SERVO**STAR**® S600 Regeneration Requirements

This Product Note addresses one of the key, and often overlooked, considerations for servo system sizing: regeneration requirements. An undersized regeneration resistor can lead to an overvoltage condition in the amplifier, resulting in the amplifier being disabled (switched off). Therefore, an evaluation of regeneration requirements is essential to ensuring that the customer purchases a system that will perform his desired task.

Energy Calculations

A rotating motor and load has kinetic energy. When the motor and load stops rotating, the energy must either be stored or dissipated. The amplifier capacitors are capable of storing a certain amount of this energy. Any energy beyond this must be dissipated by the regen resistor. If the amplifier capacitors are capable of storing all 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 (the kinetic energy of the motor and load minus the system losses).

EQUATION 1

$$E_M = (½)(J_M+J_L)\omega_M^2 - 3I^2_M(R_M/2)t_d - (½)T_F\omega_M t_d$$

Where:
- J_M = rotor inertia (kg-m^2)
- J_L = load inertia (kg-m^2) reduced by the gearbox to the motor shaft
- ω_M = motor speed before decel (rad/sec)
- 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 (Nm)

If this energy is less than that which the amplifier capacitors can store, the regen resistor is needed.

Thus the condition for which only the standard regen resistor is required is

EQUATION 2

$$E_M < E_C$$

$$E_C = (½)C(V^2_M - V^2_{NOM})$$

Where: C = amplifier capacitance (Farads)

V_M = max BUS voltage (V) (switch on level of the ballast circuit)

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

E_C has been precalculated for various SERVO**STAR**® S600 models at various line voltages and can be found in Table 3.

For an n-axis system, where the DC-link and amplifiers are coupled, the condition for no regeneration resistor is:

EQUATION 3

$$\sum_{J=1}^{N} E_{MJ} < \sum_{J=1}^{N} E_{CJ}$$

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 peak watts or regen resistance value and the resistor wattage rating must be determined.

Determing Peak Watts

The peak or pulse watts value of a resistor is given by

EQUATION 4

$$P_{max} = V_B I_M \sqrt{3}$$

where: 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 = motor back EMF constant ($V_{L\text{-}L\_RMS}$ / krpm)

N = motor speed prior to decel (KRPM)

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

Equation 4 can be expanded for the case of an n-axis system where the DC-link of multiple amplifiers are coupled.

EQUATION 6

$$P_{max} = \sum_{J=1}^{N} V_{BJ} I_{MJ} \sqrt{3}$$

P_{max} is now compared with the sum of the peak watts for amplifiers given in Table 1.

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

$$P_{AV} = \frac{E_M - E_C}{t_{cycle}}$$

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

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

$$P_{AV} = \frac{\sum_{J=1}^{N} E_{MJ} - \sum_{J=1}^{N} E_{CJ}}{t_{cycle}}$$

Where : t_{cycle} is determined by the profile of the n-axis system

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.

Equations 4 and 7 define requirements for a stand-alone system. Equations 6 and 8 define the requirements for a multi-axis system with the bus links connected.

Regeneration Calculation Example

A customer's machine is configured such that two BH-404-D motors with SR600 amplifiers having DC links coupled. The load parameters are:

Motor 1: J_{LOAD} = 0.0015 kg-m^2
T_F = 2.5 N-m
N_{MAX} = 2500 rpm

Motor 2: J_{LOAD} = 0.001 kg-m^2
TF = 1.5 N-m
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 be provided?

Motor 1 Calculation for EM

$E_{MI} = (1/2)(J_M+J_L)\omega_M^2 - 3I^2_M(R_M/2)t_d - (1/2)T_F\,\omega_M t_d$ Joules

J_M = 0.0006562 kg-m^2 (From motor specification)

J_L = 0.0015 kg-m^2

ω_M = 2500/9.55 = 262 rad/sec

I_M = 12 A (Maximum drive peak current of the SR606.)

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: $T_M = K_T\, I_M$ N-m
K_T= 1.34 N-m/A (From motor specifications)
$T_M =$ 1.34 (at 12 A) = 16.08 N-m
T_F = 2.5 N-m
t_d = (0.0006562+0.0015)(262)/(16.08+2.5) sec = 0.03 sec

$E_{MI} = (1/2)(0.0006562+ 0.0015)(262^2) - 3(12^2)(1.32/2)(0.03) -(1/2)(2.5)(262)(0.03) = 55.6J$

Motor 2 Calculations for E_M

$t_d = (J_M+J_L)(\omega_M)/(T_M+T_F)$ sec = (0.0006562+0.001)(262)/(16.08+1.5) = 0.025 sec

$E_{MI} = (1/2)(0.0006562+0.001)(262^2) - 3(12^2)(1.32/2)(0.025) - (1/2)(1.5)(262)(0.025) = 44.8$ J

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

Condition for no regeneration resistor required:

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

E_{MI} = 55.6 J

E_{M2} = 44.8 J

C = 0.000470 Farads

(2x 235μF from DC link capacitor of SERVO**STAR** S600 Model on Table 1)

V_M = 720 V (lowest regen resistor switch on level)

V_{NOM} = 566 V (at network 400 V line to line)

$44.8\text{ J} + 55.6\text{ J} < ½(0.000470)(720^2 - 566^2)$

$100.4\text{ J} < 46.5\text{ J}$

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

Determine Peak Power

$$P_{max} = V_B\, I_M\, \sqrt{3}$$

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 = 12 A

$V_{B1} = 81.2(2.5) - \sqrt{3}\,(12)(1.32/2) = 190$ V

V_{B2} = 190 V

$P_{max} = (190)(12)\sqrt{3}(2) \approx 8$ kW

$P_{max\_-regen} = 720^2 / 33 = 16$ kW

$P_{max} < P_{max\_regen}$

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} = 55.6 J
E_{M2} = 44.8 J
C = 0.000470 F
V = 720 V
V_{HYS} = 710 V
t_{cycle} = 5 + 0.029

$$P_{AV} = \frac{44.8 + 55.6 - (1/2)(0.00\ 047)(720^2 - 566^2)}{5.029} = 11 \text{ Watts}$$

BUS Module Specifications

Supply voltage	Rated data	DIM	SERVOSTAR 601 –603	SERVOSTAR 606 –620	SERVOSTAR 640	SERVOSTAR 670
3 x 230 V	Upper switch-on level of ballast circuit	V	400 – 430		-	
	Switch off level of ballast circuit (V_{HYS}) internal	V	380 – 410			
	Continuos power of ballast circuit (P_{AV}) internal	W	80	200		
	Cont. power of ballast circuit ($P_{AV\text{-}max}$) external	kW	0.75			
	Pulse power, internal (P_{max}) 1s	kW	2.5	5		
	Pulse power, external (P_{max}) 1s	kW	5			
3 x 400 V	Upper switch-on level of ballast circuit	V	720 – 750			
	Switch off level of ballast circuit (V_{HYS}) internal	V	680 - 710			
	Continuos power of ballast circuit (P_{AV}) internal	W	80	200	-	
	Cont. power of ballast circuit ($P_{AV\text{-}max}$) external	kW	1.2		6	6
	Pulse power, internal (P_{max}) 1s	kW	8	16	-	
	Pulse power, external (P_{max}) 1s	kW	16		35	50
3 x 480V	Upper switch-on level of ballast circuit	V	840 – 870			
	Switch off level of ballast circuit (V_{HYS}) internal	V	800 – 830			
	Continuos power of ballast circuit (P_{AV}) internal	W	80	200	-	
	Cont. power of ballast circuit ($P_{AV\text{-}max}$) external	kW	1.5		6	6
	Pulse power, internal (P_{max}) 1s	kW	10.5	21	-	
	Pulse power, external (P_{max}) 1s	kW	21		45	70

Table 1: Ballast Circuit Technical Data

Model	R (ohms)	SERVOSTAR	P (watts)
BAR 250	33	601...620	250
BAR 500			500
BAR 1500			1500
BAR 860	15	640	860
BAR 1600	10	670	1600

Table 2: Regen Resistor Models

Line Voltage		230 V	400 V	480 V
Model	Capacitor µF	J	J	J
SR 601	235	6	23	28
SR 603				
SR 606				
SR 610				
SR 614	470	12	46	57
SR 620				
SR 640	1500	-	148	183
SR 670	3000	-	297	367

Table 3: Energy in Joules (E_C) of BUS (DC-Link) Capacitors