Watchful eye

Field instrument diagnosis and its efficient use in process plants

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Modern field instruments provide a large number of diagnostic functions. The discussion is therefore about how the user should handle the considerable amount of additional information. In this regard, the article represents an on-going standardization activity and describes new concepts of ABB which enable clear and efficient exploitation of diagnostic information. For the customers, this means better instrument and plant performance.

The prevention of downtimes and an increase in availability are among the greatest challenges currently facing operators of processing plants. There are years when some industrial plants, owned by leading chemical companies, have maintenance costs that exceed 50 percent of their annual profits! With this background, attempts have been made to replace expensive "preventive" maintenance by event-driven "predictive" methods.

Field instrument diagnosis plays a central role in this respect. But what does "diagnosis" entail? Errors can arise in the instrument itself (eg, an electronics error without an external effect) or be induced by incorrect use in the process (eg, the entry length is too short with certain flowmeters). Each diagnosis starts with the detection of certain symptoms in the field instrument, such as an atypical fluctuation of the measured value. Needless to say, it is not enough to display such symptom messages to the user.

Diagnosis should always lead to detailed instructions for action. These can be initially determined at the level of an individual instrument (instrument-specific instructions for action). In addition, the information should be put in the context of the entire plant to provide the end user – respectively the operator – with corresponding plant-specific instructions. This subject is currently of interest to many automation manufacturers and is the mainspring for the development of advanced global diagnostic techniques.

Guideline for self-monitoring

The Expert Committee (6.21) of the VDI/VDE's (Society of German Engineers) Society for Measurement and Automatic Control (GMA) is currently working together with the Association of Process Control Technology in the Chemical and Pharmaceutical Industry (NAMUR) and members of the International Instrument Users' Association (WIB) on a new guideline (VDI/VDE 2650) for self-monitoring of field instruments with HART or fieldbus communication. It will also be published in spring 2006 as a new version of NAMUR's recommendation, NE 107.

The objective of this work is to create an understanding between instrument users and manufacturers about frequently occurring errors and appropriate types of diagnosis in the various types of field instruments.

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Status signals

In addition to this, a new description of the status signals used as standard in field instruments is being drawn up. Three have so far been defined by NAMUR's Worksheet, NA64:

- *"Function check"* (symbol "C"). Work is being carried out on the field instrument and the output signal is therefore temporarily invalid.
- *"Maintenance required"* (symbol "M"). Although the output signal is still valid, the reserve will soon be exhausted, or a function will be restricted in the near future as a result of the service conditions.
- *"Failure"* (symbol "F"): The output signal is invalid on account of a malfunction in the field instrument or its peripherals.

In future, field instruments should also be able to report an "Out of specification" (symbol "S") status. In other words, the instrument is currently operating outside its specified range, or deviations have been detected which can either be attributed to internal problems or to process characteristics.

A field instrument should always display only one of the signals at any given time. While the application of "Function check" is evident, it is not so for the status signals "M", "F" and "S". The fundamental difference lies in the desired evaluation of the measured signal by the user:

- In the case of "Maintenance required" the user can assume that the specified accuracy of the measured value is still available.
- If "Out of specification" is displayed, the measured value may still be useful, but the measurement accuracy is probably adversely affected.
- A "Failure" signal indicates that the measurement should be considered invalid.

Instrument-internal diagnoses are therefore assigned to these cases in accordance with the manufacturer's knowledge and mapped to "M", "S" or "F". To illustrate this, suppose an instrument is suitable for a specified temperature range according to the manufacturer's specification. Therefore, a "failure" no longer has to be signaled immediately when marginal infringements of the range limits occur. This would certainly improve the current situation whereby the operator has to evaluate this as a complete instrument malfunction and initiate a technically unnecessary exchange of the instrument.

The new status signal accommodates customer requirements for greater flexibility. In the case described above, an "Out of Spec" signal, indicating that something is not OK at this measuring point because of instrument-internal or process-induced errors, would be more appropriate.

The display should only change to "Failure" if an instrument or application parameter, ie, the process temperature in this case, deviates significantly from the permissible range.

Instructions for action as the goal

In addition to this, the new guideline fulfils a fundamental requirement: the most important diagnostic functions and messages are those from which either the operator can derive unambiguous individual actions. This means the operator, or maintenance personal, must receive all the information required for safe operation as early as possible. It would be appropriate if the operator only sees the status signals and can assign them to precise system-specific instructions for action. On the other hand, maintenance personnel should have easy access to all the available detailed information and also receive precise, system- and instrument-specific instructions for action.

No diagnosis is better than an incorrect one

Users have strongly indicted that they would rather dispense with diagnosis than have to deal with a spate of dubious error messages. Therefore, equipment manufacturers have ensured that detailed user experiences and requirements have been incorporated into the guideline by creating lists of desired diagnoses for instrument faults and application-specific errors.

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Nowadays, many of the generally known diagnostic functions work very simply and reliably. However, even advanced diagnostic functions are not immune from errors. This can be illustrated by the following example:

Field instruments in certain applications may be affected by a certain error "F". These instruments are equipped with a self-monitoring function which definitely determines a certain symptom "S", from which conclusions can be drawn about the error F. The result of each test for the error F, using symptom S, then falls into one of the following four categories: true positive (error discovered), true negative (no error, no symptom), false positive (no error, symptom is present in spite of this, possible false alarm), false negative (error not detected).

A result distribution of 1 million checks of the symptom S is shown in 1. The conditional probability that symptom S is activated in case of error F is referred to as sensitivity. If the sensitivity is high there is a high probability that errors are detected. In this particular case, the sensitivity is approximately 83 percent. The conditional probability that no error is indicated in error-free operation is referred to as specificity. In the above case, it is calculated at 99.99 percent. High specificity means false alarms are unlikely.

Although the values in this example inspire confidence, a sophisticated evaluation of the self-monitoring results is required since the error is actually present in only five out of ten cases in which symptom S is signaled. The so called "positive predictive power" of the error test is therefore only 50 percent. Nevertheless, monitoring of symptom S has a purpose. If a symptom, S, is not present, the instrument is not affected by an error, F, in 999,989 cases out of 999,990. This high "negative predictive power" of approx. 99.99 percent helps the user to exclude errors and thus prevent the unnecessary disassembly of the instrument. The user can then focus on finding the real cause of the problem. It may in fact be more appropriate to map the error symptom, S, to an "Out of Spec" signal and initiate a check of the measuring point.

1 Example distribution of one million error tests on a field instrument

	Error F is present	Error F is not present	
Symptom S is present	Correct-positive 5	Incorrect-positive 5	Number of cases in which the symptom is present 10
Symptom S is not present	Incorrect-negative 1	Correct-negative 999989	Number of cases in which the symptom is not present 999990
	Number of cases in which the error is present 6	Number of cases in which the error is not present 999994	Considered number of checks of the symptom S 1000000

Typical application cases

Differential pressure gauges are among the most frequently used instruments in the process industry. They measure the pressure drop at numerous points in a process line when an orifice is passed through to determine the flow. One problem, which frequently occurs in instruments used in the oil industry, is responsible for a major part of the maintenance costs for this type of instrument. The pressure measuring points upstream and downstream of

Diagnostic methods

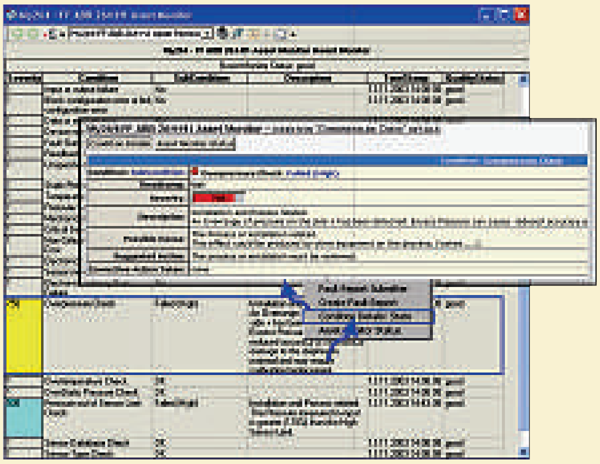
Diagnostic methods are frequently classified with regard to the use of physical models on the one hand and historical data on the other. The analytical models, based on very detailed knowledge of the device or the process, are at one end of this spectrum. The other extreme is composed of methods which are based purely on the processing of historical data. If industrial sensors and actuators, in particular, are considered, a somewhat more detailed classification is possible, namely with regard to the following:

- Test of the signal processing and electronics
- Switch-over to reference conditions
- Test signals
- Redundant sensor elements in the field instrument
- Additional non-redundant auxiliary sensors in the field instrument
- Internal signal data analysis
- Previous knowledge and experience with regard to the measurement signal (neural networks, pattern recognition)

The potential for future developments consists above all in diagnosis by means of test signals, internal redundant sensors and data analysis.

the orifice and the measuring instrument are frequently connected by means of differential pressure lines (so-called "impulse lines") which occasionally become blocked through flocculation of the process fluid. The problem in this case is that the measured value does not fall to zero, but "freezes" and is often not detected by the operator for a lengthy period. A considerable outlay must currently be invested in the regular testing of these lines to prevent an undetected "Plugged Impulse Line" situation, ie, the blocking of one of the two differential pressure lines.

2 Asset Monitor of a pressure transmitter displaying the "condition details" page



The development of an innovative diagnostic functionality would be a suitable solution. The new differential pressure gauges from ABB are equipped with a so-called "Plugged Impulse Line Detection" functionality. These ultra-modern pressure gauges can independently determine which of the two impulse lines is blocked. The respective instrument shows this on its local display.

Asset Monitors can be used at any level of the plant hierarchy. As a result, intelligent field instruments and groups of field instruments can also be continuously monitored as well as control loops, plant components, plant units or overall plants.

The added value of the integration of this instrument with its diagnostic functionality into ABB's 800xA automation is significant: regular local checks of the instrument to detect an impulse line blockage is no longer required as the signals of all instruments can not only be centrally monitored at one location, but the system also directly initiates the next steps. For example, an impulse line blockage is immediately and automatically retransmitted to the "Maintenance Workplace" via fieldbus. The Maintenance Workplace informs the responsible maintenance engineer by SMS. He also receives detailed information about the problem and a precise recommendation for troubleshooting from the **Asset Monitor** (see below).

Surveys of one ABB customer in the oil industry have shown, for example, that removing blockages in the differential pressure lines accounts for a large percentage of the overall maintenance costs of the pressure gauges. ABB Asset Optimization minimizes the time required for identification of the problem and only initiates maintenance if it is needed. A considerable outlay for routine testing is currently required to identify such impulse line blockages as early as possible. This outlay can be reduced to a fraction by means of modern pressure gauges and their integration in System 800xA.

Many further savings can be made in a great variety of areas by means of the 800xA automation system.

The interpretation of diagnostic data

If certain tasks are solved at the level of the individual instrument, the plant owner is faced with new organizational and IT challenges. Ultimately, this manager must derive efficient maintenance strategies from the field instrument diagnostics such as: who is to receive the corresponding message; what this person should do; and whether or not all the information and tools are there to initiate the correct measures?

ABB has developed a special concept in answer to these questions: System 800xA integrates the control system and Asset Management in a uniform data structure, which is served via various workstation interfaces. These so-called "Asset Monitors" scan the data from the intelligent field instruments at configurable intervals – usually in the range of a few minutes – and, if required, submit a detailed Asset Condition Document (ACD) with instructions for action. The user can electronically process this immediately and seamlessly connect to a Computerized Maintenance Man-agement System (CMMS) which he uses.

The following principles are typical of ABB Asset Monitors:

- Continuous status monitoring for all types of field instruments in the system.
- With troubleshooting tools.
- A standardized user interface.

In System 800xA, each field instrument is represented as an "Aspect

Object", a highly flexible data structure, which gives easy access to the extensive data of modern field instruments such as manuals, operating data history, data sheets or driver software simply by clicking a mouse button. 2 shows the Asset Monitor for a pressure transmitter, which has been subjected to an inadmissibly high pressure. The Asset Monitor has detected the condition "Overpressure". With the click of a button, the user can immediately call up detailed information on this condition such as:

- Time-stamp
- Severity of the error
- Description of the error
- Information about possible causes
- Suggested actions

Asset Monitors for all plant levels

Asset Monitors can be used at any level of the plant hierarchy. As a result, intelligent field instruments and groups of field instruments can also be continuously monitored as well as control loops, plant components, plant units or overall plants. Cascadability is an eminently important technological and practical property. In the case of the ABB concept, it means Asset Monitors can be created for assets ("Parents"), which in turn consist of sub-assets ("Children") with their own asset monitors. Pre-configured monitors are already in existence for many applications, namely:

- Basic Asset Monitors:
  These carry out various tests on the basis of information from plant systems, eg, quality, Boolean values, differential flow, limits or deviation.
- Field instrument Asset Monitors:
  Field instrument Asset Monitors for the generally used fieldbus protocols (HART, Foundation Fieldbus, Profibus) are supplied with the respective Device Integration Packages (DIPS). There are generic asset monitors for each protocol which access the respective standard error signals. In addition, specific asset

Diagnosis of low-voltage switchgear

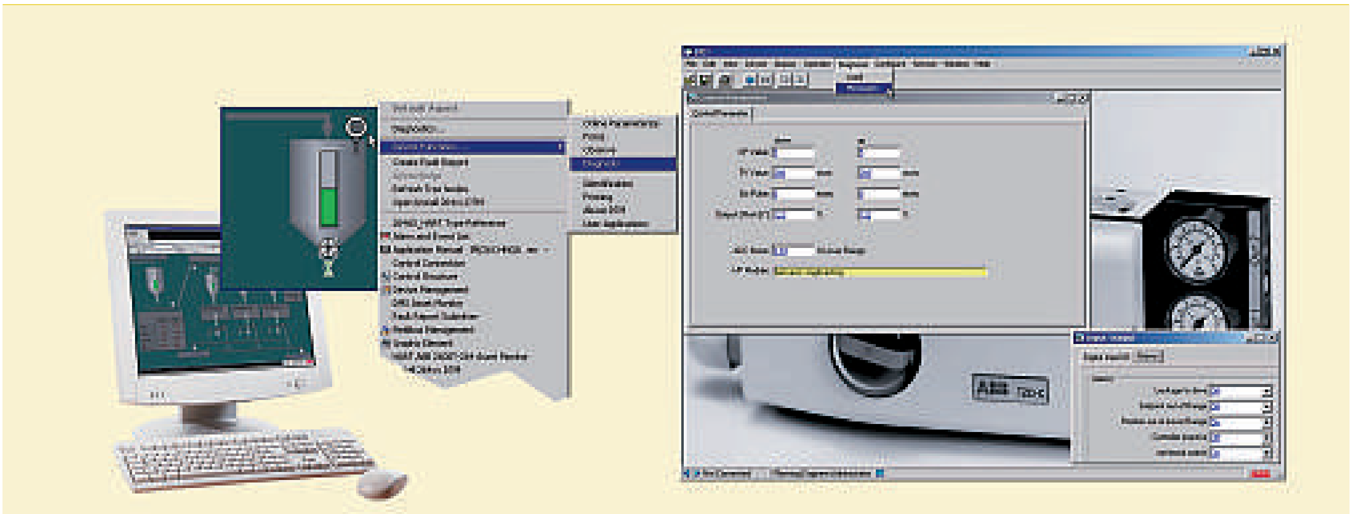
Instrument diagnosis can extend far beyond the classic area of field instruments:

The "Universal Motor Controller UMC22-FBP" was one of the first actors to be completely integrated in the 800xA asset management system. It combines high-grade motor protection and sophisticated motor control functions in one instrument. It can be used for currents from 0.24 to 63 A without the need for extra external current transformers. Digital inputs and relay outputs enable the implementation of extensive pre-defined control functions and applications such as direct starting, star-delta starting and servodrive including local control through the digital inputs.

The UMC has a so-called neutral fieldbus interface. The UMC is turned into a PROFIBUS, DeviceNet or Modebus instrument through the simple attachment of a fieldbus connector. The statuses of the inputs and outputs, detailed diagnostic information, motor current, instrument parameters and service data can be accessed via the various fieldbuses.

As a result, all the requisite information for necessary maintenance and/or repair instructions, if applicable, is available to the asset monitor. By means of the asset monitor, the maintenance personnel can recognize more quickly, whether an error is to be searched for in the instrument itself, the external electrical wiring or in the connected process.

Device Type Manager (DTM)[1] diagnostics display



[1] A DTM mirrors field device information into software applications.

monitors are offered which exploit the entire diagnostic know-how of respective manufacturer.

- Motors and drives:
  Asset Monitors are also available for motors and the associated devices, such as pumps, compressors and fans. Abnormal or unstable process and equipment statuses which can lead to overload of the electrical equipment and to wear and failures over time are detected. Asset Monitors here cover various degrees of complexity from basic functions, such as the monitoring of the operating hours and the number of starts of a motor, to special functions such as the monitoring of intelligent "Motor Control Centers". Asset Monitors tailored to closed-loop-controlled drives determine possible overloads.
- PCs, networks and software:
  Pre-defined Asset Monitors are available for computers, printers, switches or software programs. Various degrees of complexity are also covered – from simple tests (paper supply in the printer) to complex tests (utilization of the working memory).

Asset Monitors and status signals are available for the wide range of applications described above in much the same way as they are for field instruments, ie, with a user interface, alarm "severity" steps and logical content (instructions for action) that comply with the standards for instrumentation diagnostics.

Asset Monitors customized to project – and plant – specific "macro" assets can be developed beyond the existing libraries of asset monitors by means of Software Development Kits (SDK) – with full access to the existing asset monitoring system. If the data of all the instruments integrated both in the control system and in the asset management system is available, this is advantageous for efficient data transfers. To illustrate this, suppose an operator establishes that the performance of an appliance, for example a boiler or a heat exchanger, is deteriorating. Previously in such a case, he would have received a process alarm, checked the process graphics and alarms and thereby determined what was causing the problem. The operator would then either have immediately sent a maintenance job request in the form of a log entry, a hand-written memo or an e-mail, or would have laboriously searched through various systems at different locations for information on requested or scheduled maintenance measures.

In System 800xA, the maintenance engineer is now automatically informed about a maintenance event by means of the Asset Monitors. The problem and its cause are described in the associated Asset Condition Document. As a result, the user can quickly access the associated maintenance information in the CMMS by displaying the active job requests and thus determine whether a new job request is necessary.

Predictive maintenance pays off

This information can be collected, combined, analyzed and compared with historical data across the plant by means of the described functions for condition monitoring and the preparation of reports. Warnings about the deteriorating performance of appliances, components and processes and their possibly imminent failure can be detected in good time, issued to the maintenance personnel and processed in a comprehensible manner. Maintenance work can be better planned, and downtimes can be minimized. In other words: predictive maintenance, which was until recently connected with cost-intensive special measures and cost-effective only for critical and expensive process equipment, is now economically acceptable for many applications.

Autodiagnosis up to date

The example of the integrated empty pipe detection of a magnetic-inductive flow meter (FSM 4000 from ABB) is typical for modern self-monitoring by means of internal test signals, which is actuated by several application-specific errors:
The monitoring of the electrode impedance in this field instrument provides reliable information (instrument-specific) about whether changes have occurred in the measuring system (deposits or similar) or in the fluid (composition, deterioration of the conductivity) during operation. The main task of the empty pipe detector is to monitor the pipeline for partial filling, because this causes a considerable number of measuring errors.

The appropriate actions (plant-specific) taken by an operator or maintenance personnel can be configured at system level, because the instrument can communicate detailed information via the standard protocols (HART, Profibus PA, Foundation Fieldbus) with any desired filtering. There is an "Asset Monitor" for the instrument, by means of which the diagnostic information can be displayed to the user in real time.

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Further reading:

1) Johannes Prock et al.: VDI/VDE Richtlinie 2650 „Anforderungen an Selbstüberwachung und Diagnose in der Feldinstrumentierung", (2005) [VDI/VDE guideline 2650 "Requirements of self-monitoring and diagnosis in field instrumentation"]
2) Jörg Gebhardt, Peter Müller, Eberhard Horlebein, Horst Schwanzer, Ralf Huck, Wolfgang Scholz, Thomas Kleegrewe: "Diagnostics and Self-Monitoring of Field Instruments", 12th GMA / ITG – Fachtagung Sensoren und Meßsysteme [Sensors and measuring systems symposium], Ludwigsburg (2004)