EGR222 Lab 8 Comments

Dear class,

The place where most reports had problems was the design part. This was a feedback system. The first one we have done involving more than just an op-amp. A feedback system (ideally) works more or less the same way an op-amp does. There is something, the output, that you are trying to control. In our case that was the speed of the motor. Or, later, the torque. That is done by sensing the actual speed or torque, and producing a signal that is compared to the input, indicating what we want. So, the design of the feedback part of the circuit is very important.

Consider speed first. Presumably 0 Volts in (from Vref) indicates we want a speed of zero. That's the easy end of the scale. We assume things are linear. The pots are, and we know that the generator output, which is our speed sensor, is Vb, which is linear with speed. So, now we need to decide how fast we want to be able to go. In other words, when we set Vref to "Max!" (at 5 Volts) what speed do we want from our motor?

Let us suppose that for some reason we want 1000RPM at 5V. (You were free to make an arbitrary choice.) Now, that relationship needs to guide our sensor conditioning, so that we get a feedback Voltage of 5 Volts when the motor is going 1000 RPM. Suppose k_V of the motor is 5mV/RPM. (Most of your motors were close to that.) Then v_f = 1000 RPM * k_V * G, whjere G is the "Gain" of your sensor conditioning circuit. Solving for G, we get:

G=5V / (1000RPM * 5mV/RPM) = 1 V/V.

That means that with unity gain we don't need a sensor conditioning circuit at all! In the circuit shown for the lab exercise, R5= 0 Ohms and R6 = infinity. (I do have some zero Ohm resistors somewhere, but a small number, like 2.2 Ohms, would work. So would a wire. For infinity you could use 10M Ohms. Or nothing.) This would work. You'd get a noce linear graph, except at the "stall" point where you have constrained speed = 0 despite whatever Vref is. At that point the circuit is unable to apply enough Voltage to the motor to overcome whatever is trying to hold the motor still. (If that is your fingers, a sufficiently high Voltage would have done the job. To the detriment of your fingers. Or the setscrew might have given up first.) For the "extra friction point" you might or might not have been able to maintain speed. It was a matter of whether the friction was low enough that the maximum motor Voltage could still get the job done.

Many of you chose to let R5=R6. Let's suppose you chose 1KΩ. Many did. That's so much larger than Rw of the generator that we can assume Vb (of the generator) = Vg. So, now G = .5. What is the maximum speed? (That's sort of backwards; normally you'd want to choose the speed and then design the conditioning circuit to fit. This is more like designing a car and choosing the motor before deciding how you want it to perform. "What kind of car can I build with this motor?" There are times when we indeed need to do that sort of thing.) If G=.5, we solve for speed:

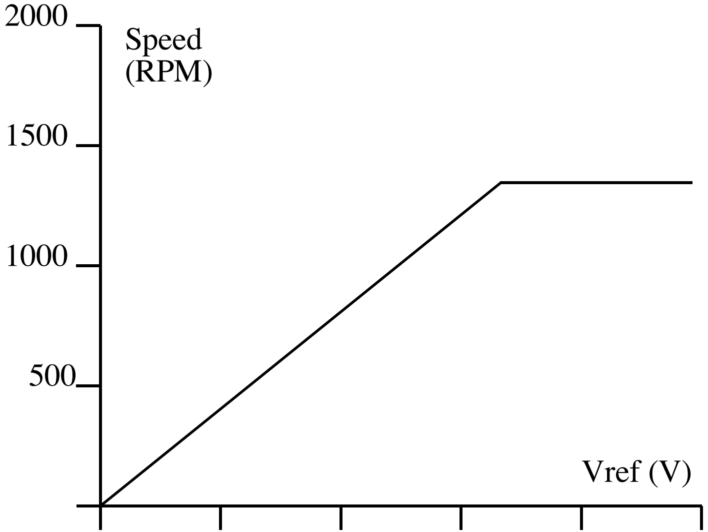
$$\omega(\max) = V_{ref}(\max) / (k_V * G) = 5V / (.005\ V/RPM * .5) = 2000\ RPM.$$

So, if this is your design, what happens? Your maximum point cals for 10V out of the generator = Vb. But, Vm of the motor has to be more than Vb. Vb of the motor should be about the same as Vb of the generator, since they should have about the same characteristics. And w know that Vm = Vb + Vw, where Vw is the windings resistance. Unlike the generator in this system, the motor current is not negligible. So to get to Vb = 10V, what motor Voltage do we need?

That can be calculated. This is a steady state motor problem. I'm going to suppose Rf (the motor frictional resistance) = .03 g-c/RPM. We are designing for 2000 RPM, so that means that for both motor and generator we have .06 g-c/RPM. So, 120 g-c total. Dividing by k_T, and using a more or less typical k_T of 550 g-c/A, we find that we need .22A. If Rw is about 10 Ohms, that's 2.2 Volts on top of Vb = 10V. We need 12.2V!

What is actually going to happen? Our power supply is only 12V. We also know that the output of the op-amp can't get all the way up to the Voltage of its power supply (also 12V). So, maybe we can assume the op-amp gets to within 2V. But then we have two .7V drops across both transistor VBE junctions. That takes us down 3.4V below 12V, to 8.6V (neglecting R_{sense}). We might get as much as 9V. (That's about what many students saw as the max output Voltage.)

So, what would be our maximum speed (with no extra frictional load)? That's another steady state motor problem. .06 g-c/RPM /(550 g-c/A * 5mV/RPM) = .0218 A/V => 46Ω. The mechanical load makes Vb look like a 46 Ohm resistance. Vb=46Ω/(10Ω+46Ω)*Vm (8.6V) Vb=6.7V which divided by kV gives 1346 RPM. We had designed for 2000 RPM at 5V, so we should get 1346RPM at about 3.4 Volts for Vref. This should give us an unloaded graph that looks like:



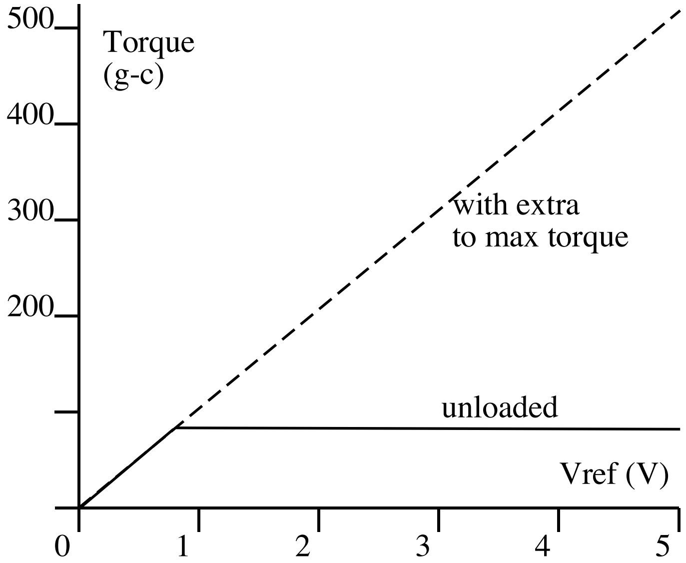
That's what most of you got. The points with the added friction would vary. The stall point should have been on the horizontal axis, at whatever Voltage Vref was. Obviously beyond the control of your circuit. The "friction" point might be as high as the curve shown, bit would be below it if you applied more friction than the circuit could handle. It can handle only a tiny extra load at high speeds, but much more at low speeds. Motor Voltage max is the constraint.

For torque, the process is similar. How much torque do you want to be able to deliver? You design the feedback circuit, specifically the sensor conditioning, to fit. In particular, you need to "design" the feedback circuit by choosing R3 and R4. So, how much torque should you ask for, maximum? We know that we can't get more than 12V out of our power supply, and I think it is limited to an ampere. An ampere would give us 550 g-c. So, let's design for 500 g-c. That means that at 500 g-c we want to see 5V at Vf, the feedback Voltage that must equal Vref if out system is operating correctly (and is under control). So, the sensitivity of our feedback System needs to be 5V/500g-c = 10 mV/g-c. Looking at the circuit, and using G for the gain of the op-amp amplifier, we have:

$$S = S(\text{sensor}) * G = R_{sense}/k_T * G = 1/(550\text{ g-c/A}) * .44\text{V/A} * G = 10\text{mV/g-c}.$$

Solving for G, we get G = 12.5. (When you do this, make sure all the units cancel!) so, that means that R4 = 11.5 R3. If we choose R3 = 1KW, choosing R4 = 12KW would be reasonably close, the nearest "standard value." So, actual G=13, and actual designed max torque would be 520 g-c, acceptably close to our original goal of 550 g-c at Vref = 5V.

Where the speed control circuit operated well over a large range of speeds, this one is going to have problems! We saw earlier that unloaded, the maximum speed was 1346 RPM. That's still true here. And with a motor Voltage of 8.6V into what looks like 56 Ohms (Vw+Vb)/I, we can solve for Im=.15A which implies T = 84 g-c! That's the maximum unloaded torque if we have no extra load on the motor. We are calling for torques higher than that whenever Vref = .8V or more! What we will see is maximum speed over most of the Vref range. However, if an extra load is imposed, torque should go up to the designed limit (that depends on Vref) and no more. So, what you might expect to get would look something like the graph below:



Indeed, I saw this on some reports, in one case very clearly. However, most groups designed to such a high torque (as much as 2660 g-c!) that you need several amperes, and that was way beyond the capability of out supply. So, what you got was a mostly flat line where the circuit was operating beyond its ability to control torque.