12-10

Application Note

Using a Shunt Resistor to Dissipate Energy

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Scope

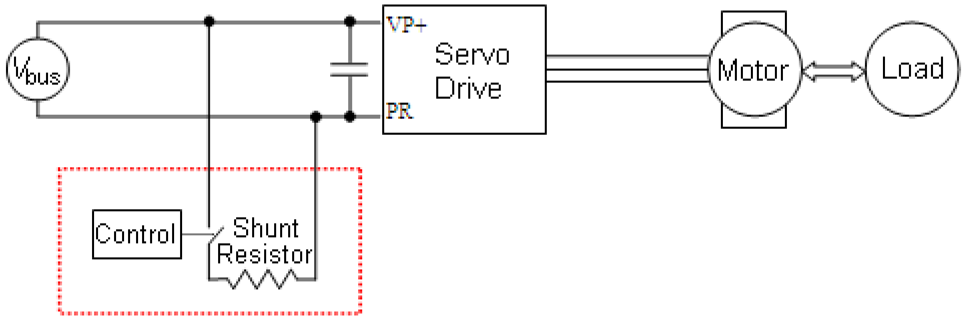
When a moving motor and load are required to decelerate rapidly, the kinetic energy of the load drives the motor's shaft to generate energy back to the servo drive. This is called "regenerative energy".

In most cases, regenerative energy is stored by the motor's internal resistance, servo drive and power supply, but in some cases, when high speed and inertia are involved, the energy becomes too great and causes the voltage on the bus (V_{bus}) to rise. A shunt resistor and a control provide a simple and effective solution to protect the power supply and servo drive by sinking energy though the shunt resistor.

This application note describes methods to calculate the resistance and power of the shunt resistor.

System Diagram

The shunt resistor is placed between the VP+ and PR terminals of the servo drive using a special control circuit, as shown below:



When the control circuit detects the presence of a voltage rise above a given threshold level, it connects the shunt resistor, and the energy sinks from the VP+ terminal to the PR terminals and dissipates as heat.

The resistor should have a low enough resistance to enable it to absorb the regenerative energy. It should also have a sufficient power rating.

Shunt Resistor Value Calculations

For a given application, the maximum resistance of the shunt resistor is derived from the motor's characteristics, the value of V_{bus}, the braking torque and the maximum speed.

The mechanical power to be dissipated is given by the following formula:

$$P = T \cdot \omega$$

where:

T is the torque in Nm,

ω is the angular velocity in rad/sec.

The braking torque can be derived from the motor's torque constant (K_t) and by measuring the value of the current on deceleration.

The mechanical power is dissipated on the motor itself and the shunt resistor. It is also partially absorbed by the capacitance on the bus.

For the purposes of this Application Note, we will neglect the bus capacitance absorption and concentrate on the shunt resistance.

The power dissipation on the motor itself is actually the copper loss and can be calculated from the formula:

$$P_{\text{mot}} = I_Q^2 R_{\text{pp}}$$

where:

R_{pp} is the phase-to-phase resistance of the motor,

I_Q is the current at brake time.

The additional power $P_{\text{shunt}} = P - P_{\text{mot}}$ needs to be dissipated on the shunt resistor. Otherwise, the bus voltage V_{bus} will rise and may cause damage to the bus components that cannot withstand the high voltage level.

Normally, we allow a voltage rise up to 90% of the drive's maximum voltage rating before engaging the shunt resistor (unless there are other voltage-sensitive components on the bus). When the shunt resistor is engaged, current flows through the resistor, causing P_{shunt} to be dissipated as heat. For good practice, we recommend using a maximum of 70% pulse-width modulation (PWM) to the R_{shunt} switching transistor.

The shunt resistance is therefore calculated at the maximum allowable voltage from the formula

$$R_{\text{shunt}} = \frac{(0.7 \times V_{\max})^2}{P_{\text{shunt}}} \cong \frac{V_{\max}{}^2}{2 \times P_{\text{shunt}}}$$

where:

$V_{\max}$ is the maximum level of V_{bus} (the voltage level at which the shunt resistor is engaged).

Shunt Resistor Power Calculations

The shunt resistor should dissipate a maximum peak power when the motor is at its maximum speed $\omega_{\max}$ and its maximum deceleration torque T:

$$P_{\max} = T \cdot \omega_{\max} - I_Q{}^2 R_{\text{pp}}$$

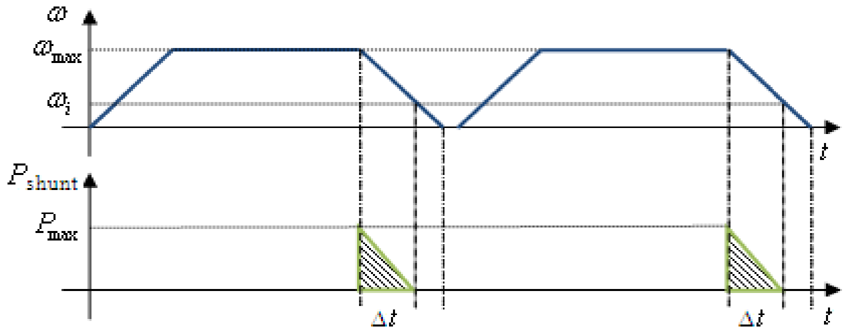
Assuming that the deceleration torque is constant, we may assume that the current I_Q is also constant. Since the speed is constantly decreasing, the power that needs to be dissipated is also decreasing.

At a certain speed ω_i , the shunt resistor's power will be zero:

$$\omega_i = \frac{I_Q R_{pp}}{K_t}$$

The power on the shunt resistor actually dissipates within a very short period of time.

Below is a typical motion diagram that shows the power dissipation on the shunt resistor.

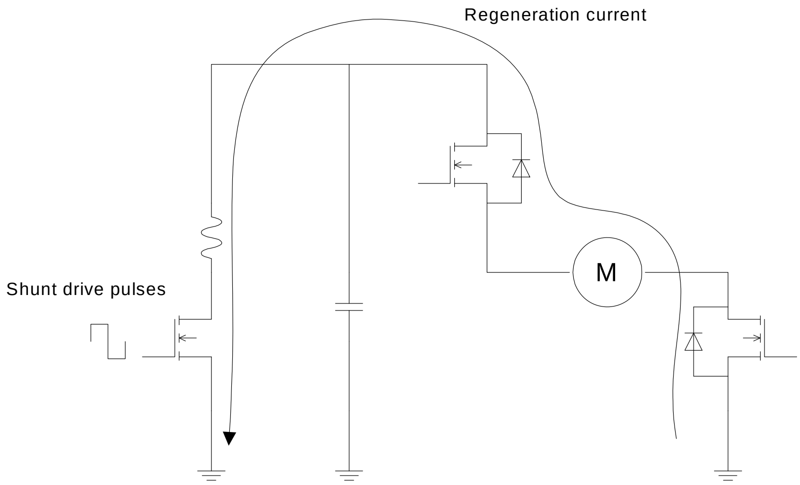


The resistor's average power is derived from the value of P_{max} calculated above and from Δt , which is influenced by the value of the deceleration a .

For a given deceleration a and P_{max} , the shunt resistor's average power is:

$$P_{shunt} = \frac{(\omega_i - \omega_{max}) \cdot P_{max}}{2 \cdot a}$$

Example



In this example, we assume the following motor data:

V_{shunt} =	0.9 x 200 V = 180 V
Speed =	2000 rpm
Braking current =	5 A
R =	10 Ω
K_e =	40 V/krpm

Therefore,

$$K_e\,[\text{V/krpm}] = \frac{40\ \text{V}}{(1000\cdot 2\cdot \pi/60)} = 0.3820\ \ \text{V sec/rad}$$

Thus $K_t = 0.3820\ \ \text{Nm/A}$

The dissipated mechanical power is:

$$P = T\omega = K_t I\omega = (0.3820\cdot 5)\cdot\left(\frac{2000\cdot 2\cdot \pi}{60}\right) = 400\ \ \text{W}$$

The copper loss on the motor is:

$$P_{\text{mot}} = I_Q^2 R_{\text{pp}} = 5^2\cdot 10 = 250\ \ \text{W}$$

This leaves 400 W – 250 W = 150 W to be dissipated by the shunt resistor.

The maximal shunt resistance is:

$$R_{\text{shunt}} = \frac{V_{\max}^2}{2\cdot P_{\text{shunt}}} = \frac{180^2}{2\cdot 150\ \text{W}} = 108\ \ \Omega$$

Therefore, the final resistance is $R_{\text{shunt}} \le 108\ \Omega$.

Now, let us assume the following deceleration: $a = -1000\ \text{rpm/sec}^2$

Then we have:

$$a = \frac{(-1000 \cdot 2 \cdot \pi / 60)}{\text{sec}^2} = -104.72 \frac{\omega}{\text{sec}^2}$$

$$\omega_i = \frac{5\ \text{A} \cdot 10\ \Omega}{0.3820} = 130.89\ \text{rad/sec}$$

Therefore the power of the shunt resistor is:

$$P_{\text{shunt}} = a \frac{\left(130.89 - 2000\left(\frac{2 \cdot \pi}{60}\right)\right) \cdot 150}{2 \cdot (-104.72)} = 56\ \text{W}$$

$$P_{\text{shunt}} \ge 56\ \text{W}$$

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