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BDS-Series
Regeneration Requirements

One of the key, and often overlooked, considerations for servo system sizing is the system's 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 could occur. an evaluation of regeneration needs is essential in ensuring that a system will perform the required tasks.

Energy Calculations

A rotating motor and load has kinetic energy. When this motor/load stops rotating, the energy must be either 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, then the system needs no regen package.

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

Define the term EM which is the kinetic energy of the motor/load minus the system losses.

E_M [Joules] $= (1.356/2)(J_M + J_L)\omega_M^2 - 3I^2_M\,(R_M/2)td - (1.356/2)T_F\omega_M t_d$ **EQUATION 1**

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) $= \frac{RPM}{9.55}$
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)

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If this energy is less than that which the BUS Module can store, then no regen resistor is needed. Thus, for a single-axis system, the condition for which no regen resistor is required is:

$E_M < (1/2)\,C\,(V^2_M - V^2_{NOM})$ **EQUATION 2a**

Where: C = BUS Module capacitance (Farads)
V_M = max BUS voltage
V_{NOM} = nominal BUS voltage (V) = V (L-L) $\sqrt{2}$

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

$\sum_{J=1}^{N} E_{MJ} < (1/2)\,C\,(V^2_M - V^2_{NOM})$ **EQUATION 2b**

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 2a or Equation 2b is not satisfied, then 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 which will hold 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 given by:

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

Where: V_M = maximum BUS voltage
V_B = motor back EMF less motor losses

$V_B = K_B N - \sqrt{3}\, I_M (R_M / 2)$ **EQUATION 4**

Where:
K_B = back EMF constant (V_{L-L}/krpm)
N = motor speed prior to decel (krpm)
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 3 is easily expanded for the case of an n-axis system with all axis decelerating simultaneously.

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

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

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:

$$P_{AV} = \frac{E_M - (1/2)C(V^2_M - V^2_{HYS})}{Td}$$ **EQUATION 5a**

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 325V and maximum DC bus of 390V. When the motor decelerates, it "pumps" the bus up to 390V. When the voltage reaches 390V, 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 and n-axis system, again set all negative E_M equal to zero and sum E_M as follows:

$$P_{AV} = \frac{\sum_{J=1}^{N} E_{MJ} - (1/2)C(V^2_M - V^2_{HYS})}{t\ cycle}$$ **EQUATION 5b**

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.

Where : t cycle = longest t cycle of the n-axis

When the time between decelerations becomes very large, Equations 5a and 5b become very small. In cases such as these, the average wattage is not a meaningful number. Peak wattage and the time which the resistor will see peak wattage become the main concerns (Call Danaher Motion Customer Support – Radford for further assistance). The peak wattage of the regen resistor is:

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

In summary Equations 2a and 2b are used to determine if regeneration is needed for a system. If a resistor is required, then Equations 3a and 5a define those requirements for a single-axis system. Equations 3b and 5b define the requirements for a multi-axis system.

Regeneration Calculation Example

A customer's machine is configured such that that two B-404-B motors with BDS4-206J amplifiers share the same PSR4-220 BUS Module. The load parameters are as follows:

Motor 1: J_{LOAD} = 0.0007 lb-ft-sec^2
T_F = 1.5 lb-ft
N_{MAX} = 3600 RPM

Motor 2: J_{LOAD} = 0.0006 lb-ft-sec^2
T_F = 0.3 lb-ft
N_{MAX} = 3600 RPM

Minimum time between decelerations = 3 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 from Equation 1 for motor 1:

E_{M1} = $(1.356/2)(J_M+J_L)W_M^{\,2} - 31^2{}_M(R_M/2)t_d - (1.356/2)T_F\, W_M td$

J_M = 0.0001275lb-ft-sec^2 (From CD Sheet)

J_L = 0.0007 lb-ft-sec^2

ω_M = 3600/9.55 = 377 rad/sec

I_M = 12 amps (This is peak current of the BDS4-206J. If amplifier has sufficient current, take I_M to be I_{PEAK} from motor CD Sheet)

R_M = 0.786 OHMS (From CD Sheet)

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

Where: $T_M = K_T I_M$ lb-ft

K_T = 0.625 lb-ft/A (From CD Sheet)

T_D = 0.625(12) = 7.5 lb-ft

$t_d = (0.0001275+0.0007)(377)/(7.5+0.5)$

$t_d = 0.039$

$T_F = 0.5$ lb-ft

$E_{M1} = (1.356/2)(0.0001275+0.0007)(377^2) - 3(12^2)(0.786/2)(0.039) -(1.356/2)(0.5)(377)(0.039)$

E_{M1} = 68.1 Joules

Motor 2 Calculations for EM

$E_{M2} = (1.356/2)(0.0001275+0.0006)(377^2) - 3(12^2)(0.786/2)(0.035) -(1.356/2)(0.3)(377)(0.035)$

E_{M2} = 61.5 Joules

Now use Equation 2b to determine if a regeneration resistor is required.

Condition for no regeneration resistor required:

$$\sum_{J=1}^{2} E_{MJ} < (1/2)C(V^2{}_M{}^{-}V^2{}_{NOM})$$

E_{M1} = 68.1 J

E_{M2} = 61.5 J

C = 0.00297 Farads (From BUS Module data on Table 1)

V_M = 390 (ibid.)

V_{NOM} = 325 (ibid.)

$68.1\text{ J} + 61.5\text{ J} < 1/2(0.00297)(390^2 - 325^2)$

$129.6\text{ J} < 69\text{ J}$

This is obviously false, therefore, a regeneration resistor is required. Using Equations 3b and 5b, calculate both the regeneration resistor's maximum resistance and average power rating.

Determine Maximum Resistance Value

The maximum resistance is given by Equation 3b:

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

$$V_{B1} = K_B N - \sqrt{3}\, I_M (R_M/2)$$

$$K_{B1} = 51.2 \text{(V/KRPM)(From motor data sheet)}$$

$$N = 3.6 \text{ KRPM}$$

$$I_M = 12 \text{ A}$$

$$R_M = 0.786\ \Omega$$

$$V_{B1} = 51.2(3.6) - \sqrt{3}\ (12)(0.786/2)$$

$$= 176.2 \text{ V}$$

Similarly,

$$V_{B2} = 176.2 \text{ V}$$

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

$$R_{MAX} = \frac{390^2}{(176.2)(12)\sqrt{3} + (176.2)(12)\sqrt{3}}$$ $R_{MAX} = 20.7$ ohms

Determine Dissipated Power

The average power is given by Equation 5b:

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

Knowns:

$$E_{M1} = 68.1 \text{ J}$$

$$E_{M2} = 61.5 \text{ J}$$

$$C = 0.00297 \text{ F}$$

$$V = 390 \text{ V}$$

$$V_{HYS} = 380 \text{ V}$$

$$t \text{ cycle} = 3 + 0.0039$$

$$P_{AV} = \frac{68.1 + 61.5 - (1/2)(0.00297)(390^2 - 370^2)}{3.039} = 38.8 \text{ Watts}$$

The PSR4/5-220 BUS Module by this equation must have a regen resistor with a maximum resistance of 20.7 ohms and a minimum average wattage rating of 38.8 watts.

Table 2 shows that the standard internal regeneration resistor for the PSR4/5-220 has 12 ohms and is capable of 40 watts continuous power dissipation.

Thus for this example, the standard internal resistor is sufficient.

BUS Module Specifications

Model	Capacitance (F)	V_{NOM}	V_{HYS}	V_{MAX}
PSR3-230/25	0.0044	325	365	385
PSR3-230/50	0.0044	325	365	385
PSR3-230/75	0.0066	325	365	385
PSR4/5-112	0.00165	163	210	220
PSR4/5-120	0.00297	163	210	220
PSR4/5-212	0.00165	325	380	390
PSR4/5-220	0.00297	325	380	390
PSR4/5-250	0.00300	325	380	390
PSR4/5-275	0.0046	325	380	390

TABLE 2- AVAILABLE REGENERATION RESISTORS

Model	Standard Internal	Optional External
PSR3-230/25	15 OHMS, 150 W	NONE
PSR3-230/50	7.5 OHMS, 300 W	4.5 OHMS, 600 W
PSR3-230/75	NONE	6.8 OHMS, 300 W
		4.5 OHMS, 900 W
		3.2 OHMS, 900 W
		2.31 OHMS, 1500 W
		2.55 OHMS, 2000 W
PSR4/5-112	15 OHMS, 40 W	5.5 OHMS, 200 W
PSR4/5-120	7.5 OHMS, 40 W	5.5 OHMS, 200 W
PSR4/5-212	25 OHMS, 40 W	8.8 OHMS, 400 W
PSR4/5-220	12 OHMS, 40 W	8.8 OHMS, 400 W
		5.8 OHMS, 700 W
PSR4/5-250	NONE	4.5 OHMS, 500 W
		4.4 OHMS, 1000 W
PSR4/5-275	NONE	4.5 OHMS, 500 W
		4.4 OHMS, 1000 W
		2.2 OHMS, 1000W
		2.2 OHMS, 2000 W

Highlighted sections are **GOLD**LINE models.

TYPICAL SERVO SYSTEM ARCHITECTURE