An Advanced Random Shaker Control Algorithm
The Advantages Offered by the High Performance of SD2550 Shaker Control Systems

Overview

Closed-loop random Shaker Control algorithms used by SD2550 Systems employ both feed-back and feed-forward control error correction processes. Feed-forward processing speeds the control correction rate without compromising overall control stability. The control algorithms are also adaptive in nature. This allows the control system to follow changes in the dynamic characteristics of the test article.

Separate control loops are dedicated to controlling the shape of the drive spectrum and the overall RMS response at the control point(s). Coordination of these control loops results in an error spectrum that is symmetric, in the least-squares sense, in the control frequency range. The SD2550 control loop design represents an advancement of the state of the art, in vibration control, as compared to other available control systems.

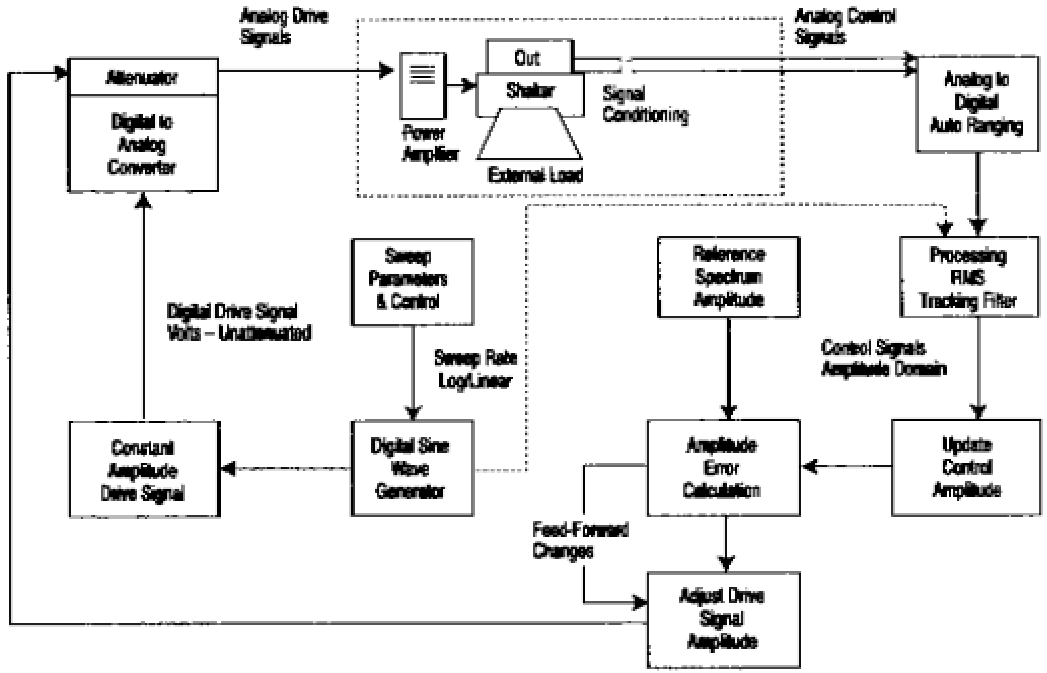
An Advanced, Adaptive Control Algorithm

Design of the SD2550 closed-loop control algorithms incorporates methods and parameters to minimize both control errors and the time the control system takes to achieve stable control. Control errors are caused by discrepancies between the Power Spectral Density (PSD) of the Control-Response acceleration signal, C(f), and a user defined Reference PSD, R(f).

To optimize both the system's control speed and loop stability, the control methods employ both feed-back and feed-forward error correction. Maximizing control speed and control stability requires proper coordination between these two control processes.

This combination of feed-back and feed-forward control processes, known as a Proportional-Integral-Derivative (PID) control process, allows the control loop to use larger feed-back gains. This design provides a very fast control process without compromising the overall control loop stability. PID control processing is a level of design sophistication not available with other vibration control systems.

The block diagram shows the control loop processing used in SD2550 Systems.



Control Loop Block Diagram

Feed-Back Control Loop Processing

The feed-back portion of the control-loop consists of measuring the error-spectrum (E(f)=R(f)/C(f)) as well as the RMS error (the ratio of the Reference RMS and the Control Response RMS). A portion of this error spectrum is added to the current Drive Spectrum to produce the Drive Spectrum for the next control loop iteration. Also, a portion of the RMS error acts on the output attenuator to quickly adjust the overall level of the drive spectrum. The control Degrees-of-Freedom (DOF) selected in the setup parameters determines the proper proportions of these two error correction terms.

Feed-back gain "α" governs the update rate for the drive spectrum. Feed-back gain "ß" governs the rate of change for the drive signal overall-amplitude. These feed-back gains are automatically calculated by the control system software. Properly choosing values for these gains, "α" and "ß", insures a responsive and stable control loop.

Feed-Forward Processing for Responsive Control

Feed-forward processing maximizes the control system's responsiveness to sudden changes in the overall level. The control loop uses feed-forward to "anticipate" changes in the overall control level based on the derivative of the RMS error. The control loop calculates this derivative by monitoring changes in the Control Response RMS between control loop iterations.

The feed-forward process mitigates the negative effects of the exponential averaging technique used to estimate the instantaneous Control Response PSD. This exponential averaging estimator acts like a low-pass filter that injects delay into the control loop iteration. Without a feed-forward, or derivative term, in the control process, control performance is degraded as the feed-back gains must be reduced to insure the stability of the control loop. Reducing the feedback gains lengthens the time required to fully correct errors in the Control PSD as smaller changes are made to the Drive PSD each loop iteration.

Without this feed-forward processing the time to re-equalize changes to the load dynamics can be unduly long. Test article exposure to high excitation levels results in either a overtest condition or damage to the test article. An example of this problem is the testing of devices with valves that actuate during a test. Closure or opening of a valve, during a test, results in a sudden change to the structural dynamics as the valve seats or unseats. Resonant frequencies shift, as the valve seats or unseats, causing over excitation at the new resonant frequencies until the control system re-equalizes. Feed-forward processing allows the control system to adjust to the change in structural response much faster than is possible if adjustments are based solely on spectral averaging in the main feed-back loop.

Inherent Control Stability

Design of the feed-back and feed-forward control loop structures limits control loop overshoot to no greater than 10% of the amplitude step or 1.25 dB, whichever is smaller. This enhanced stability, unique in the industry, allows the system to control effectively and in a stable manner even in the presence of non-linear loads. It eliminates wild loop-to-loop amplitude changes when controlling non-linear shaker systems or test articles. In fact, every day testing often demands compensating for the non-linear behavior of hydraulic shakers, or electro-dynamic shakers with hydraulic slip-tables, or complex structures.

Competitive systems do not provide this level of control system design. These systems use an older technique with fixed feed-back gain and no feed-forward processing. For these systems, the control system's stability depends on the operator's selection of "N" and "K" parameters. "N" represents the number of spectral averages per loop. "K" sets the exponential discount factor for averaging the control spectrum. These "N" and "K" parameters directly determine control spectrum DOF but indirectly affect the stability of the control system.

Larger values of "N", for a fixed DOF, reduce the effective feed-back gain of the control system, thus making the control system more stable but less responsive. The SD2550 control algorithm, on the other hand, attacks the stability problem directly. Values of the feed-back gains "α" and "ß" are designed to insure stable control loop behavior for all settings of control DOF. This eliminates the need for separate "N" and "K" parameters as operator adjustable parameters. The control system internally calculates the values of "α" and "ß" using a design formula that insures stable and fast control loop operation.

Superior Control Accuracy and Output Signal Generation

The Drive Spectrum shape results from the error between the Reference Spectrum and Control Spectrum. Amplitude normalization of the Drive Spectrum allows the resultant time-domain drive signal to use the maximum dynamic range available from the 16-bit DAC (Digital to Analog Converter). A 24-bit voltage attenuator sets the full-scale voltage level of the DAC. The attenuator allows the SD2550 to adjust the full-scale output voltage range in steps as fine as 0.1 dB. Fine output adjustment capability provides accurate control at both full and low test excitations levels. Also, the attenuator allows the RMS feed-back loop to adjust the Drive's RMS level without changing the shape of the Drive's Spectrum.

Output signal generation algorithms use time-domain randomization to generate a drive signal free of any discontinuities. Four-to-one overlap processing in the randomization processing optimizes the Gaussian purity of the drive signal. Output smoothing filters protect against out-of-band frequency content and harmonic distortion in the drive signal.

Implementation of this sophisticated design requires high-performance control system hardware. The SD2550 architecture employs multiple, high-speed processors and distributed processing to meet this computational demand.

Conclusion

SD2550 Control Systems feature an advanced adaptive random Shaker Control algorithm. This algorithm computes an adapting frequency response estimate of the test article dynamics. Based on this estimate, the control algorithm compensates for the dynamics of the test article to give the desired test spectrum. Feed-forward processing allows the system to track sudden changes in the overall level, minimizing the chances of an over-test condition. Further, the SD2550 multi-processor architecture and distributed processing provide superior control loop performance and safety.