at the moment deceleration begins, when the velocity is highest.

$$P_{shaft(peak)} = 2\pi v_{max} T$$

Not all of this peak power must be dissipated in the power resistor. Some of it will be dissipated in the copper windings of the motor—these power losses are known as *copper losses*.

$$P_{copper} = I^2 R = \frac{3}{2} \left(\frac{|T|}{k_T} \right)^2 R$$

where

I = motor current, in amps (A)

R = line – to – line motor resistance, in ohms (Ω)

k_t = motor torque constant, in newton meters per amp rms ($Nm/A rms$)

Power is also dissipated in the drive itself—these losses are known as *drive losses*. (Notice that we use the absolute value of the torque.)

$$P_{drive} = 5\sqrt{2} \left(\frac{|T|}{k_T} \right)$$

The peak power dissipated in the regeneration resistor, then, is equal to the peak shaft power, less copper and drive losses.

$$P_{peak} = P_{shaft} - P_{copper} - P_{drive}$$

Substituting the values from the previous equations, we obtain the equation for calculating peak power:

$$P_{peak} = (2\pi v_{max} T) - \frac{3}{2} \left(\frac{T}{k_T} \right)^2 R - 5\sqrt{2} \left(\frac{|T|}{k_T} \right)$$

Substitute values from your application into this equation.

- ❑ If P_{peak} is less than the Peak Power Dissipation Rating, the internal resistor is adequate
- ❑ If P_{peak} is greater than the Peak Power Dissipation Rating, install an external resistor

CALCULATING AVERAGE POWER

Time plays a role in average power calculations. Total regenerated energy is equal to the area of the triangle under the deceleration portion of the move profile. In the move profile shown earlier, the time of deceleration is t_1 . Total energy, W , is therefore:

$$W_{regen} = \frac{1}{2}(\text{height})(\text{base}) = \frac{1}{2}(2\pi v_{max} T)t_1$$

During the deceleration time, copper losses and drive losses will dissipate some of the regenerated energy. To determine how much energy these losses will dissipate, each of these losses must be multiplied by the time t_1 :

$$W_{copper} = \left[\frac{3}{2} \left(\frac{T}{k_T} \right)^2 R \right] t_1 \quad W_{drive} = \left[5\sqrt{2} \left(\frac{|T|}{k_T} \right) \right] t_1$$

The total energy that must be dissipated in the regeneration resistor consists of the total regenerated energy, less copper and drive losses:

$$W_{total} = \left[\frac{1}{2}(2\pi v_{max} T) - \frac{3}{2} \left(\frac{T}{k_T} \right)^2 R - 5\sqrt{2} \left(\frac{|T|}{k_T} \right) \right] t_1$$

To find the average power, we must consider how frequently energy is “dissipated” into the resistor. The period of the move profile is the time t_2 . Frequency and period are related by:

$$frequency = f = \frac{1}{t_2}$$

To find the average power dissipation in the resistor, we can multiply the equation for total energy by the frequency, or, as shown below, we can divide by the period of the repetitive move profile.

Finally, we obtain the equation for average power:

$$P_{average} = \left[\frac{1}{2}(2\pi v_{max}T) - \frac{3}{2}\left(\frac{T}{k_T}\right)^2 R - 5\sqrt{2}\left(\frac{|T|}{k_T}\right) \right] \frac{t_1}{t_2}$$

Substitute values from your application into this equation.

- If $P_{average}$ is less than the Continuous Power Dissipation Rating, the internal resistor is adequate
- If $P_{average}$ is greater than the Continuous Power Dissipation Rating, install an external resistor

INSTALLING AN EXTERNAL REGENERATION RESISTOR

If you install an external resistor, ensure that it is properly mounted and adequately cooled. The internal resistor is cooled by the APEX Drive's fan. The external resistor should be maintained at the same temperature, or cooler, as the internal resistor. Excessive heating of the external resistor can cause component failure.

CAUTION

Adequately cool the external resistor. Forced air cooling may be required. Maintain resistor temperature at same or lower temperature as internal resistor.

Specifications for the internal resistor are as follows:

APEX10:

- 150 ohm, 95 watt, 5% non-inductive resistor
- Manufacturer Name: Dale
- Manufacturer Part Number: NHL-95-16N 150 OHM
5%, 3/16 QUICK CONNECT
- You can order this resistor from
Compumotor. The part name is: APEX10 REGEN KIT

APEX20: (for reference only; do not install external resistor)

- 50 ohm, 100 watt, 5% non-inductive resistor
- Manufacturer Name: Memcor-Truohm Inc.
- Manufacturer Part Number: FRV01006-2500-QM-NI
("NI" - Non Inductive)
- Mounting Bracket: Memcor-Truohm Inc.
Part Number 1141-006-001

APEX40:

- 25 ohm, 100 watt, 5% non-inductive resistor
- Manufacturer Name: Memcor-Truohm Inc.
- Manufacturer Part Number: FRV01006-2250-QM-NI
("NI" - Non Inductive)

- ❑ Mounting Bracket: Memcor-Truohm Inc.
Part Number 1141-006-001
- ❑ You can order this resistor from
Compumotor. The part name is: APEX40 REGEN KIT

Use these, or equivalently rated resistors, for your external resistor. Be sure to specify a *non-inductive* resistor.

To connect the external resistor, wire its two terminals to *V Bus+* and *Regen Resistor*, located on the motor connector. Do not install more than one external resistor. The regeneration control circuit will automatically dissipate half of the excess regenerated power in the external resistor (provided that the external resistor has the same resistance (ohms) as the internal resistor.)

CAUTION

Do not install more than one external regeneration resistor with the APEX10 or APEX40.
Do not install an external regeneration resistor with the APEX20.

BUILDING YOUR OWN REGENERATION CIRCUIT

If you need more continuous power dissipation than the resistors provide (internal and external for the APEX10 and APEX40; internal only for the APEX 20), you can design and build your own network of external regeneration resistors.

The next table shows specifications for maximum continuous and peak dissipation that the drive can sustain. It also shows the minimum resistance for an external network. Do not use a resistor network with less resistance than the values in this table.

	<u>Continuous</u>	<u>Peak</u>	<u>Resistance (min)</u>
APEX10	286 watts	2080 watts	75 ohms
APEX20	1560 watts	3112 watts	50 ohms
APEX40	5760 watts	12480 watts	12.5 ohms

The drive's internal IGBT power switch is the component that determines the specifications above. With the standard external resistors discussed earlier, the switch is already at its peak power dissipation level. However, the switch can dissipate more continuous power than the standard resistors allow. Your network, therefore, can dissipate additional continuous power—but must not dissipate more peak power. This is shown in the table above.

To use an external network, you must take the following two steps.

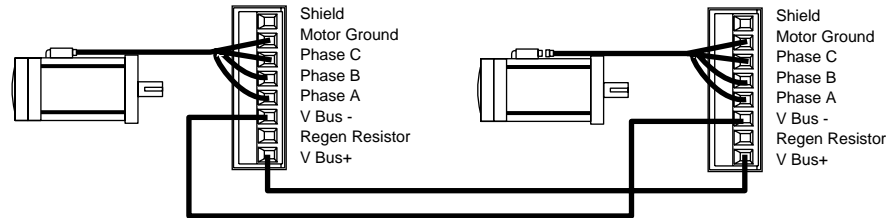
1. Set DIP Switch 1, position #1, in the ON position. This disables the drive's Regen Fault circuit.
2. Disconnect the internal regeneration resistor.

Step 2 above requires opening the drive's cover. Please call Compumotor's Applications Engineering department (see the inside front cover of this manual for the toll free number) for instructions on opening the cover and disconnecting the resistor, and to obtain additional information about designing your external resistor network.

SHARING THE HIGH VOLTAGE POWER BUS, USING *V BUS+* AND *V BUS-*

In some applications with multiple drives, one or more drives continuously receive regenerated power from their loads. For example, in a tensioning application, two drives apply tension (opposite torques) to a single moving load. In this situation, one drive could receive substantial regenerated power from its motor.

In such applications, you can connect the power buses from the drives in parallel, through the *V BUS+* and *V BUS-* terminals, located on the motor connector. With the buses connected in parallel, the regenerated power from one drive is dissipated by the power consumption of other drives. Otherwise, all of a drive's regenerated power would be continuously dumped into its own internal resistor.



CURRENT FOLDBACK (I^2T LIMIT)

The purpose of the current foldback circuit is to protect the motor from overheating due to prolonged high currents. The eight switches of DIP Switch#2 are used to set the parameters for the current foldback circuit. These parameters are:

- ❑ **PEAK CURRENT** – the highest current that the APEX Drive will produce.
- ❑ **CONTINUOUS CURRENT** – the APEX Drive reduces its current to this level when it goes into current foldback.
- ❑ **TIME CONSTANT** – the motor's thermal time constant, which is a physical parameter usually specified by the motor's manufacturer.

The APEX Drive uses an internal circuit to model the motor's thermal behavior, and predict motor temperature. Heat dissipated in the motor's windings is directly proportional to I^2 , the square of the motor current, and the length of time the current flows.

The drive monitors motor current, and uses its internal microprocessor to simulate a capacitor being charged by the motor current. The result is a number, similar to voltage on a capacitor, that represents an average, over time, of the motor's temperature.

The following equation gives an approximate time before foldback occurs, for a motor that operates from a cold start, when $I_{actual} > I_{continuous}$:

$$time_{(minutes)} = Time\ Constant \left\{ -\ln \left[1 - \left(\frac{I_{continuous}}{I_{actual}} \right)^2 \right] \right\}$$

Three variables affect this equation:

- ❑ $I_{\text{continuous}}$ is the continuous current (set by DIP switches)
- ❑ *Time Constant* is the motor's time constant (set by DIP switches)
- ❑ I_{actual} is the current that actually flows in the motor. It can be as low as \emptyset amps, or as high as the peak current (which was set by DIP switches).

The shortest time until foldback occurs will be when $I_{\text{actual}} = I_{\text{peak}}$. Notice that this can be much shorter than the time constant in the equation above.

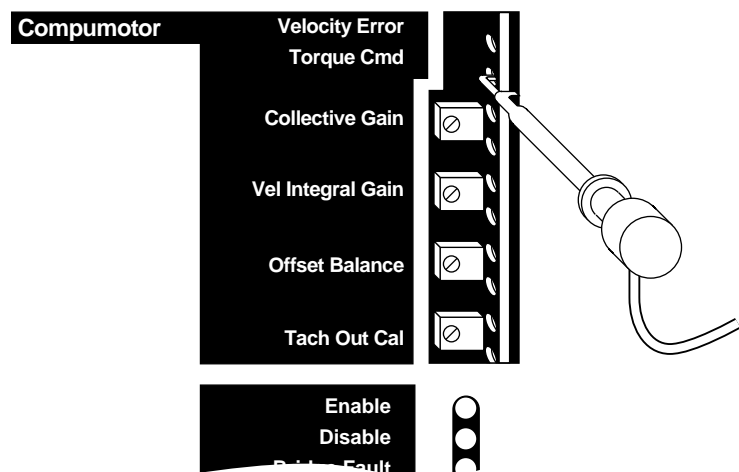
When current foldback occurs, the APEX Drive clamps its output current at the $I_{\text{continuous}}$ level, and illuminates the LED labeled **I²T Limit**, located on the drive's front panel. The drive does not put out a fault signal on its fault output. However, because torque will be reduced as a result of the drive clamping its output current, the controller will probably detect a position or following error, and produce a controller fault.

To recover from current foldback, there are three options:

- ❑ **WAIT**—allow a period of time to pass for the motor to cool. Usually, several minutes will be required.
- ❑ **REDUCE COMMAND INPUT**—lower the commanded current to a level below continuous current. This will bleed off the voltage on the simulated capacitor, and clear the foldback condition.
- ❑ **RESET the APEX Drive (or cycle power)**—this will reset the internal microprocessor, and clear the foldback condition. However, this method is not recommended if the motor is actually hot, because the motor temperature information in the microprocessor will be lost. The motor should be allowed to cool before the drive is reset (or power is cycled), and operations continue.

FRONT PANEL TEST POINTS

The APEX Drive has two test points located on the front panel. You can connect an oscilloscope probe or meter to these points, and monitor the velocity error or the torque command.



Test Points, with Probe Attached

The test point is a through-hole located near the front edge of the APEX Drive's internal circuit board. Place the tip of the test probe in the hole, as shown in the drawing above.

You can connect the negative lead of your probe to any of the drive's ground terminals, labeled **Gnd**, on the APEX Drive's front panel.

TORQUE COMMAND

The torque command test point allows you to measure the actual commanded torque in the APEX Drive's current loop.

The signal voltage at this test point is scaled so that:

- ❑ APEX10: 1 volt = 2 amps commanded torque
- ❑ APEX20: 1 volt = 3 amps commanded torque
- ❑ APEX40: 1 volt = 5 amps commanded torque

This scaling is not affected by the command input scaling (set by DIP switch #3). The torque command test point scaling will be as listed above, regardless of the command input scaling.

The voltage at this output can range from zero to $\pm 8V$.

VELOCITY ERROR

The velocity error test point allows you to directly measure the difference between commanded velocity and the feedback signal.

ALIGNING THE RESOLVER

You can operate the APEX Drive in *alignment mode* if you need to align your motor's resolver.

This is a rarely used feature. Resolvers on APEX and SM Series motors are aligned at the factory, and need no further adjustments. It is usually not necessary to align resolvers on other manufacturer's motors.

However, if you need to replace the resolver on a motor, if you have a motor with unknown characteristics, or if poor speed/torque performance leads you to suspect that the resolver is out of alignment, you can follow the procedure below.

To align the resolver, perform the following steps.

- ① Turn OFF AC power to the APEX Drive.
- ② Remove the load from the motor. The motor's shaft must be able to turn freely.
- ③ Turn DIP Switch#3, position 2, ON. Turn on AC power to the drive.
- ④ Short together the **Command+** and **Command-** inputs. Then, using only enough current in the motor to maintain holding torque (set the current below the continuous current), do one of the following:
 - 2-pole-pair motor: turn the **Offset Balance** potentiometer counterclockwise until the motor shaft turns and locks into position.
 - 3-pole-pair motor: turn the **Offset Balance** potentiometer clockwise until the motor shaft turns and locks into position.
- ⑤ With the motor shaft locked in the alignment position, loosen the screws on the resolver so that it can turn.

- ⑥ Slowly rotate the resolver while you observe the APEX Drive's front panel LEDs. When the resolver is in the correct position, both the *Motor Fault* and the *I²T Limit* LEDs will be illuminated. When the resolver is close to the correct position, only one of the LEDs will be illuminated. When the rotor is not close to the correct position, no LED will be illuminated.
- ⑦ With the resolver in the correct position (both LEDs illuminated), tighten the screws on the resolver so that its case can no longer rotate.
- ⑧ You may need to adjust the offset balance potentiometer, to stop the motor from turning. See instructions in *Chapter 2 Installation* for adjusting the offset balance potentiometer for more information.
- ⑨ Turn off AC power, and turn DIP Switch#3, position 2, OFF.
- ⑩ Resolver alignment is now complete. You can resume normal operations.

While the drive is in alignment mode, it commutates current as follows:

- For 2-pole motors: Current out of Phase B and into Phase C
- For 3-pole motors: Two equal currents out of Phase B and C. Both currents into Phase A.

COMMUTATION TEST MODE

You can operate the APEX Drive in *commutation test mode* to troubleshoot problems. The drive ignores resolver or Hall effect input, and commutates the motor at one revolution per second. Motor current is proportional to command input voltage.

See *Chapter 5 Troubleshooting* for a full description of commutation test mode operations.