

BIST (Built-in-Self-Test) Features for Electronic Valve Actuators

Abstract

The development and implementation of safety related devices in plant systems is crucial for dependable operation, not to mention peace of mind. Safety and safe operation were once only high priorities for installations that involve hazardous environments. Expensive certification testing was, and still is, paramount to meeting the hazards of such environments, but a new level of plant-wide integrity is emerging — that of Safety Integrity Level (SIL) and SIS. SIL is a safety rating that can be derived by analyzing a system to determine the risk of a failure occurring and the severity of its consequences. Safety Instrumented Systems (SIS) are systems containing instrumentation or controls installed for the purpose of preventing or mitigating a failure either by emergency shut down (ESD) or diverting the hazard. New or replacement equipment must have the ability to be introduced into plant systems without jeopardizing either the SIL of the operation or negatively impacting the SIS.

Electronic valve actuators, also known as “smart” actuators, are often selected for critical systems due to their flexible configuration capabilities. True smart actuators can present the user with a host of configuration options, usually in the form of “menus”, preferably in the user’s native language, that allow the user to easily select his or her desired operating modes. Because digital electronics based device controls can be affected by a variety of spurious activities such as electronic faults, component failures, or improper control signals, state of the art electronic actuator design should include means for verifying and validating that components are designed with Built-In-Self-Test (BIST) capabilities. Selecting a smart actuator that incorporates a high level of BIST can contribute greatly to the integrity and reliability of motor operated valves (MOVs) used in process applications. Placing a smart device into any plant system should enhance the ability of a given safety system to achieve its highest possible SIL rating. Any device which incorporates fully developed BIST features provides assurance to the user that the device has been designed with plant-wide safety and integrity of operation in mind.

BIST (Built-in-Self-Test) Features for Electronic Valve Actuators

Benefits of BIST

Smart actuation products have increased the performance capabilities for users through digital networks, ease of set-up, and elementary diagnostics. On the other hand, the introduction of electronics has also increased the level of sophistication required to troubleshoot these devices. When problems do occur, the devices can often be unpredictable. Inputs can be simulated for the purpose of controlling certain outputs, but because there are many components between any input and its resulting output, any component failure in a given signal chain can cause the entire signal chain to fail. Unfortunately, most MOVs cannot report that a signal chain has failed, a fact that typically comes to the user's attention only after an MOV fails to respond to a command, or, even worse, moves without a command. Also, the user is unable to determine what caused the failure by examining his or her control, monitoring displays, or measuring the signals at the terminal block. BIST is the technique of designing circuits with the logic required to test for the proper operation of a functional device and to help predict such failures before they occur.

When a device is designed to include BIST, much of the test functionality is embedded in the device itself. BIST design facilitates a critical component's ability to communicate its actual state to a CPU, where it is compared to the expected state. Any deviation from the expected values will be reported to the user with correlation to the failed component or sub-system.

The real benefit of BIST, not only for customers, but also for production and field service teams, is the increased speed in diagnosing the safe status of an actuator. With smart actuators on the plant floor today, maintenance or service crews must deduce which module is causing the problem when a test failure occurs. The actuator is often disassembled and suspect parts are replaced. The actuator is then reassem-

bled and tested to ascertain if the problem has been fixed. If necessary, this process is then repeated until the actuator performs satisfactorily. All but the last module replaced will then be recycled into the next actuator build and the failed module will be returned to the supplier for repair.

To counter this time-consuming trial and error repair methodology, smart actuators should have diagnostics capabilities that communicate the status of major components to the user, either via an LCD screen or over a digital network. Some smart actuators provide a rudimentary level of reporting, but they are still limited to the trial and error method of testing, offering messages such as "HARDWARE FAILURE" or "LOST SIGNAL", or simply not responding to a given command signal.

A true BIST design permits the Printed Circuit Board (PCB) to be pre-tested before assembly, thus rooting out most defects before installation into the actuator. Once field installed, diagnostics will proceed much more quickly as many of the tasks that are currently scheduled and performed by human intervention will now be automatically self tested by the actuator. With BIST, electronic defects that are detected during any stage of testing or actuator start-up will provide much more detailed feedback to the assembler, plant personnel, or service technician. BIST will allow them to quickly recognize and replace only the failed module.

Benefits of FFT (Frequency Domain Testing)

A well designed BIST based system can do more than just report failures in the electronic sub-systems. It can also determine failures or predict future failures in its associated mechanical system. One way to accomplish this is to employ frequency domain testing and analysis, which can be done using FFT (Fast Fourier Transform). This is the natural choice for rotating machinery, such as motor operated valves (MOVs).

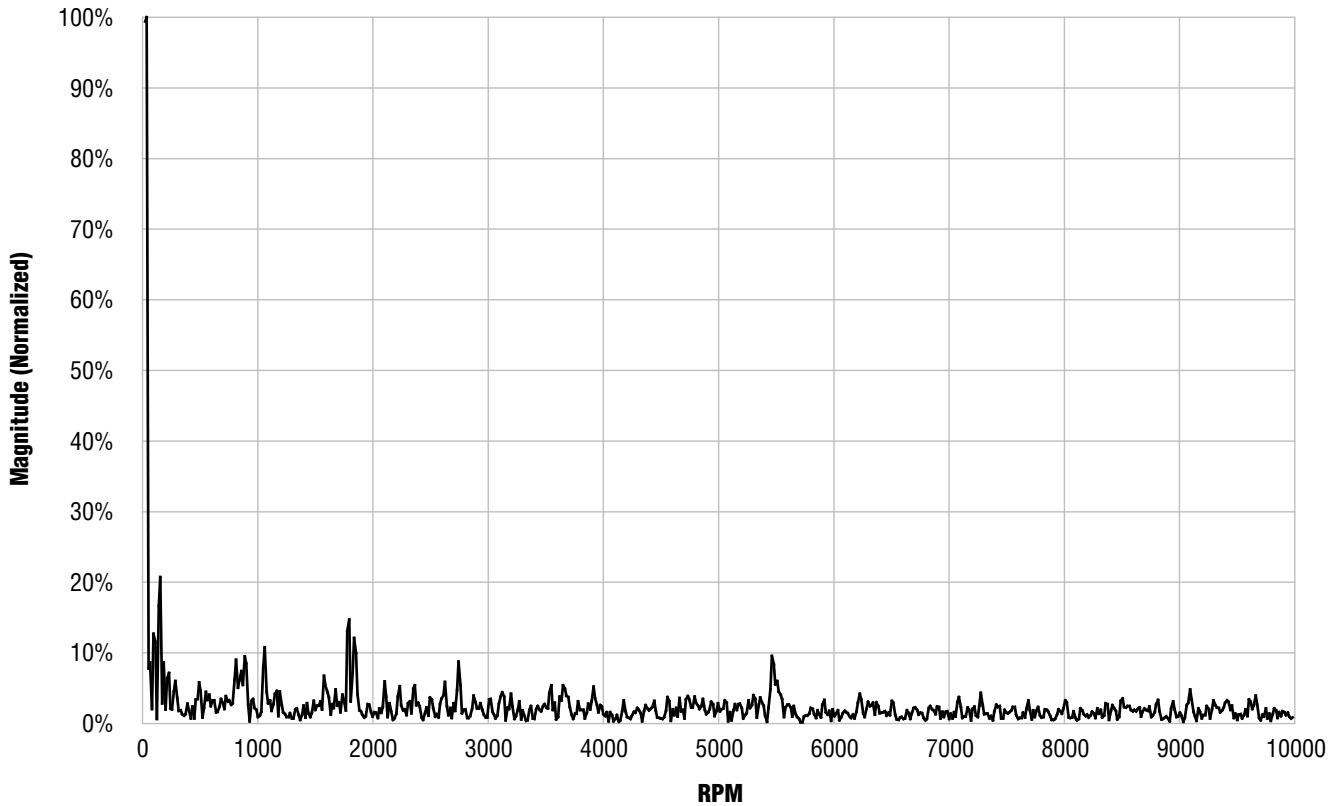


Figure 1 FFT of a sound, efficient worm gear set

Before this method is explained in more detail, some explanation of MOV operation may be beneficial to the reader. MOVs may be multi-turn, as in gate valves, or quarter-turn, as in ball valves. The actuator drive-sleeve may directly drive the valve’s threaded stem nut; be directly coupled to the valve stem; or be coupled to an interposed gear-reducer. The actuator is commonly powered by a 3-phase AC electric motor, which may be controlled by a reversing contactor, and is capable of stroking the valve in either the clockwise or counter-clockwise direction. The most common drive train uses an integrated worm gear set to increase the torque of the motor for delivery to a reduced speed drive-sleeve. As the motor rotates it drives through the worm set, which in turn is integral to the output drive sleeve moving the valve.

In sharp contrast to conventional electro-mechanical designs, smart electronic actuators use microprocessor-based printed circuit boards, various sensors, and firmware programs to drive output devices, which in turn interface to the motor controller.

It is often desirable to limit the maximum torque that can be applied to the actuator load (valve). For torque limiting applications, actuator manufacturers employ either traditional mechanical torque measuring procedures or else they replace the multitude of electro-mechanical parts with electronic torque sensors coupled with smart electronics that can use the torque signals appropriately for a given application.

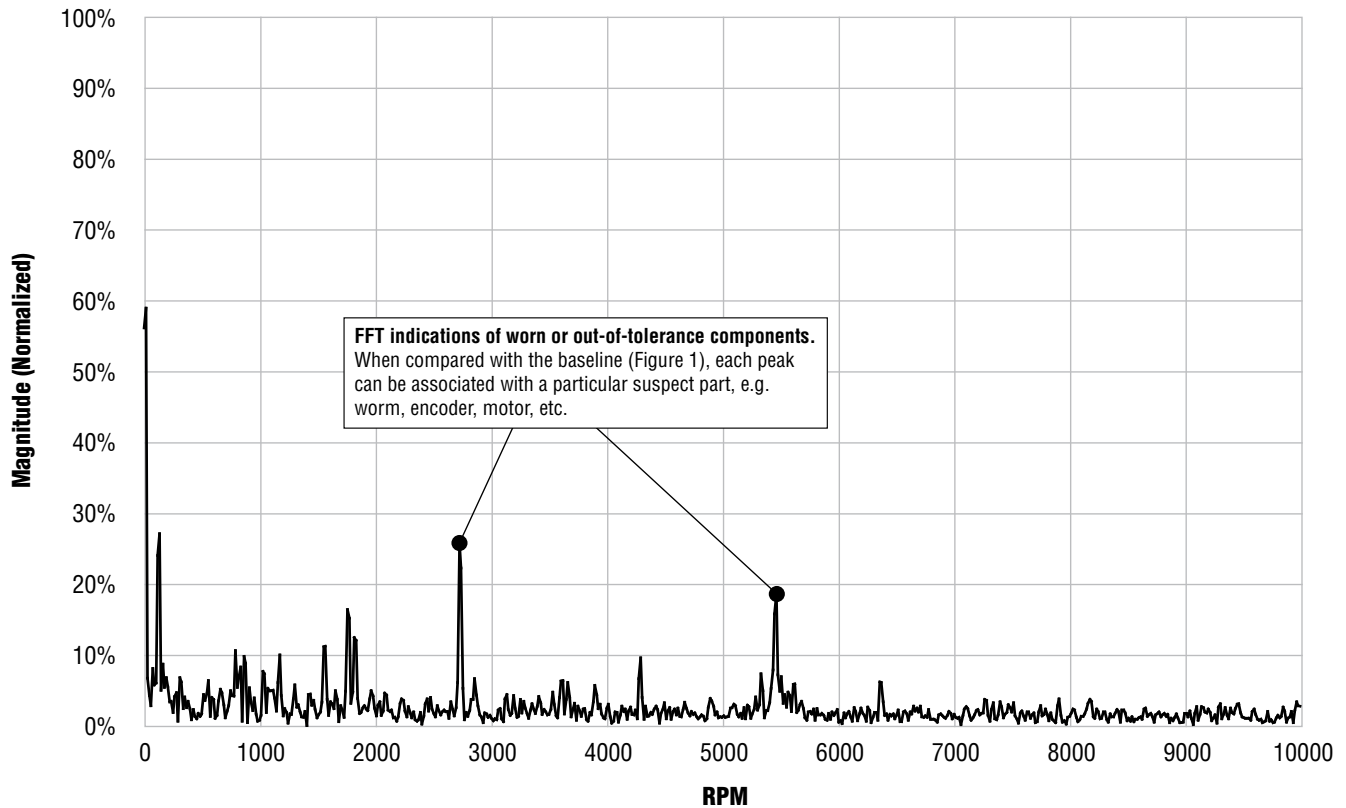


Figure 2 FFT of an actuator exhibiting a specific component that is out of tolerance due to excessive wear.

For position-sensing and limiting, an absolute or incremental encoder can provide the necessary values to the electronics package, replacing conventional gears/cams capable of forcing electrical-contacts open or closed. Not only do electronic actuators eliminate components that experience “wear”, but they also substantially reduce the number of mechanical parts, dramatically increasing service life.

Although the number of components susceptible to wear is sharply reduced in electronic actuators, there are still mechanical parts in these actuators that do experience wear. The ability to diagnose variations in the gear/motor train is critical to users who require rapid identification of potential problems. This is known as “asset management” — the acquisition of key data that enables a user to diagnose situ-

ations that may lead to down-time or adversely impact the SIL of a plant. Frequency Domain Analysis is an extremely desirable BIST enhancement to a smart actuator.

The frequency domain analysis methodology is implemented by capturing torque, position or speed values at regular time intervals while the actuator is motoring, then performing a Fast Fourier Transform (FFT) on the resulting data set, thus converting the actuator’s torque, position or speed signature from the time to the frequency domain. The resulting information is very useful for pinpointing any components in the mechanical drive train that have failed, or are about to fail. A well-built actuator will exhibit few variations and the resulting FFT should be relatively flat (See Figure 1).

However, if some part of the mechanical drive train has been fabricated with a physical defect, has been exposed to severe operational levels, or is nearing its normal end of life, then the frequency domain analysis will be able to detect and report a frequency variation in a chart or plot that can be correlated to the damaged part (see Figure 2) when compared to baseline (see Figure 1).

Because the manufacturer of the equipment is very knowledgeable about the spinning rates of all of the components of the mechanical drive train, it is easy to correlate any frequency spike on the FFT to a given component in the drive train. By embedding that knowledge into the firmware that drives the electronics, the manufacturer's expertise becomes embedded within the actuator, thus making it a true, expert device. For example, the build information for an actuator (gear ratios, motor speed, teeth per gear, balls per bearing, etc.) can be downloaded and stored in the electronics package. The on-board CPU will then be able to refer to this stored information and pinpoint which part of the drive is causing the variation in the frequency response. A plot of the FFT can be displayed directly on the LCD screen of the actuator or the data array can be downloaded to the user's asset management system or to a service technician's laptop or PDA for transmission to the home office for detailed analysis.

Creating a frequency domain analysis with sufficient detail requires a large number of data points that must be captured as quickly as possible. Shorter time intervals between samples can provide reports of wider frequency bands. On

the other hand, a large number of data points can result in higher resolution reports for better detailed analysis. Most of the data will be captured while the actuator is running at constant, steady state speed and moving from opened to closed or visa versa; not much data will be captured during a torque seating event. Even fast, short stroke valves can be analyzed in the frequency domain if the data is collected over several valve strokes. Once the data array has been filled to the point that allows FFT to run, data from any additional valve strokes will replace the oldest data in the array, thus providing the most current view of the condition of the MOV at any time.

Summary

Users should be careful to specify devices to be placed into operation that provide the most comprehensive predictive and diagnostic tools available. Safety system managers will be able to claim much higher levels of diagnosable faults, which will enable their systems to hold the preferred SIL ratings. Asset managers will also see reduced maintenance costs and great improvements in up-time because only those systems that are reporting BIST-diagnosed failures and/or predicted failures need be serviced.

Smart actuators can provide diagnostics capability with BIST and drive train Frequency Domain Analysis. These features offer the advantage of true asset management and can enhance SIL ratings. Benefits include rapid identification of potential component failure, reduced operational down-time, and the confidence to use such products in safety systems with higher Safety Integrity Levels.