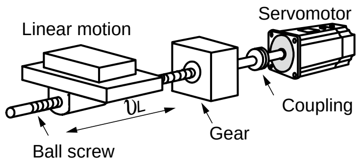
Selecting Servomotor Capacity and Regenerative Capacity

Servomotor Capacity Selection Examples

Use the AC servo drive capacity selection program SigmaJunmaSize+ to select servomotor capacity.
The program can be downloaded for free from our web site (http://www.e-mechatronics.com/).

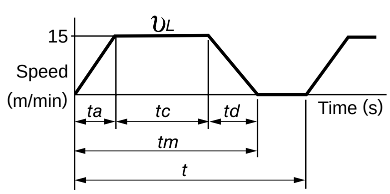
●Selection Example for Speed Control

Mechanical Specifications



- Load speed: $\upsilon_L = 15$ m/min
- Linear motion section mass: $m = 250$ kg
- Ball screw length: $\ell_B = 1.0$ m
- Ball screw diameter: $d_B = 0.02$ m
- Ball screw lead: $P_B = 0.01$ m
- Ball screw material density: ρ =7.87×103 kg/m^3
- Gear ratio: 1/2 (R = 2)
- Gear + coupling moment of inertia : $J_G = 0.40\times10^{-4}$ kg·m^2
- Feeding times: $n = 40$ times/min
- Feeding distance: $\ell = 0.275$ m
- Feeding time: $tm = 1.2$ s max.
- Friction coefficient: $\mu = 0.2$
- Mechanical efficiency: $\eta = 0.9$ (90%)

(1) Speed Diagram



$$t = \frac{60}{n} = \frac{60}{40} = 1.5 \text{ (s)}$$

where $ta = td$

$$ta = tm - \frac{60\ell}{\upsilon_L} = 1.2 - \frac{60 \times 0.275}{15} = 1.2 - 1.1 = 0.1 \text{ (s)}$$

$$tc = 1.2 - 0.1 \times 2 = 1.0 \text{ (s)}$$

(2) Rotation Speed

·Load axis rotation speed $n_L = \frac{\upsilon_L}{P_B} = \frac{15}{0.01} = 1500 \text{ (min}^{-1})$

·Motor shaft rotation speed Gear ratio 1/R = 1/2 (R=2)
Therefore, $n_M = n_L \cdot R = 1500 \times 2 = 3000 \text{ (min}^{-1})$

(3) Load torque

$$T_L = \frac{9.8\mu \cdot m \cdot P_B}{2\pi R \cdot \eta} = \frac{9.8 \times 0.2 \times 250 \times 0.01}{2\pi \times 2 \times 0.9} = 0.43 \text{ (N·m)}$$

(4) Load Moment of Inertia

·Linear motion section $J_{L1} = m\left(\frac{P_B}{2\pi R}\right)^2 = 250 \times \left(\frac{0.01}{2\pi \times 2}\right)^2 = 1.58 \times 10^{-4} \text{ (kg·m}^2)$

·Ball screw $J_B = \frac{\pi}{32}\rho \cdot \ell_B \cdot d_B^4 \cdot \frac{1}{R^2} = \frac{\pi}{32} \times 7.87 \times 10^3 \times 1.0 \times (0.02)^4 \cdot \frac{1}{2^2} = 0.31 \times 10^{-4} \text{ (kg·m}^2)$

·Coupling $J_G = 0.40 \times 10^{-4}$ (kg·m^2)

·Load moment of inertia at motor shaft $J_L = J_{L1} + J_B + J_G = (1.58 + 0.31 + 0.40) \times 10^{-4} = 2.29 \times 10^{-4}$ (kg·m^2)

(5) Load Moving Power

$$P_O = \frac{2\pi n_M \cdot T_L}{60} = \frac{2\pi \times 3000 \times 0.43}{60} = 135 \text{(W)}$$

Servomotor Capacity Selection Examples

(6) Load Acceleration Power

$$Pa = \left(\frac{2\pi}{60}\, n_M\right)^2 \frac{J_L}{ta} = \left(\frac{2\pi}{60} \times 3000\right)^2 \times \frac{2.29 \times 10^{-4}}{0.1} = 226\ (\mathrm{W})$$

(7) Servomotor Provisional Selection

(a) Selecting Conditions

·$T_L \leqq$ Motor rated torque

·$\dfrac{(P_o + P_a)}{2} <$ Provisionally selected servomotor rated output $< (P_o + P_a)$

·$n_M \leqq$ Motor rated speed

·$J_L \leqq$ Allowable load moment of inertia

The followings satisfy the conditions.
·Servomotor SGMJV-02A

(b) Specifications of the Provisionally Selected Servomotor

·Rated output	: 200 (W)
·Rated motor speed	: 3000 (min^{-1})
·Rated torque	: 0.637 (N·m)
·Instantaneous peak torque	: 2.23 (N·m)
·Servomotor moment of inertia	: 0.259×10^{-4} (kg·m^2)
·Allowable load moment of inertia	: $0.259 \times 10^{-4} \times 15 = 3.885 \times 10\text{-}4$ (kg·m^2)

(8) Verification on the Provisionally Selected Servomotor

·Required acceleration torque: $T_P = \dfrac{2\pi n_M(J_M + J_L)}{60ta} + T_L = \dfrac{2\pi \times 3000 \times (0.259 + 2.29) \times 10^{-4}}{60 \times 0.1} + 0.43$

$\fallingdotseq 1.23$ (N·m) < Instantaneous peak torque · · · Satisfactory

·Required deceleration torque: $T_S = \dfrac{2\pi n_M(J_M + J_L)}{60td} - T_L = \dfrac{2\pi \times 3000 \times (0.259 + 2.29) \times 10^{-4}}{60 \times 0.1} - 0.43$

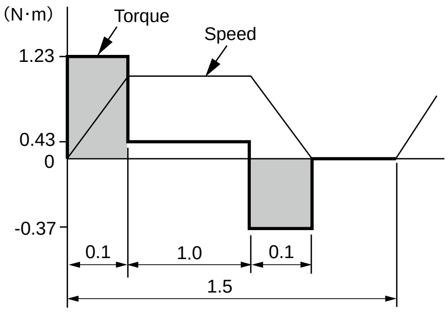
$\fallingdotseq 0.37$ (N·m) < Instantaneous peak torque · · · Satisfactory

·Torque effective value: $Trms = \sqrt{\dfrac{T_P{}^2 \cdot ta + T_L{}^2 \cdot tc + Ts^2 \cdot td}{t}} = \sqrt{\dfrac{(1.23)^2 \times 0.1 + (0.43)^2 \times 1.0 + (0.37)^2 \times 0.1}{1.5}}$

$\fallingdotseq 0.483$ (N·m) < Rated torque · · · Satisfactory

(9) Result

The provisionally selected servomotor is confirmed to be applicable.
The torque diagram is shown below.



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Servomotor Capacity Selection Examples

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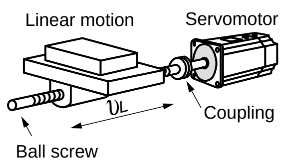
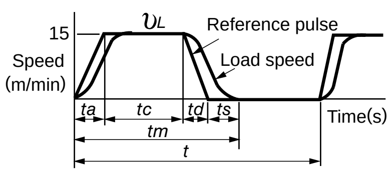
●Selection Example for Position Control

Mechanical Specifications



- Load speed: $\upsilon_L = 15$ m/min
- Linear motion section mass: $m = 80$ kg
- Ball screw length: $\ell_B = 0.8$ m
- Ball screw diameter: $d_B = 0.016$ m
- Ball screw lead: $P_B = 0.005$ m
- Ball screw material density: $\rho = 7.87\times103$ kg/m^3
- Coupling mass: $mc = 0.3$ kg
- Coupling outer diameter: $dc = 0.03$ m
- Positioning times: $n = 40$ times/min
- Positioning distance: $\ell = 0.25$ m
- Positioning time: $tm = 1.2$ s max.
- Electrical stop accuracy: $\delta = \pm 0.01$ mm
- Friction coefficient: $\mu = 0.2$
- Mechanical efficiency: $\eta = 0.9$ (90%)

(1) Speed Diagram



$$t = \frac{60}{n} = \frac{60}{40} = 1.5(\text{s})$$

Where $ta = td,\ ts = 0.1(\text{s})$

$$ta = tm - ts - \frac{60\ell}{\upsilon_L} = 1.2 - 0.1 - \frac{60 \times 0.25}{15} = 0.1(\text{s})$$

$$tc = 1.2 - 0.1 \times 2 = 1.0(\text{s})$$

(2) Rotation Speed

·Load axis rotation speed $n_L = \frac{\upsilon_L}{P_B} = \frac{15}{0.005} = 3000(\text{min}^{-1})$

·Motor shaft rotation speed with direct coupling: Gear ratio 1/R = 1/1

Therefore, $n_M = n_L \cdot R = 3000 \times 1 = 3000\ (\text{min}^{-1})$

(3) Load Torque

$$T_L = \frac{9.8\mu \cdot m \cdot P_B}{2\pi R \cdot \eta} = \frac{9.8 \times 0.2 \times 80 \times 0.005}{2\pi \times 1 \times 0.9} = 0.139(\text{N}\cdot\text{m})$$

(4) Load Moment of Inertia

·Liner motion section $J_{L1} = m\left(\frac{P_B}{2\pi R}\right)^2 = 80 \times \left(\frac{0.005}{2\pi \times 1}\right)^2 = 0.507 \times 10^{-4}(\text{kg}\cdot\text{m}^2)$

·Ball screw $J_B = \frac{\pi}{32}\ \rho \cdot \ell_B \cdot d_B{}^4 = \frac{\pi}{32} \times 7.87 \times 10^3 \times 0.8 \times (0.0016)^4 = 0.405 \times 10^{-4}(\text{kg}\cdot\text{m}^2)$

·Coupling $Jc = \frac{1}{8}\ mc \cdot dc^4 = \frac{1}{8} \times 0.3 \times (0.03)^2 = 0.338 \times 10^{-4}(\text{kg}\cdot\text{m}^2)$

·Load moment of inertia at the motor shaft

$$J_L = J_{L1} + J_B + Jc = 1.25 \times 10^{-4}\ (\text{kg}\cdot\text{m}^2)$$

Servomotor Capacity Selection Examples

(5) Load Moving Power

$$P_O = \frac{2\pi n_M \cdot T_L}{60} = \frac{2\pi \times 3000 \times 0.139}{60} = 43.7(\mathrm{W})$$

(6) Load Acceleration Power

$$Pa = \left(\frac{2\pi}{60}\ n_M\right)^2 \frac{J_L}{ta} = \left(\frac{2\pi}{60}\ \times 3000\right)^2 \times \frac{1.25 \times 10^{-4}}{0.1} = 123.4(\mathrm{W})$$

(7) Provisionally Servomotor Selection

(a) Selecting Conditions

- $T_L \leqq$ Motor rated torque
- $\frac{(P_o + P_a)}{2} <$ Provisionally selected servomotor rated output $< (P_o + P_a)$
- $n_M \leqq$ Motor rated speed
- $J_L \leqq$ Allowable load moment of inertia

The followings satisfy the conditions.
·Servomotor SGMJV-01A

(b) Specifications of Servomotor

·Rated output : 100 (W)
·Rated motor speed : 3000 (min^{-1})
·Rated torque : 0.318 (N·m)
·Instantaneous peak torque : 1.11 (N·m)
·Servomotor rotor moment of inertia : 0.0665×10^{-4} (kg·m^2)
·Allowable load moment of inertia : $0.0665 \times 10^{-4} \times 20 = 1.33 \times 10^{-4}$ (kg·m^2)
·Encoder resolution : 20 bit (1048576P/rev)

(8) Verification on Provisionally Selected Servomotor

·Required acceleration torque: $$T_P = \frac{2\pi n_M (J_M + J_L)}{60ta} + T_L = \frac{2\pi \times 3000 \times (0.0665 + 1.25) \times 10^{-4}}{60 \times 0.1} + 0.139$$

$\fallingdotseq$ 0.552 (N·m) < Instantaneous peak torque · · · Satisfactory

·Required deceleration torque: $$T_S = \frac{2\pi n_M (J_M + J_L)}{60td} - T_L = \frac{2\pi \times 3000 \times (0.0665 + 1.25) \times 10^{-4}}{60 \times 0.1} - 0.139$$

$\fallingdotseq$ 0.275 (N·m) < Instantaneous peak torque · · · Satisfactory

·Torque effective value: $$Trms = \sqrt{\frac{T_P{}^2 \cdot ta + T_L{}^2 \cdot tc + Ts^2 \cdot td}{t}} = \sqrt{\frac{(0.552)^2 \times 0.1 + (0.139)^2 \times 0.9 + (0.275)^2 \times 0.1}{1.5}}$$

$\fallingdotseq$ 0.192 (N·m) < Rated torque · · · Satisfactory

The above confirms that the provisionally selected servomotor is sufficient. In the next step, their performance in position control are checked.

(9) PG Feedback Pulse Dividing Ratio: Setting of Electronic Gear Ratio $\left(\frac{B}{A}\right)$

As the electrical stop accuracy $\delta = \pm 0.01$mm, take the position detection unit $\Delta\ell = 0.01$mm/pulse.

$$\frac{P_B}{\Delta\ell} \times \left(\frac{B}{A}\right) = \frac{5}{0.01} \times \left(\frac{B}{A}\right) = 1048576$$

$$k = \left(\frac{B}{A}\right) = \frac{1048576}{500}$$

(10) Reference Pulse Frequency

$$vs = \frac{1000\upsilon_L}{60 \times \Delta\ell} = \frac{1000 \times 15}{60 \times 0.01} = 25{,}000\text{(pps)}$$

(11) Error Counter Pulses

Position loop gain $K_P = 40$ (1/s)

$$\varepsilon = \frac{vs}{K_P} = \frac{25{,}000}{40} = 625\text{(pulse)}$$

(12) Electrical Stop Accuracy

$$\pm\Delta\varepsilon = \pm \frac{\varepsilon}{\text{(SERVOPACK control range)} \times \frac{n_M}{n_R}} = \pm \frac{625}{5000 \times \frac{3000}{3000}} \fallingdotseq \pm 0.125 < \pm 1\text{(pulse)} = \pm 0.01\text{(mm)}$$

The above results confirm that the selected servomotor is applicable for the position control.

Selecting Regenerative Resistors

(1) Simple Calculation

When driving a servomotor with the horizontal axis, check the external regenerative resistor requirements using the calculation method shown below.

(a) SGDV-□□□F, -R70A, -R90A, -1R6A, and -2R8A SERVOPACKs

These SERVOPACKs do not have built-in regenerative resistors. The energy that can be charged with capacitors is shown in the following table. If the rotational energy in the servomotor exceeds these values, then connect an external regenerative resistor.

Voltage	Applicable SERVOPACK	Regenerative Energy that Can be Processed (joules)	Remarks
Single-phase 100 V	SGDV-R70F, R90F, 2R1F	26.4	Value when main circuit input voltage is 100 VAC
	SGDV-2R8F	44.1	
Three-phase 200V	SGDV-R70A, -R90A, -1R6A	24.2	Value when main circuit input voltage is 200 VAC
	SGDV-2R8A	31.7	

Calculate the rotational energy (Es) in the servomotor from the following equation:

$Es = J \times (n_M)^2/182$ (joules)

· $J = J_M + J_L$

· J_M : Servomotor rotor moment of inertia (kg·m^2)

· J_L : Load converted to shaft moment of inertia (kg·m^2)

· n_M : Rotation speed used by servomotor (min^{-1})

(b) SERVOPACKs other than (a)

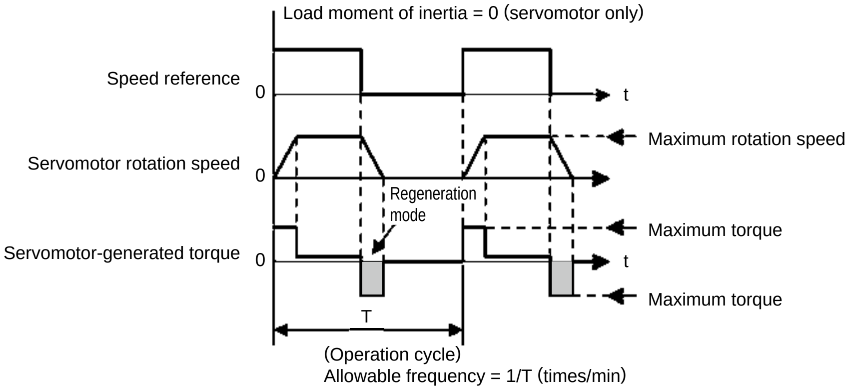
SERVOPACKs other than SGDV-□□□F, -R70A, -R90A, -1R6A, and -2R8A have built-in regenerative resistors. The allowable frequencies for just the servomotor in acceleration and deceleration operation, during the rotation speed cycle from 0 (min^{-1}) to the maximum rotation speed to 0, are summarized in the following table.

Convert the data into the values obtained with actual rotation speed and load moment of inertia to determine whether an external regenerative resistor is needed.

Voltage	Servomotor Model	Allowable Frequencies in Regenerative Mode (time/min)													
		03	05	06	08	09	10	13	15	20	25	30	40	44	50
Three-phase 200 V	SGMJV-□□	–	–	–	15	–	–	–	–	–	–	–	–	–	–
	SGMAV-□□	–	–	74	31	–	20	–	–	–	–	–	–	–	–
	SGMPS-□□	–	–	–	11	–	–	–	7	–	–	–	–	–	–
	SGMGV-□□A	39	29	–	–	6	–	6	–	7	–	9*	–	6	–
	SGMSV-□□A	–	–	–	–	–	13	–	21	28	21	10	16	–	12
Three-phase 400V	SGMGV-□□D	68	51	–	–	10	–	8	–	13	–	7	–	6	–
	SGMSV-□□D	–	–	–	–	–	24	–	30	49	38	17	16	–	12

*: This value is "4," when used in combination with SGDV-200A SERVOPACK.

Operating Conditions for Allowable Regenerative Frequency Calculation



Use the following equation to calculate the allowable frequency for regeneration mode operation

$$\text{Allowable frequency} = \frac{\text{Allowable frequency for Seromotor only}}{(1+n)} \times \left(\frac{\text{Max. rotation speed}}{\text{Rotation speed}}\right)^2 \text{(time/min)}$$

· $n = J_L / J_M$

· J_M : Servomotor rotor moment of inertia (kg·m²)

· J_L : Load converted to shaft moment of inertia (kg·m²)

(c) SGDV-470A, -550A, -590A, -780A SERVOPACKs

These SERVOPACKs do not have built-in regenerative resistors. The following table shows the allowable regenerative frequencies when the JUSP-RA04-E or JUSP-RA05-E regenerative resistor is used together with an applicable SERVOPACK.

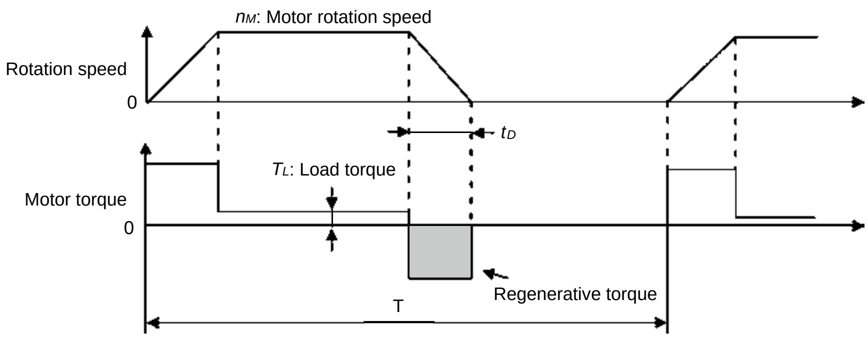
The servomotor driving conditions and the conversion equation for the allowable regenerative frequencies to the rotation speed and load moment of inertia are the same as that shown in (b) on the previous page.

Voltage	Servomotor Model	Allowable Frequencies in Regenerative Mode (time/min)				
		55	70	75	1A	1E
Three-phase 200 V	SGMGV-□□A	24	–	34	39	31
	SGMSV-□□A	–	124	–	–	–

Selecting Regenerative Resistors

(2) Calculating the Regenerative Energy

This section shows the procedure for calculating the regenerative resistor capacity when acceleration and deceleration operation is as shown in the following diagram



● Calculation Procedure

The procedure for calculating the regenerative capacity is as follows:

Step	Item	Symbol	Equation
1	Calculate the rotational energy of the servomotor.	E_S	$E_S = J n_M{}^2 / 182$
2	Calculate the energy consumed by load loss during the deceleration period	E_L	$E_L = (\pi / 60) n_M T_L t_D$
3	Calculate the energy lost from servomotor winding resistance.	E_M	(Value calculated from (4) Servomotor Winding Resistance Loss diagrams) × t_D
4	Calculate the SERVOPACK energy that can be absorbed.	E_C	Calculate from (3) SERVOPACK's Absorbable Energy diagrams.
5	Calculate the energy consumed by the regenerative resistor.	E_K	$E_K = E_S - (E_L + E_M + E_C)$
6	Calculate the required regenerative resistor capacity (W).	W_K	$W_K = E_K / (0.2 \times T)$

Note: 1 The "0.2" in the equation for calculating *Wk* is the value for when the regenerative resistor's utilized load ratio is 20%.

2 The units for the various symbols are as follows:

E_S to E_K: Energy joules (J)
W_K : Regenerative resistor required capacity (W)
J: $(= J_M + J_L)$(kg·m²)
n_M : Servomotor rotation speed (min⁻¹)
T_L: Load torque (N·m)
t_D: Deceleration stopping time (s)
T: Servomotor repeat operation period (s)

If the above calculation determines that the amount of regenerative power (*Wk*) processed by the built-in resistor is not exceeded, then an external regenerative resistor is not required. Refer to Specifications of Built-in Regenerative Resistor for regenerative resistors built into SERVOPACKs. If the amount of regenerative power that can be processed by the built-in resistor is exceeded, then install an external regenerative resistor for the capacity obtained from the above calculation.

If the energy consumed by load loss (in step 2 above) is unknown, then perform the calculation using $El = 0$.

When the operation period in regeneration mode is continuous, add the following items to the above calculation procedure in order to find the required capacity (W) for the regenerative resistor.

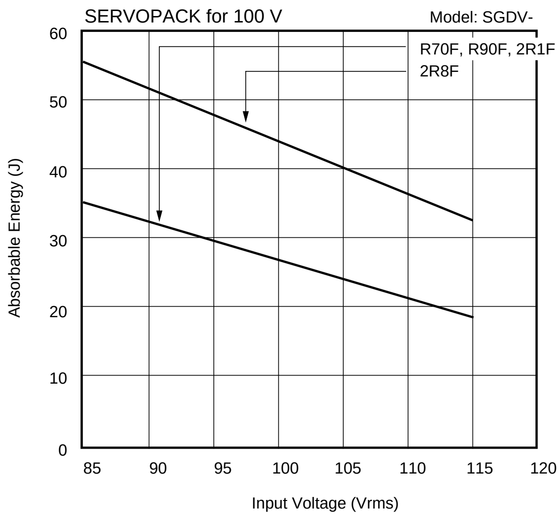
· Energy for continuous regeneration mode operation period: E_G (joules)
· Energy consumed by regenerative resistor: $E_K = E_S - (E_L + E_M + E_C) + E_G$
· Required capacity of regenerative resistor: $W_K = E_K / (0.2 \times T)$

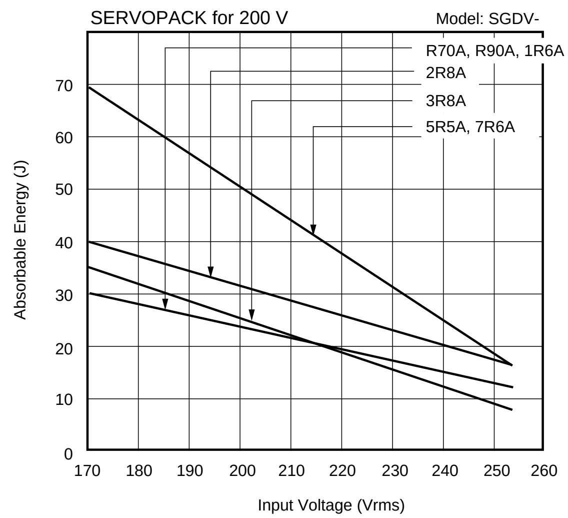
Here, $E_G = (2\pi / 60)\, n_{MG} T_G t_G$

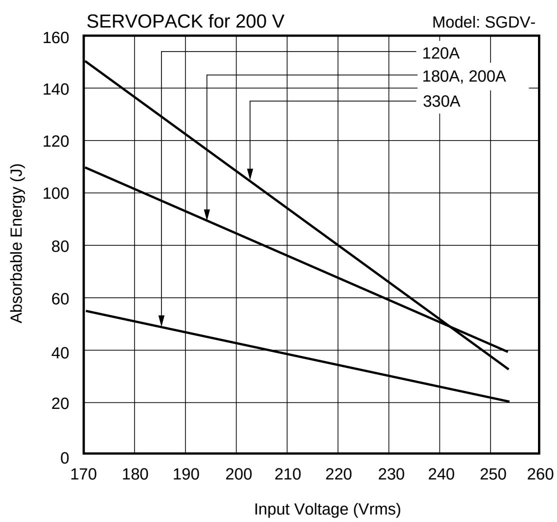
· T_G : Servomotor's generated torque in continuous regeneration mode operation period (N·m)
· n_{MG} : Servomotor rotation speed for same operation period as above (min^{-1})
· t_G : Same operation period as above(s)

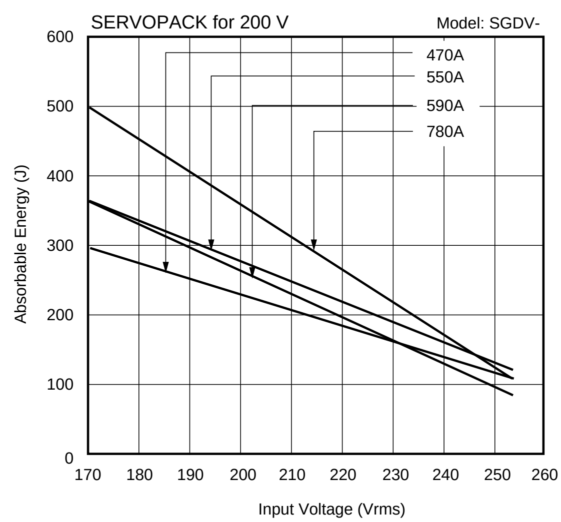
(3) SERVOPACK's Absorbable Energy

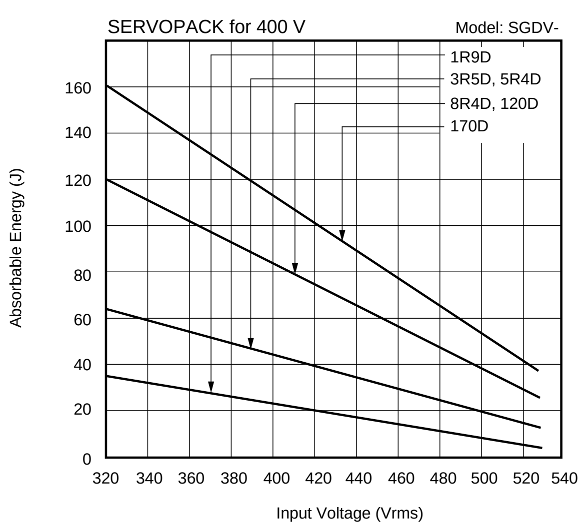
The following diagrams show the relationship between the SERVOPACK's input power supply voltage and its absorbable energy.

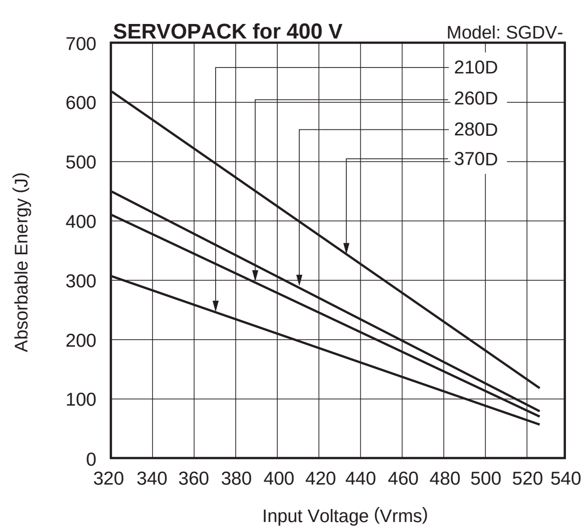










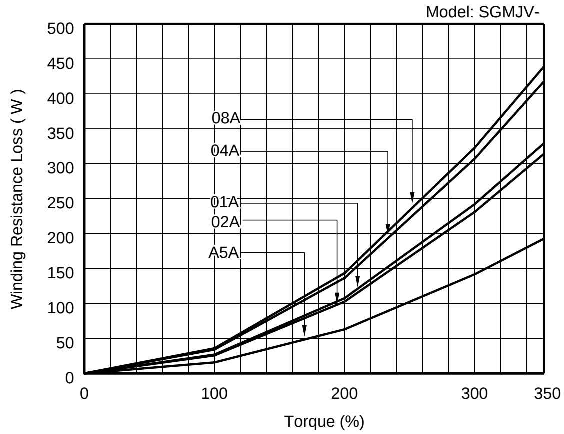


Selecting Regenerative Resistors

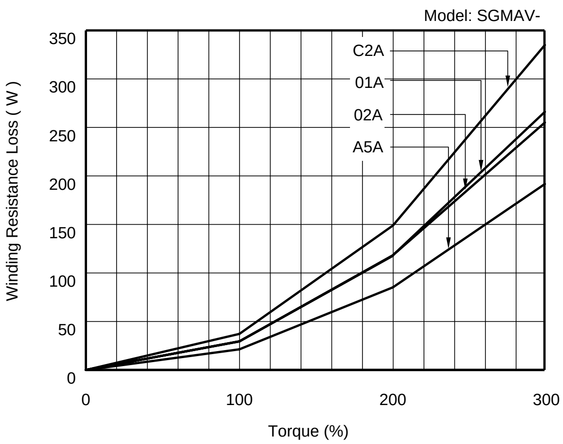
(4) Servomotor Winding Resistance Loss

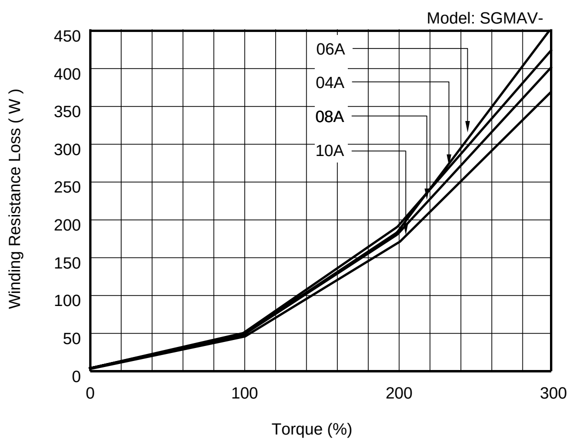
The following diagrams show the relationship, for each servomotor, between the servomotor's generated torque and the winding resistance loss.

(a) SGMJV Rotary Servomotors

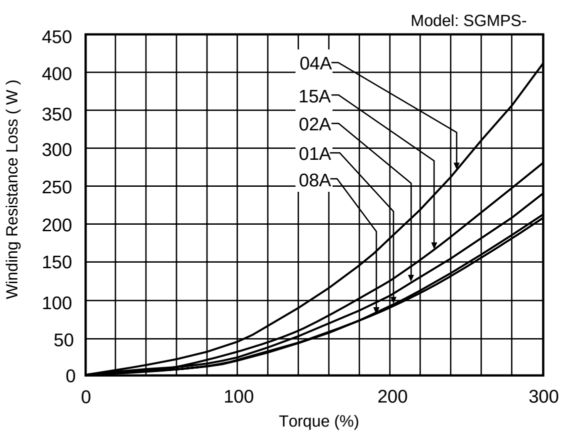


(b) SGMAV Rotary Servomotors

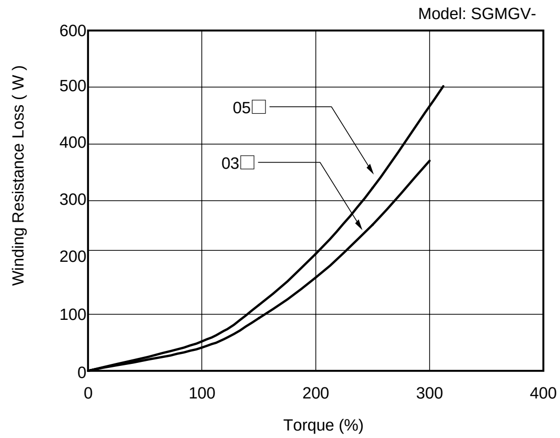


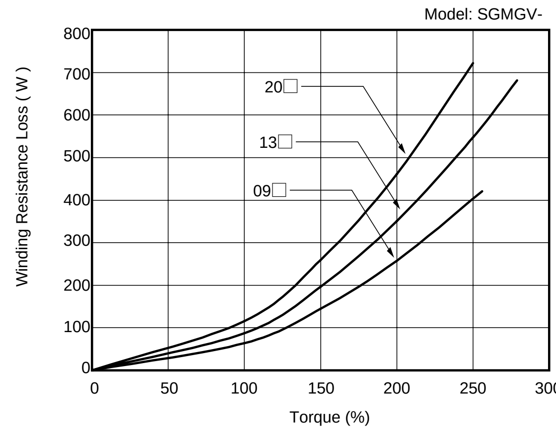


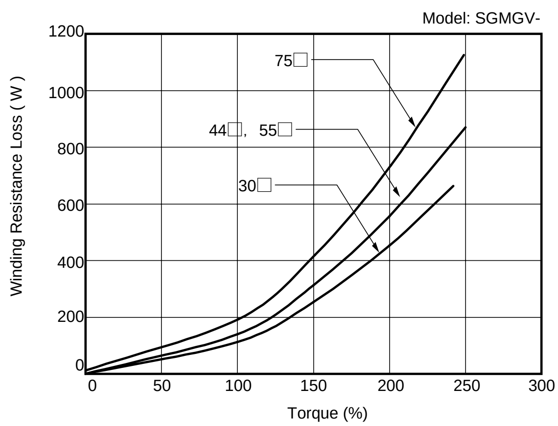
(c) SGMPS Rotary Servomotors

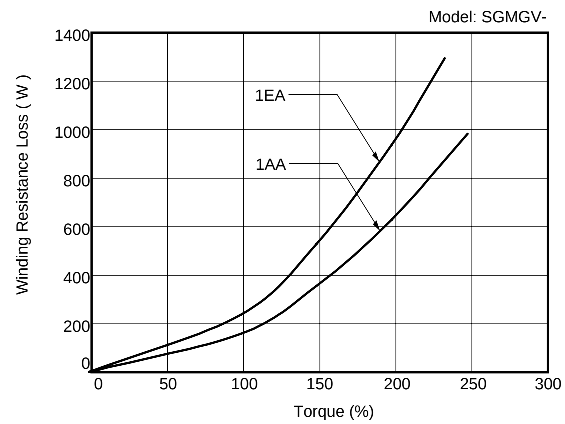


(d) SGMGV Rotary Servomotors

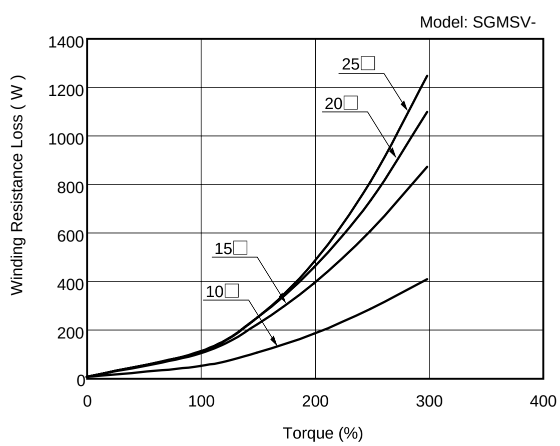


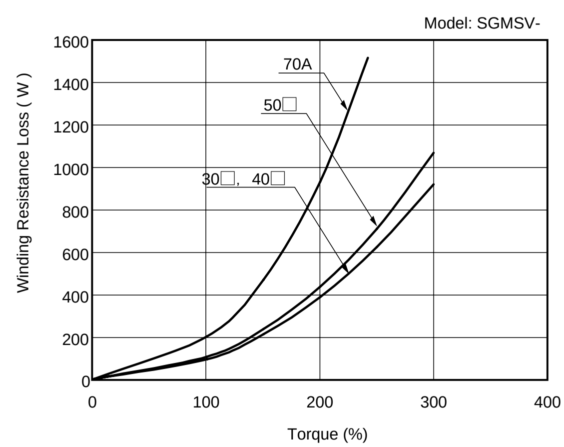






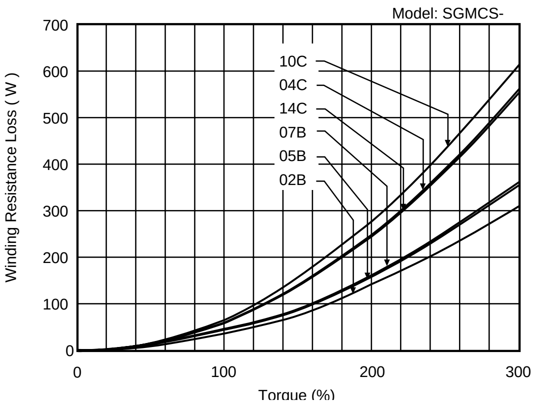
(e) SGMSV Rotary Servomotors

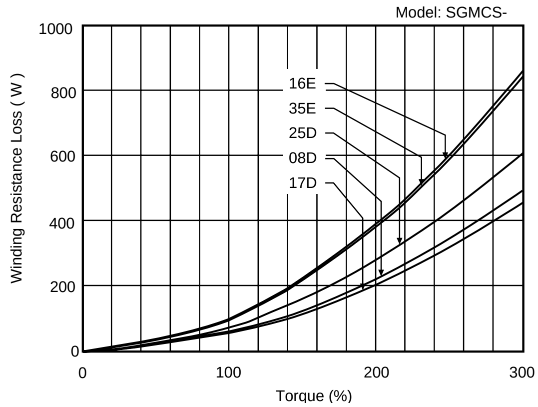




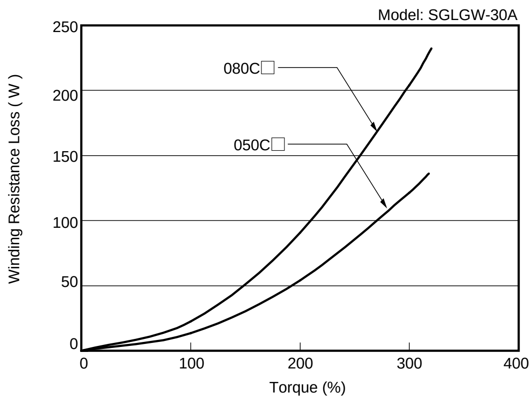
Selecting Regenerative Resistors

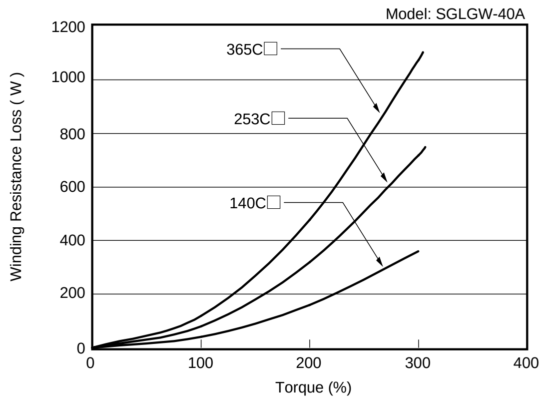
(f) SGMCS Direct Drive Servomotors

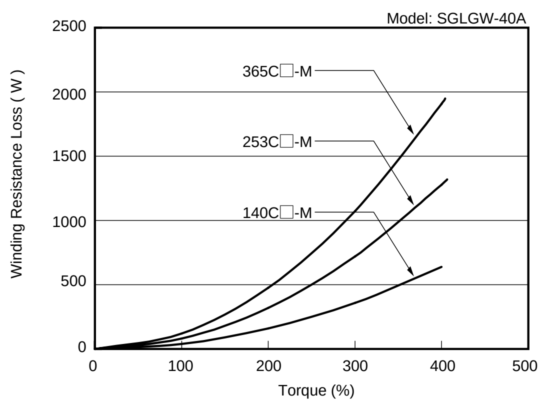


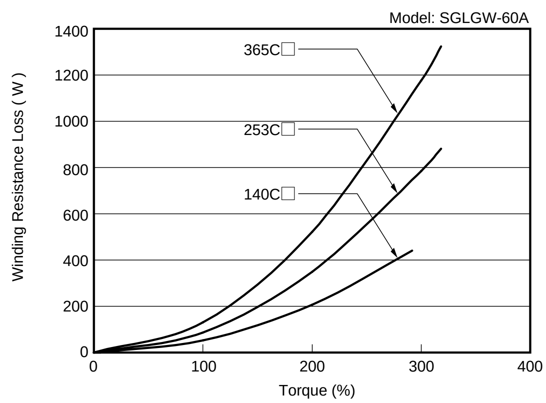


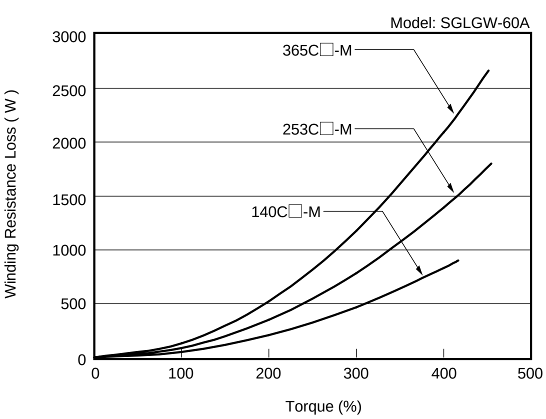
(g) SGLGW Linear Servomotors

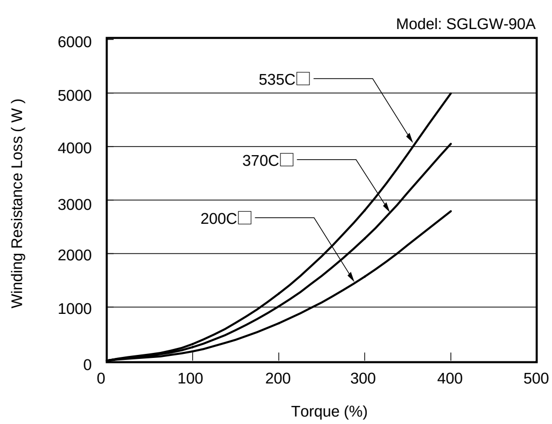




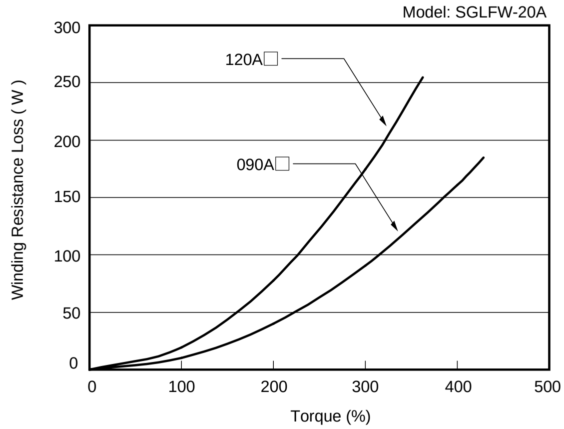


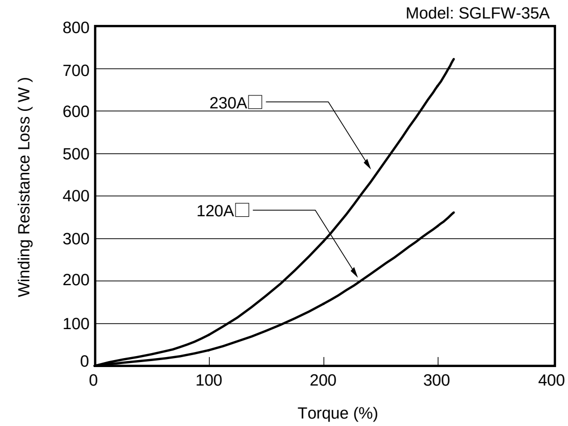


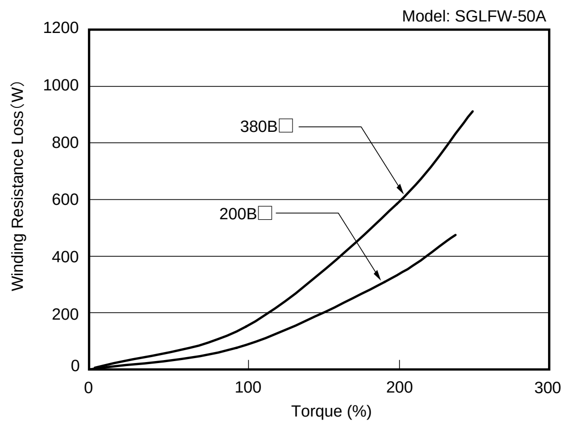


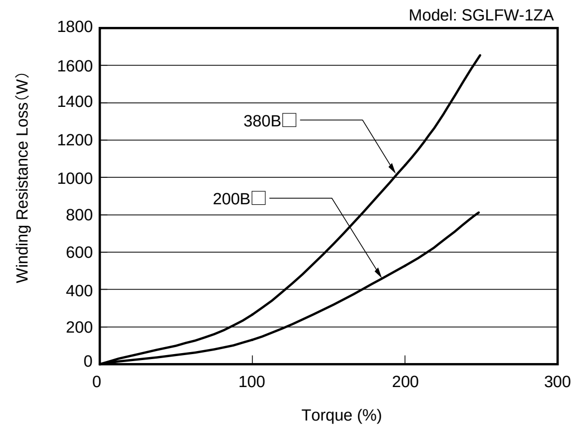


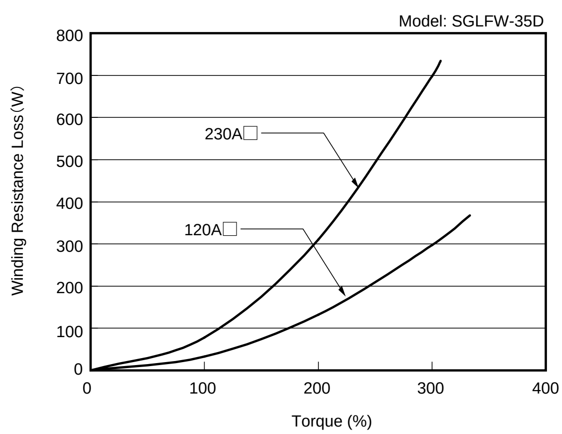
(h) SGLFW Linear Servomotors

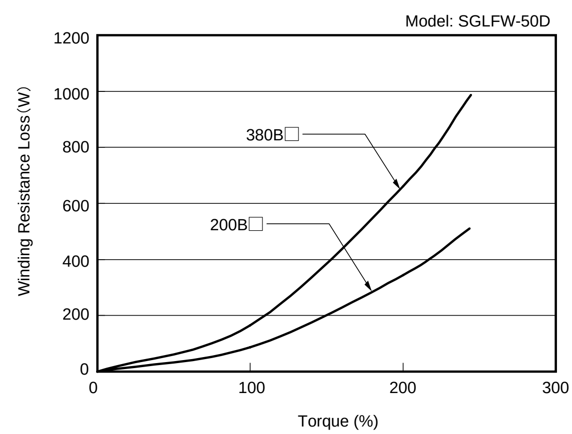


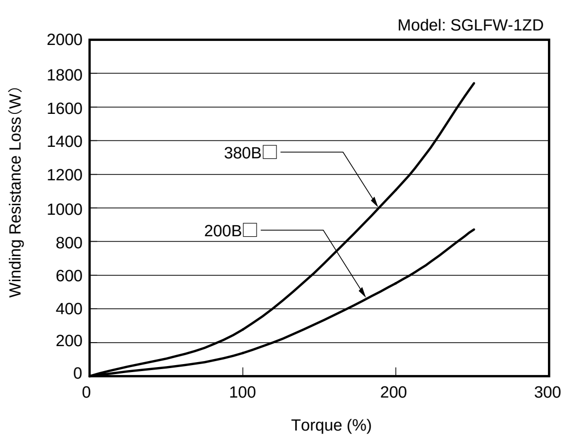












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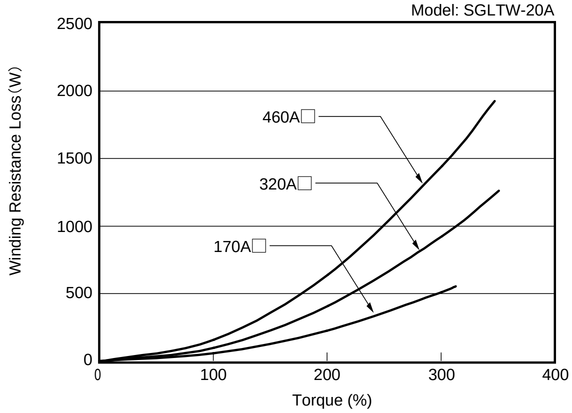
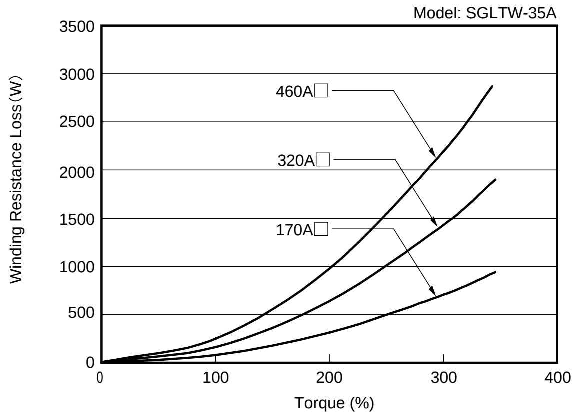
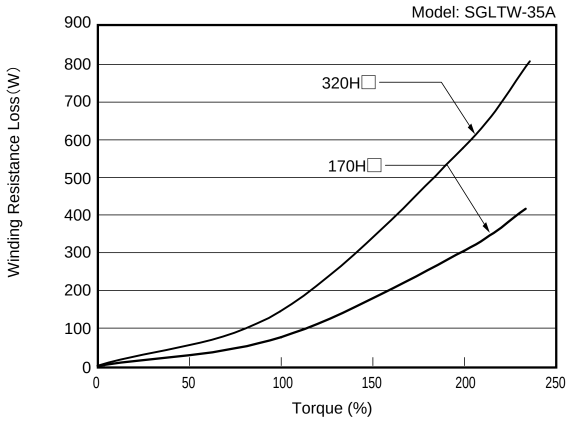
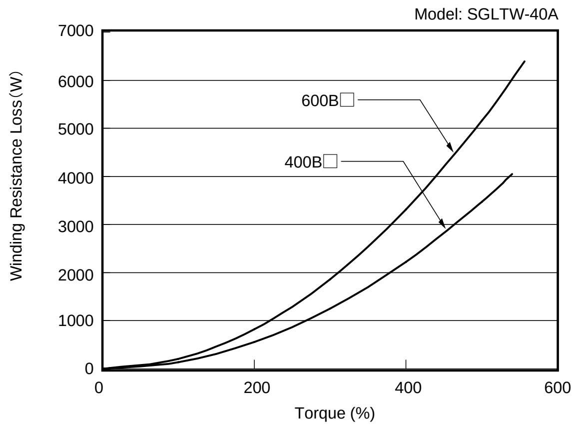
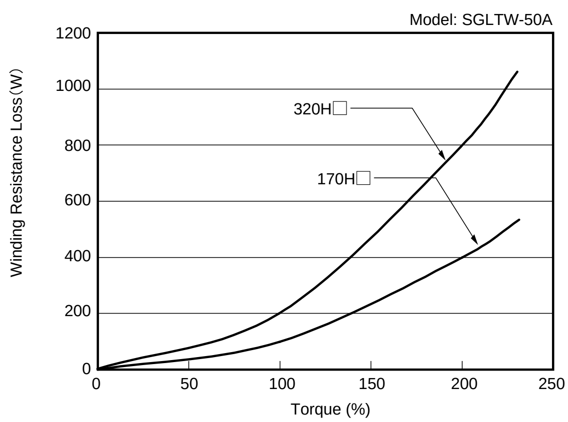
(i) SGLTW Linear Servomotors

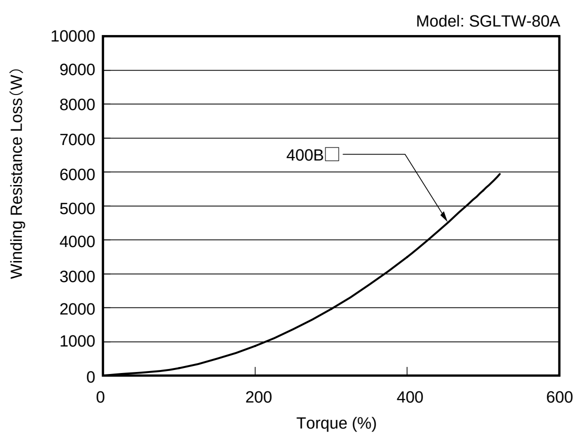






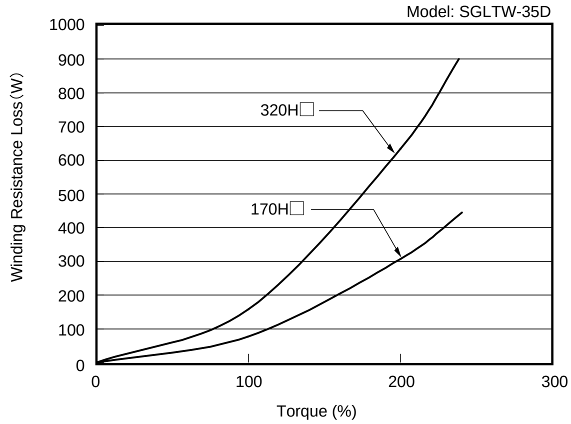


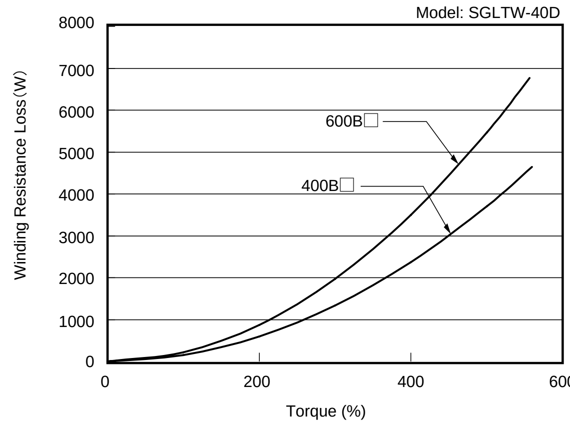


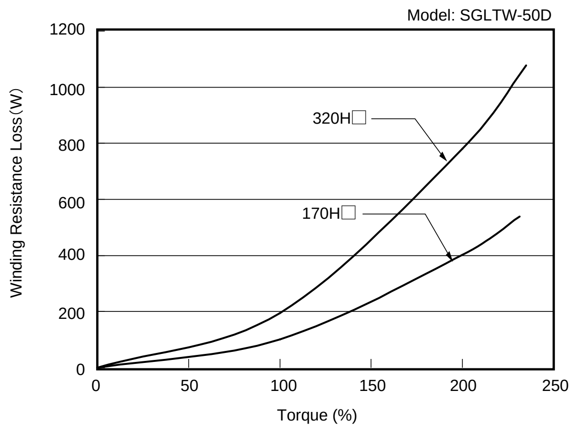


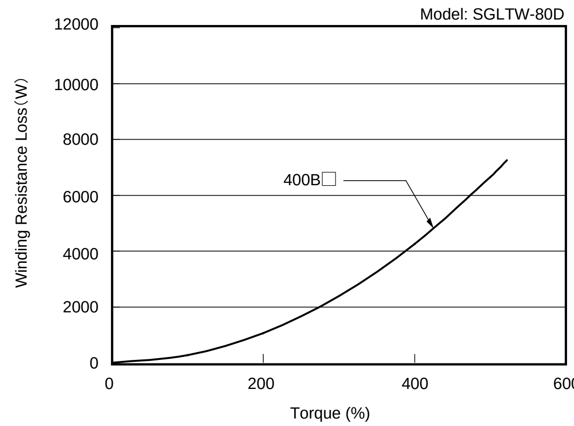
Selecting Regenerative Resistors

(i) SGLTW Linear Servomotors (cont'd)

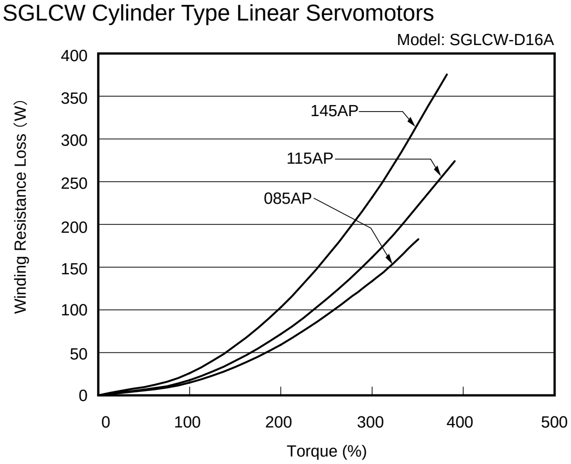


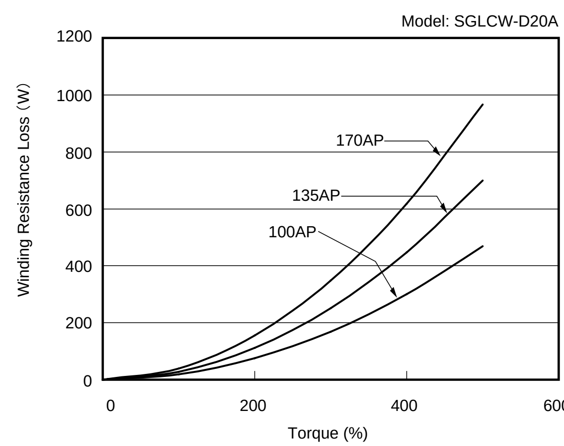


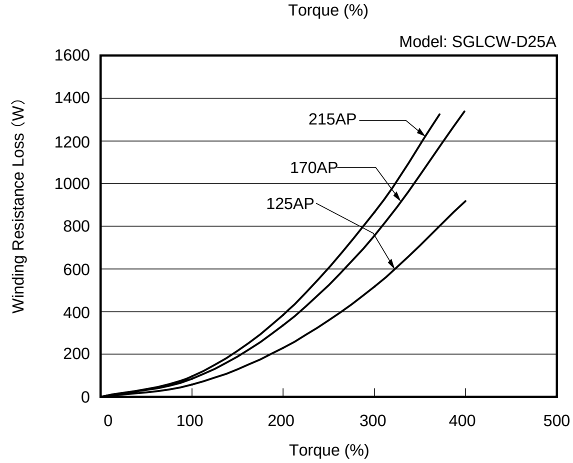


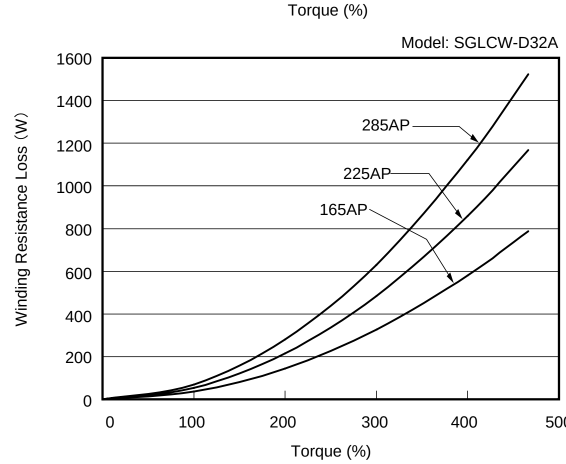


(j) SGLCW Cylinder Type Linear Servomotors









Selecting Regenerative Resistors

(k) SGT Linear Sliders