BECKHOFF New Automation Technology

Bob's Motion Control Primer

Part 1

The following lesson is Part 1 of a summary of several years (10 or so) of distilled knowledge on the basics of motion control.

First an equation to justify my worthiness:

Expnce ~ AOER   Translation: Experience is proportional to Amount Of Equipment Ruined

(Ask most anybody that I've done work for, I have LOTS of experience)

Now it's time to pass to you the things I wish someone had passed to me along the way. Oh yeah, if you have issue with anything presented here, Good!, please let me know though, I may try to argue with you.

Motion Control

Part 1: Basic need-to-know-before-sizing things

Before 'sizing' up a motion application, ANY motion application, there are FIVE basic things I ask the customer. Rarely do I get them all, but you need to have _some_ idea of these to get started. A lot of times you will get a best-guess, or make it yourself, and go from there. It is what makes motion control empirical (learn from doing) and an art form of sorts...

Need-to-know-before-sizing things:

1. Type of control (position, velocity, or torque)
2. Load Inertia
3. Speed
4. Torque
5. Acceleration and Deceleration

Let's address these one at a time.

1. Type of control (position, velocity, or torque):

This is first because it is the easiest to think through (but surprisingly, not always obvious).

Position control: Are you *mostly* starting and stopping something on a dime?

Velocity control: Are you *mostly* running something at a certain, even varying, speed?

Torque control: Are you *always* trying to pull on something with a certain tension?

There you go, obvious huh? Well torque is, but you would be surprised how many applications fall between the lines of position and velocity. Do they mutually exclude each other? No. But if you think in terms of *mostly,* that will help. Which is more important?

<Rant on>
Oh yeah, a lot of people will try to use velocity control when torque control is the way to go. Example is a web where you have to keep a certain tension on a material through a process. It could be paper, some kind of cloth, tin foil. It is true that you can do this by controlling the speeds of the individual axes, but, without going into the math, it is a 'squared' relationship. TWO times the velocity will result in FOUR times the tension. Yikes! Torque and tension are one to one – much easier to control. I always steer people from doing tension control by velocity.
<Rant off>

2. Load Inertia:

Load inertia is next on my list for a reason: it is surprisingly the biggie, and the one 'parameter' that gets scoffed at right away. Suffice it to say, it is a pain to figure out.

Buuut, a good mechanical design engineer can tell you what you are coupling to.

First some semantics: Inertia is represented by the capital letter 'J' ('I' was taken by the EE's, of which, I am one).

Jl = Load Inertia (the mechanical resistance to change in velocity of the 'load')
Jr = Rotor Inertia (the inertia of the motor rotor, always something you can look up by the motor manufacturer)

So let reveal two general rules of thumb:

First: for **Position** control you want an 'inertia ratio' of less than 10 (**IR < 10**).

IR = Jload / Jrotor

IR = Inertia Ratio
Jload = the Inertia of the coupled load
Jrotor = the Inertia of the motor rotor

The load inertia, Jload, can be tricky as it must be calculated (just algebra though). It goes beyond the scope of this document to review, but a good controls manufacturer can assist and there are many resources on the Internet. I myself have a spreadsheet I developed and use to calculate 'inertial loads', and I always calculate inertia with two different programs - or one program and by hand (pencil and paper) to spot mistakes and inconsistencies.

So why is this important? Imagine you have a large stone wheel - lot's of inertia (a resistance to a change in velocity), then imagine you have this little guy, and this little guy is trying to move or rotate that big stone wheel. He's in for a workout just to make it move, let alone trying to repeatedly start it and stop it.

The same is true for motors. It is the motor rotor that is the guy trying to get that load going. And for position control, that means starting and stopping. That motor has accelerate and decelerate that load. So for a quick peek into things, the inertia of each end tells us a lot. The bigger the motor rotor, the more magnets and electronics there are to move it (and a load) around.

And the second 'general rule of thumb' for inertia ratios.

Second: for **Velocity** (Speed) and **Torque** control an Inertia Ratio can be as much as 50 (**IR < 50**).

In other words velocity or torque control is more forgiving because you are not continually trying to start and stop something.

O.K. time to move on to the third thing you need-to-know-before-sizing:

3. Speed

Now this just makes sense, you need to know how fast your machine is going to work right? This is usually a 'max speed' of the process. You may have noticed already in a motor/drive 'torque curve' the main axis of the graph is the speed axis. And you will also notice that ALL motors, even your automobiles, have a point where the available torque at a certain speed really drops off. Ah ha! DON'T try to guess at this one, find out, and give yourself some headroom.

4. Torque

Torque comes from a Latin verb meaning 'to twist'. It's one of my favorite units (I'm a geek) because it is something you can visualize. The units are usually in lbft or Nm. You can think about it as trying to rotate something a certain distance away from the axis center. Consider loosening a lug nut on your car tire. A short wrench won't get you far. You need leverage that comes from being away from the 'axis of rotation'.

Enough about that.

I will say I usually get a value for torque from a user. Most of the time the torque needed at max speed. Looking at a motor rating this is called 'rated torque'. For classic brushless DC servo motors the 'rated torque' will always be less than 'max torque', as a brushless DC servo motor torque curve always slopes downward. Rated torque tends to be given at some nice round number of speed (like 5000rpm) before the torque drops off the map. Max torque is at zero speed, or 'locked rotor' as it is sometimes called. The torque curve for brushless DC servo motors s is really almost a straight line sloping downward from zero. Other motors have very different and much less linear curves and require more attention.

<u>5. Acceleration and Deceleration</u>

For position control as long as you keep your promise of an IR<10 your motor will usually be fine. But, what about the drive? It must supply (and dissipate) the electrical energy and transform electrical energy from the source into something the motor can use. In a nutshell, heat. Can the drive handle the getting rid of the heat. This is the essence of drive sizing. So we usually use a power unit such as Watts or Horsepower. Handling the power required to drive something means getting rid of the heat.

Again, you will have to do some math, but if you know the system inertia and know how fast and how often you need to start stop it is pretty straightforward to figure out. Otherwise you are guessing, which is not that uncommon. I'm o.k. with it as long it is an *educated* guess.

You actually can get real cute with things and do something called 'regeneration'. Regeneration is a term that gets misused a lot in my opinion. True regeneration means dumping energy back into the system to get reused (regenerated), really recycled. It is possible to do especially for DC systems using a common power bus. Unfortunately you hear often of 'regen resistors', which will take the energy from stopping a load and toss it to a resistor and basically turn (waste) that energy into heat. Effective, cheap (at least on the short term), but not very efficient.

Conclusion

Know your application! What is the end result? What are you trying to do? Then do some math and be smart. The more you figure out the less you open yourself to sending things back and reworking design. To be honest, the reason I love motion control, is because it can be a feel thing. Most of the time it is not practical (from a time/expense thing, I'm a realist) to figure out everything explicitly, you have to have a feel for what will work and what will not. Prior history on similar machines goes a long way.

O.K. So some of you may be saying, "Hey, you didn't give us much in the way of formulas". You're right. Those are everywhere. But what about the bigger picture of what you are grinding through? *That* is what is more important because you will be more equipped to spot things that do not make sense. We are engineers who understand things, not monkeys who go by rote.

And in this first installment, I have not even breached such niceties as gearing, reflected loads, types of motors, windings, analog control vs. SERCOS, update rates, electronic gearing, camming, inner loops, outer loops, all kinds of cool stuff. That will be the subjects of future articles...

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