

PT-101 transmitter calibration — Operating principles

Trainee document · test bench, 4–20 mA pressure transmitter and PLC input

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How to read this document

The simulator reproduces a calibration bench: a hand pump that generates pressure, a reference gauge, a PT-101 pressure transmitter with its two-button local interface, a series multimeter, the analog input of a PLC and the 24 V loop supply. The purpose is to learn how to **check** an instrument, how to **correct** it and how to **document** what was done.

Every number shown comes from a model solved ten times a second: if you pump, the air really heats up; if you open a fitting with the line under pressure, the action is refused; if you do the trims in the wrong order, the instrument stays out of tolerance. This document explains **why** each part exists and **how** it reacts, so that what is seen on the panel can be predicted instead of suffered.

The **instrument tags** (PT-101, PI-100, HV-101, AI-101...) are never translated: they are identifiers, not words. The instrument menu items (ZERO TRIM, RERANGE, LOOP TEST...) stay as on the display. Each chapter matches a window of the panel, and is the same text that opens with the **?** button of that window. The last chapter states what the model simplifies: knowing where the simulator ends is part of the training.

1. The pressure bench

1.1 Why a bench is needed

To know whether a transmitter measures correctly, it must be given a **known** pressure and what it says compared with what it should say. The bench produces the pressure (the pump), makes it adjustable (vent and fine adjuster) and measures it with a more accurate reference instrument (the PI-100 reference gauge). The transmitter under test is never the reference: it is the object of the test.

1.2 The pump and the air

The pump is pneumatic: at every stroke of the lever it pushes 25 cm³ of air, at atmospheric pressure, into a volume of about 60 cm³. The first stroke therefore takes the line to about 0.4 bar; as pressure rises, the pump pushes against a higher back-pressure and the gain per stroke falls, down to zero at **40 bar** (the pump limit). On the model, 3 strokes reach 1 bar, about 13 reach 5 bar and about 27 reach 10 bar: high pressure is earned with patience.

You pump by **holding the lever down**: about one stroke every 0.45 s. Pressure appears on the red seven-segment display of the pump and on the mimic.

1.3 Why pressure falls after pumping

Compressing air heats it. With the line at rest the air gives its heat to the line and cools with a time constant of about 8 s: pressure therefore **drops for a few seconds after the last stroke** before settling. On the model, after taking the line to 10 bar, pressure loses about 0.12 bar and settles in about 8 s.

This is why the record (chapter 8) accepts a point only when pressure is **still**: recording while the air is still cooling means comparing the instrument with a value that is changing.

1.4 Vent HV-101 and the fine adjuster

HV-101 is a needle vent valve: opening it lets air out to atmosphere at a rate that grows with the **square** of the opening. Fully open, it empties the line from 10 bar in under three seconds; barely open, it empties slowly — which is what lets you come down calmly onto a test point.

The **fine adjuster** (vernier) is a screw that changes the line volume by about $\pm 5\%$: with the same mass of air, less volume means more pressure. It is for the last touch: at 10 bar g it moves pressure by about ± 0.5 bar, continuously, without pumping or venting.

Both knobs are operated by dragging them vertically, with the mouse wheel, with the keyboard arrows or with the sliders below the drawing.

1.5 The PI-100 reference gauge

PI-100 is the bench reference: 20 bar g full scale, a minimal reading noise (0.2 mbar), compared with the transmitter PV at every point of the record. If pressure exceeds 102 % of its full scale the **PI-100** alarm appears (*protect the reference*): a reference taken over range loses its calibration, and a bench with an uncertain reference is worth nothing.

1.6 Chapter parameters

Quantity	Value	Notes
Bench volume	about 60 cm ³	fine adjuster $\pm 5\%$
Volume per stroke	25 cm ³	at atmospheric; falls with pressure
Maximum pump pressure	40 bar g	strokes ineffective beyond
Rate with lever held	0.45 s	
Air cooling	$\tau \approx 8$ s	origin of the drop after pumping
Discharge with HV-101 fully open	$\tau \approx 0.35$ s	quadratic in opening
PI-100 full scale	20 bar g	alarm above 102 %

2. The PT-101 transmitter: from pressure to current

2.1 The measuring chain, step by step

What the PLC reads is the result of seven steps in cascade. Knowing them is the difference between correcting an instrument and trying at random.

1. **Sensor.** It measures pressure and adds its own errors: a **zero** (offset) and a **span** (slope error), plus noise of about 0.5 mbar. A new or deteriorated sensor goes wrong here.
2. **Sensor trim.** A linear correction, $PV = a \cdot \text{reading} + b$, set with ZERO TRIM, LOWER TRIM and UPPER TRIM (chapter 5). It corrects the sensor, not the rest.
3. **Damping.** A first-order filter, adjustable from 0 to 60 s (0.4 s on the data sheet). A high value makes the measurement steady but slow: with 32 s the instrument *does not follow* the pressure any more and the person checking it suspects a fault.

4. **Percent of range.** $\% = (PV - LRV) / (URV - LRV)$, with LRV and URV the ends of the calibrated range (4 and 20 mA). With 0–10 bar, 5 bar is 50 %.
5. **Transfer function.** Linear, or **square root** (for flow measured from differential pressure). With the square root, below 4 % of range the output is forced to zero (low-flow cut-off) and resumes only above 5 %.
6. **Saturation and alarm.** The current $4 + 16 \cdot \% \text{ mA}$ is limited to the saturation levels (chapter 2.3); if the sensor is faulty the output goes to the alarm level.
7. **D/A converter.** It turns the numeric value into a real current. It has its own gain and offset errors, corrected with the **ANALOG TRIM**: errors the instrument display cannot see, because they arise *after* the PV is calculated.

2.2 Why the two trims are different things

The **sensor trim** (step 2) and the **analog trim** (step 7) correct different parts of the chain. The first aligns the PV with the true pressure: it is done by comparing the instrument display with the reference. The second aligns the current with the PV: it is done by comparing the multimeter with what the instrument says it is sending. If the display is right and the PLC is not, the sensor is not the problem: the defect is in the D/A, and touching the sensor would move the error instead of removing it.

2.3 Saturation and alarm levels

When pressure goes out of range, current does not grow forever: it stops at a **saturation** level, which the PLC recognises as “out of range but valid”. When the instrument detects an internal fault, the current goes instead to an **alarm** level, outside the saturation zone, so that the PLC can tell an out-of-range from a fault.

Levels	Low saturation	High saturation	Low alarm	High alarm
Standard	3.90 mA	20.80 mA	3.75 mA	21.75 mA
NAMUR NE 43	3.80 mA	20.50 mA	3.60 mA	22.50 mA

Which of the two alarms applies is decided by a **switch on the electronics board** (HI / LO): it is not in the menu and is moved only with the instrument **unpowered**. The data sheet prescribes NAMUR and high alarm: any other configuration must be brought back to it.

2.4 Chapter parameters

Quantity	Value
Sensor limits	$-1 \div 55.2 \text{ bar g}$
Calibrated range	$0 \div 10 \text{ bar g}$ (4–20 mA)
Minimum range allowed (RERANGE)	about 0.37 bar
Damping	$0 \div 60 \text{ s}$
Square-root cut-off	below 4 %, resume above 5 %
Output limited to	$3.5 \div 23.2 \text{ mA}$

3. The 4–20 mA loop, the multimeter and the PLC

3.1 Why a current

A current signal does not depend on cable length or resistance: the same current flows all around the loop. The lower limit at **4 mA**, not zero, is there to tell “zero pressure” from “broken loop”: at 0 mA there is a fault, at 4 mA there is a measurement of zero.

3.2 The two-wire loop

The transmitter is powered **by the same loop** that carries the signal: the 24 V supply, the series multimeter, the PLC input and the instrument form one single circuit. On the mimic, the supply switch, next to the 24 V box, opens and closes this circuit.

With the loop **off** the instrument has no power: the display goes dark, the current is zero and the PLC sees an open wire. The switch is also used to make the instrument safe: the sensor module and the alarm switch are touched **only with the power off**. Switching the loop off also cancels an open menu, a loop test and an analog trim in progress.

3.3 The series multimeter

It measures the real current reaching the PLC, with noise of about 0.6 μA . It is the tool of the **ANALOG TRIM** and of the loop test: the only way to know whether the current the *electronics say they are sending* is the one that *really goes out*. The box also shows the current as a percentage of range (4 mA = 0 %, 20 mA = 100 %).

3.4 The PLC analog input AI-101

The PLC converts the current into counts with a fixed scale:

4 mA = 0 counts = 0 bar g 20 mA = 27648 counts = 10 bar g

The scale accepts values slightly out of range (−4864 to 32511 counts) and filters the signal with a 0.2 s constant. The box shows the measurement in bar g, the raw counts, the current read and the **channel status**:

Status	Condition
VALID	current between low and high saturation
LOW / HIGH SATURATION	beyond the saturation setting, within the failure one
LOW / HIGH FAILURE	beyond the failure setting: measurement invalid
OPEN WIRE	below about 1.2 mA

The settings are those of chapter 10 and can be changed on line.

3.5 Chapter parameters

Quantity	Value
Loop supply	24 V
PLC scale	4 mA = 0, 20 mA = 27648 counts
PLC input filter	0.2 s
Open wire	below 1.185 mA

4. The two-button local interface (LOI)

4.1 Why only two buttons

The instrument is configured **only** from the two buttons of its local interface: that is how it works in the field, where there is no terminal at hand. For this reason the menu logic is repetitive and must be learned by heart.

- **SCROLL** steps through the items of a menu, or changes the digit you are on.

- **ENTER** confirms the item and goes one level down, or accepts the digit and moves to the next one.

Pressing either button from the normal display enters the main menu. At the end of every list there are always **BACK TO MENU** (one level up) and **EXIT MENU** (leave altogether).

4.2 The normal display

The display has a large line and a small one and **rotates every 2.5 s** among the quantities enabled in the DISPLAY menu: pressure in the chosen unit, percent of range, current in mA. In special conditions other screens appear: ANALOG SAT (current saturated), ANALOG FIXED (loop test running), PRES OUT LIMITS (pressure beyond the sensor limits) and, with a faulty sensor, ALARM / SENSOR FAIL. The display is the first place to look when the current does not add up.

4.3 Entering numbers

A number is written in **eight positions**, one digit at a time: SCROLL changes the digit (0–9, decimal point, minus sign in the first position, back arrow), ENTER accepts it and moves to the next. After the eighth, the **SAVE / CANCEL** choice appears: SCROLL toggles, ENTER confirms. The decimal point zeroes everything to its right: a value like 0.4 is built starting from the point.

4.4 The menu items

Item	What it does
VIEW CONFIG	Shows, read-only: TAG, UNITS, LRV, URV, TRANSFER FUNCT, DAMPING, ALARM DIR, ALARM SAT VAL, HART REV
ZERO TRIM	Zeroes the PV with the line at zero pressure (chapter 5)
UNITS	BAR, MBAR, PSI, KPA, MPA, KG/CM2
RERANGE	ENTER VALUES (writes LRV and URV) or APPLY VALUES (SET 4MA / SET 20MA with the pressure present)
LOOP TEST	Fixes the current at 4 mA, 20 mA or a value of choice (3.6 ÷ 23 mA); END LOOP TEST to leave
DISPLAY	Chooses the quantities shown (at least one always stays on)
EXTENDED MENU	CALIBRAT, DAMPING, TRANSFER FUNCT, SCALED VARIAB, ASSIGN PV, TAG, ALARM SAT VALUES, PASSWORD, SIMULATE, HART REV

4.5 Messages

After every action a message appears for about 1.6 s: **SAVED** (done), **INVALID** (value refused) or **TRIM FAIL** (the correction requested exceeds the trim limit). A TRIM FAIL is not a fault: it means the pressure applied is not the one being declared, or that the point chosen is not suitable.

5. The trims: how the sensor and the output are corrected

5.1 ZERO TRIM

With the line **vented** (0 bar g, HV-101 open), ZERO TRIM takes the PV to zero by correcting the offset only. It is refused (**TRIM FAIL**) if the instrument reads more than 3 % of its upper limit — about 1.66 bar — because a deviation that large is not an offset but another fault. It is the right correction when the error is the same at every point: the curve is only shifted.

5.2 LOWER TRIM and UPPER TRIM

They are the two points of a **linear two-point correction**, and must be done **in this order**:

1. with pressure at the low point, **LOWER TRIM** and enter the value **of the reference** (not the one the instrument shows);
2. with pressure at the high point, **UPPER TRIM** and again enter the value of the reference.

The lower trim sets the offset; the upper one calculates the slope using the low point already stored. If the upper is done first, the slope is calculated on a low point that does not exist and the result is wrong. Limits: the lower trim correction cannot exceed about 2.76 bar, the slope cannot change by more than $\pm 10\%$, and the two points must be at least 1 % of the upper limit apart (about 0.55 bar).

5.3 ANALOG TRIM

It corrects the D/A. The instrument **forces the output to 4 mA**, and you enter what the **multimeter** reads; then it forces **20 mA**, and you enter the reading again. From the two pairs (declared, read) the instrument derives the D/A gain and offset. It is refused if the correction exceeds 5 % of gain or 0.5 mA of offset. It does not change the PV: it only changes the current that comes out for the same PV.

5.4 FACTORY RECALL

It restores to factory values, separately, the **sensor trim** and the **analog trim**. It is the way out when a trim went wrong and nobody remembers where it started.

5.5 Which trim for which symptom

Symptom	Likely cause	Correction
Same error at every point, PLC and display agree	Sensor zero	ZERO TRIM (or LOWER TRIM)
Error growing upward, right at the bottom	Sensor span	LOWER TRIM then UPPER TRIM
Display right, PLC wrong	D/A	ANALOG TRIM with the multimeter
Display right, PLC right, but different configuration	Configuration	Menu, per the data sheet
PV does not follow pressure, moves slowly or not at all	High damping, plugged connection	Check DAMPING, then the connection

6. The calibration data sheet and the configuration

The data sheet is the instrument's **reference document**: it says how it must be configured for the plant. A transmitter taken from the store does not have the plant configuration: it must be checked item by item.

Item	Prescribed value
Tag	PT-101
Calibrated range	0 – 10 bar g
Display unit	BAR
Transfer function	Linear
Damping	0.4 s
Saturation and alarm levels	NAMUR NE 43
Alarm direction	High (HI)

Item	Prescribed value
Allowed tolerance	± 0.25 % of span
Test points	0 – 25 – 50 – 75 – 100 %

The **VIEW CONFIG** menu shows almost everything read-only: compare it item by item with the data sheet. One item, the **alarm direction**, is not in the menu but on the **electronics board switch**: it can be read in VIEW CONFIG, but changed only physically, with the instrument off (chapter 7).

The ± 0.25 % of span tolerance applies to **two separate quantities**: the PV (± 0.025 bar on a 10 bar range) and the current (± 0.04 mA on 16 mA). An instrument with the right display and the wrong current is out of tolerance.

7. Maintenance: physical actions on the transmitter

The window shows the instrument drawn and lets you act on its components, as the technician would. Every action has a **precondition**, and the simulator enforces it: it is exactly what separates a correct intervention from an accident.

Action	Precondition	Effect
Alarm switch HI / LO	loop off	Changes the alarm direction
Replace the sensor module	loop off and line vented	Replaces the sensor (see 7.1)
Remove and clean the connection	line vented	Removes the blockage
Tighten the fittings	line vented	Removes the bench leak

If the precondition is missing the action is refused and the part lights red; if it goes through, green, with a note saying what was done.

7.1 Replacing the module: the last resort

The new sensor module is not “perfect”: it has its own zero (about 0.045 bar) and span (about -0.4 %) errors, and starts from the **factory trim**. After replacement the instrument is almost always **out of tolerance** and must be recalibrated. The configuration stays in the electronics.

Replacing a module that was not faulty is an **unnecessary** action: it is recorded and a scenario criterion penalises it. A good technician finds the fault first and replaces only when the diagnosis requires it (sensor in alarm).

7.2 Plugged connection and fittings

A **plugged impulse connection** isolates the sensor from the line: pressure can rise and fall, but the transmitter stays still or moves very slowly. A **leak** at a fitting makes pressure fall continuously. They are two defects with different symptoms, and telling them apart is part of the diagnosis (chapter 9).

8. The record: before and after calibration

8.1 Why two columns

A calibration record documents two distinct things:

- **Before calibration** (*as found*): what the instrument was like **as it arrived**, before anyone touched it. It is evidence of its drift over time, and serves to decide whether products made with that instrument so far must be reassessed.
- **After calibration** (*as left*): how it was **returned**. It is the proof that it is now within tolerance.

That is why the “before” column is recorded **before any action**: as soon as anything is touched (a trim, a unit, the switch, the module...) the “before” record is no longer possible. And, conversely, **any later change** after the “after” record **clears** it: an instrument that was touched afterwards is not certified.

8.2 The five points

0 – 25 – 50 – 75 – 100 % of range, that is 0 – 2.5 – 5 – 7.5 – 10 bar g, going **up** in pressure. For each point you pump to the value, let it settle, bring the reference within ± 0.10 bar of the point (refining with the fine adjuster) and press **Record point**. The simulator refuses the record if:

- pressure is not still (**dp/dt** stability above 3 mbar/s);
- the reference is not close enough to one of the five points;
- the loop is off;
- you try to record the “before” column with the instrument already modified.

8.3 What is recorded and how it is judged

For every point the record shows: the reference value, the instrument PV with its **error** ($(PV - reference)/span$), the current read by the multimeter with its error ($(mA - ideal)/16$, where the ideal is $4 + 16 \cdot reference/10$) and the value read by the PLC. A point is **within** tolerance only if **both** errors stay within ± 0.25 %.

8.4 How to carry out the check

1. Line at 0 bar, loop powered. Record the 0 % point.
2. Go up to 2.5 bar, wait for stability, record. Repeat for 5, 7.5 and 10 bar.
3. If one or more points are out, **look at the shape** of the error: constant (zero), growing (span), different between display and multimeter (D/A). Only then choose the trim (chapter 5.5).
4. Correct, then repeat the five points in the “after” column.
5. Return the instrument to service: menu closed, no fixed current, line vented.

9. Injectable faults

Faults are injected from the *Fault injection* window, **in free practice only**: during a scenario the scenario decides them, and the chips stay off so as not to reveal the cause.

Fault	What it does	How to recognise it	How to remedy it
Zero drift	Offset of about +0.12 bar, the same at every point	Constant error; PLC reads pressure even with the line vented	ZERO TRIM
Span error	Offset of about +0.02 bar and slope error of about +1.2 %	Right at the bottom, wrong at the top	LOWER TRIM and UPPER TRIM
D/A error	Gain -0.6 %, offset +0.09 mA on the output	Display and reference agree, PLC and multimeter do not	ANALOG TRIM
Plugged connection	Practically infinite time constant on the connection	The PV does not move (or hardly) while the reference does	Remove and clean the connection, line vented

Fault	What it does	How to recognise it	How to remedy it
Bench leak	Pressure falls all the time (about 0.7 bar per minute at 10 bar)	dp/dt never reaches zero; the thermal drop does	Tighten the fittings, line vented
Sensor failure	The output goes to the alarm level (HI or LO per the switch)	LOI: ALARM / SENSOR FAIL; PLC in failure	Replace the sensor module, then recalibrate

9.1 Leak and cooling: two things not to confuse

After pumping, pressure falls because the air cools, and the drop dies out in a few seconds (chapter 1.3). A leak, instead, **does not die out**: dp/dt stays above the limit however long you wait. It is the difference the trainee must learn to read before blaming the bench for leaking.

10. Channel diagnostic settings and PLC alarms

10.1 Why the PLC has its own settings

The PLC does not know whether the instrument is in saturation or in failure: **it only sees a current**. The diagnostic settings tell it how to interpret it, and that is why they must lie **between** the instrument levels: saturation and alarm must fall in different zones.

Variable	Tag	Starting value	Meaning
Low current — saturation	IAL-101	3.80 mA	Low saturation notice
Low current — failure	IALL-101	3.55 mA	Measurement invalid
High current — saturation	IAH-101	20.50 mA	High saturation notice
High current — failure	IAHH-101	21.00 mA	Measurement invalid

Starting values compatible with the NAMUR levels: the low alarm (3.60 mA) lies **below** the saturation setting and above the PLC failure one, and the high alarm (22.5 mA) lies above the failure setting. With the *standard* levels and low alarm, 3.75 mA falls between the two settings and the PLC reads it as **saturation**, not as failure: the setting must then be moved, which is the purpose of making it editable.

10.2 The rule the panel enforces

The **failure** setting always stays beyond the **saturation** one, with at least 0.05 mA of margin: if one is moved past the other, the second realigns by itself and a note says so. A failure that trips before its own saturation would make no sense: it would take away the saturation's role as a warning.

10.3 The alarms

PLC alarms follow the **ISA-18.2** scheme with three states — **ACT** (active), **ACK** (acknowledged), **RTN** (returned) — and three priorities. There are four, plus the reference:

Tag	Description	Priority
IALL-101	Current below the failure setting: measurement invalid	Critical
IAHH-101	Current above the failure setting: measurement invalid	Critical
IAL-101	Signal in low saturation	Low

Tag	Description	Priority
IAH-101	Signal in high saturation	Low
PI-100	Reference over range	High

11. The training and the exam session

11.1 How a scenario works

Every scenario takes the bench to an **identical** initial state, introduces a fault or a wrong configuration and gives an **objective**. The criteria are evaluated at every scan and must stay satisfied **continuously** for 5 s: whoever meets them for an instant and then loses them has not finished. The *hint* indicates how to reason, not what to press.

The criteria common to every scenario are: “before” recorded, “after” complete and within tolerance, configuration matching the data sheet, instrument returned to service (menu closed, no fixed current, line vented) and no unnecessary replacement.

No.	Scenario	Level	What it trains
1	Zero is off	Basic	Five-point check and zero correction
2	Error at full scale	Intermediate	Lower and upper trim, in order
3	The current does not match	Intermediate	Analog output trim with the multimeter
4	Badly configured instrument	Intermediate	Configuration against the data sheet
5	The instrument does not follow	Advanced	Diagnosing a plugged impulse connection
6	Pressure will not settle	Advanced	Diagnosing a bench leak
7	Output in alarm	Advanced	Faulty sensor, replacement and recalibration

11.2 The exam session

The seven tests in sequence, **fifteen real minutes at most** for each, with a 4-second pause between them. At the end the **report** shows, for every test, result and solving time, with room for the instructor’s and the trainee’s signatures. The report is **on screen only**: for a paper copy use your own browser’s print function.

12. The 60-second trend

The chart shows three curves over the last 60 s: the **reference** (light blue), the instrument **PV** (cyan) and the **current** (amber, scale 0 ÷ 24 mA). It is the tool for seeing what the display does not show:

- the **thermal drop** after pumping (a curve that falls and flattens);
- a **leak** (a curve that never flattens);
- a **plugged connection** (the reference moves, the PV does not);
- **high damping** (the PV follows the reference, but with an evident delay);
- a **current step** during a loop test.

13. What the model simplifies

Knowing where the simulator ends is part of the training. The declared simplifications:

- **The air behaves as an ideal gas with simple heat exchange:** one volume and one time constant (8 s). On a real bench the cooling depends on materials, fittings and ambient temperature.
- **The pump has a linear efficiency curve** with pressure, up to 40 bar.
- **The transmitter has a single sensor** with zero and span. There is no dependence on temperature or static pressure, and no drift over time beyond the injectable faults.
- **The sensor trim is linear and two-point;** sensor linearity is assumed ideal.
- **The menus reproduce the structure of a real local interface,** but not all its items: SCALED VARIABLE, ASSIGN PV, PASSWORD and SIMULATE are shown without function.
- **The HART interface is not simulated:** work is done from the LOI only. The revision can be read but not changed.
- **The multimeter and the PLC have no errors of their own** beyond noise: the multimeter is assumed to be the exact current reference and the PLC scale ideal.
- **The PLC filters with a fixed constant** and has no signal-quality handling beyond the settings of chapter 10.

None of these simplifications touches what the bench is meant to train: pressurising without being fooled by the thermal drop, reading the shape of an error before choosing the trim, keeping to the order of the trims and to the safety preconditions, and documenting the instrument before and after the intervention.