SERVO**STAR**® S- and CD-Series Regeneration Requirements

One of the key (and often overlooked) considerations for servo system sizing is regeneration requirements. An undersized regeneration resistor can lead to blown fuses or overload relay trips in the regen protection circuitry. If proper protection is not applied, damage to the BUS module capacitors and drive transistors can occur. Therefore, an evaluation of regeneration requirements is essential to ensuring that the customer purchases a system that will perform the desired task.

Energy Calculations

A rotating motor and load has kinetic energy. When this motor and load stops rotating, the energy must either be stored or dissipated. The BUS module capacitors are capable of storing a certain amount of this energy. Any energy beyond this must be dissipated by the regen resistor. If the BUS module capacitors are capable of storing all of the kinetic energy, the system needs no regen package.

To determine if a system needs a regeneration resistor, use the following procedure:

Define the term E_M which is the kinetic energy of the motor and load minus the system losses.

EQUATION 1

$$E_M = (1.356/2)(J_M + J_L)\omega_M^2 - 3I^2_M(R_M/2)t_d - (1.356/2)T_F\omega_M t_d \text{ Joules}$$

Where:
- J_M = rotor inertia (lb – ft – sec^2)
- J_L = load inertia (lb – ft – sec^2)
- ω_M = motor speed before decel (rad/sec) = $\frac{\text{RPM}}{9.55}$
- I_M = motor current during deceleration (A_{RMS}/phase)
- R_M = motor resistance (Ω L-L)
- t_d = time to decel (sec)
- T_F = friction torque (lb-ft)

If this energy is less than that which the BUS module can store, no regen resistor is needed.

For a single-axis system, the condition for which no regen resistor is required is:

EQUATION 2

$$E_M < \tfrac{1}{2}C(V^2_M - V^2_{NOM})$$

Where: C = BUS module capacitance (Farads)

V_M = max BUS voltage (V)

V_{NOM} = nominal BUS voltage (V) = V (L-L) $\sqrt{2}$

For an n-axis system, the condition for no regeneration resistor is:

EQUATION 3

$$\sum_{J=1}^{N} E_M < \tfrac{1}{2}C(V^2_M - V^2_{NOM})$$

Where: all negative E_M are set equal to zero before summation (sum all non-negative E_M). This represents a worst case in which only the motors that are regenerating ($E_{MJ} > 0$) decelerate while those whose system losses exceed their regenerative energy ($E_{MJ} \leq 0$) remain idle. If Equation 2 or Equation 3 is not satisfied, a regeneration resistor is required.

Regeneration Calculations

The procedure for calculating regeneration requirements is twofold. Both the regen resistance value and the resistor wattage rating must be determined.

Determining Resistance Value

The maximum allowable resistance of the regen resistor is that value that holds the BUS under its maximum value when the regen circuit is initially switched on. For a single-axis AC servo system, the maximum allowable regen resistance is:

EQUATION 4

$$R_{MAX} = \frac{V^2_M}{V_B I_M \sqrt{3}}$$

Where: V_M = maximum BUS voltage

V_B = motor back EMF less motor losses

EQUATION 5

$$V_B = K_B N - \sqrt{3}\, I_M (R_M / 2)$$

Where: K_B = back EMF constant (V (L-L) /K_{RPM})

N = motor speed prior to decel (K_{RPM})

I_M = deceleration current in motor (A_{RMS}/phase)

R_M = motor resistance (Ω L-L)

I_M = deceleration current in motor (A_{RMS}/phase)

Equation 4 is easily expanded for an n-axis system with all axes decelerating simultaneously.

$$R_{MAX} = \frac{V^2{}_M}{V_{B1}I_{M1}\sqrt{3} + V_{B2}I_{M2}\sqrt{3} + \ldots\ldots + V_{BN}I_{MN}\sqrt{3}}$$

EQUATION 6

$$R_{MAX} = \frac{V^2 M}{\sum_{J=1}^{N} V_{BJ} I_{MJ}\sqrt{3}}$$

Determining Dissipated Power

The average wattage rating of the regen resistor is a function of energy to be dissipated and the time between decelerations. This average wattage rating for a single axis system is given by:

EQUATION 7

$$P_{AV} = \frac{E_M - (1/2)C(V^2{}_M - V^2{}_{HYS})}{t_{cycle}}$$

Where: t_{cycle} = time between decels + time to decel (sec)

V_{HYS} = hysteresis point of regen circuit

The hysteresis point of the regen circuit is the voltage level at which the resistor switch opens following an "on" cycle. For example, consider a BUS module with nominal DC bus 325 V and maximum DC bus of 390 V. When the motor decelerates, it "pumps" the bus up to 390 V. When the voltage reaches 390 V, the regen circuit gates on and bleeds the bus down. When the bus bleeds down to a certain level, the regen circuit opens the resistor path thus allowing the bus to "pump" up again. The voltage at which this occurs is the hysteresis point.

For an n-axis system, again set all negative E_M equal to zero and sum E_M as:

EQUATION 8

$$P_{AV} = \frac{\sum_{J=1}^{N} E_{MJ} - (1/2)C(V^2{}_M - V^2{}_{HYS})}{t_{cycle}}$$

Where : t_{cycle} = longest t cycle of the n-axis

This is the average power dissipated over one time period which all axes simultaneously decelerate to a stop. This represents the worst case for a multi-axis system.

When the time between decelerations becomes very large, Equations 7 and 8 become very small. In cases such as these, the average wattage is not a meaningful number. Peak wattage and the timethe resistor sees peak wattage become the main concerns.

The peak wattage of the regen resistor is:

$$P_{PK} = \frac{V^2_M}{R_{REGEN}} \qquad \text{Where:} \quad R_{REGEN} = \text{REGEN Resistance}$$

In summary, Equations 4 and 5 are used to determine if regeneration is needed for a system. If a resistor is required, then Equations 4 and 7 define those requirements for a single-axis system. Equations 6 and 8 define the requirements for a multi-axis system.

Regeneration Calculation Example

A customer's machine is configured so two B-404-B motors with SR10000 amplifiers share the same PA2800 BUS module. The load parameters are:

Motor 1: J_{LOAD} = 0.0010 lb-ft-sec^2
T_F = 1.5 lb-ft
N_{MAX} = 2500 RPM

Motor 2: J_{LOAD} = 0.0005 lb-ft-sec^2
T_F = 1.0 lb-ft
N_{MAX} = 2500 RPM

Minimum time between decelerations = 5 sec

Assume that both motors decelerate at peak current simultaneously from maximum speed to zero. What, if any, regeneration capacity must the BUS module provide?

Motor 1 Calculation for E_M

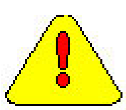
E_{M1} = $(1.356/2)(J_M+J_L)\omega_M{}^2 - 3I^2_M(R_M/2)t_d - (1.356/2)T_F\,\omega_M t_d$ Joules

J_M = 0.000484 lb-ft-sec^2 (From motor specification)

J_L = 0.0010 lb-ft-sec^2

ω_M = 2500/9.55 = 251 rad/sec

I_M = 20 amps (Maximum drive peak current of the SR10000.



Do not exceed I_{PEAK} from the motor.

R_M = 1.32 ohms (From motor specifications)

t_d = $(J_M+J_L)(\omega_M)/(T_M+T_F)$ sec

Where: $T_M = K_T\, I_M$ lb-ft
K_T = 0.99 lb-ft/A (From motor specifications)
T_D = 0.99 (20) = 19.8 lb-ft
T_F = 0.5 lb-ft
t_d = (0.000484+0.0010)(251)/(19.8+1.5) sec = 0.0175 sec

E_{M1} = $(1.356/2)(0.000484+0.0010)(251^2) - 3(20^2)(1.32/2)(0.0175) - (1.356/2)(1.5)(251)(0.0175)$
= 45.1 Joules

Motor 2 Calculations for EM

$t_d = (J_M+J_L)(\omega_M)/(T_M+T_F)$ sec = (0.000484+0.0005)(251)/(19.8+1.0) = 0.0120 sec

$E_{M2} = (1.356/2)(0.000484+0.0005)(251^2) - 3(20^2)(1.32/2)(0.012) -(1.356/2)(1.0)(251)(0.012) =$ 30.5 Joules

Now use Equation 3 to determine if a regeneration resistor is required.

Condition for no regeneration resistor required:

$$\sum_{J=1}^{2} E_M < ½C(V^2_M – V^2_{NOM}$$

E_{M1} = 45.1 J
E_{M2} = 30.5 J
C = 0.00198 Farads (From BUS module data on Table 1)
V_M = 390 (ibid.)
V_{NOM} = 325 (ibid.)

$$45.1 \text{ J} + 30.5 \text{ J} < 1/2(0.00198)(390^2- 325^2)$$
$$75.6 \text{ J} < 46 \text{ J}$$

This is obviously false, therefore, a regeneration resistor is required.

Determine Maximum Resistance Value

The maximum resistance is given by Equation 6:

$$R_{MAX} = \frac{V^2_M}{\sum_{J=1}^{Z} V_{BJ} I_{MJ} \sqrt{3}}$$

Knowns:
$V_{B1} = K_B N - \sqrt{3} I_M (R_M/2)$
K_{B1} = 81.2(V/KRPM)(From motor specifications)
N = 2.5 KRPM
I_M = 20 A
R_M = 1.32 ohms
$V_{B1} = 81.2(2.5) - \sqrt{3}\ (20)(1.32/2) = 180$ V
V_{B2} = 180 V

$$R_{MAX} = \frac{V^2_M}{V_{B1}I_{M1}\sqrt{3} + V_{B2}I_{M2}\sqrt{3}} \quad V_M = 390 \text{ V (From BUS module data)}$$

$$R_{MAX} = \frac{390^2}{(180)(20)\sqrt{3} + (180)(20)\sqrt{3}} = 12.2 \text{ ohms}$$

Determine Dissipated Power

The average power is given by Equation 8:

$$P_{AV} = \frac{\sum_{J=1}^{N} E_{MJ} - 1/2\, C\, (V^2{}_M - V^2{}_{HYS})}{t_{cycle}}$$

Knowns:

E_{M1} = 45.1 J
E_{M2} = 30.5 J
C = 0.00198 F
V = 390 V
V_{HYS} = 370 V
t_{cycle} = 5 + 0.018

$$P_{AV} = \frac{45.1 + 30.5 - (1/2)(0.00198)(390^2 - 370^2)}{5.018} = 12.1 \text{ Watts}$$

The PA2800 BUS module by this calculation must have a regen resistor with a maximum resistance of 12.2 ohms and a minimum average wattage rating of 12.1 watts.

Table 2 shows the standard internal regeneration resistor for the PA2800 has 12.5 ohms and is capable of 40 watts continuous power dissipation.

Comparing these values indicates adequate wattage, but marginally high resistance for the internal resistor. Prudence would dictate the use of the external ER-30 resistor. On a high volume OEM application, testing of the BUS module's internal resistor might prove it adequate when considering additional friction or perhaps the IR drop in the motor cable.

BUS module Specifications

Model	Capacitance (Farads)	V_{NOM} (VDC)	V_{HYS} (VDC)	V_{MAX} (VDC)
PA08	0.00165	325	370	390
PA14	0.00165	325	370	390
PA28	0.00198	325	370	390
PA50	0.00336	325	370	390
PA75	0.00504	325	370	390
PA85	0.00504	325	370	390
CR,CE03*	0.00082	325	370	390
CR,CE06*	0.00164	325	370	390

Table 1: BUS Module Data

Model	Standard Internal Resistor	Optional External Resistor Kit
PA08	NONE	N/A
PA14	40W, 12.5 Ω	ER-30 400W, 8.8Ω ERH-40 100W, 8.8Ω
PA28	40W, 12.5 Ω	ER-30 400W, 8.8Ω ERH-40 100W, 8.8Ω
PA50	NONE	ER-20 500W, 4.5Ω ER-21 1000W, 4.4Ω
PA75	NONE	ER-22 1000W, 2.2Ω ER-23 2000W, 2.2Ω
PA85	NONE	ER-22 1000W, 2.2Ω ER-23 2000W, 2.2Ω
CR, CExx *	NONE	ERH-26 200W, 20Ω

** Integrated Amplifier and Bus module*

Table 2: Available Regeneration Resistors

Typical Servo System Architecture