Control Systems

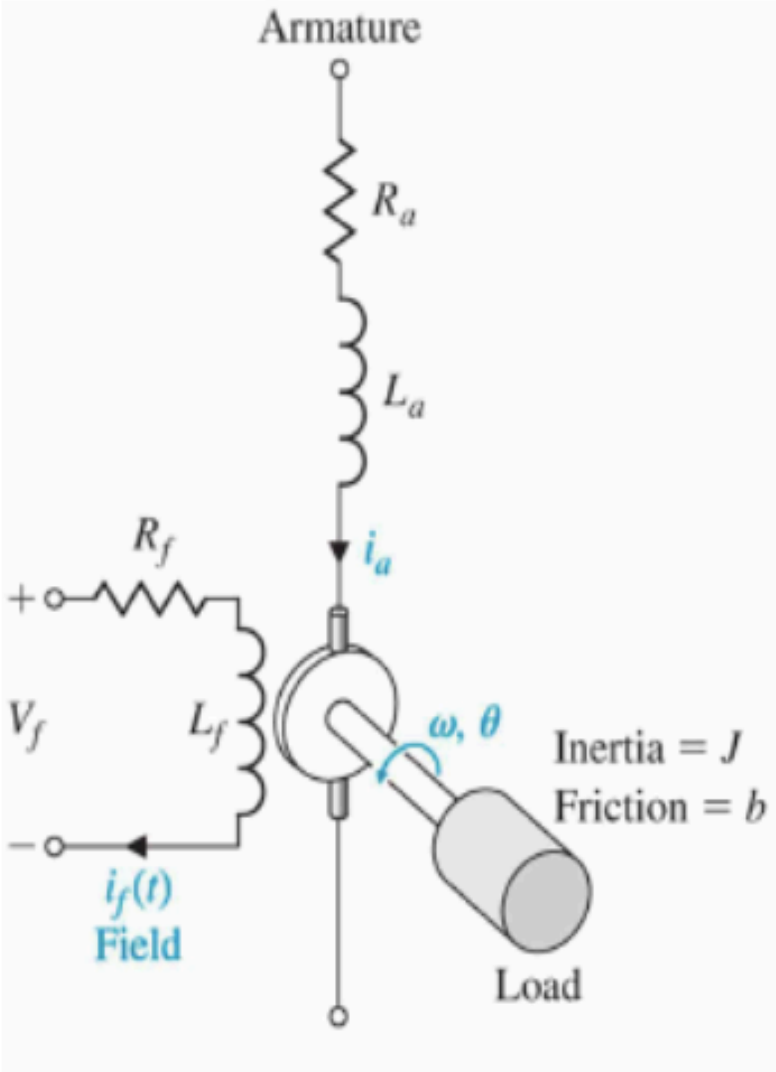
Tutorial Sheet 2

Armature Controlled DC Motor

We have shown in class that motor shaft position can be obtained by controlling the *field coil* voltage, and we obtained the system transfer functions for this, with and without external torque disturbance, and showed that open loop control is sufficient if the motor constants are known *a priori*. This was in Lecture 2 and is known as field control of a DC motor.

It is also possible to control the motor shaft position by controlling the armature control voltage, and that is the topic of this tutorial.

Q1. By referring to the Figure below write down one feature of the DC motor system that immediately distinguishes armature control from field control.


Armature
R_a
L_a
i_a
R_f
+
V_f
L_f
−
$i_f(t)$
Field
ω, θ
Inertia = J
Friction = b
Load
(a)

Q2. The back EMF is a voltage and can be used as a measure of motor speed, as follows:

$$V_b(s) = K_b\omega(s).$$

We note that K_b is a constant associated with the armature coil and its ability to generate back EMF. The back EMF has to be added on to the voltages proportional to the resistive and inductive terms in the Kirchhoff voltage equation (see Lecture 2 for that equation). Write down the modified form of the Kirchhoff voltage equation as required for armature control.

Q3. Use the modified Kirchhoff voltage equation to show that the armature current is given in the s-domain by the following:

$$I_a(s) = \frac{V_a(s) - K_b\omega(s)}{(R_a + L_a s)}.$$

What is the unit of current?

Q4. Identify the load torque equation from the field control analysis (Lecture 2), and then restrict it to the motor-load combination to show that:

$$\theta(s) = \frac{T_m(s)}{s(Js+f)}.$$

Q5. In the time domain the general equation for motor torque is:

$$T_m = K_1 K_f i_f(t) i_a(t).$$

Show that the motor torque for *armature control* in the s-domain is given by:

$$T_m(s) = \overline{K}_m I_a(s) \text{ and define } \overline{K}_m.$$

Q6. Proceed to show that the motor position, in the s-domain, is given by:

$$\theta(s) = \frac{1}{s(Js+f)}\left(\frac{\overline{K}_m V_a(s) - \overline{K}_m K_b \omega(s)}{(R_a + L_a s)}\right)$$

Q7. By noting that $\theta(s) = \frac{1}{s}\omega(s)$ go on to show that the transfer function is given by:

$$G(s) = \frac{\bar{K}_m}{s[(Js+f)(R_a+L_a s)+\bar{K}_m K_b]}$$

Q8. Attempt to draw the block diagram, with identified block transfer functions and signal lines, for the armature controlled DC motor without external disturbing torque.

Q9. Finally, try to modify this to include the effect of an external disturbing torque.

Appendix

Back EMF

From: https://en.wikipedia.org/wiki/Counter-electromotive_force

The counter-electromotive force (abbreviated counter EMF, or CEMF) also known as the back electromotive force, is the voltage, or electromotive force, that pushes against the current which induces it. CEMF is the voltage drop in an alternating current (AC) circuit caused by magnetic induction (see Faraday's law of induction, electromagnetic induction, Lenz's Law). For example, the voltage drop across an inductor is due to the induced magnetic field inside the coil. The voltage's polarity is at every moment the reverse of the input voltage.

The term back electromotive force, or just back-EMF, is most commonly used to refer to the voltage that occurs in electric motors where there is relative motion between the armature of the motor and the magnetic field from the motor's field magnets, or windings. From Faraday's law, the voltage is proportional to the magnetic field, length of wire in the armature, and the speed of the motor. This effect is not due to the motor's inductance and is a completely separate effect.

In a motor using a rotating armature in the presence of a magnetic flux, the conductors cut the magnetic field lines as they rotate. This produces a voltage in the coil; the motor is acting like a generator (Faraday's law of induction) at the same time it is a motor. This voltage opposes the original applied voltage; therefore, it is called "back-electromotive force" (by Lenz's law). With a lower overall voltage across the armature, the current flowing into the motor is reduced. One practical application is to use this phenomenon to indirectly measure motor speed and position, since the back-EMF is proportional to the armature rotational speed.

In motor control and robotics, the term "Back-EMF" often refers most specifically to actually using the voltage generated by a spinning motor to infer the speed of the motor's rotation for use in better controlling the motor in specific ways.