Intelligent Device Management Tutorial: Calibration

In the early days of smart transmitters the concept of range setting from a central location ("remote calibration") and re-ranging without applying input was revolutionary. It took years of education to be accepted and understood. Calibration can be carried out using a handheld communicator in the field, a laptop on the bench in the workshop, or from intelligent device management (IDM) software as part of an asset management system. Electronic Device Description Language (EDDL) is the technology used by device manufacturers to define how the system shall display the device information and functions to the technician. EDDL makes calibration of smart transmitters and other intelligent devices easier thanks to user guidance such as wizards and help, and unparalleled consistency of use.

This tutorial explains the common principles of calibration, re-ranging, and trim as they apply to various kinds of transmitters. The detail procedure varies slightly depending on the measurement done, sensing principle, and each manufacturer. Refer to the device instruction manual. But once the common principles are understood, the product manual becomes easier to understand.

1 Calibration

By definition, the term "calibrate" means several different things:
1) Set the range (scale)
2) Trim (correct) the sensor (transducer) reading or current output against a standard
3) Simply compare the sensor (transducer) reading or current output against a standard to see how large the error is without correcting (trim) it. This is often done in five points, increasing and decreasing. If the error is too large, the transmitter may be trimmed or replaced.

ANSI/ISA–51.1 Definition of Terms
Calibrate: To ascertain outputs of a device corresponding to a series of values of the quantity which the device is to measure, receive, or transmit. Data so obtained are used to: 1) determine the locations at which scale graduations are to be placed; 2) adjust the output, to bring it to the desired value, within a specified tolerance; 3) ascertain the error by comparing the device output reading against a standard.

2 Calibrating Intelligent Transmitters

The term "calibration" in the context of smart/intelligent transmitters is often misunderstood. In the days of analog transmitters calibration meant applying a physical input and turning the trim potentiometers to adjust the transmitter so that the analog output current becomes correct according to the desired measurement range. Once smart transmitters appeared, this "calibration" process was divided into three parts:

- Sensor trim
- Range setting (re-ranging)
- Current trim

The reason for separating these functions is that the range can be changed without applying a physical input. This was a huge time and cost saver and one of the major reasons for the rapid adoption of smart transmitters. However, do not confuse "sensor trim" with "range setting". Both are part of calibration, but two very different things. In the view of many, range setting is more like configuration than calibration.

2.1 Sensor Trim (Digital Trim)

Over time all sensors drift. Depending on the type of sensor it may be due to extreme pressure or temperature, vibration, material fatigue, contamination, or other factors. Sensor reading may also be offset due to mounting position.

Sensor trim is used to correct the digital reading as seen in the device local indicator LCD and received over the digital communication. For instance, if pressure is 0 bar but transmitter reading shows 0.03 bar, then sensor trim is used adjust it back to 0 bar.

Sensor trim can also be used to optimize performance over a smaller range than was originally trimmed in the factory.

The basic principle for calibration (sensor trim) of all transmitters is the same:
1. Apply a known input
2. Tell the transmitter what it is
3. The transmitter calculates internal correction factors
4. The transmitter uses the new correction factors to compute a new correct measurement reading

Sensor trim requires the technician to apply a physical input to the transmitter. Therefore the technician must either do sensor trim in the field at the process location, or the transmitter has to be brought back into the workshop to perform sensor trim. This applies to 4-20 mA/HART, WirelessHART, FOUNDATION fieldbus, as well as PROFIBUS transmitters. Sensor trim in the field is easiest done using a handheld communicator connected to the running bus which is supported by 4-20 mA/HART, WirelessHART, and FOUNDATION fieldbus. For PROFIBUS-PA the trim command can either be sent from the control system, or the transmitter can temporarily be disconnected from the running bus to perform the sensor trim.

Typically there are three forms of sensor trim:
- Zero sensor trim
- Lower sensor trim
- Upper sensor trim

Zero trim requires the physical input applied to be zero, this is often used with pressure transmitters For best accuracy perform sensor trim in two points, close to lower range value and upper range value. This is where lower and upper sensor trim is used. A known physical input is applied to the transmitter to perform the sensor trim, the technician keys in the applied value (on a computer or handheld communicator) communicated to the transmitter, allowing the transmitter to correct itself. The physical input values applied for lower and upper sensor trim respectively are stored in the transmitter memory and are referred to as Lower Sensor Trim Point and Upper Sensor Trim Point respectively. EDDL plays an important role in sensor trim because a “wizard” created by the device manufacturer guides the user step by step through the process.

Sensor trim requires a very accurate input to be applied. The factory calibration equipment is usually more accurate than the portable calibrators at site. Moreover, transmitters these days are typically very stable. Therefore, sensor trim of brand new transmitters is rarely done at commissioning.

Note that sensor trim is done in firmware in the transmitter microprocessor; it is not done in the sensor itself. The trim is really a mathematical function, adjusting numerical bias and gain factors. That is, it is the sensor reading after the A/D conversion which is trimmed, not the sensor hardware

Sensor trim is the aspect of calibration which this white paper focuses on. That is:
- Pressure calibration

- Flow calibration
- Temperature calibration
- Level calibration
- Etc.

2.1.1 Sensor Trim Points

The purpose of the (CAL_POINT) parameters is to tell at which points sensor trim was last done, and to perform sensor trim points sensor trim if needed. If the sensor trim points parameters are 0 and 360 mbar this means these are the points at which it was calibrated (sensor trim). The transmitter may still be able to measure -600 to +600, but remember the transmitter is now extrapolating so it may not be full accuracy, but it may be OK anyway. This is not uncommon. If sensor trim is performed at -600 and +600 greater accuracy may be achieved.

Note that the sensor trim points are not just “set”; they are NOT range configuration parameters. These two parameters are written when sensor trim is performed. The transmitter then remembers these points were the trim was made. Typically there is a sensor trim wizard (“method”) that takes the technician step by step through the calibration process and it is this sensor trim wizard that writes the sensor trim point parameters.

2.2 Range Setting (Re-range)

Range setting (re-ranging) refers to setting the scale for the 4 mA and 20 mA points. This scale is usually referred to as "calibrated range" or "calibration range". That is, at what input shall the transmitter analog output be 4 mA; Lower Range Value (LRV) often referred to as "zero" meaning 0%, and at what input shall it be 20 mA; Upper Range Value (URV), sometimes called "full scale" meaning 100%. Note that the term "span" is not the same as URV. Span is the magnitude of difference between URV and LRV. For instance, if LRV is 20 and URV is 100, the span is 80. Since Fieldbus, PROFIBUS, and WirelessHART do not use 4-20 mA, range setting is not required for such devices in most applications.

Note that calculating what the output current value should be is done in firmware in the transmitter microprocessor. It is a mathematical function.

Internally the 4-20 mA/HART transmitter computes:

*Percentage = (PRIMARY_VARIABLE - LRV) / (URV - LRV) * 100 [%]*

*Analog Current = (PRIMARY_VARIABLE - LRV) / (URV - LRV) * 16 + 4 [mA]*

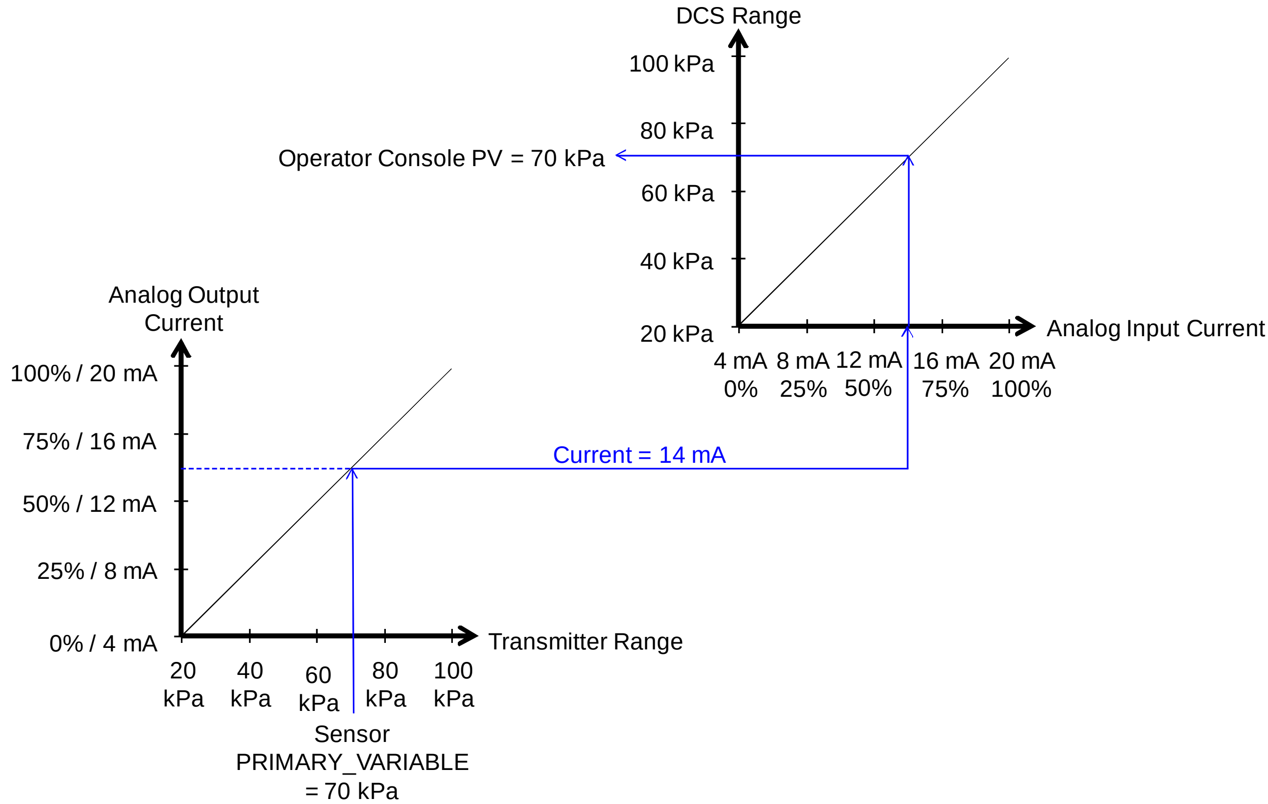


Figure 1 Range/scaling of transmitter and indication

Internally the 4-20 mA control system, recorder, or indicator computes:

*Percentage = (Current - 4) / 16 * 100 [%]*

*PV = (Current - 4) / 16 * (URV - LRV) + LRV [E.U.]*

The analog 4-20 mA output of a transmitter is limited to the LRV to URV range. Thus the analog output does not benefit from the full LSL to USL capability of the sensor.

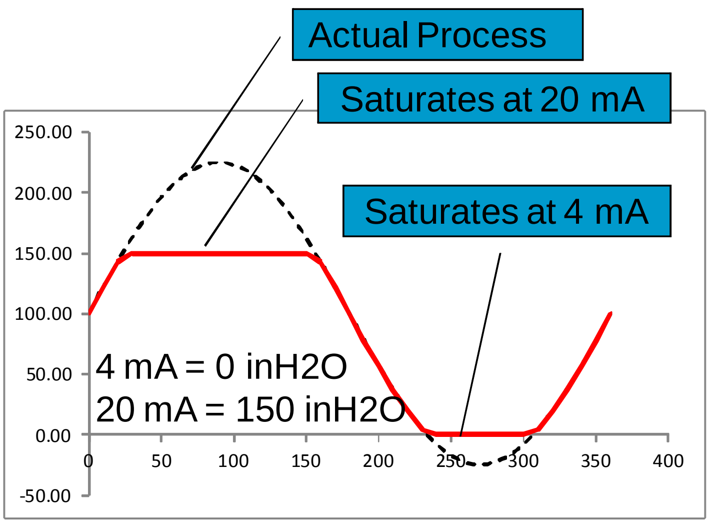


Figure 2 In an analog signal system the measurement is confined within range values

However, FOUNDATION fieldbus, PROFIBUS, and WirelessHART transmitters as well as the digital output of 4-20 mA/HART transmitters are not limited to the LRV to URV range, but can benefit from full LSL to USL capability of the sensor.

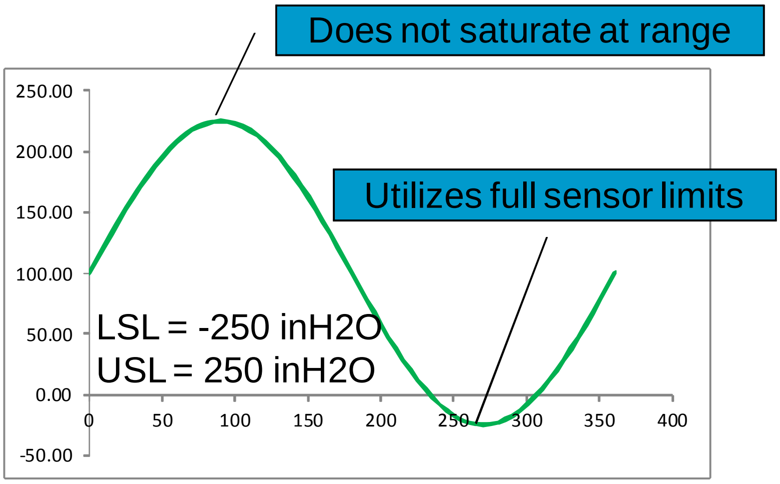


Figure 3 In a digital bus signal system the measurement enjoys the full sensor limits

History Lesson: Rangeability and Turn-down Ratio

Rangeability is the ratio of the smallest permitted span to the Upper Sensor Limit. For instance, if the Upper Sensor Limit is 80 kPa and the minimum span is 2 kPa, then the turndown ratio (rangeability) of that transmitter is 40:1.

Transmitter range setting is done without applying input, and therefore can be done remotely from a central location. For instance, set range of pressure transmitter to get 4 mA when input is 0 bar and 20 mA when pressure is 40 bar. Range must be set within the Lower Sensor Limit (LSL) and Upper Sensor Limit (USL). Transmitters usually also have a minimum span to be observed. The difference between URV and LRV must exceed the minimum span, or else the analog output resolution and percentage accuracy is too poor since with a small span the quantization error from the sensor A/D converter gets amplified too much. The transmitter will reject range setting and sensor trim attempts not observing the LSL, USL, and minimum span limits.

Error When Attempting to Reverse the Range

In some applications, particularly DP level, it is necessary to reverse the range such that the LRV > URV. For instance, the range may have been set -87 to -1 mbar initially, but the application may actually require the range to be -1 to -87 mbar. That is the range has to be reversed:

LRV = -87 mbar	Change to:	LRV = -1 mbar
URV = -1 mbar		URV = -87 mbar

To make this range change the technician would typically make the mistake of directly keying in -1 mbar for LRV which would be rejected since both URV and LRV would then be -1 mbar leaving a span of 0 mbar which would violate the minimum span. Or, the technician would attempt to directly key in -87 mbar for URV which would also be rejected since both URV and LRV would then be -87 mbar also violating the minimum span. The solution is to first key in an intermediate value. For instance, setting the LRV to -40, then setting URV to -87, and lastly setting LRV to the final -1 mbar.

The same procedure applies if the sensor trim points are to be reversed

The sensor limits depend mostly on physical restrictions of the sensor. The sensor limits cannot be changed, therefore they are always read-only. Different sensors have different sensor limits. For example, various RTDs and thermocouples have different sensor limits. In temperature applications, a sensor type with sufficient sensor limits has to be selected to accommodate the range of the application. Since the range limits are physical and cannot be changed, to get wider sensor limits to accommodate a wider range, it is necessary to purchase a new sensor. Similarly, pressure transmitters have a selection of sensor modules with different range limits from the lowest “draft” up to very high pressures. To get wider sensor limits to accommodate a wider range, it is necessary to purchase a new sensor.

ANSI/ISA–51.1 Definition of Terms

zero elevation: For an elevated-zero range, the amount the measured variable zero is above the lower range-value.

zero suppression: For a suppressed-zero range, the amount the measured variable zero is below the lower range-value.

History Lesson: Elevation and Suppression

When the lower range value (4 mA point) is above zero, for instance a range of 20 to 100, is called zero suppression. When the lower range value (4 mA point) is below zero, for instance range of -25 to +100, or -100 to 0, or -100 to -20, this is called zero elevation. That is, elevation and suppression relates to the lower range value (the 4 mA of the transmitter range).

Elevation and suppression are chiefly used in differential pressure measurement since this make it possible to measure liquid levels with wet legs and remote seals etc. In smart transmitters it is all done in firmware and nobody ever asks about it anymore. The ability of a transmitter to do elevation and suppression was stated in % and relates to rangeability (turndown). A popular analog pressure transmitter had a 6:1 rangeability and therefore used to sport 600% elevation and 500% suppression. Modern smart pressure transmitters have capabilities in order of several thousand percent so it is no longer discussed.

Range setting is only applicable to transmitter with 4-20 mA analog output. That is, for 4-20 mA/HART transmitters, not for pure digital solutions like FOUNDATION fieldbus (FF) or WirelessHART transmitters. The reason being that FF and WirelessHART transmitters has no 4-20 mA analog output, therefore there is no need to set 4 mA and 20 mA range points. For 4-20 mA systems the range is set in both the transmitter and controller. For FF and PROFIBUS the range is set in the controller, and need not be set in the transmitter which can lead to some confusion for beginners. The only exception for FF, WirelessHART, and PROFIBUS transmitters may be for differential pressure (DP) flow and level measurement where the end-points of the DP scale (e.g. 0-250 inH2O in XD_SCALE) and corresponding flow or level scale (e.g. 0-400 bbl/day in OUT_SCALE). This also enables DP transmitters to locally indicate in flow or level units. FF and PROFIBUS devices have provision for setting a range in the transmitter even though it may not be used for the application.

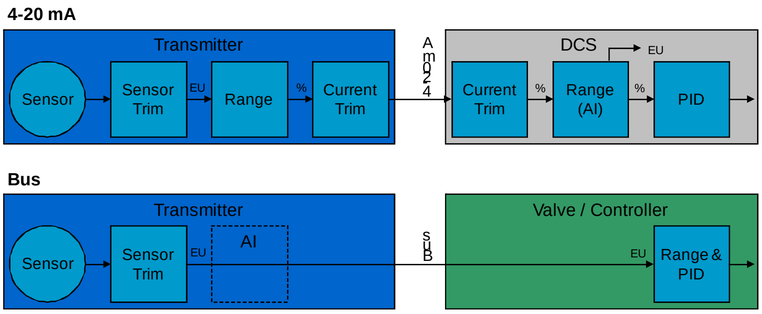


Figure 4 An analog signal system requires range, current trims, and scaling. A digital bus system does not

However, the nominal operating range has to be specified also for FOUNDATION fieldbus and WirelessHART transmitters for sizing purposes when purchasing, such that the device supplier can pick the appropriate sensor model. There is also a need to select the desired engineering unit in the device. The DCS may need a range set in database as scaling end-points for bargraphs and trend and will also need a range for PID control even though there is no range in the FOUNDATION fieldbus or WirelessHART device. In control applications, level is usually expressed in percentage of full tank.

The output of both the FF transducer block and the AI function block is engineering unit. For most applications there is no need to set range in either block in order to get the PV. However, many systems use the range in the FF transmitter AI block to scale the faceplates bargraphs. A narrower range may optionally be set to increase the resolution of the faceplate bargraph. If a range is set in the AI block, the percentage of range can be seen from the FIELD_VAL parameter.

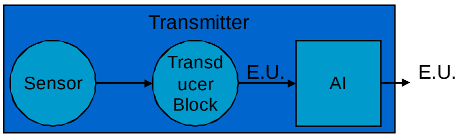


Figure 5 Digital transmitters internally operate in engineering units

4-20 mA Range Mismatch

If the range set in the transmitter does not match the range in the DCS, alarms, controls, and indication will not function correctly. Therefore it is important to document any range changes such that the correct range is set when transmitters are replaced.

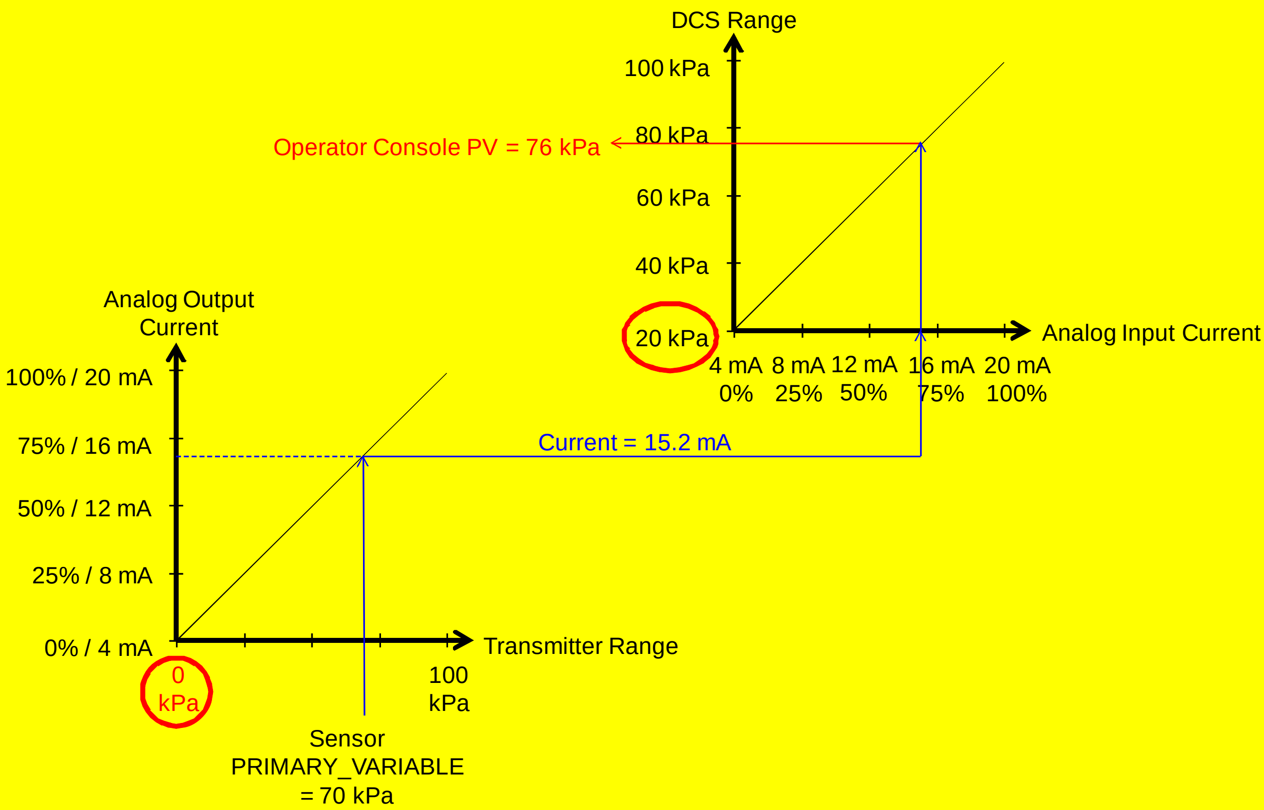


Figure 6 In this example a mismatch in LRV results in erroneous indication

Range in Instrument Specification Forms

Range is not required to be set in transmitters using pure digital communication, but it is required to be specified in instrument specification forms (ISA20) such as with bid documents for sensor element selection. For instance, the pressure transmitter supplier needs to know the pressure range (and other process data) to select the sensor module for the application. The temperature transmitter vendor needs to know the temperature range (and other process data) to select the temperature element model for the application.

There are typically two ways to set the range of the transmitter:

- Direct numeric value entry
- To applied input

2.2.1 Direct numeric value entry

Direct numeric value entry means the desired lower and upper range values are simply keyed in from device software or handheld field communicator, and sent to the transmitter, for instance, keying in 20 to 100 kPa.

2.2.2 To applied input

Range setting to applied input requires a physical input corresponding to the desired range value to be applied to the transmitter. This is sometimes used in level measurement applications. Because the mounting (datum) of the level transmitter plays a part in the range, the range shall be adjusted at site, it cannot be done in a lab. Basically it is a zero cancelation such as DP wet leg. For instance, first the tank is emptied to its lower level and then the "set PV LRV command" is sent to the transmitter to set the lower range value to whatever the input happens to be. For instance for a DP level transmitter, if the pressure is 20 kPa when the tank is empty (the pressure tap is slightly below the datum), this becomes the new lower range value, thus ensuring the reading is 0% and analog output current is 4 mA whenever the tank is empty. Conversely, next the tank is filled to its upper level and then the "set PV URV" command is sent to the transmitter to set the upper range value to whatever the input happens to be. For instance, if the pressure is 100 kPa when the tank is full, this becomes the new upper range value, thus ensuring the reading is 100% and analog output current is 20 mA whenever the tank is full. In between the reading is linear. Note that the technician need not know what the physical input is, just that the tanks is full and empty respectively. EDDL plays an important role in range setting to applied input because a "wizard" created by the device manufacturer guides the user step by step through the process.

The set PV LRV command is also common to cancel wet-leg for DP transmitters in all kinds of application including flow. The set PV LRV and set PV URV commands are equivalent to pushing the 'zero' and 'span' buttons respectively found on some transmitters.

ANSI/ISA–51.1 Definition of Terms

range: The region between the limits within which a quantity is measured, received, or transmitted, expressed by stating the lower and upper range-values. For example:
a) 0 to 150°F
b) –20 to +200°F
c) 20 to 150°C

range-value, lower: The lowest value of the measured variable that a device is adjusted to measure.

range-value, upper: The highest value of the measured variable that a device is adjusted to measure.

range-limit, lower: The lowest value of the measured variable that a device can be adjusted to measure.

range-limit, upper: The highest value of the measured variable that a device can be adjusted to measure.

span: The algebraic difference between the upper and lower range-values. For example:
Range 0 to 150°F, Span 150°F
Range –20 to 200°F, Span 220°F
Range 20 to 150°C, Span 130°C

FOUNDATION fieldbus uses the term "scale" for "range"

History Lesson: Non-interactive zero and span

One of the major time saving benefits that came with microprocessor-based transmitters was non-interactive zero and span:

When lower range value is set to applied input, the span (i.e. the difference between upper range value and lower range value) is maintained. That is, the upper range value is shifted by the same amount as the lower range value. For instance, if the original range was 0-100 kPa, and lower range value is set to applied input when the applied input is 20 kPa, the new range will be 20-120 kPa, maintaining the original span of 100 kPa. That is, the upper range value was also shifted by 20 kPa just like the lower range value. However, if upper range value is set to applied input, the lower range value zero) is not changed. For instance, if the original range was 0-100 kPa, and upper range value is set to applied input when the applied pressure is 80 kPa, the new range will be 0-80 kPa, maintaining the original zero of 0 kPa. That is, the lower range value was not shifted.

That is, changing the zero does not affect the span, changing the span does not affect the zero. This is non-interactive zero and span.

Corrupting the range to make 4-20 mA right

Don't use range setting to correct a sensor error. For example, a 4-20 mA/HART pressure transmitter ranged 0-100 inH2O may due to mounting position get a shift in reading of 1 inH2O. The analog output will be 4.16 mA when no pressure is applied, making the field indicator or HMI show 1 inH2O.

A common mistake is to isolate, equalize, and vent the manifold and click the 'Set PV LRV' command in the device management software or handheld field communicator, or pushing the 'zero' and button on the device thus changing the range bringing the analog output to 4 mA.

However, checking the PV in the device management software or local transmitter indicator will reveal the sensor reading with no pressure applied is still 1 inH2O and the range is changed to 1-101 in H2O. Two wrongs appear to make a right

The correct way to correct for shift or drift is to do a sensor trim

Corrupting the sensor reading to make 4-20 mA right

Don't use sensor trim to cancel a wet-leg. For example, a 4-20 mA/HART pressure transmitter ranged 0-100 inH2O may when mounted below the tank read 1 inH2O. The analog output will be 4.16 mA when the level is zero (at the tank datum point), making the field indicator or HMI show 1 inH2O.

A common mistake is to click the 'Zero Trim' command in the device management software or handheld field communicator thus changing the sensor reading bringing the analog output to 4 mA.

However, if the 4-20 mA/HART pressure transmitter is isolated and vented, and the PV checked in the device management software or local transmitter indicator, it will show the sensor reading with no pressure applied is -1 inH2O. Two wrongs appear to make a right

The correct way to cancel a wet-leg is to set the range

2.3 Transmitter Output Current Trim (Analog Trim)

It is rare for the analog output current circuitry of a 4-20 mA transmitter to drift. However, should the analog output current be incorrect, use current trim to correct the analog output signal. For instance, if the analog output current is 4.13 mA when it should be 4.00 mA, then current trim is used to adjust it to 4 mA.

Current trim is used to match the transmitter analog output current to the current input of the analog input (AI) card channel on the DCS. For instance, the transmitter may be reading 0.00% but the DCS may show 0.13% because of differences in current calibration. The DCS may not support current trim of channels in the AI and AO cards. If there is drift in the DCS input circuitry A/D conversion or D/A conversion and output circuitry, current trim has to be done in each device instead.

Current trim is only applicable to transmitter with 4-20 mA analog output. That is, for 4-20 mA/HART transmitters, not for FOUNDATION fieldbus (FF), PROFIBUS-PA, or WirelessHART transmitters, the reason being pure digital transmitters have no 4-20 mA analog output.

Current trim requires the technician to measure the physical output current from the transmitter. Therefore the technician must either do current trim in the field at the process location by connecting a multimeter to the transmitter test terminals, or the transmitter has to be brought back into the workshop to perform current trim. Current trim in the field is possible using a handheld communicator. EDDL plays an important role in current trim because a "wizard" created by the device manufacturer guides the user step by step through the process.

2.4 Trim Quick Reference

The difference between sensor trim, range setting, and current trim are summarized in the table below

Task	Local / Central	Example	4-20 mA HART	FOUNDATION Fieldbus	PROFIBUS
Sensor trim	Local	Correct the sensor reading to applied input. For instance, if pressure is 0 bar but transmitter reading is 0.03 bar, then sensor trim is used adjust it to 0 bar.	Yes	Yes	Yes
Range setting	Local or central	Set the 4 mA and 20 mA points. For instance, set range of pressure transmitter to get 4 mA when input is 0 bar and 20 mA when pressure is 40 bar.	Yes	No*	No*
Current trim	Local	Correct the analog output current. For instance, if the analog output current is 4.13 mA when it should be 4 mA, then current trim is used to adjust it to 4 mA.	Yes	No	No

* Range setting in transmitter with digital output only done for DP-flow and DP-level measurement

2.5 Range Values and Limit Summary

The relationship between range values and limits are summarized in the table below

		Description

		Description
LSL	Lower Sensor Limit	Lowest possible value for the 4 mA point
LRV	Lower Range Value	The 4 mA point
URV	Upper Range Value	The 20 mA point
USL	Upper Sensor Limit	Highest possible value for the 20 mA point
	Span	URV minus LRV
	Zero	Same as LRV
	Turndown	Span divided by URV

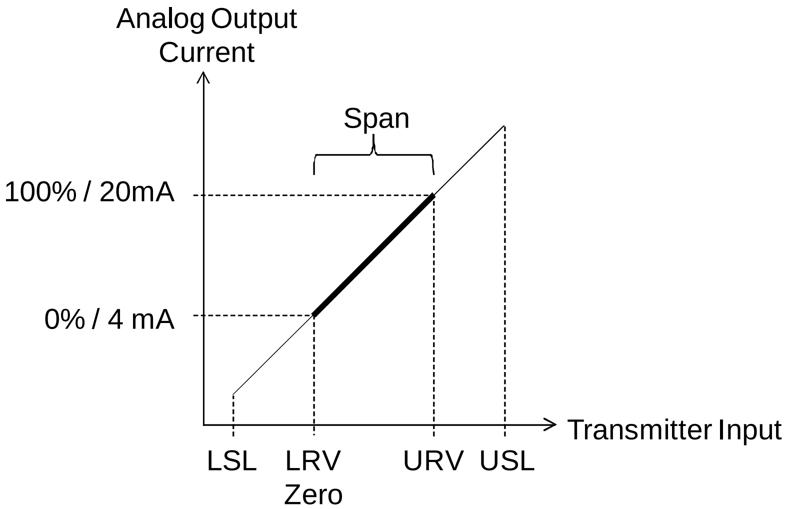


Figure 7 Range values and limits

3 Valve Positioner Setpoint Current Trim

Similarly, it is rare for the setpoint input current circuitry of a 4-20 mA positioner to drift. However, should the input current sensing be incorrect, use current trim to correct the input signal. For instance, if the current input reads 4.13 mA when it should read 4.00 mA, then current trim is used to adjust it so that the setpoint reads correctly.

Current trim is used to match the positioner current input to the analog output current of the analog output (AO) card channel on the DCS. For instance, the DCS PID output may be 0.00% but the positioner setpoint may show 0.13% because of differences in current calibration.

Current trim is only applicable to positioners with 4-20 mA input. That is, for 4-20 mA/HART positioners, not for FOUNDATION fieldbus (FF) positioners, the reason being pure digital positioners have no 4-20 mA input.

Current trim requires the technician to connect a precision current source or to measure the physical input to the positioner. Therefore the technician must either do current trim in the field at the valve by connecting a multimeter to the positioner test terminals, or the valve has to be brought back into the workshop to perform current trim. Current trim in the field is possible using a handheld communicator.

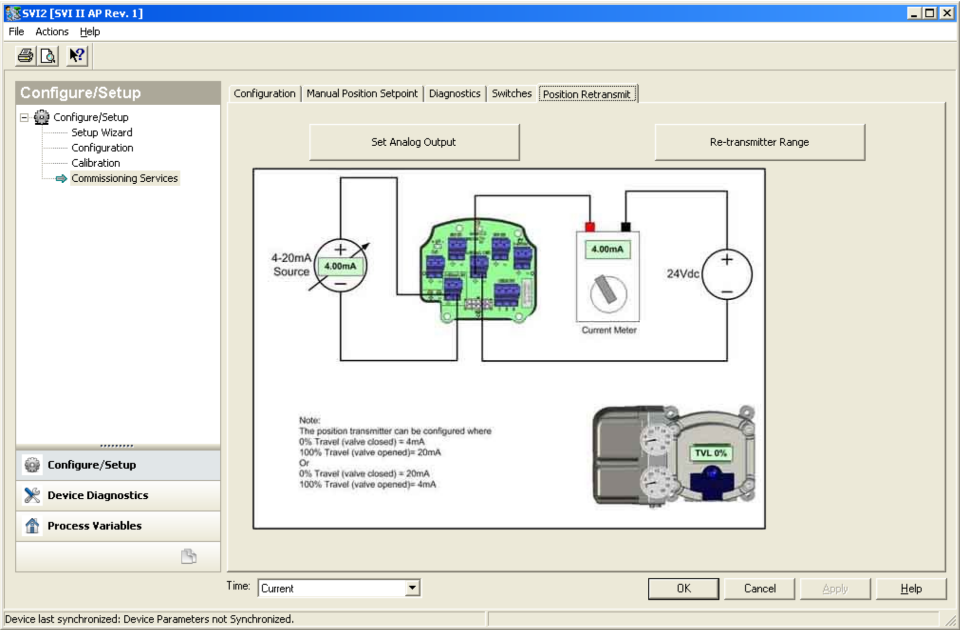


Figure 8 Positioner manufacturer uses EDDL to illustrate connection for current trim procedure

4 Valve Positioner Travel Stroking (Position Feedback Sensor Trim)

Stroking a valve positioner to find its fully opened and fully closed positions is in fact an automated procedure to among other things trim (calibrate) the position transmitter feedback sensor. That is, it is just like sensor trim for a pressure or temperature transmitter, only that a known reference need not be connected, the positioner will automatically stoke the valve over its full travel to discover the open and closed end-positions.

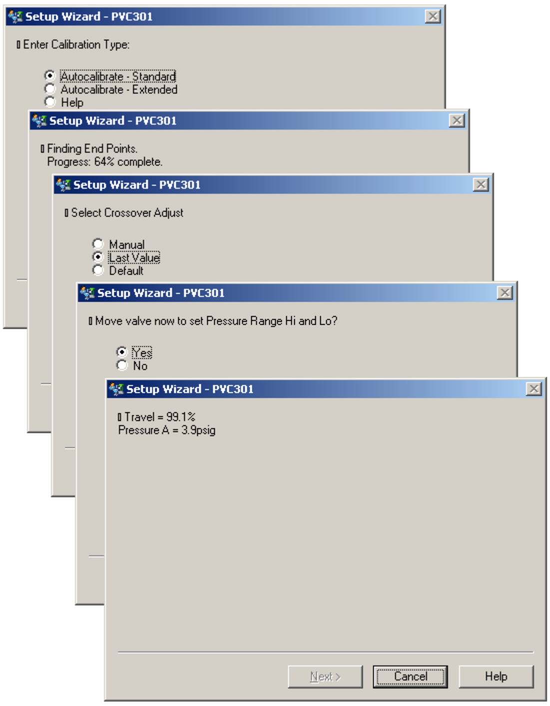


Figure 9 Automatic valve positioner travel calibration wizard rendered by the system from EDDL

Likewise, the analog 4-20 mA actual valve position feedback current output of a 4-20 mA positioner is calibrated just like a 4-20 mA transmitter. EDDL plays an important role in position feedback sensor trim because a “wizard” created by the device manufacturer guides the user step by step through the process.

Again, this process is not required for FOUNDATION fieldbus positioners or for position feedback transmitters based on WirelessHART.

5 Sensor Trim Procedure

Plants have a great mix of transmitters for different kinds of measurements from different manufacturers. Since all sensors drift, at some point in time all sensors need a trim. The procedure for calibration depends on the type of transmitter:

- Pressure transmitter: apply pressure from calibrator or dead weight tester or the manifold can be equalized for zero trim
- Temperature transmitter: apply milli-voltage or resistance from calibrator or resistance decade box
- Flowmeter: has to be calibrated against a prover or master meter
- Valve position transmitter: stroke the valve fully opened and fully closed
- pH transmitter: put the pH sensor in buffer solutions

The procedure for sensor trim may also vary slightly from one manufacturer to the next depending on the requirement for the particular sensor technology. EDDL plays an important role in sensor trim because a “wizard” created by the device manufacturer guides the user step by step through the process.

Some calibration is easier in the workshop, such as pH sensor buffering where the pH sensor has to be put into with buffer solutions and distilled water. This is easier in the lab. Smart pH sensors have a memory chip inside making it possible to calibrate the sensor in the lab and bring it to the field, carrying the calibration offset and slope data inside its memory chip. Once connected, the pH transmitter/analyzers upload the calibration data from the sensor memory.

6 Poor Hosts

The original DD technology from 1992 made it possible to calibrate all transmitters using the same handheld field communicator or laptop software. Before DD only proprietary solutions existed.

The most basic content of a DD file is the *Device Definition* describing the blocks and the parameters in the device, including limits, options, and help etc. The original DD technology from 1992 also included *Business Logic* such as "wizards" (aka "methods") which is a kind of script created by the transmitter manufacturer to guide the technician through the sensor trim process. Wizards thus make sensor trim easy. Wizards, conditionals, and help are explained further in the section on EDDL. However, not all transmitters provided wizards in their DD file and not all intelligent device management software supported wizards. That is, on many systems and for many types of transmitters, sensor trim in the past was not so easy. For instance, FOUNDATION fieldbus transmitters which in the past had to set the correct mode, in the correct block, write value to correct parameter, and remember to return block mode. At the same time the technician also had to remember to inform operations. All of this in addition to actual sensor trim task itself such as applying input, or working the manifold etc. Lack of wizards was not a problem with the DD technology itself, it was poor implementation in many early products.

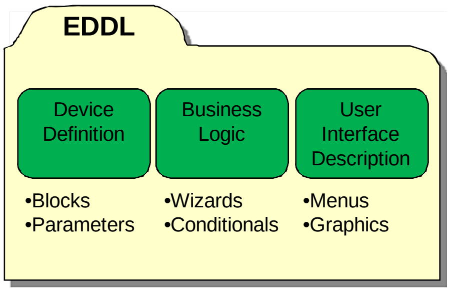


Figure 10 Not all systems supported EDDL "Business Logic", and the graphical User Interface Description was not introduced until 2006.

The EDDL enhancement done in 2006 is a *User Interface Description* which includes graphics such as trend charts, waveform graphs, dial gages, bargraphs, bar charts, and tables etc. Graphics, menu system, wizards, and conditionals are now mandatory for all FOUNDATION fieldbus and 4-20 mA/HART compliant host systems. Therefore, make sure to use a control system which supports enhanced EDDL.

7 Sensor Trim Made Easy

Sensor trim is usually done in the field since there is normally a need to access the transmitter to perform sensor trim. For instance, for a pressure transmitter it is necessary to isolate, equalize, and vent the manifold. For a temperature transmitter there is a need to connect a calibrator. In the field, sensor trim is carried out using a small portable field communicator. In a workshop it may be done using configuration software on a laptop computer or intelligent device management software part of asset management system. EDDL (IEC 61804-3) is the only device integration that supports all, not just laptop (see separate technical white paper on field work). Thanks to EDDL wizards, sensor trim for FOUNDATION fieldbus is now just as easy as 4-20 mA/HART.

7.1 Interactive Wizards

Wizards, also known as EDDL methods, are used by transmitter manufacturers to guide tasks such as calibration. Calibration capability may include wizards for:

- Sensor zero trim
- Sensor lower trim
- Sensor upper trim
- Set lower range value to applied input
- Set upper range value to applied input
- Current 4 mA trim
- Current 20 mA trim

Using wizards the transmitter manufacturer's expert embeds their calibration know-how in the EDDL file taking the technician through the task step-by-step. This ensures the correct sequence is followed, thereby simplifying tasks and reducing mistakes. Entries provided by the technician as part of the procedure, such as applied input, are validated for plausibility before being accepted by the transmitter avoiding gross errors. This same sequence will be followed regardless which EDDL software the technician chooses to use.

Typical steps in a sensor zero trim calibration wizard for a pressure transmitter are:

- Instruct technician to tell operations to put the associated control loop in manual so control is not upset when PV changes when sensor reading changes.
- inform the technician the sensor reading will change
- Instruct the technician to apply zero physical input (e.g. by isolate, equalize, and vent the manifold)
- Instruct the technician to wait while the sensor reading stabilizes and is corrected by the transmitter.

- Inform the technician the zero sensor trim was successful
- Instruct technician to tell operations the associated control loop can be put back in automatic

Because the sequence is driven according to the steps defined by the transmitter manufacturer, all technicians will follow that same sequence when calibrating that type of transmitter. All transmitters will be calibrated the same way every time. Transmitter manufacturers use conditionals to make the wizards more intelligent, for instance only ask for user input which is relevant based on prior selection, only display valid options, and evaluate plausibility (if it is reasonable) of any user input.

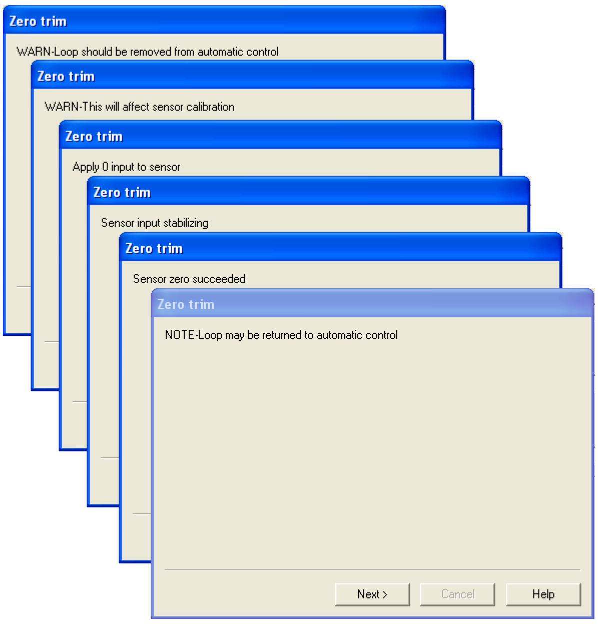


Figure 11 Calibration wizard is created by the device manufacturer's expert to guide the user

7.2 Consistent

EDDL (www.eddl.org) has a multilingual dictionary including standard text for user prompts in the wizards, error messages, parameter labels, and even help. This dictionary is references by transmitter manufacturers, thus providing consistency making work more intuitive and reducing errors because transmitters of different type from different manufacturers will use the same message (refer to separate white paper on consistent look & feel).

7.3 Context Sensitive Help

The transmitter manufacturer’s factory experts share their know-how in the form of help text embedded into the EDDL file for their device. This includes help for configuration/setup and diagnostics parameters, status indicators, and wizards such as for sensor trim. The help for any wizard or parameter can be pulled up at the click of a button. This simplifies work by minimizing the need to refer to manuals. Even if the information is buried deep in the manual, it's easily accessed from the device management software thanks to EDDL.

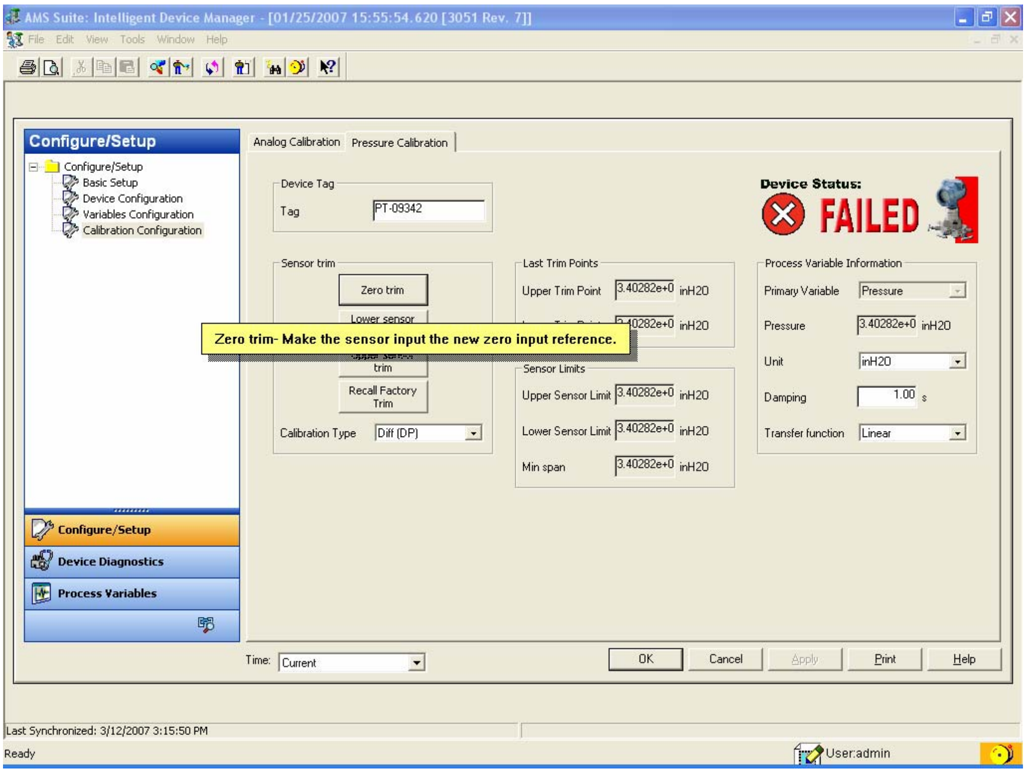


Figure 12 Transmitter know-how provided by the device manufacturer's expert

8 Better Calibration Results

EDDL reduces sensor trim mistakes and enforces work consistency among technicians. Calibration work can be completed faster as the need to carry and refer to manuals and procedures is reduced. Transmitters perform better when properly calibrated

Other device integration technologies do not work on handheld field communicators, thus are not as convenient and portable. Other device integration technologies do not have a standard dictionary and therefore do not provide the consistency and ease of use.

Mixing EDDL with other device integration technologies will make calibration more difficult. If transmitters are used only with EDDL they are all calibrated the same way. If EDDL is mixed with other technologies there will be more than one way of doing calibration. Moreover, the drawbacks and limitations of other technologies will be introduced into the system (refer to white paper on system administration).

9 Pre-Commissioning Calibration

If there is a need to "calibrate" (perform sensor trim) or not the transmitters before installation is a common question. Don't calibrate for the sake of calibrating. Since sensor trim is done in the factory when the transmitter is manufactured, to trim the sensor or not before installation depends on if it will drift during shipment. These days transmitters are very rugged and don't drift during shipment. Hence there is typically no need to perform sensor trim before installation.

The 4-20 mA/HART, FOUNDATION fieldbus, WirelessHART, and PROFIBUS version of a device use the same sensor. Therefore they have the same basic accuracy and stability. The 4-20 mA current loop adds a little inaccuracy and drift, but less than the sensor. Thus doing sensor trim or not before installation does not depend on the protocol, it's how rugged the sensor is.

Pressure transmitters needs zero trim to correct mounting position effect.

Usually, this question only comes up for pressure and temperature transmitters - presumably because portable calibrators exist for temperature and pressure. There is no discussion about site calibration of the flowmeters for gas or liquid, and not for many other transmitters - presumably because it would be very much more difficult to do.

9.1 Loop Check

Loop check moved to a separate tutorial document. See www.eddl.org

10 Beyond Sensor Trim

EDDL-based device management software goes beyond sensor trim and range setting.

10.1 Manuals and Notes

EDDL-based device management software is also capable of giving access to related documentation. Instruction manuals from the transmitter manufacturer and plant procedures can be opened at the click of a button.

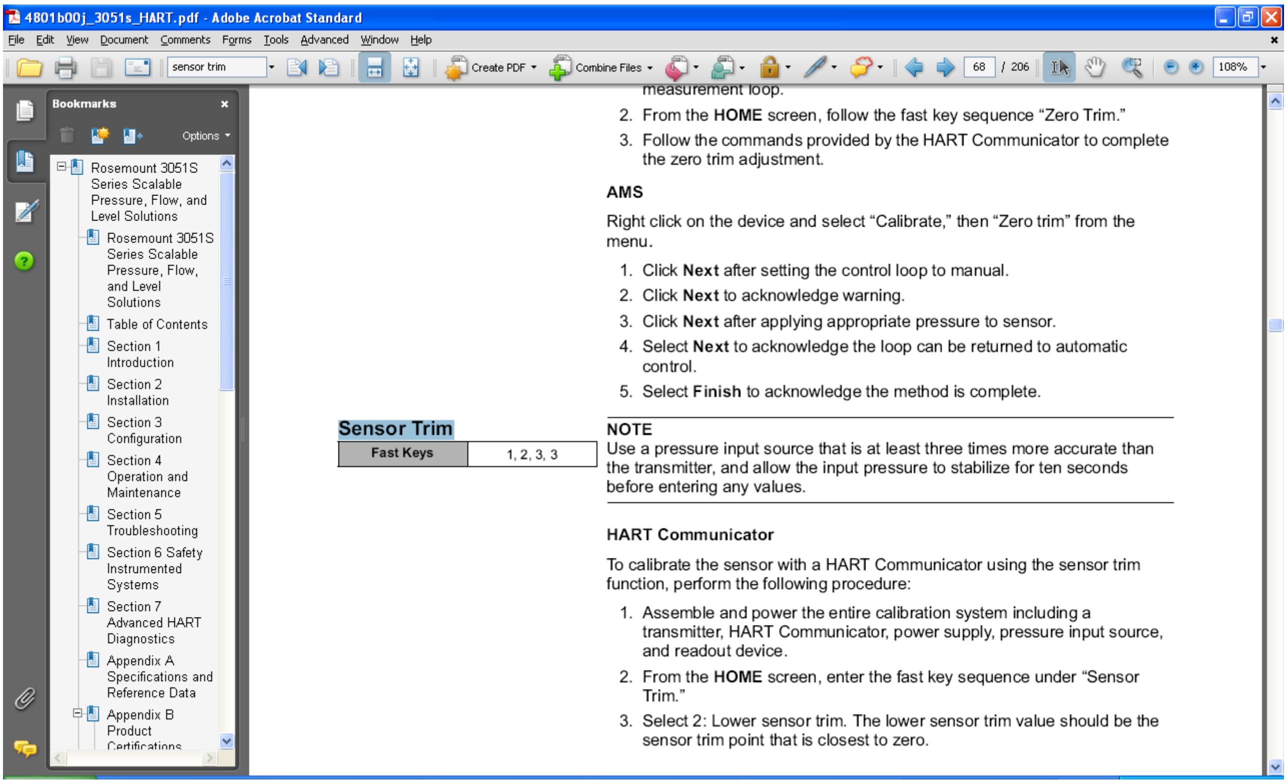


Figure 13 Intelligent Device Management (IDM) software gives access to documentation like instruction manuals

10.2 Audit Trail

EDDL-based IDM software also supports audit trail functionality of sensor trim and range changes etc. Since the audit trail function is independent of the EDDL file, EDDL-based IDM software supports audit trail for all devices, not just some.

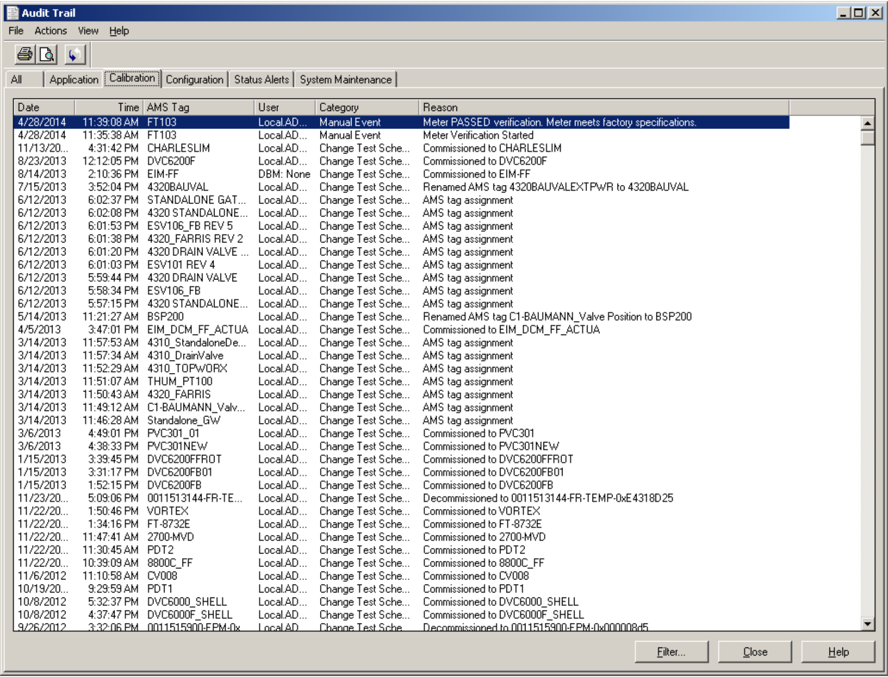


Figure 14 IDM software based on EDDL supports audit trail for all devices, not just some

When used with documenting calibrators, the calibration records include "as found" / "as left"; that is percentage error graph at five points before and after sensor trim was performed.

10.3 Maintenance Schedule

EDDL-based device management software is also able to schedule maintenance tasks such as inspection and calibration.

11 Documenting Calibrators

A calibrator can be used to perform sensor trim or current trim, but is not required for range setting. Calibrators are primarily used for pressure and temperature sensor trim. For smart transmitters using 4-20 mA/HART, FOUNDATION fieldbus, or PROFIBUS-PA, a documenting calibrator is a good option as it enables “paperless calibration”.

11.1 Communication

Traditionally an instrument technician on a calibration job carries two tools: a portable calibrator for the input to the transmitter and to measure the analog output plus a handheld field communicator to send the trim commands.

A documenting calibrator combines the functionality of a portable calibrator with that of a handheld field communicator into a single tool. The portable documenting calibrator communicates digitally with the intelligent transmitters and is able to retrieve all the identification information in the transmitter as well as range information and sensor limits etc. The documenting calibrator also retrieves the measured value digitally from the transmitter. The documenting calibrator not only compares the sensor reading against the standard, but is also able to send the trim commands to the transmitters when the technician performs sensor trim or current trim so as to achieve an accurate reading. Documenting calibrators supporting 4-20 mA/HART, FOUNDATION fieldbus, and PROFIBUS-PA are available. Some documenting calibrators are based on EDDL supporting wizards, thus making the instrument technician’s job easier.

Therefore, instead of having to carry two tools, the instrument technician carries a single tool.

11.2 Record Keeping

Traditionally an instrument technician on a calibration job carries two tools also carries a clipboard with a calibration form where the calibration job is documented.

A documenting calibrator can automatically document the calibration performed, thus also eliminating the need to carry a clipboard for writing down all the data by hand in the field. The documenting calibrator internally stores the input points applied and the corresponding output generated by the transmitter in the calibration process. These data points can be stored for both "as found" before trim and "as left" after trim was done based on the transmitter's measured value digitally preserving full precision. Identification information such as manufacturer, device type, version, and serial number and include as part of the calibration result documentation without requiring manual data entry. This saves time by avoiding manual data entry and mistakes. Documenting calibrators store the calibration data internally, until they are docked and the data automatically uploaded to (synchronized with) the audit trail in the Intelligent Device Management (IDM) software or their dedicated calibration management software. The software permits the calibration report to be generated and printed.

Manual data recording and data entry is not required, reducing the burden on technicians and minimizing mistakes. While handwritten paperwork documentation for the calibration may be illegible or incomplete, data from a documenting calibrator is always legible and complete for record keeping.

11.3 Calibration Route

A calibration route is the order in which instruments around the plant will be visited and calibrated. Generally, those instruments in one area of the plant, but it could be by instrument type or by calibration due date, whichever is most efficient. The route list of devices to be calibrated is created in the Intelligent Device Management (IDM) software or their dedicated calibration management software, and then downloaded to the documenting calibrator.

12 Single Solution

Because EDDL is a text file from which the device page graphics is rendered by the device management software, the calibration wizards and help are rendered the same way for all devices regardless of protocol, manufacturer, or type. This consistency achieved thanks to EDDL makes calibration easier and intuitive (see separate technical white paper on consistency of use). No other technologies can provide a comparable result.

13 Conclusion

For plants that are looking for an easy solution to calibrating multiple types and versions of transmitters, EDDL technology is a perfect match. EDDL meets the need of plants to calibrate all types of devices from a single software application using a single technology while at the same time making it fast and easy to keep the system up to date with new device versions. Plants should upgrade existing DD systems to EDDL with enhancements to enjoy the greater ease of use afforded by the standard graphical display.

Calibration trim is just one of the ways in which intelligent device management software based on EDDL reduces maintenance & operational cost. Please refer to other technical white papers on advanced diagnostics, configuration/setup, and system administration etc.

14 Questions

Post your questions on transmitter calibration and intelligent device management with the EDDL group on Linkedin:
http://www.linkedin.com/groups?gid=3736433

15 References

EDDL Brochure and Technical Description on www.eddl.org site

Jonas Berge, "Fieldbuses for Process Control: Engineering, Operation, and Maintenance", ISA, 2002, ISBN 1-55617-760-7

ANSI/ISA–51.1–1979 (R1993) “Process Instrumentation Terminology”, Reaffirmed 26 May 1995, ISBN 0-87664-390-4

Appendix A: FF Parameters

Systems based on enhanced EDDL shows range, calibration, and other information organized in hierarchical menu trees, tabs, and frames with human readable labels etc. However, older systems based on traditional DD (without EDDL enhancements) typically show parameters in list or table form, displayed with a cryptic parameter name. These are the parameters:

Data	Block	Parameter Name
Lower Range Value (LRV)	AI function	XD_SCALE.EU_0
Upper Range Value (URV)	AI function	XD_SCALE.EU_100
Converted	AI function	OUT_SCALE.EU_0
Converted	AI function	OUT_SCALE.EU_100
PV%	AI function	FIELD_VAL
Lower Sensor Limit (LSL)	Transducer	SENSOR_RANGE.EU_0
Upper Sensor Limit (USL)	Transducer	SENSOR_RANGE.EU_100
Minimum Span	Transducer	CAL_MIN_SPAN
Lower Sensor Trim Point	Transducer	CAL_POINT_LO
Upper Sensor Trim Point	Transducer	CAL_POINT_HI
*Lower Range Value (LRV)	Transducer	PRIMARY_VALUE_RANGE.EU_0
*Upper Range Value (URV)	Transducer	PRIMARY_VALUE_RANGE.EU_100

In most devices, the transducer block PRIMARY_VALUE_RANGE cannot be configured from the transducer block. If at all used, transmitter range is configured in the AI function block parameter XD_SCALE which automatically updates the transducer block PRIMARY_VALUE_RANGE. However, some transmitter may require the range to be configured manually in both places. That is, there are two types of FF transmitters:

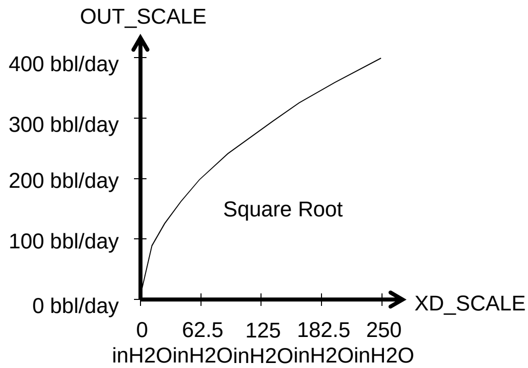
1. Transmitters where range can only be set in the AI block XD_SCALE parameter (not in the transducer block) making BLOCK_ERR due to XD_SCALE mismatch impossible. This is easy to use.
2. Devices where range can be set in both the XD_SCALE parameter in the AI block and in the PRIMARY_VALUE_RANGE parameter in the transducer block making BLOCK_ERR due to XD_SCALE mismatch possible. This can be confusing..

Internally the FF AI block computes:

*FIELD_VAL = (PRIMARY_VARIABLE - XD_SCALE::0) / (XD_SCALE::100 - XD_SCALE::0) * 100 [%}*

*PV = (FIELD_VAL / 100) * (OUT_SCALE::100 - OUT_SCALE::0) + OUT_SCALE::0*

Note the AI block must be in Out of Service mode in order to change XD_SCALE or OUT_SCALE



If the pressure transmitter is measuring pressure or DP (L_TYPE is ‘direct’), there is no need to set XD_SCALE. Setting XD_SCALE is only required for DP flow and DP level applications where the transmitter shall convert and scale a DP into flow or level. When L_TYPE is ‘direct’ the pressure reading will be seen in the transducer block and on the AI block PV and OUT

Appendix B: History of 3-15 psi, 10-15 mA, and 4-20 mA signals

Digital HART communication is superimposed over the analog 4-20 mA signal. Before 4-20 mA the signals were 3-15 psi and 10-50 mA. These signals all have a “live zero” (3 psi, 10 mA, and 4 mA) rather than a “dead zero” (0 psi, 0 mA) which can be used to detect a severed pneumatic tube or signal wire. The live zero can also be used to power a 2-wire loop powered device. 3-15 psi, 10-50 mA, and 4-20 mA etc. all have a ratio of 1:5 (20% bias). Nobody remembers the exact reason why the signal ranges 3-15 psi, 10-50 mA, and 4-20 mA were selected and there appears to be no definite source documenting this decision such as minutes of meeting from a standards committee. Some research has uncovered the following technical reasons why these signal ranges were chosen.

3-15 psi pneumatic signal

Pneumatic instruments operate on the flapper-nozzle (baffle-nozzle) principle. It appears 3-15 psi with the 1:5 ratio was chosen because it the most linear portion on the curve for the movement of the flapper (baffle) and the backpressure resulting in the nozzle.

10-50 mA analog electronic signal

Early analog electronic instruments used magnetic amplifiers. 10 mA live zero was chosen as it is the lowest at which instrument based on magnetic amplifiers could operate. Maintaining the 1:5 ratio the signal was chosen 10-50 mA.

4-20 mA analog electronic signal

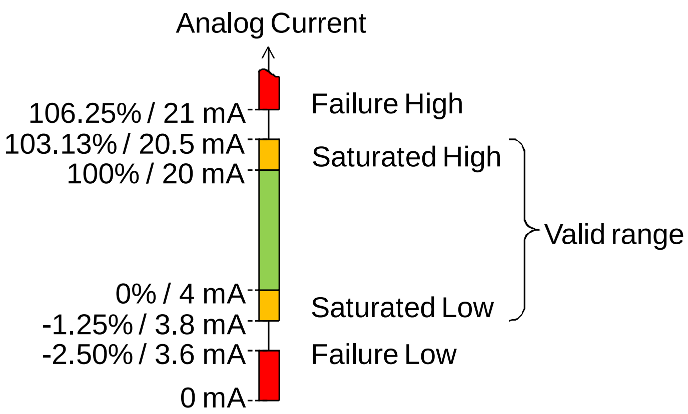
With the introduction of the transistor it became possible to make devices operating on 4 mA. Thus the signal was chosen 4-20 mA maintaining the 1:5 ratio.

With the introduction of microprocessors in instrumentation and digital communication, the HART protocol was introduced superimposed over the 4-20 mA signal. The HART commands supported by the device, how device information is displayed, and the wizards to make tasks like calibration easy are described using EDDL.

Appendix C: “Failure mode alarm” and NAMUR NE43

4-20 mA instrumentation and controls usually support a signal range slightly below 4 mA and above 20 mA. For transmitters, current values below 4 mA and above 20 mA are used to signal a fault such as a thermocouple burnout or other sensor failure. The transmitter can be configured for failure indication low or high. Unfortunately manufacturers use different signal levels to indicate failure which prevents tight analog signal integration and interpretation in single loop controllers, control systems, and safety systems. Some transmitters may use 3.75 mA while others may use 3.6 mA or less. Some transmitter may use 21.75 mA or more while other use 23 mA. This inconsistency of signal levels for failure indication makes it difficult to take full advantage of the failure information in control strategies. The NAMUR NE43 “Standardization of the Signal Level for the Failure Information of Digital Transmitters” recommendation was created to standardize failure indication from transmitters and interpretation in control systems to enable better analog integration. NE43 defines 3.8-20.5 mA as a valid (‘Good’) measurement value where 3.8-4 and 20-20.5 mA indicates saturation. A signal of <3.6 mA or >21 mA indicates a transmitter failure (‘Bad’).

mA	%	
3.6	-2.50	Failure low
3.8	-1.25	Saturated low
4.0	0.00	Lower Range Value
20.0	100.00	Upper Range Value
20.5	103.13	Saturated high
21.0	106.25	Failure high



By using transmitters and systems that both conform to the NE43 recommendation, it is possible to flag faults to the operators and control strategies. However, note that all device errors, severe and trivial, are flagged the same way so the operator cannot tell the difference and that if any error occurs it is flagged and the measurement value is not provided.

FOUNDATION fieldbus and PROFIBUS-PA transmitters use fast digital communication with separate status indication for each measurement including measurement validity flagged in real-time as ‘Good’, ‘Bad’, or ‘Uncertain’. This allows operators and control strategies to severe problems from trivial issues. This allows the control strategy to put the loop in manual in case of failure, with the option to trip. For non-severe issues the value is still displayed with ‘Uncertain’ status.

Smart Valve Positioners

Smart valve positioners are not in the scope of NAMUR NE43. However, signals <4 mA and >20 mA also have specific meanings. Control systems and single loop controllers with 4-20 mA output use a similar scheme to achieve tight shut-off for control valves. That is, they may set current <<4 mA or >>20 mA. Some control systems set the output current to 0 mA to achieve tight shutoff. This is impractical in the case of smart valve positioners since they need 3.6 mA to operate and will be completely switched off at 0 mA. Therefore make sure to configure the control system or single loop controller to provide at least 3.6 or 3.8 mA for tight shutoff to ensure that the smart valve positioner can continue to operate and respond to HART communication.

Appendix D: Bench Calibration Tools

The same handheld field communicator is used to calibrate 4-20 mA/HART and Fieldbus transmitters.

Alternatively, the same Intelligent Device Management (IDM) software or configuration software is used to calibrate 4-20 mA/HART and Fieldbus transmitters. A 4-20 mA/HART transmitter requires the laptop to be fitted with a HART-USB interface while a Fieldbus transmitter requires a Fieldbus-USB interface. A PROFIBUS-PA device requires a PA-USB interface.

A 4-20 mA/HART transmitter has to be powered by a DC power supply and 250 ohm resistor, all connected in series. A Fieldbus or PROFIBUS-PA transmitter has to be powered by a fieldbus power supply, connected in parallel. Portable fieldbus power battery packs are convenient both for field work and on the bench. A fieldbus transmitter could also be powered by the Fieldbus-USB interface eliminating the need for separate power.

Thanks to enhanced EDDL graphics and wizards, the procedure for calibrating the 4-20 mA/HART version of a device is the same as calibrating the Fieldbus version of that same device.

Appendix E: Low Cut-Off

Low cut-off is used in flow metering in order to avoid irratic control and false totalization. It is predominantly used for DP flow meters. The low cur-off function turns off the square root function below the cut-off point. This is done because the square root function has very high gain closer to zero so any measurement noise gets amplified and results in irratic control and false totalization etc. All DP transmitters have this function. In the past this was a "hard" cut-off making flow zero below the cutoff point. Today "soft" cutoff is more common, linearly interpolating the flow between zero and the cut-off point below the cut-off.

In some 4-20 mA devices the cut-off point is specified on DP while in other transmitters the cut-off is defined on flow. There is a big difference in that a 4% cut-off in DP units corresponds to a 20% cutoff in flow units.