

# **USING HART TO INCREASE FIELD DEVICE RELIABILITY**

Bud Adler  
Director, Business Development  
Moore Industries-International, Inc.  
North Hills, CA 91343

## **KEYWORDS**

HART Loop Monitor, Increasing Diagnostic Coverage, Safety Instrumented System (SIS), Safety Instrumented Function (SIF), Increased Reliability, Safety Integrity Level (SIL), Safe Failure Fraction (SFF), Failure Modes Effects and Diagnostic Analysis (FMEDA)

## **ABSTRACT**

For years, our industry's technical journals have been saturated with articles describing the numerous benefits that can be derived from implementing fieldbus strategies. One of the most significant is continuous on-line sensor, instrument, and loop diagnostics made possible through the use of microprocessor technology combined with digital communications.

No one would deny that detailed diagnostic information would be great to have. But at what cost? A wholesale upgrade to a full fieldbus strategy typically necessitates scrapping in-place analog and smart instruments, and replacing them with more expensive fieldbus-capable versions.

Cost considerations, in most cases, make a major retrofit like this out of the question. Most of us must continue to live with existing instrumentation. The irony is, continuous on-line diagnostic data becomes even more valuable as instruments age, and become increasingly less reliable. This is an especially valid concern when they are installed on critical applications. In such applications, an instrument malfunction could result in loss of life or limb, or could have serious economic impact from lost or sub-standard production.

What many don't realize is that scores of plants have all of the fieldbus diagnostic functionality needed already in place. The over 5,000,000 smart HART instruments installed in plants worldwide are capable of providing a wealth of diagnostic and performance data. The trick is to "unlock" the smart transmitter's full capabilities.

The key is the use of HART loop monitoring techniques that are rapidly gaining momentum through continuing education and a new sensitivity to improved measurement reliability for safety applications.

This paper will address the technology and methodology of using the HART protocol to increase the reliability and functionality of measurement and control devices.

## **INTRODUCTION**

Recently, catastrophic results of neglect or poor design in process plants have inundated the news with multimillion-dollar fines being imposed on manufacturers by OSHA, often followed by enormous settlements paid to victims or their families. Simultaneously, published standards (like ANSI / ISA 84.01 and IEC 61508) have heralded the guidelines of what constitutes a safe system. Concerned corporate management is paying more attention to risk analysis within their plants, and suitable measures are being taken to assure a reasonable degree of safety within the process operations. These measures include addressing the reliability of the measurement and control functions associated with critical processes. They speak of Safety Instrumented Functions (SIF) within Safety Instrumented Systems (SIS).

In March 2000, OSHA officially recognized ANSI/ISA 84.01 and considers systems designed to meet the requirements of the standard, to be in compliance with OSHA Process Safety Management (PSM) requirements for SIS. This recognition is now focusing more attention towards safety in many process plants.

A risk analysis determines a target Safety Integrity Level (SIL) to be reached by considering the reliability of all components of the SIF "pipe-to-pipe" (from the measurement to the final control element). Where reliability needs to be improved, the standards suggest methodologies ranging from additional equipment, to increased maintenance and augmented diagnostic coverage.

It is generally accepted that over 50% of potential loop problems may be attributed to improper or faulty operation of final control devices. The most frequent offenders include control valves, solenoid operated valves (SOV's), and emergency block or vent valves. Another 35% is attributed to sensor/transmitters where failed sensors or clogged impulse lines may allow dangerous conditions to develop unnoticed.

Mention of a safety or emergency shutdown system typically brings an image of a triple modular redundant Programmable Logic Controller (PLC) to mind. Most users assume that the decisions made by this system are based on reliable process information, and that emergency control devices within the

strategy would function upon demand. Many assume that their reliability concerns are answered by having three, or even four, layers of redundancy in the logic solver.

More recently, there has been increased concern over the other links in this “safety” chain. Some users assume that if one transmitter is good, comparing the measurements of two or even three was that much better. Little attention is placed on diagnostic coverage of measurement or control devices, apart from normal maintenance schedules.

When a risk analysis indicates that a particular loop is critical to the safe operation of a process, close attention must be focused on verifying the proper functioning of all components of that loop. This safety critical loop is referred to as a Safety Instrumented Function (SIF). Some plants do little more than perform scheduled maintenance and calibration to ensure the reliability of a field device. Others have realized there is much more required. On-line, continuous diagnostic coverage is the ideal strategy. If this coverage can warn of potential problems before they can cause trouble, all the better.

Many process engineers have been tolerating these problems for years. Some because the aggravations were small compared to other issues, and others because they just did not know there might be a solution.

Some examples include: Safety shut-off valves that either do not operate upon demand or operate unexpectedly; Control valves that go into oscillation because of sticking or low air pressure; and temperature or pressure measurements that do not accurately report true process conditions. Any of these may have catastrophic results.

When a risk analysis dictates that a particular loop must have increased reliability, every component of that loop must be analyzed for its contribution to the overall Safety Integrity Level (SIL). Achieving the designated SIL typically includes some combination of application of policies, procedures, and improved instrumentation. The solution may lie with more frequent maintenance or testing, a documented (and enforced) method of proper operation, and/or instrumentation upgrades.

## **HARDWARE CONSIDERATIONS**

### **RELIABILITY OF A FIELD DEVICE**

Keeping detailed failure records for all devices in the plant and using this data to evaluate probability of failure best quantifies the reliability of a device. Since this data collection is rarely done over a long period in typical plant operations, an alternative measure of reliability has been adopted. Using data accumulated by a number of different agencies, generic (and usually very conservative) data may be substituted. Some vendors, to provide more realistic reliability data, have used third-party evaluation agencies to conduct a Failure Modes Effects and Diagnostic Analysis (FMEDA) on their products. A result of this analysis is the calculation of the Safe Failure Fraction (SFF) for the device. The SFF considers both inherently safe failure modes and dangerous failures. It then considers which of the dangerous failures are identified by diagnostics and, of those, which are converted over to safe failures.

From a safe failure point of view, the higher the SFF, the more reliable the device. It must be recognized that even safe failures are still failures that may shut down a process. If they are due to failed sensors, they are considered nuisance failures.

## **BENEFITS OF CONTINUOUS HART MONITORING**

Most users are only aware of HART's advantage in providing remote configuration and the occasional loop check with a Hand-Held Configurator (HHC). While available in every HART device, they leave the wealth of diagnostic and performance data untouched. What most don't realize is the "hidden" information available from using smart HART technology offers tremendous opportunities to increase the effective diagnostic coverage of a field device.

To "unlock" valuable process and diagnostic information, a HART Loop Monitor is permanently connected across the 4-20mA signal wires just like you would when accessing the transmitter using a HHC. Once installed, it continuously monitors process and diagnostic data available on the HART digital protocol's data string. Many users have found this to be an easy way to extract a second measurement from a coriolis meter or a multivariable transmitter. Others want valve stem position as a 4-20mA value for control loop feedback.

The biggest growth area that has evolved for HART monitoring deals with vital diagnostic information that may be extracted from a field device. Intuitive use of this information can dramatically increase the reliability of the loop containing this device.

(REF 3)

## **CONTROL VALVES - REDUCED MAINTENANCE AND INCREASED**

While most valve operational problems are avoided by timely maintenance, this is seldom the norm. Reduced maintenance staffing, requirements for uninterrupted process operation, and reduced budgets are contributing factors that result in a "If it's not broken, don't touch it" mentality.

Valve manufacturers introduced smart positioners to their offering several years ago. These positioners provide dramatically improved valve performance and offer a capability for continuous monitoring of the valve's operational integrity. Remote readout of the performance parameters can actually diagnose developing situations before they become problems with potentially dangerous consequences.

Judicious use of the HART protocol has been the most successful method of achieving these goals. Smart HART positioners encode valuable performance and diagnostic information into a digital signal that is superimposed on the 4-20mA control signal. By monitoring this data back in the control room, overall performance is continually monitored, and abnormal conditions are immediately identified.

## **HART MONITORS CAN IDENTIFY/ACCESS:**

- Sticking/jumpy valve operation resulting from excess packing friction or shaft build-up.
- Sluggish operation, due to low air pressure that is often caused by clogged filters or piping leaks.
- Excess temperature within the positioner that may indicate degraded performance and shortened life.
- Actual stem/shaft position to allow monitoring of total travel (a monitor of packing wear), hysteresis (from excessive friction or low air pressure), excessive travel (worn packing with potential fugitive emissions), travel vs. flow (an indication of trim wear).
- Up to seven status bits may be monitored that will indicate any of several problem conditions identified by a change in state within the positioner.

By using a HART Loop Monitor, a myriad of potential failure conditions can be identified, and actions initiated to ensure more reliable operation. This increased diagnostic coverage effectively increases the SFF of the valve installation.

A HART Loop Monitor can be a single loop, stand-alone device that provides both relay status and analog signal interface between the HART data string and the DCS or PLC. This monitoring function may also be performed on a large scale by adding a HART front-end I/O subsystem and an appropriate software package to a host system (DCS, PLC or PC). The costs range from \$600 for a single loop approach on up to several hundred thousand dollars for a large system. For safety-certified PLC systems, a HART multiplexer is not included in the certification. Using external monitors with analog and discrete interface to the PLC is suggested.

(REF 1)

## **AUTOMATED BLOCK VALVES - INCREASING RELIABILITY**

For safety critical process operations, even a highly reliable control valve may not be depended upon to provide a tight shut-off in the event of a run-away condition. Another On/Off valve is often placed in the same line to afford this absolute shutoff capability. This is referred to as an Emergency Shut Down (ESD) or emergency block valve. Most commonly, automated block valves use a Solenoid Operated Valve (SOV) to apply air pressure to a diaphragm actuator to hold it open against a spring. In an emergency, the solenoid is tripped to vent air from the actuator, allowing the spring force to close the valve.

Reliability issues associated with ESD's that must be considered when doing a risk analysis:

- The SOV may not operate upon demand if it is an Energize-To-Trip (ETT) design.
- The SOV may operate unexpectedly if it is a De-energize-To-Trip (DTT) design.
- The SOV may function as required, but the block valve itself may not be operational.

There is an obvious solution for these problems that dictates frequent operational checks be done to verify operation of the SOV and proper stroking of the block valve. However, many continuous process operations have severe product quality or cost penalties associated with the loss of flow, due to the closing of a block valve. Consequently, these operational checks are not done frequently enough to achieve the SIL requirements of many processes.

Improving the reliability of ESD installations can employ other techniques to verify operational integrity that do not require closing the block valve. The concept is to increase the diagnostic coverage to a level high enough to provide the proper measure of reliability. The solution is different for systems using ETT or DTT schemes. Some designers prefer DTT schemes where any potential problem in the SOV circuit will cause a trip to a safe condition. If these trips are due to a nuisance failure in the SOV circuit, the result can be a costly and/or dangerous shutdown. To avoid nuisance trips, other designers use ETT schemes. However, they must ensure that the SOV will operate upon demand. Both solutions are described below.

- For ETT solenoids (normally de-energized), a trickle current through the SOV coil can be developed and monitored for abnormal conditions like terminal corrosion and progressive coil shorting, that could keep the SOV from operating upon demand. This technique also identifies wiring or power problems. Identification of any problem should trigger an immediate replacement of the entire SOV. This technique is referred to as cold coil monitoring or end-of-line monitoring. IEC standards suggest this method to achieve added diagnostic coverage. The benefit is that a potential catastrophe may be avoided without any interruption of the process flow.
- For DTT solenoids (normally energized), the energized coil current is monitored to detect potentially serious safety conditions and/or loss of production, caused by an unexpected nuisance trip. Excessive terminal corrosion will decrease current flow, while progressive coil shorting will increase current flow. If identified soon enough, a nuisance trip may be prevented. Coil failure is considered the leading cause of SOV failure. However, since there are also mechanical considerations that could keep the valve from operating, a wise user will replace an entire valve with questionable integrity as cheap insurance. This will require an approved safety procedure to jack the block valve in its open position to maintain process flow while the replacement is effected, and then verifying that the valve jack is removed. (REF 4 & 5)
- Some plants increase reliability by installing redundant SOV's. However, the costs associated with installation and wiring are high for retrofit installations. For new installations, installing dual SOV's will provide an added Layer Of Protection (LOP). Suitable installation enables isolation and testing of each SOV separately, while the other remains in service. Additional protection is provided by the monitoring just described.

Ensuring the reliable operation of an SOV on a block valve is only part of the story. The SOV may operate flawlessly, yet the block valve may not move due to corrosion or jamming.

## **ON-LINE PARTIAL STROKE TESTING OF ESD VALVES**

Safety shutdown valves typically stay in the open position for months or years awaiting a command signal to operate. In many plants, little attention is paid to these valves outside of regularly scheduled maintenance during “scheduled turnarounds”. The pressures of continuous production often stretch these intervals even longer. In some processes, build up or corrosion on the moving parts of these valves or their actuators can prevent them from moving. They are stuck in the open position. It is clear that for safety critical applications, something must be done to insure operability of the valve upon demand.

On-Line Partial Stroke Testing of the ESD’s has been demonstrated to provide a dramatic improvement in reliability. By regularly exercising the valve with partial stroking, the ability of the valve to move from its fully open seated position is verified. While this does not prove that the valve will, in fact, move all the way to its seat and close tightly, it offers far more confidence than doing nothing at all to test the integrity of the installation. A knowledgeable user will know the severity of the service and will draw conclusions accordingly. For clean gas, air, steam or water flow, the probability of full closure is high. For service with suspended solids or polymer, positive seating may be questionable. For clean service, the full stroke test interval may be extended, while for dirty service, a more frequent, full-stroke test may be required. In considering the diagnostic coverage provided, allowances must be made for the possibility that tight shut-off may not be achieved on the dirty or polymer service valves.

Partial Stroke Testing requires some method to verify valve stem travel. While limit switches have been used over the years, they present several problems. As a two-state device, there is no way to verify operational capability without a complete functional test. In addition, calibration/set-up is expensive and time consuming. Installation of an analog feedback device will considerably improve reliability. Using a smart HART positioner offers a reliable and self-diagnostic method to accurately determine stem position and verify actuator air pressure. Just as with the control valve scenario described above, the positioner communicates with the logic solver (PLC, PC or DCS) using a 4-20 mA signal with HART data digitally encoded and superimposed on the 4-20 mA using frequency shift keying (FSK).

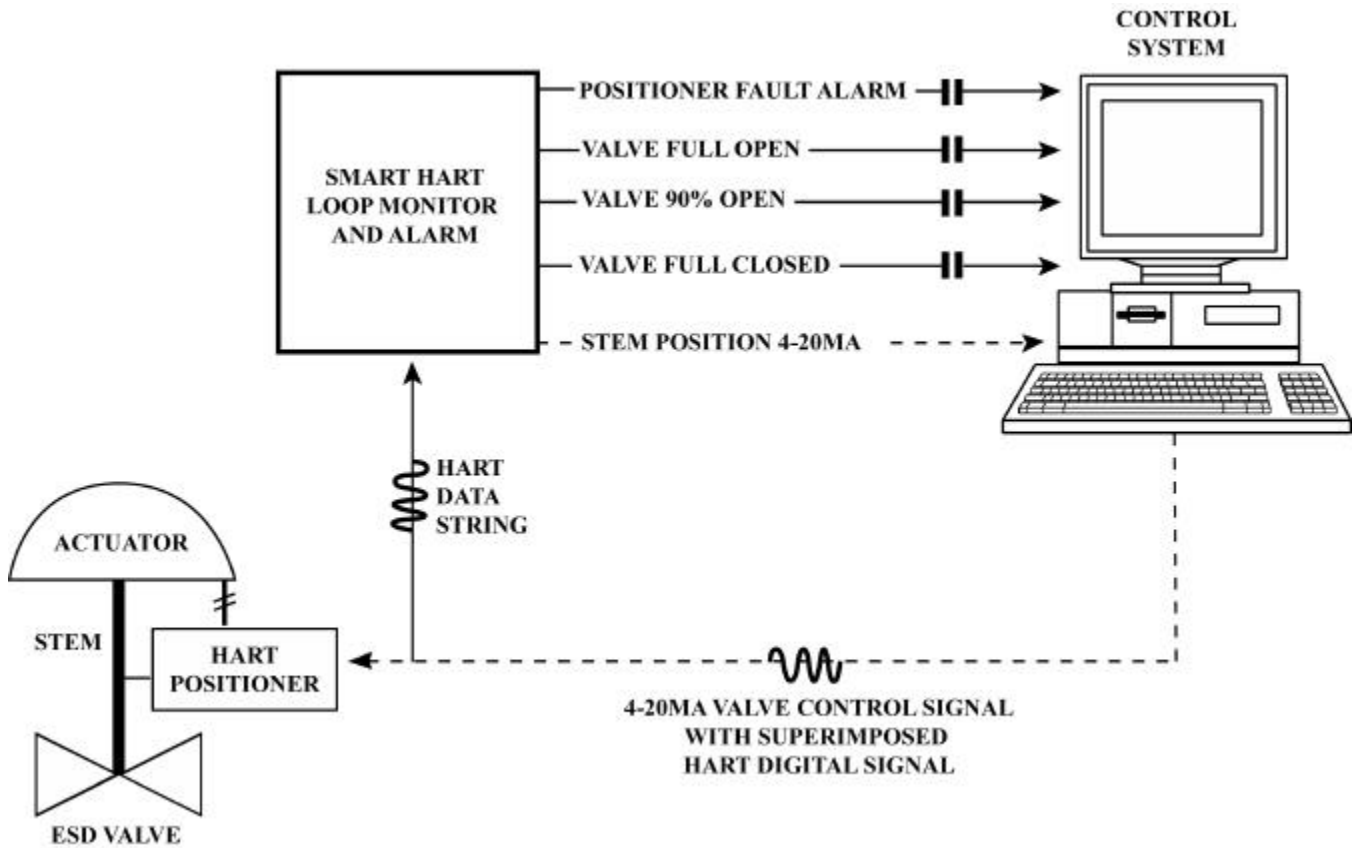
For this application, a HART I/O subsystem on the safety PLC is typically not used due to regulatory reasons. The hardware and software configuration of the safety PLC are precisely documented and certified by a recognized authority as suitable for use in a safety related system. Changes to the configuration are not permitted without recertification. However, a HART Loop Monitor is an external device that is mounted in the control room external to the PLC. It communicates through the standard I/O of the PLC with a 4-20 mA signal for stem position and relay status for stem position verification, air pressure and positioner diagnostic information.

The performance test is accomplished by changing the control signal from the PLC to initiate a partial close. For example, decreasing the signal from 20mA to 18.4mA should move the valve from 100% open to 90% open. The HART Loop Monitor is configured to close a relay when this 90% position is reached, which is used as a verification of stem movement. The signal is then returned to 20mA and a second relay verifies that the stem has returned to the full open position. Before beginning this test, the PLC can verify that there is adequate air pressure to reopen the valve using yet a third monitoring function that provides a relay-warning signal for low air pressure. The PLC can monitor the valve stem

movement vs. time to detect sticky operation that could indicate build-up on the stem or tight packing, providing yet another layer of diagnostic coverage.

Since most ESD valves are oversized, a 10% (or even 20%) partial stroke will have little effect on the process. Accordingly, this partial stroke test can be performed on a regular basis to add a high level of diagnostic coverage to the loop, and increase the interval for full stroke testing.

Many ESD valves are designed to provide rapid response to dangerous process conditions. For these applications, the SOV is used for the emergency trip function since it will vent actuator pressure very quickly. The 4-20 mA signal to the positioner can be dropped to 4mA as a back-up command to close the ESD, should the SOV fail to function. The somewhat slower closing is certainly better than no movement at all. This scheme increases the diagnostic coverage even further.  
(REF 2)



**FIG. 1 – A HART COMMUNICATING VALVE POSITIONER USED IN CONJUNCTION WITH A HART LOOP MONITOR PROVIDES A RELIABLE AND COST-EFFECTIVE ESD PARTIAL STROKE TESTING STRATEGY.**

## INCREASING TRANSMITTER RELIABILITY

It is widely accepted that pressure and temperature are the most common measurements in safety critical applications. When a risk analysis indicates that the reliability of these measurements must be improved, the user has several options to consider: 1). Replace the device with a newer and theoretically more reliable model; 2). Implement more frequent maintenance; 3). Install redundant transmitters, or 4). Implement on-line diagnostic coverage.

The amount of risk reduction needed to reach the required Safety Integrity Level (SIL) is suggested by the standards. Both ANSI/ISA 84.01 and IEC 61508 provide guidance on these various options. In many cases, the reliability of the measurement is determined by limits on the sensing of the variable. For pressure transmitters, a clogged or leaking impulse line could invalidate the signal from even the finest transmitter. Similarly, an improperly selected or installed temperature sensor limits both the accuracy and the integrity of the temperature measurement.

It has been a common assumption that Mean Time Between Failure (MTBF) data supplied by a vendor was an indication of the quality of the product. More recently, users have found that there is much more to the story. The MTBF data has wide latitude in its methods of calculation and may produce questionable results. In addition, MTBF does not consider whether failures are safe or dangerous. When a user wants to ensure a reliable measurement, he must consider diagnostic coverage of the measurement subsystem. The pressure impulse line and the temperature sensor are part of this subsystem and must be included in the consideration. It has never been truer that the system is only as strong as its weakest link.

Frequent cleaning of pressure impulse lines definitely improves reliability, but this procedure usually requires taking the transmitter out of service (a potentially dangerous situation). Temperature sensor problems can be subtle and difficult to isolate. Things like EMI/RFI, corroded terminals, shorted leads, poor response speed, and drift may cause significant errors. General guidance suggests that an error in excess of 2% is considered dangerous in a safety critical application.

Fortunately, there are several solutions to these problems. The MTBF issue is addressed by what is termed Failure Modes Effects and Diagnostic Analysis (FMEDA). There is a documented procedure for analyzing a device to consider what the effect is on the output, due to any of a wide variety of component failure scenarios. Further, these potential failures are classified as either safe or dangerous. Then an analysis is made of the ability of any on-board diagnostics to identify the failure, and convert any dangerous failures to a safe condition.

As an example, an open sensor lead on the input to a temperature transmitter is diagnosed, and the output is driven to a fail-safe value, usually full upscale or full downscale. The assumption is made that the logic solver will interpret this as a failure, and take the appropriate action. For a pressure transmitter, the on-board diagnostics address problems internal to the transmitter and may drive the output appropriately, but cannot identify clogged impulse lines. As of this writing, there are several pressure transmitter manufacturers, and only one temperature transmitter vendor that can supply FMEDA reports for their products. Use of these products provides a comfort factor that a high reliability device is being used with documented diagnostic coverage.

Smart HART transmitters offer added capability to increase measurement reliability. They encode a great deal of performance and diagnostic data into the HART signal that is superimposed on top of the 4-20mA output signal. By extracting this data, a user has the ability to remotely monitor the health of the transmitter and take corrective action for diagnosed problems, often before they cause dangerous conditions in the process.

Just as with the example of monitoring control and ESD valves, the user may use a HART I/O subsystem along with his DCS or PLC to monitor hundreds of HART field devices. For smaller projects on a budget, stand-alone single-channel HART Loop Monitors may be used. These single-channel units provide a 4-20mA output that may be assigned to any of the analog variables in the HART data string, and relay channels that can be configured to trip when any of these analog variables exceeds preset limits. Another relay channel will trip when any of several diagnostic conditions within the field device occur. By monitoring this information in the host system, a very significant increase in diagnostic coverage is provided. As a result, the reliability of the measurement is increased and the risk associated with the measurement function is reduced.

(REF 3)

## **HART BASED DIAGNOSTICS**

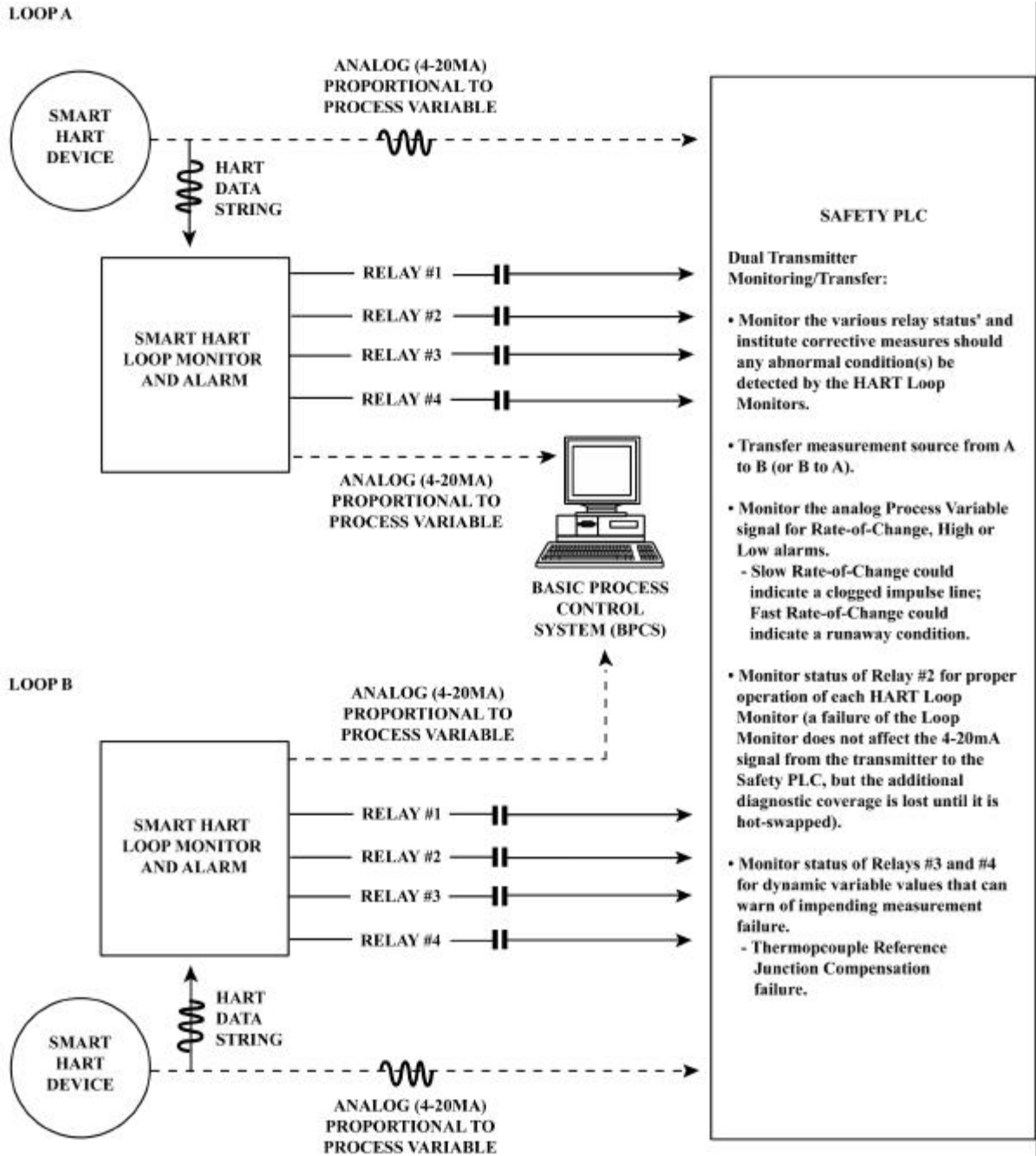
These are some of the insights that HART diagnostics can provide:

- Primary variable out of range (could indicate invalid measurement or possible sensor damage).
- Secondary variable out of range ( such as failed temperature compensation).
- Output fixed (device left in manual loop test mode, or locked up, or clogged impulse line, or failed sensor).
- Over-temperature within field device, such as with a positioner, coriolis meter, differential pressure or pressure transmitter (could cause damage).
- Configuration changed (warns of potentially unauthorized access).
- Degraded pH probe performance.
- Low air pressure in a valve actuator.
- Excess valve friction.
- Excess travel warning on valve (may indicate worn packing).
- Loss of HART communication.
- Device malfunction (output may still be within range).

## **HART MONITORING**

Within every HART-smart transmitter there are up to four dynamic variables. A HART Loop Monitor can extract up to three of the four as independent 4-20mA signals, and even provide alarming functions with relay outputs. For example:

- Density signal from a coriolis mass flow meter.
- Temperature measurement from a multivariable or pH transmitter.
- Valve stem position feedback (With Open/ Closed status).
- Pressure, DP and temperature from a multivariable mass flow transmitter.



**FIG 2. – A SMART HART LOOP MONITOR IS ABLE TO “EXTRACT” VALUABLE PROCESS AND DIAGNOSTIC INFORMATION THAT WAS PREVIOUSLY UNAVAILABLE ON A CONTINUOUS BASIS.**

**HART Loop Monitor Diagnostic Opportunities (FIG. 2):**

- **Relay #1**—Triggered by any or all of the HART diagnostic status bits defined as:
  - Bit 1:** Primary Variable (PV) Out of Range.

**Bit 2:** Secondary Variable (SV) Out of Range (such as with failed T/C Reference Junction Compensation).

**Bit 3:** Primary Variable Analog Output Fixed (loop was left in manual mode or no input change).

**Bit 4:** More Status Available (signals a change in any of up to 40 other available status bits defined in the device).

**Bit 5:** Cold Start (power was interrupted).

**Bit 7:** Field Device Malfunction (inclusive of all abnormal conditions).

- **Relay #2—HART Loop Monitor Fault Alarm**

Monitors itself and trips if any operational irregularities are detected.

- **Relay #3—High/Low Alarm**

Configures to monitor any of the four Dynamic Variables (such as low device temperature that could indicate heat trace failure).

- **Relay #4—High/Low Alarm**

Configures to monitor any of the four Dynamic Variables (such as high pressure to trigger local shutdown procedure).

- **Analog (4-20mA) Output**

Configures to be proportional to any one of the four Dynamic Variables (including sending the Primary Variable to a BPCS).

**NOTE:** There are conditions monitored by a HART device that may be crucial to the proper functioning of the device that are not overtly covered in the above list. Usually these conditions change the status of a specific HART diagnostic status bit. These status changes will, in turn, trigger a status change in bit 4 and be indicated by a trip of Relay #1. A Hand-Held Communicator can then be used to identify the precise condition that triggered the alarm using Command 48.

## CONCLUSION

The benefits of a digital fieldbus are many for new installations or major upgrades. However, HART protocol exists today in almost every process plant. All that is needed is the commitment to use it. Using HART Loop Monitoring can provide benefits from extracting additional measurement information from an existing transmitter with no pipe penetration, installation or cabling costs. Also, reduced maintenance costs may be realized by using the remote analysis capabilities of HART Loop Monitors for valves and pH transmitters. Adding HART diagnostic coverage to a transmitter or a valve may be the difference between improving the reliability of an existing installation, and needing to purchase and install a redundant device to meet the required SIL of the function.

## REFERENCES

- (1) Adler, Bud, "Save Maintenance Costs with HART Loop Monitors", HART LINE Newsletter, 2000, Number 2, Cover page.

- (2) Adler, Bud, "HART Provides Cost-Effective Alternative for Online ESD Valve Testing", HART LINE Newsletter, 2000, Number 3, Cover page.**
- (3) Adler, Bud, "Continuous HART Communication Increases Safety Integrity Level (SIL)", HART LINE Newsletter, 2000, Number 4, Cover page.**
- (4) Adler, Bud, "AC Solenoid Coil Monitoring", Moore Industries Tech Note, March, 2001.**
- (5) Adler, Bud, "DC Solenoid Coil Monitoring", Moore Industries Tech Note, March, 2001.**
- (6) Gruhn, Paul, LeBlanc, Tom, Pittman, Joe, Wiley, Susan, "Increase Plant Safety With Online Valve Testing", Intech, February, 1999**
- (7) Summers, Angela, Zachary, Bryan, "Partial-Stroke Testing of Safety Block Valves", Control Engineering, November, 2000**