DIRECT DIGITAL CONTROL IN MATERIALS TESTING SYSTEMS

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Abstract: Digital control techniques as presently used in material testing systems are essentially analog-/ digital hybrids. Physical advantages of digital technology, therefore relates to the digital part of the control only. The real advantage of digital control is its inherent flexibility. However, not all available systems use this potential. Based on software, different control algorithms can be downloaded to the digital controller. Control algorithms can use numerous feedback signals that can even be influenced by mathematical operations in real time (calculated variable control). This presentation outlines important issues of analog and digital control and points out the potential of digital technique using software written control modes.

1. Introduction

With the advances in digital technology have come its application to materials testing systems. Although this technology is exciting, some of the benefits it can provide for controlling test systems are still to be realized. This article will look at digital control in the context of materials testing systems, why digital control is replacing analog controllers, the real benefits digital control can provide in running materials tests and ultimately what really is important when considering a control system.

2. Understanding Digital Control

Analog and Digital Loop Closure

The materials testing industry has been using digital electronics in materials testing systems for many years in the area of data acquisition and computer automation. In these systems the computer was in a supervisory role with the analog controller closing the servo loop. More recently with the development of cost effective digital systems, digital electronics now replace a portion of the traditional analog closed loop. The key here is: "a portion of", since even in a digital system there are still key analog subsystems just as there always were in an analog system. Let's look at this further by comparing a simple functional diagram of an analog controller and a digital controller.

Figure 1 shows a basic schematic that could represent any analog controller.

In Figure 2 a digital system replaces the analog summing junction and the function generator with analog to digital converters (ADC), digital to analog converters (DAC) and a microprocessor (in current systems typically several microprocessors).

In a digital system the generation of the command signal is no longer done by electronic components generating an analog signal; instead it is software code running on a microprocessor that generates the digital data defining the desired command. Similarly the closed loop summing junction is not a number of analog components comparing two analog signals, but a software algorithm that mathematically calculates the error signal. The rest of the system, though, is still analog; there are still analog conditioners which calibrate and convert the transducer signals to useful levels and analog valve drivers to drive the hydro-mechanical servo-valves. ADC and DAC converters are needed is to link the digital parts of the system with the analog parts.

The importance of signal conditioning is often ignored when considering digital systems because the word 'digital' seems to imply by itself repeatability, accuracy and stability. This is only true of the controller part of the system. A digital controller does nothing to change the importance of low noise, low temperature sensitivity and accuracy of this important piece of electronics.

A digital controller is a discrete time system. An analog system by definition has essentially infinite resolution of the signals being used to control the system. A digital system on the other hand has a fixed resolution due to the ADC and DAC. In modern systems the resolution is 16 bits or roughly one part in 65,000. The desire is to use the highest resolution possible to be able to measure small changes in the transducer signals and more closely approach the continuous nature of an analog signal. Another key performance parameter in a digital system is its update rate, or how fast it does the closed loop calculations and updates the servo-valve. Unlike an analog system where the error signal, the closed loop control, is happening continuously, in a digital system it happens in discrete steps or time intervals. The ADC converts the transducer signal and gives that data to the microprocessor which then does the error calculation and other manipulations before handing the data off to the DAC to drive the servo valve. Even with today's current high speed digital electronics this process takes time. Up to a point, the faster this occurs the better the system will control and react to changes in specimen response, and the higher test frequencies can be. Generally analog systems today still have the edge in performance in frequency response over digital systems, but there are some unique capabilities that digital systems give us that can compensate for this deficiency.

Summarizing a comparision of analog and digital control systems will point to a few highlights:

- Today 's digital control systems are really analog-digital hybrids;
- The pros of using digital technology apply only to closing the loop;
- Many of the cons of analog are still present and still important considerations (conditioner accuracy, noise etc.);
- Since a digital system is a discrete time system, it has a finite resolution in terms of sampled values and time;
- Generally, greater sampling resolution and faster update rates are desired to more closely approximate an analog system.

Despite a digital system has lower resolution and lower frequency response than an analog system, the industry is moving to digital systems. Some of it is marketing bravado, but if you strip that away there are real benefits, particularly in the area of more sophisticated control capabilities.

Physical Advantages of Digital Control

Digital systems can be compared to analog systems by means of:

Temperature Effects

- Analog circuits are subject to temperature drifting and have time dependent characteristics. In other words, they age (e.g. calibration tweak pots change their resistance values over time).
- Digital components have no inherent temperature effects and no aging characteristics. Stored digital data does not vary with time (e.g. calibration parameters stored digitally never change, although since the conditioning electronics are still analog, some of the above problems with analog systems still apply).

Speed

- Analog leads in speed performance of loop closure rate, and transient response.
- With ever-increasing processor technology, digital systems are continuously catching up. Digital systems can also more intelligently anticipate the command and with the right control algorithms may in fact have better control of transient and high frequency waveforms.

Accuracy

- Analog devices are at the mercy of component tolerances which build up through the closed loop circuit.
- In a digital system:
  - Once digitized, accuracy is a function of the number of bits utilized;
  - Control algorithms can be used to control a variable of interest, that can not be directly measured i.e. plastic strain;
  - Algorithms can be used to linearize transducer input or valve driver output;
  - With sophisticated control algorithms more accurate control of the system is possible, (this is a key issue which will be discussed later).

Repeatability

- Analog designs will have more variation from one unit to another and from one point in time to the next due to temperature, aging and component tolerances.
- Manufacturing and maintaining analog systems often requires more "tweaking".
- Digital systems (exclusive of the analog parts) are by nature repeatable.

Flexibility

- Analog systems are generally limited in their capability to realize desired control logic functions and are more difficult to modify i.e. to change the control logic you need a soldering iron.
- Changes to a digital system are made in software and can be adapted to quite diverse control applications.
- Complex control algorithms are much more easily and cost effectively implemented digitally.
- Flexibility (if taken advantage of) is probably the single most significant benefit of a digital system.

Reliability

- Analog components, and analog pots are common failure points.
- Analog designs are more sensitive to board layout and "parasitics". Board layout is still part science and part art.
- The greater density of digital integrated circuits leads to higher reliability. Also board layout is more deterministic (although designing with high speed digital logic has its challenges).

Troubleshooting

- Analog systems are generally simpler, requiring standard tools such as digital voltmeters and oscilloscopes.
- Digital systems are complex. Troubleshooting often requires both a knowledge of the hardware and controlling software.
- Digital systems may lend themselves more to the use of diagnostic software, simplifying troubleshooting.

3. Advantages Digital Control Can Provide by Use of Software

All the issues discussed so far are important when it comes to providing benefits to the materials testing engineer. But in terms of truly advancing capabilities over analog systems, the benefits of digital controllers was only touched on above. The most important benefit is the ability to run more advanced control algorithms on the microprocessors closing the servo loop. In many of the current digital systems on the market today, the standard analog PID controller has been replaced in part by a digital loop without taking advantage of what digital control can offer. The real benefit of using digital control is the potential of using more sophisticated algorithms to control the system. Instead of running a traditional PID algorithm in the microprocessor, different algorithms can be used that are specifically tailored to the test.

With digital control it is also possible to control variables that cannot be directly measured, - calculated variable control. This is where the microprocessor closing the loop, instead of just comparing the desired command to the feedback from a transducer, compares the desired command to a calculated feedback. This process may, in fact, involve the feedback from more than one transducer.

As an example Figure 3 shows the digital control diagram in Figure 2 and with another feedback channel added. The microprocessor takes both feedback channels and passes them through an algorithm to generate a calculated feedback or calculated variable. This is then used to close the loop on a point-by-point basis (calculated for each update of the closed loop). The example shown mixes force feedback and strain feedback to get a form of strain energy. This may be an unlikely control mode in real life, but it demonstrates the type of control that may allow more accurate control of test variables that cannot be measured directly.

As another example a test can be set up that will be controlled by plastic strain. The control set up would combine two feedback channels strain and load. The load feedback would be modified by input of cross section of the specimen and modulus of elasticity of the material. The controlled parameter would be the difference between total strain and calculated elastic strain.

Numerous other examples could be set up depending on the needs of the operator. The control algorithm will be designed by the operator following a procedure that leans on general calculation rules and the possibility to combine feedback channels.

Using the TestStar digital controller as an example; the base system uses a standard PID controller which is perfectly adequate for many tests, but the system can be downloaded with different control algorithms and different software code, that enable it to generate and control in ways that were very difficult or impossible to do in an analog system. An example is an optional phase amplitude controller (PAC, patent pending) available with TestStar (Figure 4). If the feedback from

the specimen does not agree with the desired waveform the test controller will compensate for errors automatically with the PAC algorithm.
This allows accurate control of the amplitude of the waveform and the phase relationship between different channels of control (e.g. axial and torsion).
Figure 5 shows a typical feedback and the correction required by PAC to compensate for the errors inherent in a multi-axial test system. The PAC algorithm adjusts the valve command generated by the controller on every update of the control loop so that the phase and amplitude of the sine waveform agrees with the requested phase and amplitude. Every test system has a phase error due to the valve delay, the PAC algorithm anticipates this and removes it. This greatly reduces the need to optimize tuning of the system control loop, and the phase correction greatly simplifies multi-axial testing. Since PAC adjusts the waveform every time the controller updates the command to the servo-valve (point-by-point update, 5000 times a second), the feedback converges very rapidly to the desired waveform.

Other areas for advanced control algorithms in digital products are in compensation for non-linearities in the system. As a test system is pushed towards full scale of its operating range, the servo-valve response becomes more significantly non-linear which leads to inaccuracies in meeting the peak levels demanded by the system. To a large part these can be compensated for.

Other examples are adaptive control algorithms that learn how the system responds to a spectrum loading sequence, for example, and learns how much to adjust the peak values to ensure the desired command end levels are met. These are just a few examples of the real benefits that a digital system can provide.

It is important to realize that not every digital system has these capabilities. A digital system runs the software algorithms on a microprocessor. Many current implementations lock that software code in read only memory chips which makes changes to the algorithms very difficult (usually a service call is required). However the MTS TestStar, system as part of its start up sequence, down loads the control algorithms from the personal computer. Not only can different algorithms be run on the same machine, but as new capabilities are developed they are easily delivered to users on floppy disks. This makes updating the system very easy.

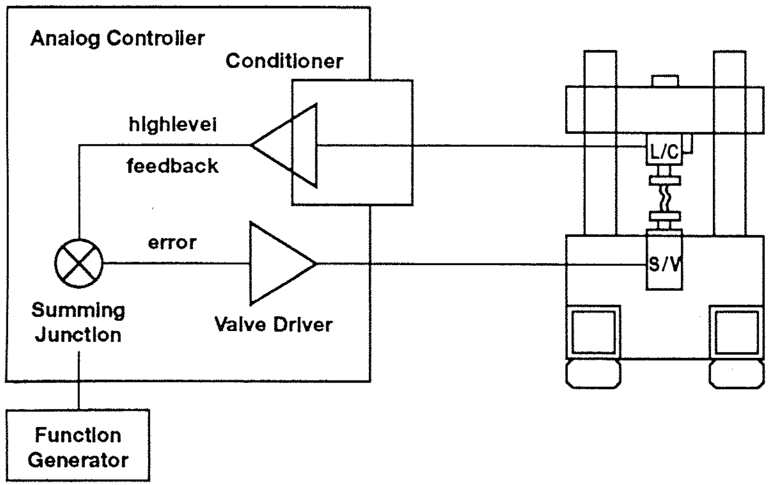

Figure 1. Analog Control System

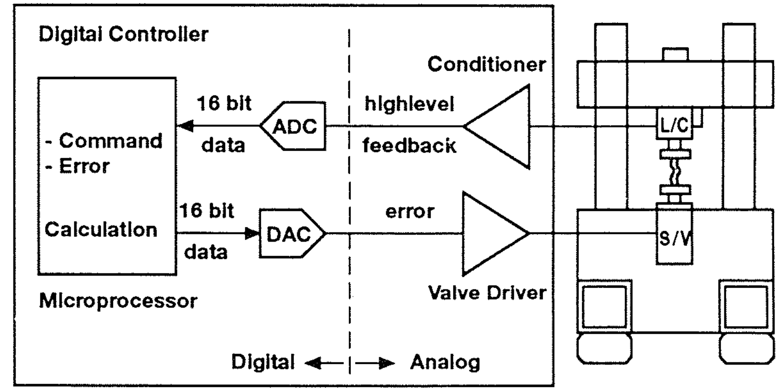

Figure 2. Digital Control System

Comparison of Analog and Digital Control Systems

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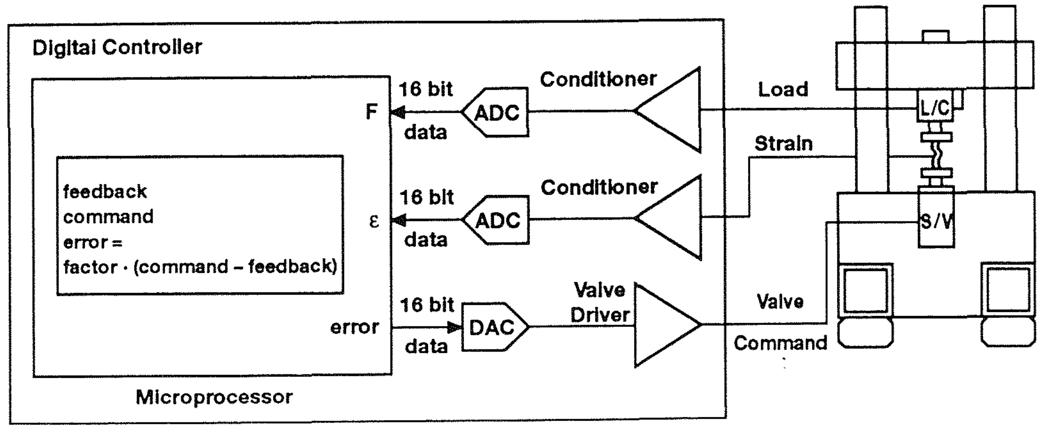

Figure 3. Calculated Variable Control

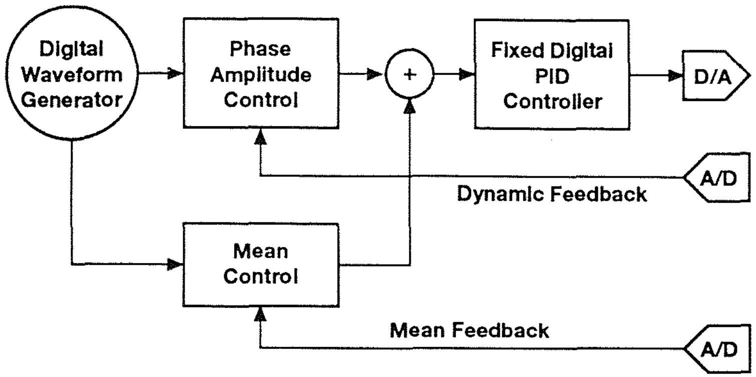

Figure 4. Phase Amplitude Controller (PAC)
Mixed Mode (PAC) utilizes three separate feedbacks in a cascaded control loop. Displacement for stable control
- *Amplitude feedback*
- *Mean feedback*

Compensation is continuously updatet in real-time

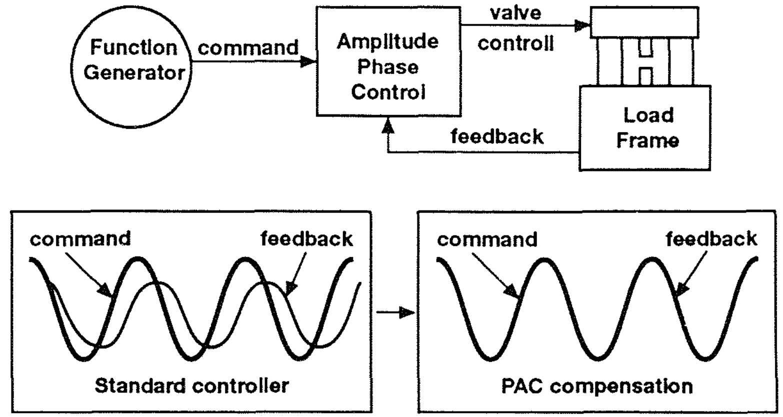

Figure 5. Phase Amplitude Controller (PAC)

Control Algorithms Used with TestStar Digital Controller

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