Chapter 5

A Common Sense Approach to System Analysis

Features

Introduction
Analyzing Processed Signals
Stable and Unstable Motion Systems

Introduction

One of the most difficult tasks a designer is faced with is having to analyze how a system will react to applied forces without having that system physically available for study (pictures or concepts only). When trying to figure out the type of control (or motion controller) required for a task, the reaction capability of the controller selected must be faster than the *real-time* needs of the system. The objective of this chapter is to help in developing an analytical approach that will first zero-in on the way a system will operate, and second, will outline a software flow method to control that system.

Analyzing how a system will operate without having the system at hand is based on clarity of system design and/or concept description, your experience with understanding how to figure out areas of mechanical instability, mechanical failure points, etc. Your ability to figure out as close as possible how system mechanics will react to *real-time* events such as discontinuities in movement, friction, inertia changes, velocity and acceleration changes, . . . *before* you select the control method or control is what analyzing a system is all about.

A system can only be analyzed after certain operational criteria are known. Parameters relating to what the system is required to do, the environment, the human factors involved (i.e., operators, safety) must be gathered. Anything and everything that might have a direct consequence on the outcome of the operation to be analyzed (such as engineering capability of the design house) needs to be known at the beginning of the design effort. Items that will affect the system or product after the design completion also must be known (such as produce-ability of the system, customer use, and maintenance capability).

Does this mean that to do a *simple* control analysis we need to acquire masses of bulk data? No! The amount of data is directly related to system reliability, timing, and general use. How deep you need to go to gather data is based on how critical the criteria is to the operation. It is up to you as the designer to keep, discard, or obtain more information.

There are two example problems in this chapter. The first deals with two analog photocell pickup stations in which the signal readings are not stable. This particular problem was solved after the main system was built, which makes it a hindsight engineering solution. The second example problem to be considered is one in which the solution was worked out before choosing the control system, but after a design concept had been developed. The method used to control the first example, worked as the analysis indicated, and the second was close to what was modeled. Note that in both cases, minimal math was used to come up with a solution.

Example 1: Analyzing Processed Signals

This example was chosen because of the overwhelming number of opto-electronic devices in use today without consideration for the *real-time* problems that are encountered. Noise, waveform distortion, timing of the signal pickup point(s), and other factors all come into play regardless of the system processing speed. As a matter of fact, in this example there is no motion consideration at all.

In photographic work, the measurement of light intensity in the three primary colors: red, green, and blue, is critical to the operation of the equipment used to develop picture negatives. The individual color intensities and ratio of the colors to each other are used to decide such things as time of exposure, shutter settings, and density. To ensure proper film exposure, the color settings must be known at all times.

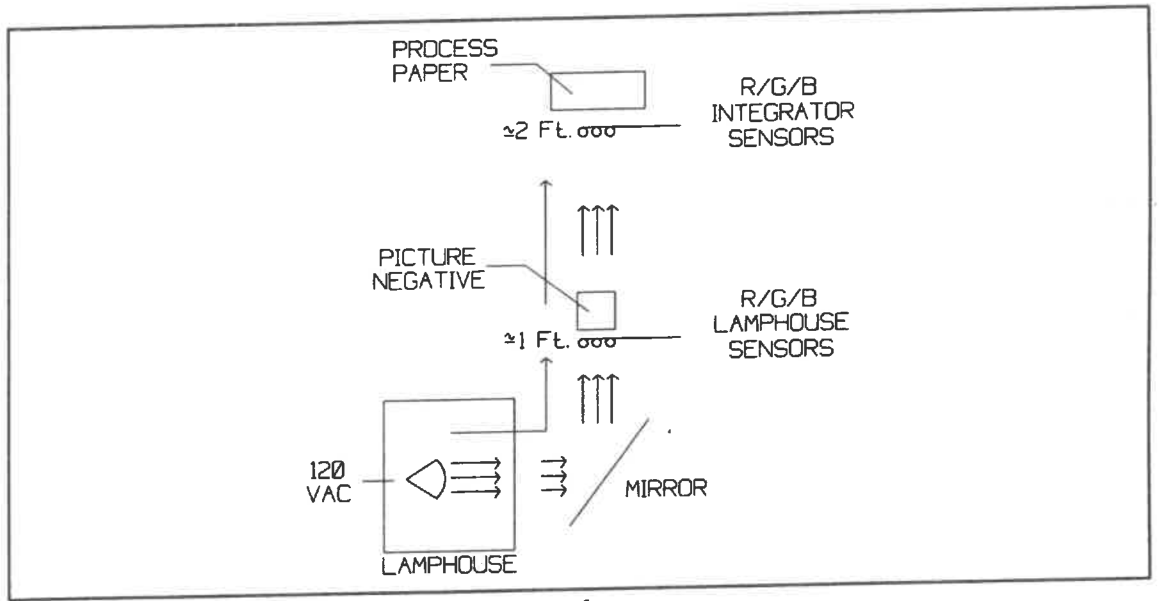

Figure 5.1 A motion system used to process photographs.

I was called in to resolve a problem with the intensity readouts. At high light intensity levels, the Red, Green and Blue readouts were unstable (±10%). At low light intensity levels the readouts would jump between zero and 500% of what they should have been (sometimes going negative). Figure 5.1 outlines the system mechanical configuration. Electrically, the white light source was powered by 120VAC to maintain the longest lamp life and lamp clarity. The photo sensors were operated by a low level DC current source feeding a logarithmic amplifier.

Any Ideas?

A clue to the solution for this problem, is to consider how the 120VAC power source for the lamp is affecting the light intensity and what the photo sensors are actually responding to. Also, keep in mind that light intensity received is reduced as a function of the square of the distance; that is, if the distance is doubled, the light intensity is reduced by a factor of four.

Example 2: Stable and Unstable Motion Control

A friend from California and I were discussing the dynamics of the mechanism shown in Figure 5.2. The system required a 100-count ballnut position-move to be made in 10.0 milliseconds or less. The required move for the motor in this case was slightly under one third of a revolution (113 degrees).

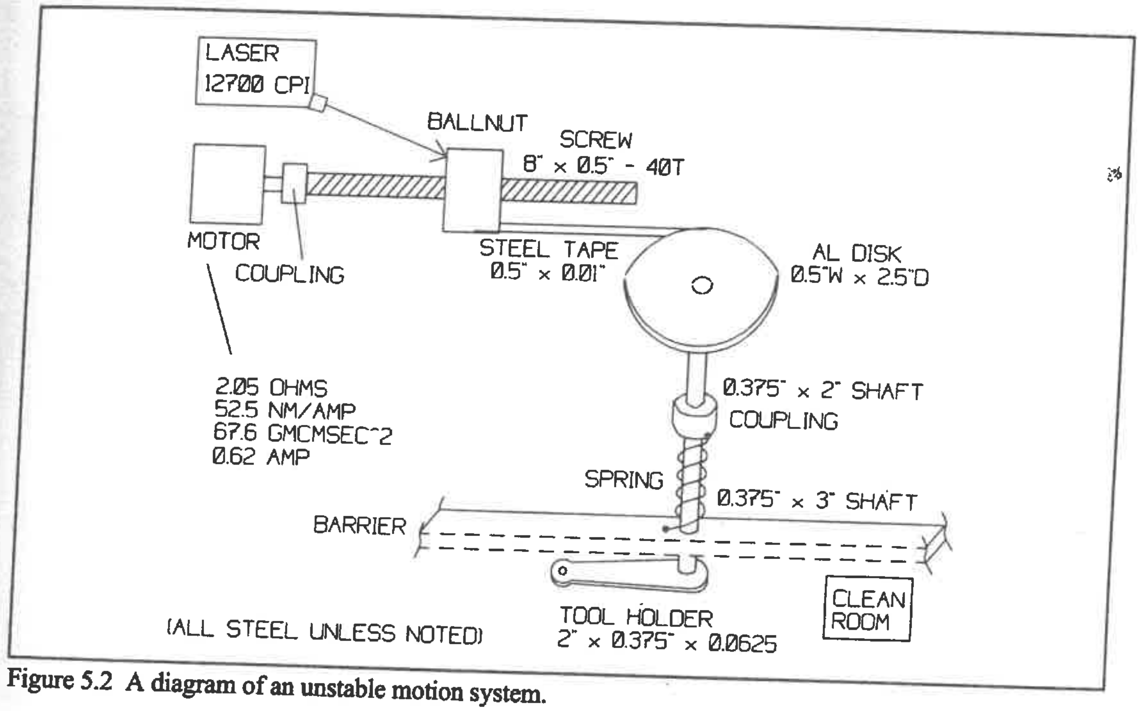

Figure 5.2 A diagram of an unstable motion system.

Any Ideas?

The interesting point of the design shown above is that it is **not stable** by any consideration. Notice that the forward move velocity of the ballnut is limited for all practical purposes by the spring. The reverse move of the ballnut can execute faster, but in this direction the spring will exhibit a restricting set of dynamics. In other words, you need to wait for the spring in one direction and fight it in the other. Also, if you allow the steel band to become slack when moves are in progress, it will eventually re-tighten and vibrate causing tool oscillation.

Obviously, the key to this design flaw is the spring and the steel band. Given the specifications for this system (approximately 0.334 degree tool-arm move in 10 milliseconds or less, including settling time), I cannot think of any reason why I would want to base the operation on a **spring**.

Something to note here is that the motion device must move a 1/2 inch wide x 2.5 inch diameter aluminum disk (7.853982 inch circumference). Assuming the couplings have no resonance and the tool arm as designed has no tendency to oscillate at the completion of a move, the inertia of the section from the ballnut through the tool arm is about 0.6 gm.cm.sec^2. Divide this inertia by 40^2 to get the reflected inertia at the screw, add the screw and coupling inertia, and it becomes obvious that the reflected torque at the motor shaft (even without the 40:1 screw ratio) is low enough so as not to be considered a factor in the ability of the motor to perform. The reflected inertia at the motor shaft is under 1.0 gm.cm.sec^2 without using the 40:1 screw compared to the motor inertia of 67.6 gm.cm.sec^2).

The real question then becomes . . .

What must the profile look like to do the required move, and can the motor and/or the motion controller produce it?

An analogy to this design is shown in Figure 5.3. What would the profile look like in order to move yo-yo #2 one foot to the left, as fast as possible, and stop without yo-yo #2 oscillating? How about moving yo-yo #2 (or yo-yo #1 for that matter) one foot to the right without oscillation? Where would the best spot for the feedback device be for either of these move requirements?

Determining the control of a system in *real-time* prior to working out the rest of the system requirements can and should be done to ensure minimal waste of time and money. Modeling a system mathematically, physically, or by time response analysis can do this for you.

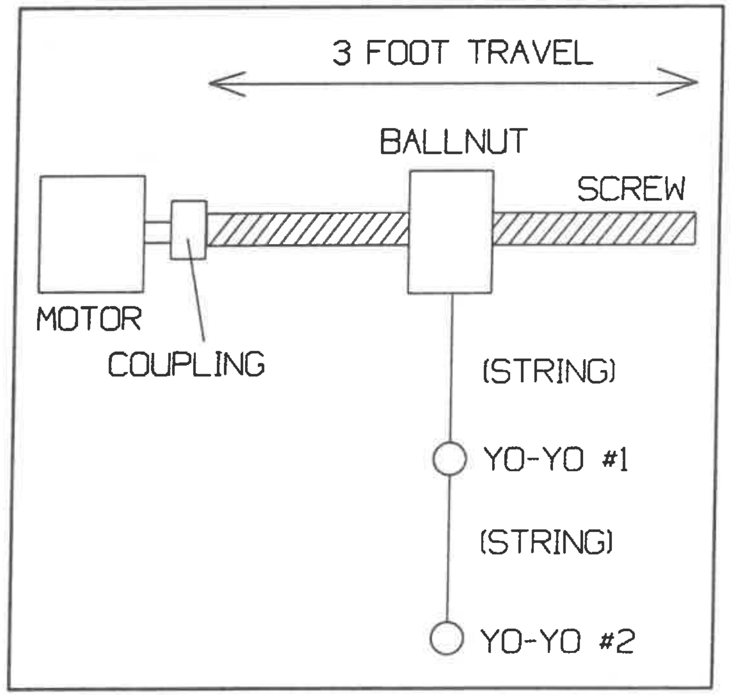

Figure 5.3: An analogy to the mechanism shown in Fig. 5.2.

Without diverting into a complicated discussion of periodic signal analysis, Baron Jean Baptiste Fourier demonstrated that any waveform existing in the real world can be generated by adding sine waves. Conversely, any real world signal can be broken down into component sine waves that can simulate the desired waveform. These two statements provide us the means to analyze what is happening (or about to happen) in our two examples.

By analyzing the light intensity signal generated by the light source in example 1 and then analyzing what the received light signal looks like at each of the opto-receivers stations, the problem and the solution becomes quickly apparent and *with no math!*

Similarly, by analyzing each mechanical section in Example 2 for its resonance frequency (or response time constant), and then overlaying each of these responses it becomes a simple operation to find out what the mechanical driving force requirement will be for the hi-speed, low-count move of the tool arm. It also allows us to figure out whether a given motor or computer control has the *real-time* capability to meet it and *with minimal math!*

Solution for Example 1:

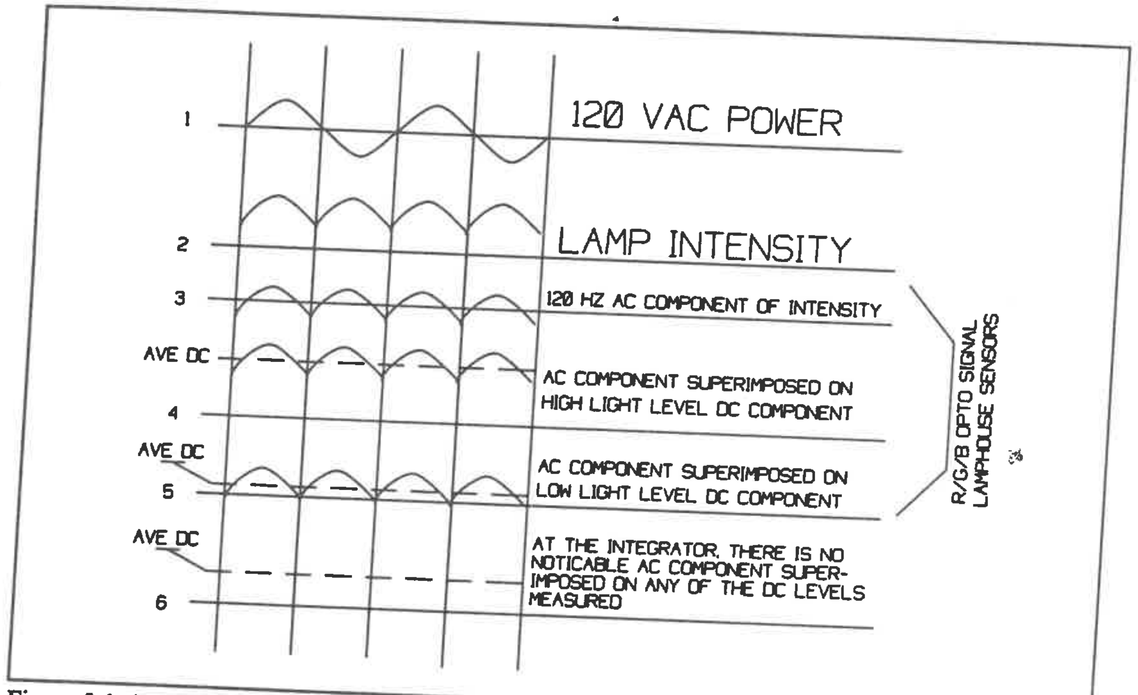

Figure 5.4 A periodic signal behavior diagram.

Figure 5.4 shows each of the power and intensity curves of the photographic development station in such a way that allows them to be viewed for analysis with respect to each other.

The lamp intensity shown in Figure 5.4, line 2 was created by the 120VAC power source shown in Figure 5.4, line 1. It is shown to have a base level (or DC) component on top of which an AC component (appearing like half-wave rectification) is riding (line 5.4-3). Notice that the intensity is always shown in the positive direction even when the power producing it is shown going negative. The DC level is formed by the time constant of the lamp filament producing the light and the peak 60 Hz voltage source value.

Figure 5.4 lines 4 and 5 show what happens when high and low level light intensities are received by the lamphouse R/B/G photo pickups. The AC component of the light intensity signal is significant at low light levels, and less significant at high light levels. If the software is not properly synchronized with the intensity producing signal source (in other words, the lamp voltage), then arbitrary readings will occur. At the lamphouse, the synchronizing position is at the zero crossover point of the intensity, which is 45 degrees after the zero crossover point of the 60 Hz power signal. This reading position will only allow average DC level reading to be taken.

Figure 5.4 line 6 shows that no AC component waveform is riding on the Integrator DC level. Therefore, we elected to take the readings at the zero crossover points of the power source 60 Hz.

The original problem was that none of the R/G/B readings were ever synchronized to the intensity source. Therefore, the computer was accessing the signal values randomly, at any point on the analog slope of the intensity. Hence, erratic reading operation.

Solution for Example 2:

To begin with, I passed on this project, for the simple reason that part of the given specification stated, "nothing mechanically is allowed to be changed". The underlying message here was that if there were any problems (even mechanical), they were to be resolved by electronic hardware or software methods. Since it is known that a system is an ordered set of interrelationships (a mechanical, electrical, and software integrated network of handling requirements), it would be like playing with a loaded gun to accept a restriction such as this. Although I'm still not certain whether or not this project has ever seen a completion date, it does not prevent me from discussing it in the light of what would have been a better solution, although far from the *best* solution and definitely not the only solution.

My first objective was to calculate the various system inertias. After doing that, I judged that by the size of the motor (67.6 gm.cm.sec^2) and the mechanics that it had to move (under 1.0 gm.cm.sec^2 without gearing), the screw was used simply to amplify the count resolution as it applied to the tool holder angular move. As a matter of fact, doesn't the leadscrew together with the steel band and the 2.5 inch diameter aluminum disk sort of remind you of a *worm gear* setup?

The resolution of the laser feedback device at the tool tip was approximately 272 *counts* per degree of tool rotation (1 count = 0.0036 deg.). However, using a zero backlash 40:1 worm gear drive with a 900-line encoder mounted on the motor shaft, you can achieve 400 *counts* per degree of tool rotation (1 count = 0.0025 deg.), which is 30% better, and have significantly less (if any) instability problems (refer to Figure 5.5).

An alteration such as this would have preserved the basic concept but would have eliminated the high precision ballscrew and nut, the steel band, the spring, and the expense of the laser ranging unit; not to mention reducing the overall physical size of the system itself. Also, the change would have eliminated the need for the highly intense math work required to deal with the system instabilities. Thus, the DSP processor could have been eliminated, simplifying the control. This, in turn, would have simplified the software requirement. In essence, the cost of this project would have been reduced by an estimated 50% for engineering, 30% for software, 60% for hardware; and perhaps 50% for construction labor, not to mention the long term maintenance and setup costs. Notice that by changing one thing, we created a domino effect in the outcome of all facets of the project.

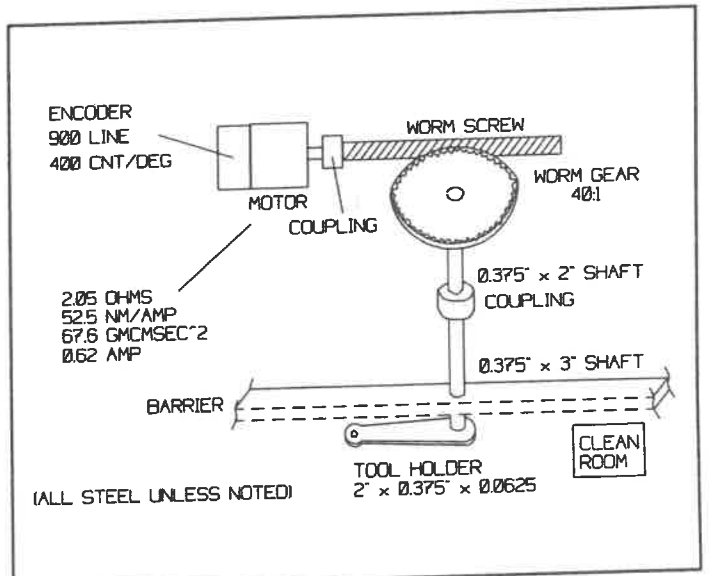

Figure 5.5 An improved motion system diagram.

The method used to solve this example is not the only method; and perhaps, it is not even close to a *best* method, but it should be obvious at this point that by using a little imagination and eliminating unnecessary restrictions, very complex problems can be reduced to everyday handling situations.

Going from a mechanically unstable system (Figure 5.2) to a stable system (Figure 5.5) is not only reasonably easy, it is good business. Why would someone actually **want** to try and make the system in Figure 5.2 work (other than as a learning exercise)? If it's *Pride of Authorship*, then you are not engineering, you are experimenting—and at someone else's expense.

The key here is to use your imagination. Each time you do a project, remember things about the tuning operation that was done, the resulting stability of the system, and the mechanics involved. Try not to invent methods that place enormous burdens on both the hardware and labor budgets.

P.S. – The DSP implemented to attempt to resolve the stability problem was only able to achieve stability in 19 milliseconds, almost twice the time called for in the specification.

P.P.S. – At one of my Tutorials, a mechanical engineer said, "Why not just mount the motor vertically on the main rotating shaft—thus eleminating the leadscrew, etc.?"—**Why not!**