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Basic Brushless Servomotor System Sizing

This Application Note provides basic information regarding brushless servomotor sizing. Its purpose is to introduce you to the various aspects involved in motor, amplifier, power supply, and transformer selection. Formulas are included to aid in calculating motor requirements. However, this information is in no way complete. For more detailed information or considerations regarding DC servo system, please contact Danaher Motion.

Motor Sizing

Evaluation of load requirements can be divided into two major categories:

1. **Forces required to accommodate the required task, including:**
   - **A.** Cutting or thrust forces
   - **B.** Counterbalancing forces (vertical axes)
   - **C.** Acceleration forces taking into account the total system inertia
2. **Forces to overcome frictional losses, including:**
   - **A.** Bearing surface losses
   - **B.** Screw or rack and pinion inefficiencies
   - **C.** Reducer inefficiencies
   - **D.** Static and dynamic motor losses

The motor calculated torques are summed when acting concurrently and then applied together based on the overall machine duty cycle. A root-mean-square (RMS) calculations used to determine an effective torque required by the motor to be compared with the continuous torque rating of the motor.

An RMS calculation may lead to an erroneous conclusion if the intermittent torque (T_p) is large with respect to the motor rating (T_c), and the "on time" is significant fraction of the motor thermal time constant (TCT). For Example: $T_p = 2T_c$ for the period of 0.1 TCT. In this case, the cycle should be checked with respect to a maximum duty cycle calculation.

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Once the torque rating of the motor is established, a winding should be chosen with the minimum speed to satisfy the maximum speed requirement of the application. A penalty is paid in terms of the current required to meet a given torque rating with a motor having higher speed capability (having lower K_T = torque/amp) than necessary.

Operation in ambient temperatures other than 40^0 C affect the nominal torque ratings. Warmer ambients reduce the torque rating, whereas cooler ambients increase the torque rating.

Amplifier Sizing

For brushless motor systems, performance curves are published based on specific motor/amplifier combinations. Many curves show the capability of a motor with various amplifier current ratings.

Power Supply and Transformer Sizing

Brushless motor amplifiers perform as power converters generating three sine wave of current by pulse-width modulating a high voltage DC bus. Power into the drive equals power out plus drive losses, regardless of the values of voltage and current supplied to the motor. The transformer and power supply deliver their power at high voltage. Thus, their currents may be significantly lower than the corresponding motor currents, particularly if the motor is running at a low speed (low volts).

An RMS calculation of torque and speed can yield an effective power requirement of the load (HP = NT/5252, where N = rpm, T = torque in lb-ft). Caution should be taken when the effective (RMS) speed is either very low or near N_{MAX}" In out/power in). The worst case requirement would be the power rating of the motor. This is defined as the maximum continuous power output of the motor.

Taking motor and drive losses into account, a simple rule may be use for determining power supply and transformer requirements. For AC synchronous permanent magnet servos, a minimum of one kw/HP (load) is needed; for AC induction servos, use the ratio of 1.25 kw/HP (load). Compare this with the power ratings of available power supplies and transformers to determine the required sizes. [Power supply and transformer power in watts, w = 230v (L-L) x (Secondary Line Current) x $\sqrt{3}$.]

Requirements, based on multiple motor/drive systems powered from a common supply and transformer, can be determined by summing the power needs of each axis.

Other Considerations

The determination of shunt regeneration (power dumping) requirements is a function of load dynamics and power supply capacity.

Calculations

Linear to Rotary Formulas

$$1/2\,(MV^2) = 1/2\,(J\omega^2)$$

$$FV = T\omega$$

$$F = MA,\ T = J\alpha$$

M = Mass
V = Velocity
J = Inetia
w = Angular Velocity
F = Force
T = Torque
α = Acceleration

Torque Conversion

$$T(\text{lb - ft}) = \frac{\text{Force (lbs.) x Lead (in / rev)}}{24\pi \text{ x } \eta_s \text{(Screw effciency)}}$$

Where:

Force = Cutting force of load or

Friction load = Weight xμ (Coeffcient of friction)

Inertia Conversion

Linear to Rotary

$$J(\text{lb - ft - s}^2 = \frac{\text{Weight (lbs.) x Lead}^2\text{(in / rev)}}{1.8 \text{ x}10^5 \text{x} \eta_s \text{ (Screw effciency)}}$$

Rotary

J(lb-ft-s2) = Diameter4 (inches) x Length (inches) x 6 x 10-6 [For solid steel cylindrical screws]

J Reflected Through a Gear Ratio = N

$$J\ ref = \frac{\text{J Load}}{N^2 \text{ x } \eta_n \text{ (R to effciency)}}$$

RMS Torque

$$Trms = \sqrt{\frac{T_1^2 t_1\ T_n^2 t_n}{t_1 + t_2 + t_n}}$$

T_1, T_2, T_n = Torques 1 - n; t_1, t_2, t_n = Times 1 - n

Maximum Duty Cycle

$$\frac{T_p}{T_c} = \sqrt{\frac{1 - e^{-t_{on}} \ / \ \text{duty cycle (TCT}}{1 - e^{-t_{on}} \ / \ \text{TCT}}}$$

Where: $X = \dfrac{t_{on}}{t_{on} + t_{off}}$

T_p	=	Output torque
T_c	=	Continuous torque rating
TCT	=	Thermal time constant
t_{on}	=	Time on
t_{off}	=	Time off

Constant Torque Acceleration

$$T(\text{lb - ft}) = \frac{J(\text{lb - ft - s}^2)n(\text{RPM})\pi}{30\ t\ (\text{seconds})} + T_f\,(\text{Friction torque, lb - ft})$$