Automated Test Solution for MEMS Pressure Sensor ICs in Robots

Pressure and Temperature Tests for Pneumatic, Vacuum and Hydraulic Actuation

Complete DAQ Solutions from DOEWE

DOEWE Application Notes-ROBOT-PRESSURE-V1.0

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1. Solution Overview

This solution targets pressure sensor ICs and packaged devices based on MEMS (micro-electro-mechanical systems) technology. Robots use pressure sensors in pneumatic gripping, vacuum handling and hydraulic actuators to provide feedback for supply regulation, suction-state detection and motion monitoring. Soft pneumatic actuators can also use pressure feedback to help control deformation. These applications involve positive pressure, negative gauge pressure or port-to-port differences, with different media, ranges and response requirements. Sensor error, temperature drift and response delay affect pressure decisions and control, requiring device evaluation under defined inputs.



Figure 1. Robot pneumatic and vacuum sensing

Valve switching, filling and exhaust, load changes and heating during robot operation can all affect pressure readings. Device tests first relate actual pressure to output, then evaluate hysteresis, repeatability, drift and dynamics. Estimating gripping or contact force

additionally requires system calibration that accounts for effective area, friction and mechanism state. Chip tests evaluate pressure-measurement performance and retain the raw data needed for later combined analysis.

DOEWE integrates pressure control, independent reference measurement, temperature conditioning, fixtures, power and acquisition, and software into an automated robot pressure-sensor IC test system. Pneumatic and vacuum devices use appropriate gas circuits; hydraulic devices use dedicated circuits compatible with the medium. Each branch establishes the actual input, while common software handles points, acquisition, calculations and reporting. Multiple positions can share verified pressure and temperature conditions, with results managed separately by channel.

Test objects include packaged devices with pressure ports and ICs mounted on boards and pressurized through sealed fixtures. The fixture routes pressure to the sensing location and provides positioning and electrical connections. Tests cover loading and unloading over positive or vacuum ranges, temperature behavior, drift, power and interfaces. Dynamic pressure, pressure cycling and overpressure recovery can be added for valve-controlled motion and repeated gripping. Bare-die or wafer testing requires separately developed pressure chambers and electrical contact arrangements.

Configuration starts with the pressure definition and medium. Pneumatic loading uses clean gas, vacuum-sensing devices use a controlled vacuum branch, and hydraulic loading uses media, lines and seals compatible with wetted materials. Acquisition is selected for voltage, current, bridge or digital output. Ranges, temperatures, change rates and limits follow the device specification and robot task. Application scenes, equipment appearances and interface data are illustrative.



Figure 2. Automated test system for robot MEMS pressure sensor ICs

2. Overall Test Workflow

The operator enters sample ID, pressure type, medium, range, interface and position and selects the positive pneumatic, vacuum or hydraulic branch. Software loads the device's supply, acquisition and stability settings before defining pressure points, temperatures, directions and cycles. Response tasks additionally record the intended pressure waveform, reference bandwidth and time-alignment method.

After loading the samples, the operator verifies the mapping between pressure ports, position IDs and electrical channels. Sealing surfaces and fittings are kept clean, and clamping force follows the fixture design. When several positions share a manifold, each branch is checked for sealing integrity to confirm that all positions can be tested under the specified pressure conditions.

The startup sequence checks the pressure supply, valves, reference measurements, chamber and vent path, then performs a sealing check at the specified check pressure. Once these conditions are confirmed, the system powers the devices and records operating current, communication status and the first valid output. Formal testing begins after the prescribed warm-up period.

Static testing starts at the specified zero or lower-range point, increases pressure step by step to the upper limit, and then decreases pressure through the same points. At each point, the software evaluates pressure variation, trend and the prescribed waiting period using the reference pressure. Temperature tests also check the reference temperature near the device. Sampling begins when both pressure and temperature meet the stability

requirements. The equipment's in-position status is retained as an auxiliary record. If stabilization exceeds the configured time limit, the software records the reason and prompts a review of the affected point.

Temperature tests repeat the pressure-loading and unloading sequence at each target temperature. Drift tests continuously record data at a fixed pressure and temperature. Equipment setpoints, measured reference values, device outputs and operating status are saved with each test point. Static measurements are associated by point ID and sampling window; dynamic measurements are aligned using a common trigger or a validated time reference.

Reference data, sample records and frame completeness are checked before calculation. Environmental and communication exceptions retain reason flags, and retests are stored separately and linked to the first result. Positive-pressure tasks vent under control; vacuum tasks return gradually to ambient. Hydraulic circuits depressurize and collect fluid as required by the apparatus. Samples are removed after the permitted pressure condition is reached, and initial, exception and retest records are archived together.

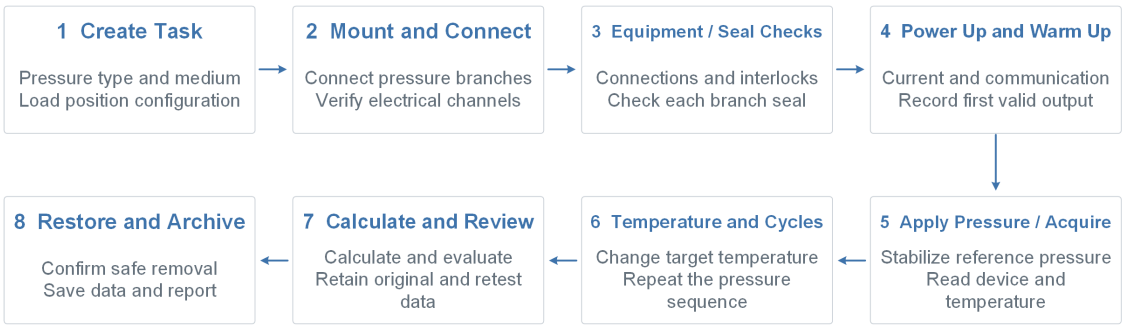

Figure 3. Robot MEMS pressure sensor IC automated test workflow

Table 1 summarizes common tests. Pressure and temperature points, cycle counts, hold times and acceptance limits are configured according to the device documentation and test objectives. The measurement method is retained with the task.

Table 1. Common tests for robot MEMS pressure sensor ICs

Test	Method	Main Results
Supply and startup	Power up at the specified voltages and modes; record current and the first valid output.	Operating current; startup and recovery times

Test	Method	Main Results
Positive-pressure and vacuum cycles	Load and recover using the defined pressure reference; acquire after stabilization.	Zero or lower-limit output, sensitivity, nonlinearity
Hysteresis and repeatability	Compare corresponding points on the forward and return runs and across complete cycles.	Hysteresis; cycle-to-cycle variation
Temperature characteristics	Repeat the specified pressure sequence at each temperature.	Zero and sensitivity temperature drift; error over temperature
Drift at constant pressure	Record the reference and output continuously at fixed pressure and temperature.	Change relative to the reference
Sealing check	Isolate the branch at the specified check pressure; observe pressure and temperature.	Branch pressure decay; mounting or seal anomalies
Response time	Apply a fast pressure input; acquire reference and device waveforms together.	Delay; rise and fall times
Overpressure recovery and cycling	Apply loading per the specification; retest reference points after recovery.	Changes in zero, sensitivity and sealing
Output and interfaces	Check loads, frames and abnormal-condition recovery for the actual interface.	Output range; update interval; diagnostic status

3. Test System Components

Pressure and temperature equipment establish the test conditions, while the test board and acquisition unit provide device connections and electrical measurements. The host software coordinates their operation. Figure 4 distinguishes the pressure path, electrical measurement paths and equipment control connections. Test-point IDs and sampling times associate actual reference pressure, device output and environmental records for subsequent characterization and result review.

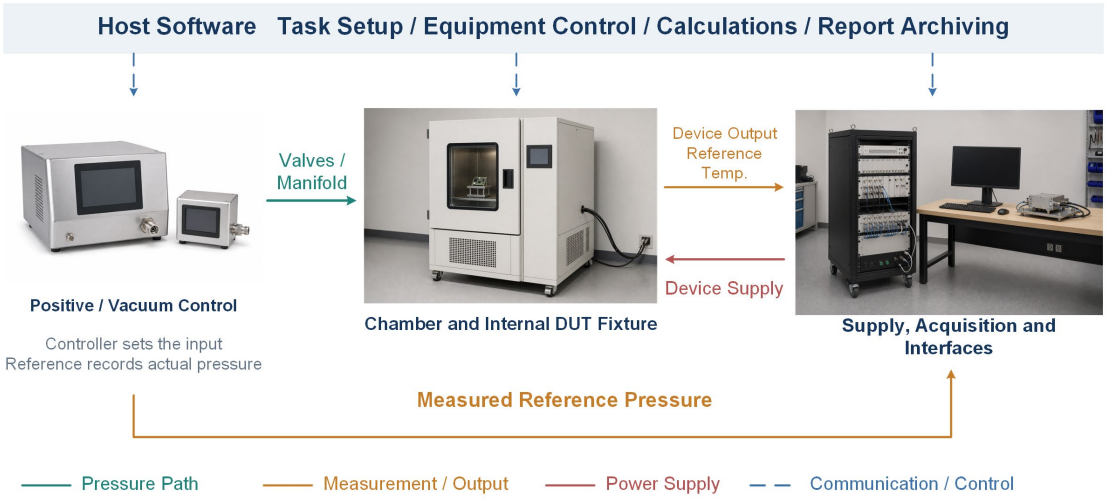

Figure 4. Pressure paths, electrical acquisition and equipment control

3.1 Pressure Generation, Control and Reference Measurement

Pneumatic circuits establish positive pressure with clean gas and a controller. Vacuum branches use a vacuum source and suitable regulation for evacuation, admission and stabilization. Hydraulic circuits use medium-compatible pressure generators with air removal, cleaning and fluid collection. Equipment is selected for the target absolute or gauge range, change rate and circuit volume. Gas, vacuum and liquid branches are checked separately for ratings and contamination control.

This solution uses an independent pressure reference to record the actual device input. The reference instrument and the device under test connect to a section of pipe verified to be at uniform pressure, allowing their readings to be directly associated. The reference instrument's calibration range and measurement uncertainty are assessed against the device range and target error. When the controller's internal measurement channel is used as the reference, its measurement accuracy is evaluated separately from its calibration results and uncertainty. Control stability is used to evaluate the pressure regulation process.

Valves and manifolds distribute, isolate and release pressure. Multiposition static tests first verify sealing and equalization time. Dynamic tests control line length and the internal volume of fittings and fixtures between valve and device. Vacuum branches also record pressure recovery, while hydraulic branches correct elevation differences between reference and device using fluid density. Valve, fixture or line changes require renewed checks of pressure transfer and stabilization.

Gauge devices share an ambient atmospheric reference. Vacuum tasks explicitly state whether values are negative gauge or absolute pressure, including units. Absolute devices use an absolute reference; differential devices connect through both ports and are checked for differential and common-mode limits. Actuator chamber pressures can be measured separately or through a suitable differential channel, with results linked to measurement locations and loading direction.

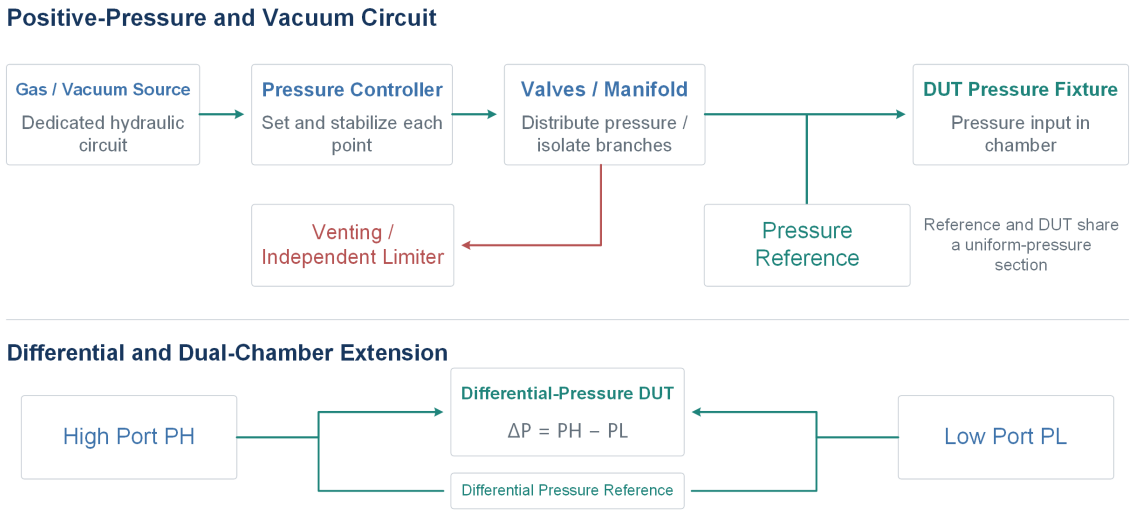

Figure 5. Positive-pressure, vacuum and differential test circuits

3.2 Test Boards, Package Fixtures and Pressure Connections

The test board routes the device pins to the supply and acquisition interfaces and provides decoupling, protection, loads and any necessary signal conditioning. Power and signal test points are retained. Changing the package primarily requires changes to the socket, test board and pressure adapter block. The carrier connection, electrical channel numbering and software task framework can continue to be used.

Each fixture combines sealing, positioning and electrical contact. Seal materials are selected for gas, oil or the actual medium and checked over the pressure and temperature range. Datums and clamping stops maintain repeatable mounting, with branch, board and channel IDs assigned to each position. Pressure change in a defined volume screens connection leaks; vacuum branches are checked for pressure rise. Leak-rate calculations account for volume, temperature and background system changes.

During temperature tests, fixtures, cables and pressure lines enter the chamber with the devices, while the controller and reference instruments normally remain outside. A reference temperature sensor near the devices records their local ambient temperature.

Gauge and differential pressure configurations are checked for reference-pressure differences between the inside and outside of the chamber. Long pipe runs and hydraulic connections are checked for pressure transmission and elevation corrections at the device. Sampling begins after both reference temperature and pressure meet the stability requirements.

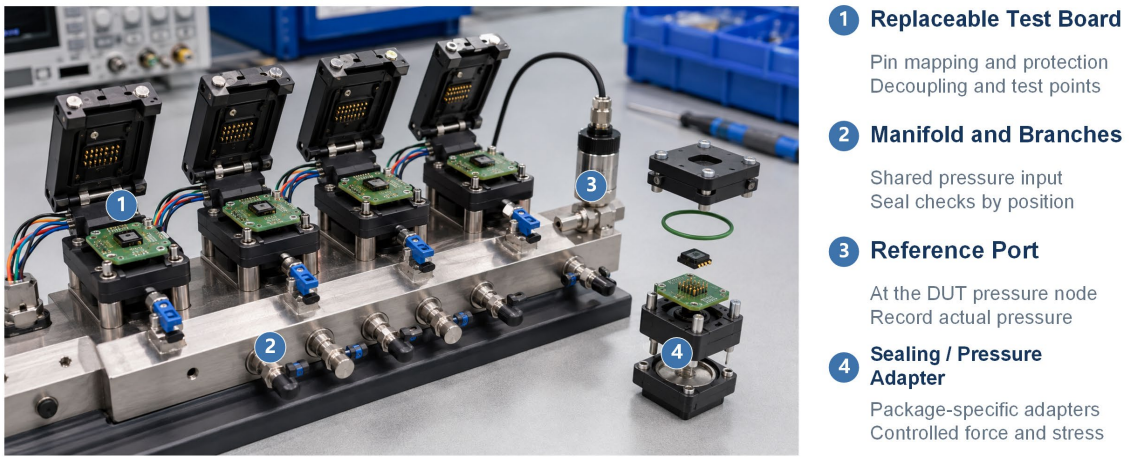

Figure 6. Multiposition pressure fixture and device connections

3.3 Power Supply, Data Acquisition and Digital Interfaces

A programmable power supply powers the devices while the acquisition unit measures voltage at the device terminals, current and output. Ratiometric voltage outputs are evaluated using the output-to-excitation ratio specified for the device. Millivolt-level bridges use low-noise excitation and differential measurements. Current outputs use suitable sensing resistors or current measurement channels. Devices at multiple positions can be powered in groups, with isolation of shorted branches or branches drawing abnormal current.

The acquisition method follows the test being performed. Steady-state tests calculate mean values and dispersion over a defined window, while response tests retain complete waveforms. Reference pressure, temperature and device output sequences are stored separately with their time information. Sampling rates, ranges and filter settings are retained with the task. Interface units receive digital outputs close to the devices and associate them with the external reference data.

Chip interfaces use the logic levels, clocks and reception method required by I^2C, SPI or the actual protocol. Software decodes raw values, status and pressure conversion. Analog bridge, voltage and current outputs use suitable conditioning and acquisition.

Sensor modules with industrial communication can be added through a dedicated interface unit, retaining separate records of chip output, module conversion and communication delay.

3.4 Automated Test and Analysis Software

Software supports manual setup and automatic operation, loading the appropriate pneumatic, vacuum or hydraulic configuration. Manual setup controls pressure, valves, chamber and supply while displaying raw output. Automatic runs perform seal checks, warm-up, loading and unloading, temperature changes and acquisition. The interface shows pressure definition, setpoint, measured reference and position results, with valve events and exceptions recorded in the log.

Each result is associated with the sample ID, position, test-board revision, device configuration, reference instrument and calibration information. Calculation methods and limits have separately controlled versions. Out-of-limit results can be reviewed against raw waveforms and run logs. Abnormal pressure, temperature or current stops the current sequence and invokes the configured isolation, venting or power-off strategy. Mechanical pressure limiting and hardware interlocks remain independent of the software. Reports are exported using project templates, with barcode, database or manufacturing execution system integration available as required.

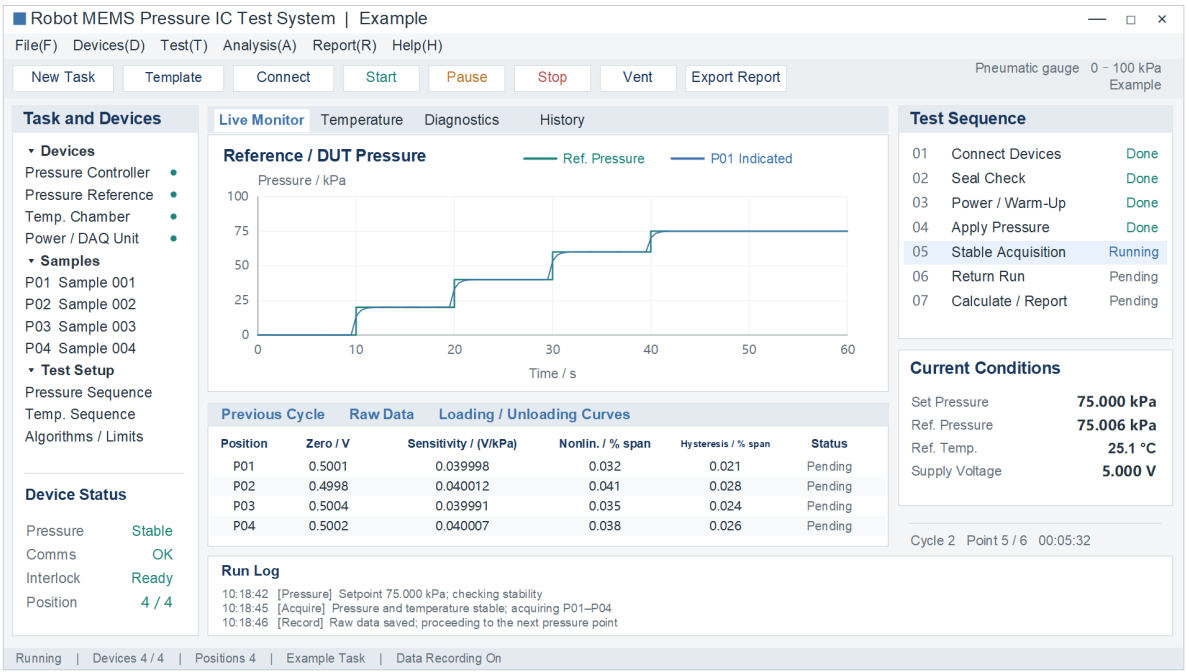

Figure 7. Illustrative MEMS pressure sensor automated test and analysis interface

4. Typical Test Methods

4.1 Multipoint Pressure Loading, Hysteresis and Repeatability

Pressure is stepped from the specified lower limit to the upper limit and back through the same points. Vacuum tasks also identify evacuation from ambient and recovery directions. Additional points can be placed around regions used for suction-state or pressure-threshold decisions. Stabilized reference and output samples retain mean, standard deviation and count. Repeated complete cycles compare hysteresis, repeatability and directional differences.

Sensitivity can be calculated from the output span divided by the reference-pressure span, or from the slope of a multipoint fit. For an approximately linear output, S = (YH − YL)/(PH − PL), where PH and PL are the high and low reference pressures for the same temperature, loading direction and cycle, and YH and YL are their corresponding outputs. Zero output is measured under the device's specified zero-pressure condition, while lower-range output is measured at the lower-range pressure point. The two results are recorded according to the device's pressure definition.

Nonlinearity is the maximum deviation from the selected reference line, with the endpoint, best-fit straight-line or device-specified method identified. Hysteresis

compares the outputs at the same actual pressure during increasing and decreasing pressure. Repeatability compares outputs from different cycles at the same direction and actual pressure. When measured pressures differ slightly between the forward and return runs, the software uses neighboring measured points within their common pressure interval to interpolate the two outputs to the same pressure before comparison. The interpolation method and the points used are saved with the results.

For outputs converted to pressure, the error at a point is $E_i = P_{DUT,i} - P_{ref,i}$. When normalized to pressure span, $\delta_i = E_i/(P_H - P_L) \times 100\%$. The report identifies the normalization basis and algorithm and retains the uncertainty assessment for the reference standard, temperature, acquisition and pressure branches. Nonlinearity, hysteresis and total error are reported separately, with acceptance assessed using the agreed decision rule.

4.2 Temperature Characteristics and Drift at Constant Pressure

The same pressure sequence is used at each temperature, with fixed supply conditions, sampling windows and mounting configuration. After the chamber reaches its setpoint, the reference temperature near the devices is monitored until both temperature and pressure are stable. Where thermal hysteresis is to be evaluated, the same points are tested during heating and cooling.

Zero temperature drift compares zero output at the specified zero condition across temperatures. Sensitivity temperature drift compares the corresponding slopes. Temperature-compensated devices are evaluated using their final compensated outputs, with on-chip temperature codes retained as supplementary data. Where compensation coefficients are calculated and written to the device, separate coefficient-calculation points and independent validation points are defined. The validation points check output after programming, while coefficient versions, point assignments and before-and-after data are retained.

Drift tests record indicated and independently referenced pressure continuously at fixed pressure, temperature and supply, analyzing their difference over time. For repeated gripping or prolonged holding, separate sequences can compare steady holds with holds after cycling and check changes in zero, sensitivity and temperature state. Duration, cycle

conditions, sampling and reference uncertainty are retained to distinguish device drift from slow circuit changes.

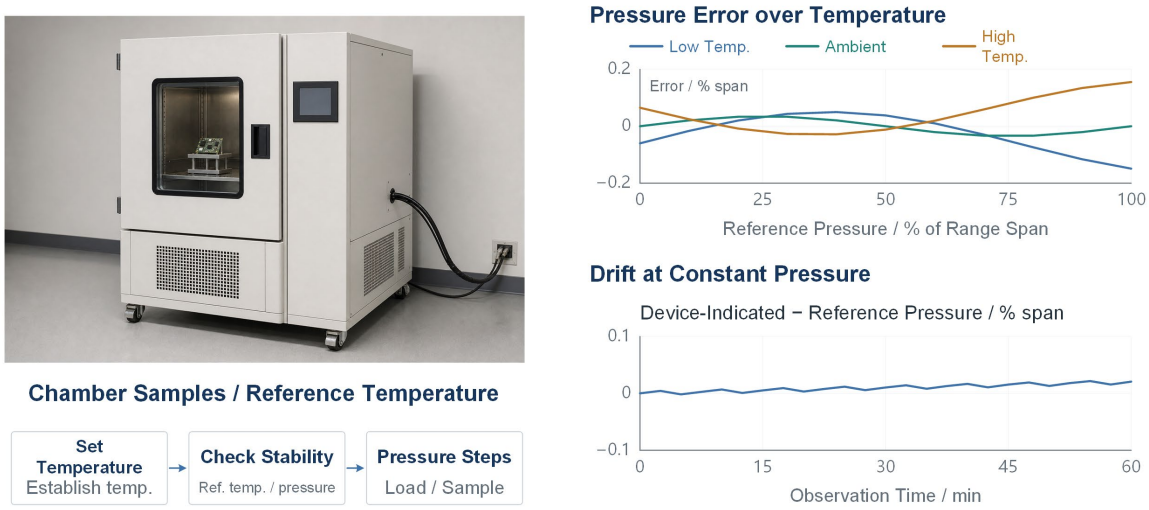

Figure 8. Temperature test arrangement and illustrative result analysis

4.3 Valve-Driven Response, Pressure Cycling and Overpressure Recovery

Response tests use fast valves or a dedicated dynamic pressure generator to produce the loading and recovery relevant to pneumatic, vacuum or hydraulic circuits. A high-bandwidth reference sensor is placed near the device, and reference and device signals share a trigger or validated time base. Valve speed, circuit volume and reference bandwidth are checked against the expected response. Valve-command timing and actual pressure changes are retained to separate device response from circuit pressure-establishment time.

Analysis first checks the actual pressure waveform, then calculates delay, rise and fall times using the specified thresholds. Figure 9 illustrates a 10–90% rise time. Vacuum establishment and release are evaluated separately. Pressure-cycle limits, rates, holds and counts follow device and task requirements. Overpressure recovery returns the device to normal conditions before rechecking zero, sensitivity, sealing and communication, with results linked to the initial test.

Overpressure and cycling branches are rated for the maximum test pressure and include independent limiting, isolation and release. Hydraulic media require collection and contamination control; vacuum circuits are checked against permitted device and fixture pressure differences. Burst or other destructive tests use separately protected

equipment, remote operation and dedicated circuits. Routine performance and destructive-test records are archived separately.

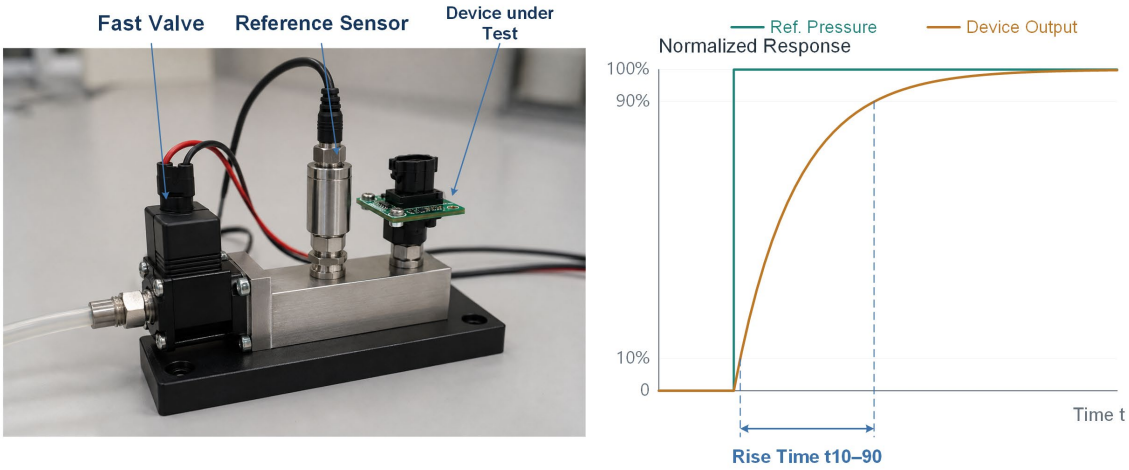

Figure 9. Dynamic pressure test arrangement and response-time definition

4.4 Power Supply, Analog Output and Digital Interface Tests

Supply tests operate the device at its specified voltages and modes, recording terminal voltage, operating current and the first valid output. Current and output transients are retained separately for startup, sleep wake-up and mode changes. Analog outputs are checked for range, ratiometric behavior and saturation under specified loads. Recovery conditions following abnormal supply states are also defined by the device documentation.

Digital tests check pressure data, update intervals and the status, integrity and diagnostic information actually provided by the device, retaining raw messages. Configuration checks cover registers and parameter writes; operating checks cover continuous updates and recovery. Where pressure thresholds or switching outputs are provided, switching pressure, hysteresis and response are recorded. Industrial-communication modules have separate checks that retain the timing relationship between communication data and pressure references.

5. Core Advantages

DOEWE integrates pressure equipment, temperature conditioning, acquisition and software so that pneumatic, vacuum and hydraulic devices for robots use consistent recording and analysis. The main benefits are as follows:

- Corresponding measurements of pressure input and device output. Each test point retains actual reference pressure and electrical output. Temperature and supply records support error-source analysis and provide a complete basis for characterization.
- Automated pressure and temperature test sequences. Software schedules pressure loading and unloading, temperature changes, stability checks and acquisition. This reduces manual setpoint entry and transcription and makes the same test conditions easier to repeat.
- Shared equipment with results managed by channel. The manifold and chamber provide common conditions for multiple devices. Position IDs are mapped to acquisition channels for batch comparison and retesting of individual positions.
- Fixtures and interfaces that support device changes. Test boards, sockets and pressure adapters are adapted to the package and output format. Pressure equipment, the chamber, acquisition platform and software framework can be reused within their applicable ranges.
- Traceable results that can be reviewed. Raw data, reference-instrument calibration information, and algorithm and limit versions are archived with the task. Initial and retest records are saved separately, supporting point-by-point review of waveforms, frames and run logs.
- Tests extend with the robot task. Static and temperature characterization can be supplemented by vacuum establishment and release, valve-driven response, pressure cycling, overpressure recovery and assembly comparisons.

6. Conclusion

Robot pressure-sensor tests define pressure reference, medium and pressure changes for the intended pneumatic, vacuum or hydraulic task. Independent pressure and temperature records establish the inputs, multipoint and cycling tests evaluate error and repeatability, and dynamic tests characterize pressure transfer and device response during valve operation. Results linked to raw data, fixtures and interface settings support device selection, actuator development and fault analysis.

DOEWE can configure pressure circuits, fixtures, test boards, acquisition and automated software for the package, medium, range and interface of robot pressure-

sensor ICs. Contact DOEWE to discuss performance verification and test platforms for pneumatic gripping, vacuum handling or hydraulic actuation.