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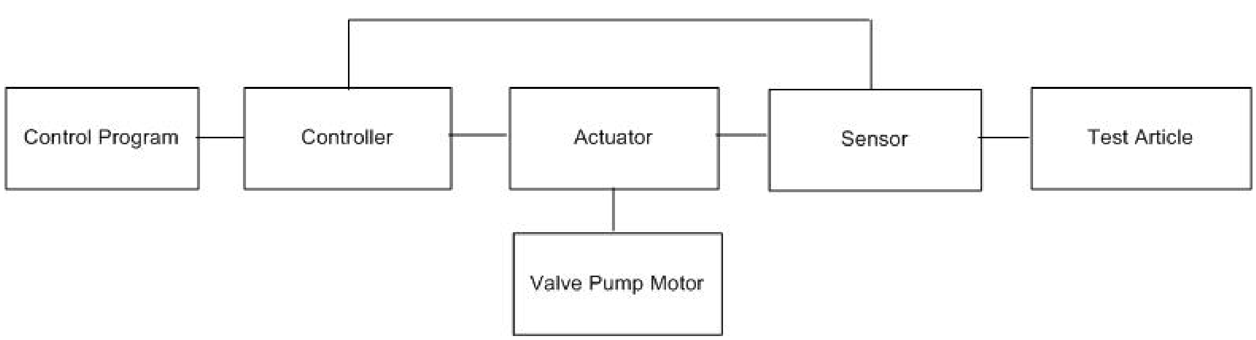
An Overview of Motion Control

Dynamic motion control through six degrees of freedom is an area that manufacturers have been reluctant to address because of its complex nature. Some examples of the types of motion control that can be associated with specific industries are shown below:

- Submarines- simulating emergency dive conditions
- Rocket – simulating fuel sloshing
- Biomedical- simulating vector loading on the human body
- Military tank – simulating multi axis vibration loading
- Wind turbines – simulating wind loads transferred to the main bearings and gearbox
- Helicopter- simulating pitch and roll motion
  -simulating evasive action
  -high frequency vibration loading
- Marine – simulating waves beating against the hull of a ship
- Combustion engines – simulating motion induced oil aeration
- Construction equipment- simulating driving on rough roads
  - simulating operation on hilly slopes
  - simulating digging operation
  - simulating digging in different soil conditions

Such systems can be divided into either of two categories. Slow systems that require response times in the one minute range and fast acting systems requiring a one second response. Each of these types of systems involves a different type of actuation, controller and control algorithms as shown in the figure below.



The current technology now is sufficiently advanced that test stands can provide realistic simulation of actual field conditions such that the results from a unit under test correlate very closely or in some cases provide an absolute correlation to field results. This is achieved by implementing a hardware in the loop(HIL) concept. HIL consists of the following functional capabilities:

- extremely fast responding mechanical and/or electrical hardware with low inertia and torsionally stiff components
- powerful computational hardware and associated processing capabilities
- high fidelity math models and load conditions

Control Strategy Summary

Of the three major building blocks of any motion control system, it is the control strategy that is the truly enabling factor. There are numerous types of control strategies that can be implemented to operate a test stand. The following table describes some of these and their characteristics based on increased complexity.

Comparison of Different Control Strategies

Control Type	General Characteristic	Precision	Linearity	Complexity
Logic Based	Mildly Nonlinear	Precise	Nonlinear	Simple
Gain Scheduled PID	Variability	Approximate	Nonlinear	Simple
Adaptive Gain Scheduling	Optimization	Approximate	Nonlinear	Mildly Complex
Fuzzy Logic	Robustness and Heuristic Intelligence	Approximate	Nonlinear	Mildly Complex
H-Infinity	Robustness	Precise	Linear	Mildly Complex
Quantitative Feedback	Uncertainty in the System	Precise	Linear	Very Complex
Model Based	Design Process	Precise	Nonlinear	Very Complex

Description of Various Control Strategies

A brief explanation of the above control strategies is as follows:

Logic Based- Use of mathematical logic for both declarative and procedural actions and is a backwards reasoning approach. Logic based control strategy uses cascaded binary logic for bang-bang control, supervisory functions and state machines.

Gain Scheduled PID – Provides control of nonlinear systems and is the simplest and most intuitive form of adaptive control. Gain scheduled PID employs gains that are scheduled based upon dominant system states. It is typically used for heuristic control of nonlinear systems to guarantee the same performance over various operating regions.

Adaptive Gain Scheduling – A control strategy made up of Finite Impulse Response adaptive modeling that requires a minimum of prior knowledge about the plant to be controlled. The system uses an algorithm that learns and stores the Adaptive Model Control weighted vectors under various operating conditions in a gain scheduling matrix. Adaptive Gain Scheduling is a time varying system involving effects such as wear and mass change. A characteristic of such a system is that it requires that it be controlled slowly relative to changes in time. A simple PID or gain scheduled PID will deteriorate in performance or even lose stability with age or time. To compensate for this, special adaptive algorithms change PID gains based on a cost function that embodies a time variance.

Fuzzy Logic – Is a multi valued logic approach that deals with reasoning that is approximate rather than precise. Fuzzy logic allows for human experience to be incorporated to control systems which in turn can be directly translated into logic that can deliver superior results compared to the previous listed methods.

H-Infinity – Synthesizes controllers to achieve robust performance using mathematical optimization applicable to multivariable systems. H-Infinity is a formal control synthesis approach that involves control of a system with a low level of uncertainty. The performance criteria used is translated into a mathematical optimization problem. It can deal with multivariable (multi-axis) systems with significant cross coupling. Using H-Infinity Control assures that stability is always maintained at the expense of control action with such action being dependent on the controller hardware characteristics such as actuator sizing and bandwidth.

Quantitative Feedback – Desired robust design over a specified region of plant uncertainty with time domain responses that are translated into frequency domain tolerances which lead to bounds on the loop transmission function. Quantitative Feedback is also a formal controller synthesizing approach that is used with a system to be controlled and that can be modeled with some uncertainty. It is a frequency domain based method that can allow for the design of a very high order controller, compared to a PID controller. Quantitative Feedback provides an excellent balance between performance and stability.

Model Based Control – Involves analyzing, synthesizing and simulating a plant and its associated controller and then integrating this into a complex structure to define models having advanced functional characteristics which allow for software testing and verification in support of HIL.

Model Based Control – There are several variations of model based control (MBC). In its most effective form, this method uses both a plant (system to be controlled) model and a reference model. It drives the behavior of a system so that it imitates a reference model. Typically the reference model is a well behaved, linear system. For example, to achieve the best step response, the reference model could be a second order system with critical damping. MBC is also very effective in HIL testing technology. All of the previous methods can still be re-used with MBC by defining desired performance as a response for the reference model to external inputs.

Actuation Hardware

For systems that require changing inputs to a unit under test on a per second basis the actuation hardware must have an ultra fast response. In the case of a typical hydraulic actuation system, the actuation components would consist of a control valve, cylinder and load cell. One type of a fast acting control valve uses an electrohydraulic direct- operated, servo proportional control valve. In order to be effective, such valves employ low friction pilot stages and have high resolution and low hysteresis. Typical response times of such valves are approximately 10 msec.

To achieve very high system response times, fast acting cylinders are required. Typically these are custom cylinders that do not contain seals and thus eliminate the associated friction drag associated with them. With the removal of the seals there is an obvious leak path around the piston. In these types of cylinders the piston to cylinder clearance is dramatically reduced along with its associated leakage. Working in conjunction with the hydraulic cylinder would be a load cell that would provide force feedback to the controller. The response time of a typical load cell is in the 1 second range.

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