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Calibration and documentation for process manufacturing: **Costs, benefits and feasibility**

White Paper

Process manufacturing plants require hundreds, even thousands of sophisticated devices that perform countless critical operations ceaselessly, accurately, and reliably. Those devices in turn require regular inspection, testing, calibration, and repair.

Two centuries of industrial experience has established the value of carefully recording the details of those inspections, tests, calibrations, and repairs. More than a best practice, businesses and governments often require highly specific record keeping to assure that full value is delivered to customers and that the health and safety of citizens is protected.

However, traditional testing, calibration and documentation practices are also labor-intensive, and with senior operators in scarce supply, downsized teams sometimes choose to defer regular calibration.

This paper reviews route-based, automated calibration practices as an alternative to traditional methods. Findings suggest that smaller teams can feasibly conduct and document device calibrations, at a lower overall cost, with additional productivity and operational reliability benefits.

Why calibrate? Why document?

Calibration defined

In process manufacturing, calibration is the process of comparing the reading of a field device to a calibration standard to determine whether the device's accuracy meets performance requirements. It can also include adjusting these devices so that they operate within limits. Calibration is typically performed when installing a new device, changing the settings of an existing device, or reinstalling a repaired device. The devices to be calibrated, often called field instruments, are located on factory floors, atop cooling towers, within pressure vessels—anywhere that process variables such as temperature and pressure need to be known and process control is required.

Safety

The most important reason to calibrate is to ensure safety. A tragic example of this necessity was an explosion at a Texas refinery. Valves on an isomerization tower had not been calibrated or "stroked" (put through their full range of motion) on a regular basis, and neither the valves nor the tower's level gauge had been calibrated regularly before they failed, causing the explosion.

Quality

To perform at the highest efficiency and quality, equipment must be well maintained and adjusted. Instruments that are not well maintained and adjusted reduce quality and ultimately deduct from the bottom line. In the case of fine chemicals or pharmaceutical products, for example, reduced quality might require the destruction and disposal of an entire batch. Minor mis-adjustments can have costly consequences.

Revenue

Calibration and documentation may be required to insure that purchased products (gasoline or natural gas, for example) are measured and taxed correctly. Calibration of the devices that make these "custody transfer" measurements, especially on pipelines are one of the most accurate performed in industry.

Compliance

Government regulation and enforcement agencies often require calibration and documentation to verify that devices conform to rules and standards. Many government agencies require timely and documented calibration of both field instruments and final control elements.

For example, the U.S. Food and Drug Administration's Current Good Manufacturing Practices require detailed, accurate, and up-to-date calibration records. International quality standards ISO 9001, 9002, and 14001 require that detailed calibration procedures be performed prior to audit approval. ISO 9000 and other quality standards typically require that the calibration of the field instrument be checked at regular intervals.

In so-called "validated" industries (such as the pharmaceutical industry), any changes to a process line, including repair or replacement of a process instrument or a final control element, must be re-validated and traced to documentation before the process line can be put back into service. Poor calibration documentation can make this validation process time consuming and expensive and put the manufacturer at risk of fines by the regulating government agency.

Savings

Calibration and documentation are usually considered expenses, and the higher efficiency resulting from good calibration practices may be hard to distinguish. Consider, then, the known costs. On the one hand: loss of an entire batch due to quality issues. On the other: legal costs and lost revenue from accidents, which at the refinery mentioned earlier has exceeded $100 million. If disaster strikes, good calibration records can be a part of a facility's defense in the event of legal action (just as poor records can put an organization in a less defensible legal position).

How do field instruments work, and what kind of calibration do they require?

Most field instruments are made up of two parts: a primary element and a transmitter.

- **Primary elements** include flow tubes, orifice plates, pressure sensors, wet chemistry sensors such as pH, ORP, and conductivity probes, level gauges of all types, temperature probes, and others. Primary elements typically produce a signal—usually voltage, current, or resistance—that is proportional to the variable they are designed to measure, such as level, flow, temperature, pressure, or chemistry. Primary elements are connected to the input of field transmitters.
- **Field transmitters** include pressure, temperature and flow devices. They process the signal generated by the primary element, first characterizing it in linear format and applying engineering unit coefficients to it, before then transmitting it in analog (usually 4-20 mA dc) or digital format (usually some variety of fieldbus).

Note: When a field instrument is manufactured, both the primary element and the transmitter (or the actuator, if a control valve) are calibrated at the factory and the calibration information is supplied with the unit. This calibration data is often lost. Entering this information into centralized calibration records when the device is put into service should be part of standard work, and not just for efficiency's sake. Centralizing calibration information ensures knowledge stays with the facility even as teams change.

Analog devices

Analog devices—often called "4 to 20 milliamp loop" devices—are so called because they transmit a signal that is an electrical "analog" representation of a measured physical quantity (temperature, for example). They transmit an electric current that is proportional (analogous) to the magnitude of a measured physical quantity, with 4 milliamps of current representing the minimum scaled value and 20 milliamps representing the maximum scaled value. This relatively simple technology has low sensitivity to electrical "noise" and has been used for many years. Although many system aspects are now digital, analog devices are still in active use throughout the process manufacturing world. A 2010 survey in *Control Global* magazine found that 30% of plants surveyed continued to use analog instruments and current loops. Because analog circuits such as current loops drift over time, they require regular calibration.

Digital devices

Digital devices convert a measured physical value into a digital signal. Many different digital encoding methods are used in the process industry, including Foundation, Profibus, and HART.

There is a widespread belief that fieldbus (digital) field devices do not require calibration. This is not true.

Although a fieldbus signal (whether Foundation, Profibus, or connected HART) provides diagnostic information, it does not provide information about the accuracy of the device, nor does it verify that the device is reporting the process accurately and precisely. For example, a Foundation fieldbus differential pressure transmitter can report diagnostic information about the transmitter, but it cannot report on the physical condition of the orifice plate across which it is measuring pressure. Consequently, even if the electronics are operating perfectly, the flow reading transmitted may be inaccurate. Thus, calibration is required even for digital devices.

Fieldbus systems do not have an analog output that technicians can use to verify the accuracy of instrument transmissions to the control system. Without an easily readable output, facilities must either install a readout display at the device or perform calibrations with one technician at the device and the other in the control room. Both options increase calibration costs.

Control valves

Control valves have actuators that also require calibration to adjust for wear and the effects of stiction. Often these valves must be given a partial stroke test if they haven't been actuated regularly.

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How is calibration performed?

Calibration is typically performed either where the device is located (called in situ calibration, from the Latin for "in position") or in an instrument shop.

- In situ calibration typically tests only the performance of a device's transmitter and electronics (unless there is some way of valving the instrument offline and testing performance of its primary element against a calibration standard). In situ calibration may be performed on a single device or as part of a "round" of calibrations performed on a technician's calibration route.
- In-shop calibrations are both more thorough and more time consuming. Additional paperwork must be submitted, downtime scheduled, and then the device must be removed, transported, calibrated and then reinstalled.

Permitting and paperwork

Administrative tasks, from getting permits to documenting and filing results, can add to the cost and time required to perform even an in-situ calibration. As Ian Verhappen, of Industrial Automation Networks, and a former Chair of the Fieldbus Foundation User Group, says, "In many cases getting all the necessary paperwork (permits, isolation, etc.) in order often takes longer than the work itself." Some facilities are able to reduce this cost by applying a single set of paperwork to one long route of multiple calibrations, in place of performing one-off calibrations.

Why is documenting calibration problematic?

Traditionally, documenting a calibration has meant using a log book to hand-write the date and time, the pre-calibration readings, the post-calibration readings, and any other observations the technicians made. Surprisingly, many plants continue to document calibration work by hand. In a 2008 survey by *Control* magazine, 74 % of respondents said that they were still using pen-and-paper documentation.

Pencil-and-paper documentation, while common practice, has many shortcomings.

First, it both produces and perpetuates errors. The data in hand-written records is often simply illegible or insufficient. "Documentation/transcription errors are likely more significant than the field costs (of calibration) themselves," says Verhappen. "How many times do you get illegible information on a work order, and how often is the data entered actually useful with statements like 'Completed' or better yet 'recalibrated' without saying recalibrated from what to what, or 'fault found and repaired' or simply 'repaired' without saying what was done?"

Facilities that use a computerized maintenance management system (CMMS) must then account for the additional time required to manually enter hand-written data, with additional possibilities for error.

Many facilities store field data in more than one database. Calibration data entered in the operations database may not be cross-entered into or accessible by the maintenance database.

Several methods are being used to reduce the time and cost of calibration and documentation, including:

- Installing more digital instruments and valves
- Using interconnected asset management software to help manage documentation
- Using handheld documenting process calibrators to automate field calibrations and upload digital documentation to a CMMS
- Using route-based calibration

Who performs process calibration?

From the 1920s to the 1960s, engineering schools graduated large numbers of skilled workers willing to work in manufacturing as operators and technicians. They performed the majority of process calibrations, using the traditional pen-and-paper methods referenced above.

Starting in the 1960s, however, young people became less interested in manufacturing work, and those employers began having difficulties filling positions.

The 1980s brought budget cuts and layoffs. Engineering, maintenance and operations staffs were cut substantially and a new "lean manufacturing" philosophy took root that continues today, especially in developed economies.

"With downsizing and retirements, it is getting harder to have over a dozen different mechanics doing rounds. It is more common to have many less, and calibration rounds often become an afterthought," a plant engineer commented at a recent section meeting of the International Society of Automation.

While those reductions in team size would seem to be balance out the decreased workforce supply, another problem has since developed. Smaller teams have less time for mentoring and on-the-job-training, to the point where equipment and system-specific knowledge is not being successfully transferred from the individual to the institution. As older operators and engineers retire, they take their equipment and system knowledge with them.

"Every day at 4 pm, the plant's institutional knowledge walks out the front gate," says the Chief Instrumentation and Controls Engineer of a large Midwestern refinery, "and sometimes it doesn't come back."

Meanwhile, many facilities still need two technicians for each in-situ calibration—one at the transmitter and one at the control system. The Fieldbus Foundation estimates that commissioning requires two techs for a minimum of two hours. Calibration requires similar time and manpower. In the United States, the typical automation maintenance technician in the process industries is paid about $30 an hour. Two technicians working two hours at $30 an hour equals a cost of $120 for every calibration. ***Average-sized process plants performing regular calibrations on two to three thousand devices will spend approximately $300,000 per year on calibration labor, where large plants with 10,000 or more calibrations may spend up to $1.2 million.***

How can calibration and documentation be done more efficiently?

Use multifunction, documenting calibrators

A new generation of "smarter" field calibration tools introduced in the late 1990s began increasing worker productivity by consolidating multiple tools into one and performing functions beyond basic test and measurement, such as assisting with analysis and documentation.

Multifunction "documenting process calibrators" are handheld, electronic test tools that consolidate multiple calibration steps and functions into a single device, sourcing simulating and measuring pressure, temperature, and a wide variety of electrical and electronic signals.

Benefits:

- Fewer tools that technicians need to train on and carry into the field
- Similar calibration processes and data output across multiple devices, compared to a different process to collect a different set of data from each tool and device
- Automated procedures replace many manual calibration steps
- No second technician required to record the as-found and as-left state of the field device.
- Faster calibration time per device
- Calculate the error of a single tool rather than adding the errors of several tools

Calibrate in place when possible

In the words of engineer, columnist and current Fieldbus Foundation User Group chair John Rezabek, "The introduction of documenting calibrators is a chance to revise past practices and maybe switch to calibrate-in-place. That is, you isolate the device from the process, verify that it's depressurized, and apply signals with a hand pump."

Use calibration routes

The biggest savings from using a documenting calibrator comes in the route management tool built into the device. Using a single set of permits and paperwork for an entire set of calibrations reduces costs considerably. As one lead I&C engineer at a prominent refinery put it, ***"If somebody goes out to calibrate a single instrument, that's expensive. If he's going to do a route with maybe twenty instruments, and then come back, the cost per calibration is much less."*** Rezabek agrees. "The main efficiency gained from the documenting calibrator is that it loads up a 'round' of calibrations and walks the techs consistently through the steps of each procedure."

Implement an asset management, calibration management, or computerized maintenance management system (CMMS)

Unlike paper documentation, calibrator data is never illegible, cryptic, or partial. Documenting calibrator data can be directly downloaded into a variety of different CMMS systems with no transcription or filing. According to Verhappen, ***automatic documentation commonly reduces errors by 80 % to 90 %***. Data downloaded from a documenting process calibrator into a CMMS can even automatically trigger work orders for repair of field devices.

Increase the productivity of calibration technicians

Because documenting process calibrators automatically record the as-found and as-left state of each field device, in situ, and can be operated by a single technician, route-based documenting calibrators can save as much as 50 % of the time and cost of traditional manual, single-device calibration methods. Stated differently, the same lean team can accomplish twice as many calibrations in a given period of time.

Running a lean team under the traditional operational requirements is a recipe for error. Calibrations simply don't happen the way they should. Instead of ignoring the looming threat, investigate how existing practices can be made more efficient. Implement route-based calibration, paperless documentation, and CMMS data management. More calibrations will occur more consistently, knowledge will be transferred from the individual to the team and to the institution, and both productivity and quality will increase.

"Dollars and sense"

The plant's institutional knowledge is often kept by individual technicians and engineers and it departs with them when teams change. Instituting a robust route based paperless calibration management practice helps mitigate that risk, facilitates knowledge transfer and helps less experienced technicians get up to speed quicker.

Calibrating multiple instruments in the course of a route reduces the cost per calibration, compared to individually calibrating single instruments. Route-based documenting calibrators can save as much as 50 % of the time and cost of traditional manual, single-device calibration methods. Stated differently, the same lean team can accomplish twice as many calibrations in a given period of time.

If an average-sized process plants spends $300,000 per year on calibration labor that puts the potential cost savings at $150,000 per year by adopting route based practices with modern documenting calibrators and software management tools where large plants with that spend up to $1.2 million could realize $600,000 per year in annual savings.

Besides saving maintenance costs, the legal costs and lost revenue from accidents can exceed $100 million per incident. Good calibration maintenance practices help reduce the probability of such an incident. If the event that disaster strikes, good calibration records can be a part of a facility's defense in the event of legal action just as poor records can put an organization in a less defensible legal position.

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