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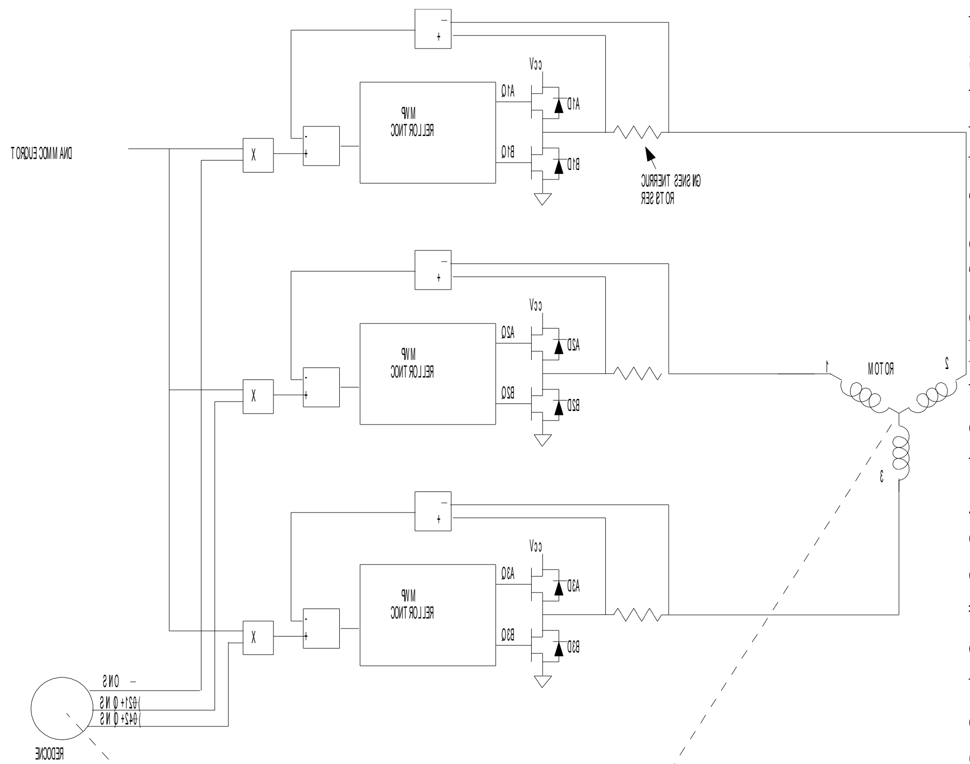
Subject: Brushless DC servo motor operation

Figure 1 shows a 3-phase motor connected to a single power supply via three totem pole drivers. This is the arrangement used by Kollmorgen and by IDC. Each of the motor terminals can be connected either to Vcc or ground, depending on which transistors and diodes are conducting.



The torques supplied by the three windings are given by $T_1 = K_T \cdot I_1 \cos\theta$, $T_2 = K_T \cdot I_2 \cos(\theta + 120°)$, and $T_3 = K_T \cdot I_3 \cos(\theta + 240°)$, where K_T is the torque constant. If the three currents are given by: $I_1 = A \cos\theta$, $I_2 = A \cos(\theta+120°)$, and $I_3 = A \cos(\theta+240°)$, the torque will be constant (independent of angle) and will have a value of $3K_T A/2$. The motor contains a position encoder so that the controller knows the position of the shaft at all times. Analog or digital signals are produced to represent $\cos\theta$, $\cos(\theta+120°)$, and $\cos(\theta+240°)$. These normalized values are multiplied (via either analog or digital multiplication) by the input torque command to produce the proper current command for each winding.

Note that, since the currents must sum to zero, only two of the currents need to be controlled. Nevertheless, it is convenient to control all three independently, as shown in the figure. This avoids the need to change modes as the shaft rotates; all three regulators remain active and independent. (If both positive and negative power supplies were available, two independent controllers could do the job).

The transistors operate as switching regulators rather than as linear "dropping resistors". Suppose first that positive current is flowing into terminal 1. This current will flow either from Vcc via Q1A (if Q1A is on), or from ground, via the free-wheeling diode D1A (if Q1A is off). In this case Q1A and D1B operate as a step-down (buck) converter. The filtering inductance is provided by the inductance of the winding. As less current is required, Q1A will be pulsed with a lower duty cycle. So far, Q1B hasn't been needed.

Now suppose that the current is negative (i.e. outward). The current flow is either to Vcc via D1A (if Q1B is off) or to ground via Q1B (if Q1B is on). The "negative duty cycle" required for negative current is accomplished by pulsing Q1B instead of Q1A. When the duty cycle is negative but not saturated at -100%, Q1B and D1A operate as a step up (boost) converter and energy is pumped back into the power supply bus (regeneration). The coil in this boost converter is the winding inductance.

Regeneration

Let's look more closely at regeneration. Assume that the rotor is in a position where Terminals 1 and 2 are "active" while Terminal 3 is grounded . Suppose the carriage house is not moving - the currents into Terminals 1 and 2 provide just the necessary torque to counteract gravity. Now suppose we start to move the carriage house down hill very slowly, without acceleration. As it turns, the motor will produce induced EMFs in its windings. These induced voltages will have the polarity to aid the power supply. Since the torque requirement hasn't changed (no acceleration), the duty cycle must be reduced slightly to keep maintain the same currents. So far, we're not recovering any energy, we're simply spending less to power the (resistive) motor windings. The necessary duty cycle reduction will be done automatically by the controller's current feedback loop.

Now suppose the speed is increased. Again, the duty cycle will be reduced. At some speed, the duty cycle goes to zero. Q1A and Q2A never turn on, since, at this speed, the induced EMF is just enough to produce the required torque. This speed is the "self-damped" descent rate of the system. At this speed, potential energy is being converted into heat in the windings at just the rate needed to produce the necessary torque.

Finally, suppose that we want to increase the speed even more. Now we will have more power being developed (via loss of potential energy) than is needed to maintain the necessary torque. This is when regeneration is needed. The totem pole at terminal 3 will begin operating as a boost converter. Energy pumped back into the power supply bus raises the bus voltage, cutting off the power line rectifiers. A shunt regulator ("regeneration card") senses the bus over-voltage and applies a shunt resistor until the bus voltage has gone below the threshold. Again the bus voltage rises and the shunt resistor is connected, etc. (The shunt regulator operates in a switch mode or "bang bang" control mode).