DC Motors

1.0 Basic Principles (Permanent Magnet Motor)

You are probably already familiar with the basic principle of a DC motor: exposing a conductor that is carrying a current to a magnetic field tends to move the conductor. The kind of motor you are most likely to come across in this course is the permanent magnet DC motor. Very briefly, here are some of its properties:

Speed is proportional to voltage:

\[ E_A = K_E \omega \]

where \( E_A \) is the armature (rotating conductor) voltage, \( K_E \) is the voltage constant of the motor, and \( \omega \) is the angular velocity (speed) of the motor.

Torque is proportional to current:

\[ T = K_T I_A \]

where \( T \) is the torque, \( K_T \) is the torque constant of the motor, and \( I_A \) is the armature current.

In the process of rotating, the motor also acts as a generator, producing a voltage across the armature that is known as a ‘back emf’ \( E_A \). Thus, the relationship of the supply voltage \( (V_s) \) to the armature voltage is:

\[ V_s = E_A + I_A R \]

where \( R \) is the armature resistance\(^1\). Here is a subtle point: if the motor speed were to increase for some reason (e.g. the motor load became lighter), then \( E_A \) would increase, according to the first equation. Now this would cause \( V_s - E_A \) to decrease, so that the armature current \( I_A \) decreases. But \( I_A \) is proportional to the torque, so the torque also decreases. So the back emf acts as a kind of feedback that helps to keep the motor speed constant\(^2\).

\[ V_s \quad + \]
\[ I_A \quad R \]
\[ + \]
\[ - \]
\[ E_A \]

Figure 1.

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\(^1\) Resistance in the armature is usually very small, so most of the supply voltage is used to overcome the back emf \( E_a \).

\(^2\) Actually, when a DC motor is started, there is no back emf, so that a very large current \((V_s/R)\) flows, which can cause damage to the armature windings. Thus the motor should theoretically be started at a smaller voltage, and then the voltage should be increased as the motor comes up to speed.
2.0 Torque-Speed Characteristic and Motor Control

Manipulating the above equations,

\[ T = K_T I_A = K_T \frac{V_s - E_A}{R} = K_T \frac{V_s - K_E \omega}{R} \]

Equivalently,

\[ \omega = \frac{1}{K_E} \left( V_s - \frac{R}{K_T} T \right) \]

This tells us the relationship between the motor torque and the motor speed: torque is maximized when the speed is zero, and the speed is maximized when the torque is zero, as seen in Figure 2. When designing a motor control circuit, clearly the operating point will be somewhere along this line. There are two key points on this figure: the stall torque, when \( \omega = 0 \) and \( T = \frac{K_T V_s}{R} \), and the no load speed, when \( T = 0 \) and \( \omega = \frac{V_s}{K_E} \). This tells us that the line can be shifted (in a parallel manner) by changing the supply voltage, as seen in Figure 2.

![Figure 2](http://lancet.mit.edu/motors/motors3.html)

So, just as the first two equations in section 1 suggest, the voltage controls the speed, and the current controls the torque. Note that practical motors require some small (non-zero) current before there is sufficient torque to turn the motor; this is known as the stall torque. This means that up to some small current (known as the stall current), the motor will not turn.

Note that there are a large number of different types of motors, both DC and AC, and that the principles of operation are different between them. For those of you fortunate enough to be studying electrical engineering, you will learn much more about motors and their control in later years, through one of the most rigorous electric energy courses currently offered in Australia.

Some useful resources:

http://lancet.mit.edu/motors/motors3.html
3.0 Electric Drive Circuits

A few minutes in the lab will be sufficient to convince yourself that you can make a DC motor turn in one direction by applying some kind of DC power supply. To be useful in practical applications, however, often some kind of control is required, i.e. not just starting and stopping the motor, but controlling its speed and direction.

Bearing in mind the previous sections discussing the relationships between voltage, current, torque and speed for a DC motor, it is clear that speed control can be obtained by a variable voltage drive circuit. We have already examined one: Figure 2 in the transistor notes, where the motor can be considered as the load \( R_C \), across which the voltage can be controlled by \( V_{in} \) as \( V_{CC} - V_c = \beta R_C \frac{V_{in} - V_{BE}}{R_B} \). Note that a variation on this has the motor as an emitter resistor rather than a collector resistor; this is known as the common-collector configuration. So a current amplifier circuit based on a transistor can provide variable speed control, depending on \( V_{in} \).

Direction control can be achieved by reversing the polarity of the voltage applied to the motor. In practise, this permits two possibilities: (i) a single-sided power supply (e.g. 0V and 6V as the two connections) whose polarity is reversed automatically as needed, or (ii) a double-sided power supply (e.g. -6V, 0V and 6V as the three connections) with a drive circuit that whose output can take on either polarity. (i) might be achieved using a relay or h-bridge. (ii) can be achieved by mirroring a transistor amplifier circuit for the negative voltage supply, to create a “push-pull” configuration (see http://www.ecircuitcenter.com/Circuits/pushpull/pushpull.htm or http://engg1000.ee.unsw.edu.au/lecture_notes/chapter3.pdf).

Please note: These notes are intended to give the key basic knowledge required to get started in ENGG1000. They are certainly not comprehensive, and very likely you will need to consult other sources even just to complete your project in this course.