Chapter 1

Defining the Problem

Features

Where Do We Begin?
How to Define the Problem
Problem Definition Example
So, What IS the Problem?
How Do We Solve the Problem?

Where Do We Begin?

When beginning a control system design for **ANY** application, consider the electronics **LAST**. This may be the most often violated maxim of motion control design. Two considerations which should govern the choice of control are:

- How is the end product or system to be moved?
- How will the required motion be monitored?

Other considerations such as inter-machine communication, multiple machine interlocking, safety (machine, product, and personnel), and other external factors should be designed into the control operating flow sequence **after** developing the unit operating sequence. It is important to keep in mind the following controlling device objectives:

- Produce at the highest possible rate.
- Produce with the highest possible quality and reliability.
- Interact with the operator to the greatest extent possible.
- Maintain system operation with the least possible confusion.
- Reduce overall operating costs and system maintenance.
- Limit the cost of the electronics, *with the sole exception of the motor/amplifier package*, including installation and labor, to a reasonably tight budget with respect to the total system selling price.
- Meet the customer specifications with at least a 10 percent design overhead.

The general design guideline to conform to is:

> **Design the electronics to meet the requirements of the mechanics....**
> **NOT**
> **...the other way around!**

The capability designed into the mechanics should **never** exceed that of the electronics. This means that the mechanical system should not *Limit out* before the electronics has reached its peak handling capability! Many engineers design the control before considering the system mechanics, the product being handled, or both. Possible reasons why a designer might do this include:

> ***Market oriented executives or designers are selecting the system control and honestly feel that their product can perform the task.*** These individuals are likely operating under a misconception that since the system control is CPU or DSP based, the control can overcome any problem encountered. In the final analysis, they understand their customer's needs only to a limited extent.

Engineers, who by reason of time constraints, cannot research more effective alternatives. In cases such as these, whatever scheme the designer is familiar or comfortable with will more often prevail, in spite of common sense. This strategy will generally result in system designs plagued with shortcomings and inadequacies.

Engineers are designing a particular system using good design practices and techniques; and therefore, need only qualify their choice. If designers take into account the machine operating specifications and overall system restrictions, the final outcome will be successful.

The first two scenarios above do not use good design techniques and do not further the best interests of the customer. Bear in mind that software should not be used to solve mechanical problems—this practice seldom works. Selecting the proper system control follows the difficult task of defining system requirements.

How to Define the Problem

In order to define system requirements, ask questions when developing a motion control system:

How can the system travel from point A to point B with the greatest degree of simplicity?

How heavy is the system (machine plus product weight)?

- How fast is the product moving?
- What are the accel/decel limitations?
- Will you use indexed motion or continuous motion?
- What type of system: in-line, rotary, or tangential?
- What level of accuracy do I need?
- How repeatable must the system be?
- How much resolution does the system need?
- What is the best motor for the job: stepper or servo?

How stable is the product?

- Can the item be touched or handled?
- Is the item secured or held in place by friction?
- Is the item sensitive to external forces, such as electromagnetic forces or UV light?
- What are the physical dimensions of the product or controlled device?
- What are the limiting characteristics of the product material (i.e., brittle, porous, hard)?

What kind of tool will be implemented?

- saw (rpm, number of teeth, angle of attack, horsepower)?
- laser (type, power)?
- water jet (pressure, stream type, nozzle, . . .)?
- lathe (rpm, cutting depth, tool type, . . .)?
- mill or drill (rpm, cutting depth, flutes, . . .)?

What is the system environment?

- humid?
- dirty?
- extremely hot or cold?
- noisy?
- industrial considerations? (i.e., a welding operation)
- electrical considerations? (i.e., power and ground)
- operator capabilities?
- chemical interaction?

Many issues can affect the successful completion of any motion control design. The more we understand the system requirements, the environment, and the available technology, the more successful the design outcome will be.

Problem Definition Example

Before jumping into a control method, let's engage in a thought-provoking discussion of a specific application case study.

A systems house called me in to determine if I could make the machine described in Figure 1.1 functional. The OEM had previously hired two control manufacturers to find a system solution. They were unsuccessful, and the system was over two months late.

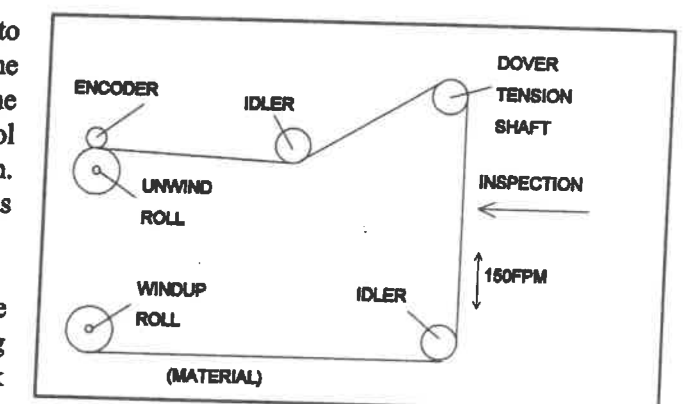

Figure 1.1 A motion control inspection system.

The OEM provided me with the system requirements and general handling restrictions. I proceeded to lay out the task as follows:

System specifications:

- Maximum inspection velocity: 150 feet per minute.
- Maximum roll diameter: 20 inches.
- Maximum roll width: 40 inches.
- Tension requirement: 4 lbs/inch of product width.
- Operation in either direction.

System constraints:

- Add 10 percent to the velocity.
- Cost to less than $5000.00 (if possible).

Since they had already purchased the motor drives, I simply verified that the motor/amplifier package would work.

Now, If we look at the problem from the perspective of a computer-based motion control equipment manufacturer, it is merely a classic *Master/Slave* operation with tension override. So why were the two nationally known, board-level motion control manufacturers unable to solve this problem?

As a systems engineer since 1964, experience has taught me one main rule to bear in mind when designing:

Solve the (customer's) problem....
then...
worry about the product!

I cannot emphasize this point strongly enough. Failure to make the system in Figure 1.1 functional was simply due to over powering the motion control product with a specification beyond its *real-time* capability (you can fix anything with software, right??). Neither manufacturer remembered to **define the problem**.

So, What IS the Problem?

The problem is to match the unwind velocity of one roll to the windup velocity of the other roll, while maintaining the proper tension on the material (product) at all speeds. (Notice that this is not a position, or point-to-point, control problem, so we have one less variable to deal with.) In simpler terms, we may define the problem as: match velocities while maintaining tension.

Or we may further simplify it: *maintain operating tension.*

The objective is to develop a good problem definition using the fewest possible words to describe the problem at hand.

HOW Do We Solve the Problem?

Problem solving here begins by defining the variables, and in this case, the variables are *velocity*, *acceleration*, and *deceleration*. However, note that these are not variables that *cause* the tension to change, but rather variables that allow us to *correct* for tension changes. Referring to the system in Figure 1.1, the acceleration and deceleration profiles of the fully-loaded windup and unwind rolls must match with a slight advantage to the unwind roll (slightly faster response to change). This will ensure that no over-winding or un-spooling of either roll will occur during the operation. The systems house previously selected *smart* motor drives, so I knew they would meet this requirement.

What conclusion can we draw from the above?

We can conclude that the windup roll velocity could be simply controlled by a potentiometer. An operator-controlled potentiometer would allow the velocity to range between 0 and 110 percent of the required system velocity. No matter which roll is switched in as the *Master*, the operator controlled potentiometer would be the sole control of its velocity. It would be up to the operator to set this potentiometer to the required system speed and the control function of the *Slave* roll (unwind roll) to maintain the proper tension. Using a tachometer mounted on the windup roll material, we could feed an actual analog material velocity signal back to the windup motor drive amplifier. This feedback signal would ensure ample stability of the windup velocity, with no computer motion control interface. The speed regulation of the windup roll could then be maintained within 0.5 percent. The windup roll control problem is now solved. All of the tension control at this point will be produced and controlle by the unwind roll.

Three questions regarding tension you should ask are:

1) How might we apply the tension and read back the tension changes for unwind velocity control?

One possible answer to this question would be to use an air-loaded linear *dancer* arm to apply the required tension to the material (see Figure 1.2). We could plumb air pressure to the *dancer* arm (4 lbs. per inch of material width) to force it against the material. Onto this arm, we could mount a linear potentiometer that would have a positive and negative voltage applied to opposite poles with the center tap at electrical zero. The *dancer* arm, with the product at the proper tension, would send a tension error signal of zero volts to the unwind motor drive. As the material tension changed, the dancer arm would deflect, causing the potentiometer arm to move, which in turn would send a tension error feedback voltage to the unwind motor amplifier. This error voltage change would cause the unwind roll to rotate faster or slower to compensate for the tension error. The unwind motor would quickly and constantly correct for tension changes. Operation in either direction could now be initiated by simply switching the *Master/Slave* interface signals, making the unwind roll the windup and the windup roll the unwind, respectively.

2) How can we maintain tension as simply as possible, but with response that meets the system requirement?

You can achieve base speed stability between the unwind and windup rolls merely by mounting a second tachometer to ride on the unwind roll material. The *difference voltage* developed between the two tachometers could represent the difference in the unwind and windup material velocities. This voltage could then be applied as a *base speed* signal to the unwind roll motor drive, allowing the tension error signal generated by the pot on the dancer arm to act as a trim signal (25 percent changes). In other words, the greatest percentage of the velocity command would be generated directly by the difference in linear windup and unwind velocities.

As an added feature the two tachometers could help maintain the required constant material velocity with changing roll diameters (since the tachometers are riding directly on the unwind and windup roll material).

3) Is it possible to substitute for computer generated gains, propagation delays of electronics, and other items which are normally used when programming *Master/Slave* tension control systems?

At this point, we could use the computer to coordinate the operator interface, system reversal, system I/O, general safety considerations, and other miscellaneous data collection functions.

As you can see, this design problem was solved with nothing more than a potentiometer mounted on an air-loaded dancer and two tachometers, and the bottom-line cost came in well under $5000.

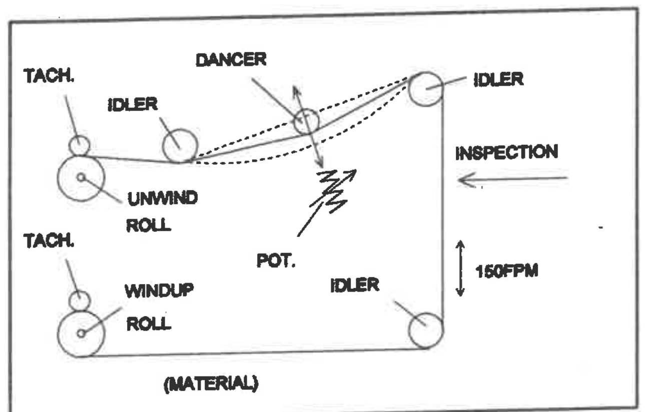

Figure 1.2 A typical motion system with simple control.

Conclusion

Sometimes the simplicity of things eludes us. In dealing with applications every day, it is often necessary to persuade customers to consider totally different approaches. These approaches may allow simpler solutions that provide for a better customer *fit*. If we forget the bottom line—*Solve the problem*—we will waste the customer's time and money; and in the end, we will most likely lose the customer.

Good design practices and techniques are not something we are born with—we must learn them. If we, as designers, are willing to take our time, draw from our resources, exercise common sense, and remember to **DEFINE THE PROBLEM**, we will succeed in developing cost effective motion control systems that will produce desired results.

Notes: