Automated Test Solution for MEMS Six-Axis IMU ICs in Robots

Six-Axis Performance, Temperature and Motion-Response Tests for Attitude Feedback

Complete DAQ Solutions from DOEWE

DOEWE Application Notes-ROBOT-IMU-V1.0

https://www.doewe.com

1. Solution Overview

This solution targets six-axis IMU ICs based on MEMS (micro-electro-mechanical systems) technology. Robots use inertial measurement units (IMUs) to measure three-axis acceleration and angular rate for estimating body attitude, balance and motion changes. Mobile platforms, legged robots and manipulators that use inertial feedback have different requirements for range, bandwidth and mounting orientation. Motor and transmission vibration, body motion and operating temperature all affect the output. Device testing relates these inputs to measured output, supporting sensor selection, attitude fusion and control-parameter development.



Figure 1. Robot attitude and motion feedback

Robot IMU evaluation first establishes bias, scale factor, nonlinearity, range and axis mapping, then examines temperature drift, noise and dynamics for the intended

mechanism. Balance and rapid-motion applications also require attention to phase and data delay, while slow-motion and standstill detection emphasize zero-rate output, small changes and repeatability. Power, SPI/I²C access, self-test, data-ready interrupts and FIFO operation are checked using the actual device configuration, with range, output data rate and filter settings retained for every test.

Different instruments provide the traceable physical inputs required for these tests. A single-axis temperature-controlled rate table with a six-face indexing fixture supports six-position orientation, steady angular-rate testing, and orientation or rate tests at different temperatures. A precision centrifuge provides acceleration above 1 g. A temperature chamber supports fixed-orientation temperature tests, while linear and angular vibration systems test the dynamic responses of the accelerometer and gyroscope respectively. The IMU test board and synchronous acquisition unit provide power, communication and reference measurements. Host software schedules tasks, analyzes data and generates reports.

DOEWE integrates motion and environmental rigs, a six-face indexing fixture, IMU test boards, synchronous acquisition and host software into an automated platform for MEMS six-axis IMU ICs used in robots. Separate rigs provide the physical inputs, while the board and common carrier connect and transfer the device. Software schedules tests, associates reference and device data, and retains the mapping between device axes and the intended robot mounting frame for later board-level and system verification.

Six-position tests apply approximately ±1 g to each sensitive axis in turn, and a single-axis table supplies positive and negative steady angular rates. A precision centrifuge can verify higher acceleration ranges, while linear and angular vibration rigs support bandwidth and filter evaluation. The equipment combination is selected for the robot type, IMU specification and test objectives. Temperatures, frequency ranges and limits are stored with the task. Application scenes, equipment appearances and interface data are illustrative.

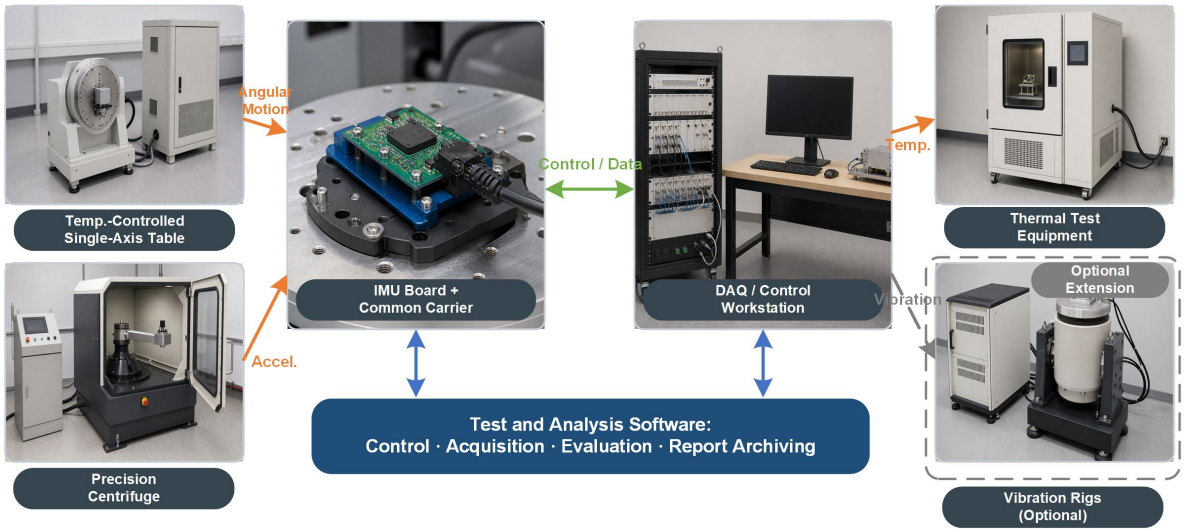

Figure 2. Automated test system for MEMS six-axis IMU ICs in robots

2. Overall Test Workflow

The operator enters sample ID, package, test-board revision, sensitive-axis orientation and intended mounting location, then selects supply, range, output data rate, filtering and excitation settings. Attitude and balance tasks can emphasize low rates, bias and dynamic phase, while rapid-motion tasks set angular-rate and acceleration points from the mechanism's motion envelope. The software lists the rigs, fixtures and reference sensors and stores the coordinate transformation used for the task.

The device is mounted on a dedicated IMU test board, which connects to a common carrier. The carrier defines the electrical interface, mechanical datums and sensitive-axis orientation. Each rig uses an adapter and fixture suited to its mechanical structure. Individual wires do not need to be reconnected when changing rigs, but the carrier, adapter and orientation are checked to ensure that the software axis mapping matches the actual installation and that the parameters match the current rig and test. For high-speed rotation, centrifugation and vibration, checks also cover locking, eccentricity, cable restraint and protective measures.

At startup, the software identifies the test board and rig adapter, then checks door interlocks, emergency stops, travel limits, reference sensors and communication. The device is powered, its identification registers are read, and range, filter and self-test settings are configured before data-ready operation is checked. Automatic testing

begins when the rig matches the selected test and the safety circuits and equipment status are satisfactory.

For six-position and angular-rate tests, the single-axis temperature-controlled table completes positive and negative tests for the current sensitive axis. After the table stops, the fixture is reoriented using its indexing datums, and testing proceeds through the X, Y and Z axes. Centrifuge testing applies acceleration point by point and repeats the same points on the return sequence. Measured rotational speed, calibrated effective radius, fixture orientation and device output are stored together. Linear and angular vibration tests run at specified frequencies or follow a frequency sweep, recording reference measurements and IMU data on a common time base.

Temperature testing can use the single-axis temperature-controlled table to repeat orientation or rate tests at different temperatures. A conventional temperature chamber supports fixed-orientation temperature cycling of multiple samples and continuous observation of static output, noise, current, communication, startup and self-test over temperature. Three-axis zero-g temperature drift is calculated from multiple orientations at each temperature to separate the effects of bias, scale factor and small mounting-angle changes.

Every test point retains both equipment setpoints and measured reference quantities. The rate table records actual angle or angular rate. The centrifuge records measured rotational speed, associated with the calibrated effective radius, fixture orientation and device output. Vibration tests record reference acceleration or angular rate, while temperature tests record a reference temperature near the IC. The IMU test board reads raw six-axis data in response to data-ready events and timestamps the samples. Common triggers, test-point IDs and timestamps associate external references, device outputs, supply voltage, current and equipment status.

After acquisition, the software checks frame continuity, data-ready counts, FIFO sample counts and equipment status, then performs unit conversion, axis transformation and reference alignment. It calculates bias, scale factor, nonlinearity, temperature drift, noise, amplitude ratios, phase differences and dynamic cross-axis response, and evaluates the results using the current device configuration. Points affected by communication interruption, abnormal reference data or an unstable rig are

flagged and excluded from statistical calculations. Their raw records and any retest results remain stored with the task.

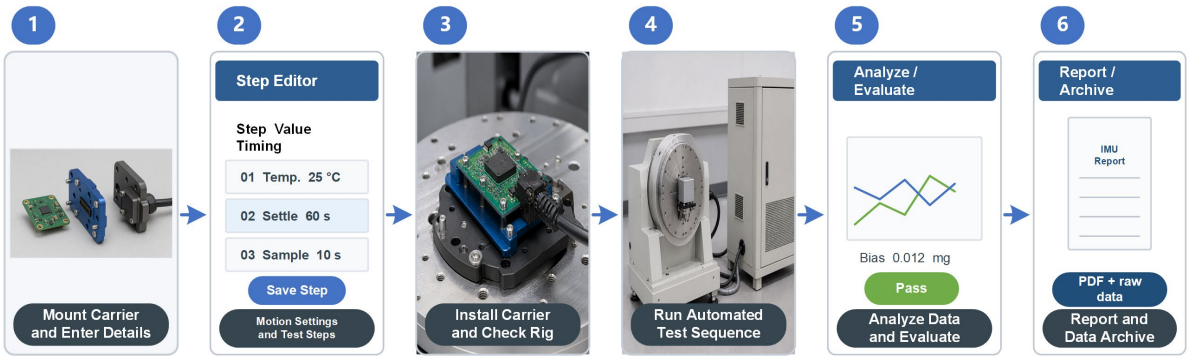

Figure 3. Robot MEMS six-axis IMU IC automated test workflow

Table 1 summarizes common MEMS six-axis IMU tests and their main outputs. Tests are selected according to the device specification, development stage and verification objectives. The table does not prescribe universal acceptance limits.

Table 1. Common tests for robot MEMS six-axis IMU ICs

Test	Method	Main Results
Supply and operating modes	Apply low, nominal and high supply voltages and different operating modes; measure voltage, current and digital output together.	Startup status, steady-state and sleep current, mode-change response
Six-position orientation	Align +X, −X, +Y, −Y, +Z and −Z with gravity in turn; record three-axis acceleration and angular rate.	Zero-g bias, scale factor around ±1 g, axis polarity, zero-rate output at each orientation
Steady angular rate	Apply several positive and negative angular rates to each sensitive axis.	Gyroscope range, scale factor, nonlinearity, directional consistency, cross-axis response
High-g acceleration	Use measured centrifuge speed and effective radius to apply multiple acceleration points; reverse the fixture for the negative direction.	Accelerometer high-g range, scale factor, nonlinearity, loading/unloading differences
Temperature characteristics	Repeat static, six-position or rate tests at low, ambient and high temperatures.	Bias and scale-factor changes, noise, current, communication, temperature output

Test	Method	Main Results
Static noise	Acquire continuously with the rig stationary and fixed configuration and bandwidth.	RMS noise, standard deviation, noise density, power spectral density
Linear vibration	Perform fixed-frequency or sweep tests using a reference accelerometer.	Accelerometer dynamic sensitivity, amplitude/phase response, filter bandwidth, cross-axis response
Angular vibration	Apply sinusoidal angular motion using an encoder or reference angular-rate sensor.	Gyroscope dynamic sensitivity, amplitude/phase response, filter bandwidth, cross-axis response
Communication and functions	Test SPI/I²C access, self-test, interrupts, FIFO operation and communication recovery.	Interface operation, update intervals, missing samples, overflow, startup time, self-test response

3. Test System Components

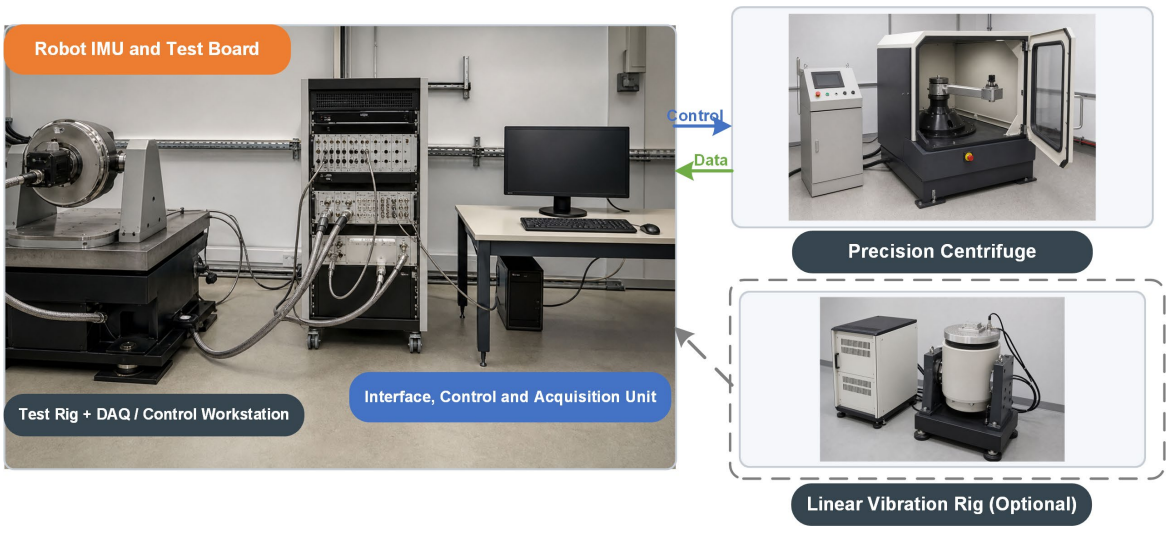

Figure 4. Architecture of the robot MEMS six-axis IMU IC test system

3.1 Motion and Environmental Test Rigs

The different excitation systems use separate rigs. A single-axis temperature-controlled rate table combines six-position orientation, steady angular-rate testing and thermal conditioning. A precision centrifuge generates high-g radial acceleration. A

linear vibration system applies controlled sinusoidal acceleration to the accelerometer, while an angular vibration system applies periodic angular motion to the gyroscope. A conventional temperature chamber supports static tests at a fixed orientation or temperature cycling of multiple samples. The rigs connect to the host through common control, synchronization and safety interfaces while retaining their own controllers, reference measurements and protection systems.

A single-axis table aligns one sensitive axis at a time. The six-face indexing fixture provides +X, −X, +Y, −Y, +Z and −Z positioning faces. After testing one orientation, the table stops before the fixture is moved to the next face. This uses gravity for accelerometer six-position tests and aligns each gyroscope axis with the rotation axis in turn. For orientation or rate testing over temperature, selection and calibration also cover the table's thermal range, temperature uniformity, stabilization time, and positioning and rate performance at temperature.

A precision centrifuge produces acceleration from angular velocity and effective radius, making it suitable for multipoint loading above 1 g. The rig includes an encoder, effective-radius calibration, a reversible fixture, counterweights, dynamic balancing and an enclosure. Linear vibration testing uses a reference accelerometer close to the IC for feedback. Angular vibration testing uses a high-resolution encoder or reference angular-rate sensor. Both require synchronized records of actual excitation, reference measurements and device output.

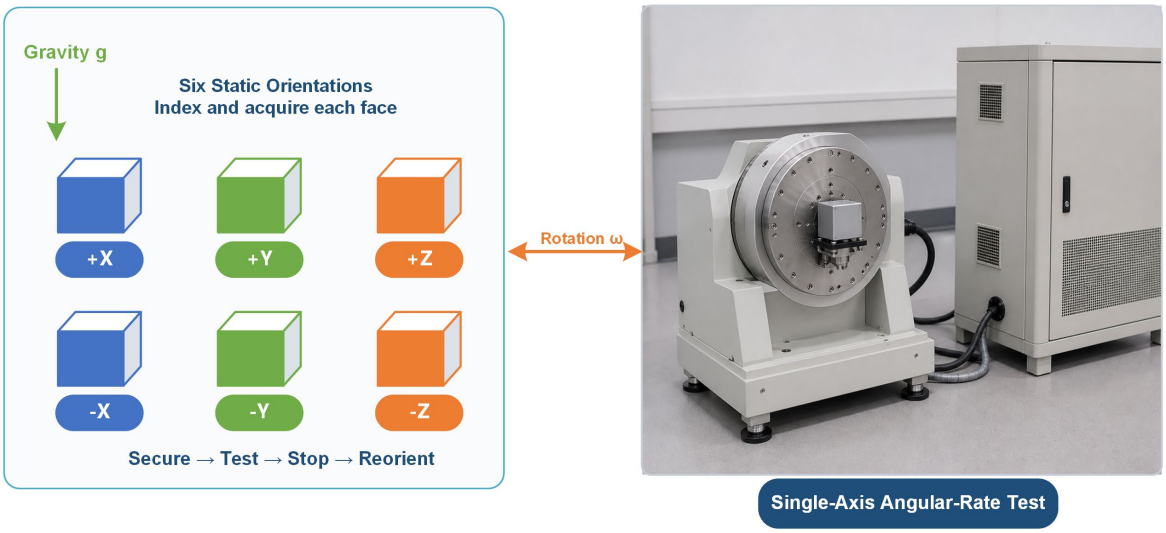

Figure 5. Six-position orientation and single-axis angular-rate test methods

3.2 IMU Test Boards and Fixtures for Multiple Rigs

The IMU test board provides power, supply filtering and decoupling, interface protection, register configuration and digital data acquisition. Its controller can act as an SPI or I²C master to configure range, output data rate, digital low-pass filtering, self-test, FIFO, interrupts and low-power modes. It reads raw three-axis acceleration, three-axis angular-rate and temperature values in response to data-ready events. Key supply, clock, data and interrupt signals are brought out to test points for electrical-level and timing checks.

The mechanical arrangement has three levels: the test board, a common carrier and the rig adapter. The test board changes with the device, while the carrier retains consistent connectors, mechanical datums and keying against incorrect insertion. Each rig adapter connects the carrier to the rate table, centrifuge, vibration fixture or chamber mounting surface. The software identifies the test board and adapter separately and loads their pin mapping, axis orientation, range settings and rig operating limits. This reduces rewiring between rigs and preserves much of the system when the IMU package or interface changes.

For high-speed rotation and centrifugation, data can pass through a slip ring or be buffered on the rotating assembly. Vibration tests control board, carrier and cable mass and stiffness and first check fixture resonances. Robot body or joint mounting structures can later be used as comparison fixtures, with device axes, mounting surfaces and mechanism coordinates recorded separately. This supports analysis of chip response alongside mounting location, connection stiffness and transmission vibration.

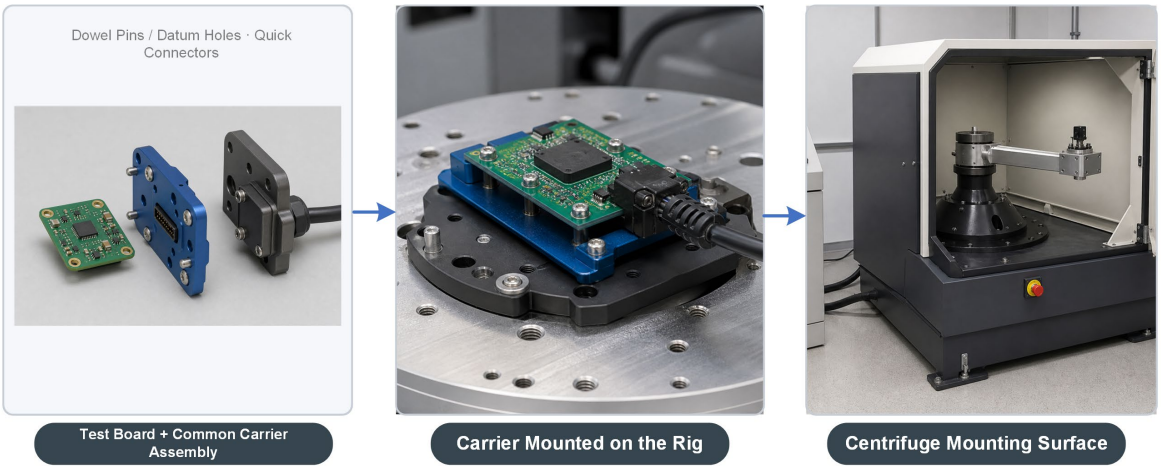

Figure 6. IMU test board and common carrier for changing test rigs

3.3 Data Acquisition and Synchronization

The acquisition system records rate-table encoder signals, centrifuge speed, reference acceleration, reference angular rate, temperature near the IC, synchronization triggers, supply voltage and current. The test board reads the IMU's own six-axis digital data close to the device. These sources have different timing: external reference channels follow the acquisition time base, while IMU samples are associated with DATA_RDY events or interface read times. Each source retains its own timing information and test-point identifiers during acquisition.

Common triggers, hardware timestamps or test-point IDs associate the data. Steady-state tests sample after stabilization; continuous-motion and sweep tests retain reference waveforms and raw IMU samples aligned to a validated time base. When joint encoders or other sensors are included, their sampling times and coordinate definitions are recorded separately. Device data-ready, interface-read and host-receive times are retained to examine update timing and scheduling delay in the control data path.

3.4 Automated Test and Analysis Software

The test software provides a common operator interface for the system. Manual setup mode supports equipment jogging, homing, register access, waveform inspection and reference-channel checks. Automatic mode follows test templates to power and configure the device, verify interlocks, control excitation, acquire synchronously, check stability and calculate results. Register maps, data formats, scale factors, temperature conversions and acceptance limits are managed as device-specific configurations, while rig control and report generation can be reused.

Each test point stores the sample ID, test-board and adapter revisions, mounting orientation, device register configuration, equipment setpoints, measured references, raw six-axis data, temperature, voltage, current and equipment status. The software reports bias and scale factor, best-fit straight-line results, temperature curves, noise spectra, amplitude and phase responses, and PASS/FAIL decisions. Out-of-limit points can be reviewed against raw waveforms, communication status and rig logs to distinguish device anomalies, mounting errors and unstable excitation.

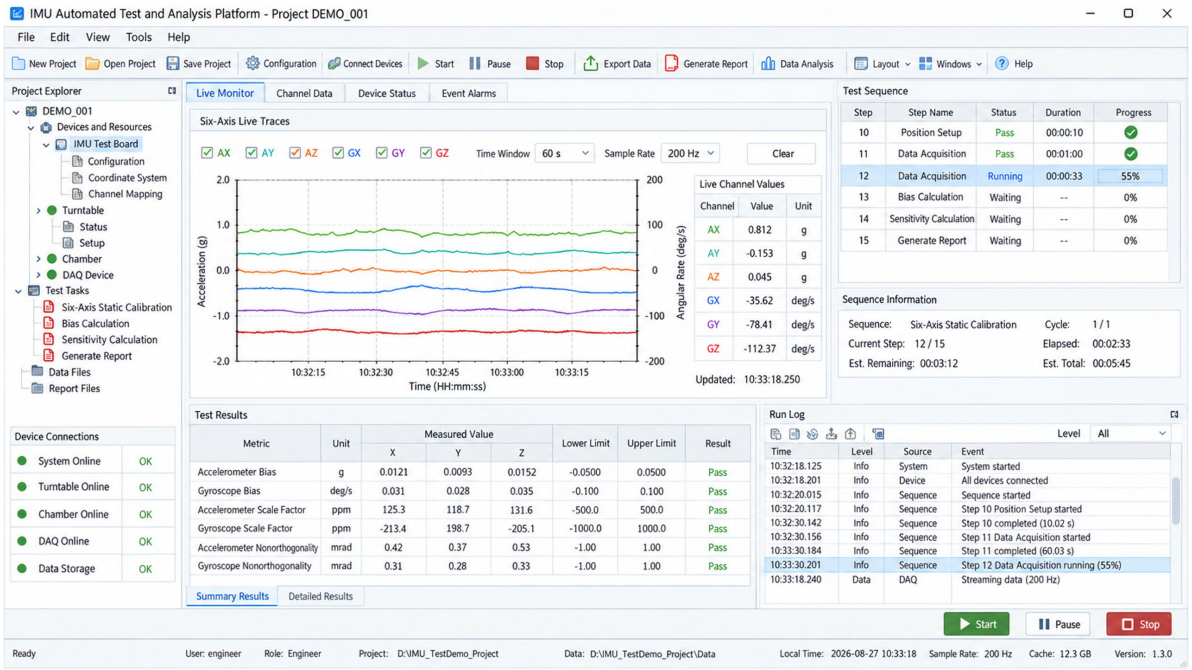

Figure 7. Illustrative IMU automated test and analysis interface

4. Typical Test Methods

4.1 Six-Position Orientation and Steady Angular-Rate Tests

Six-position testing aligns the device's +X, −X, +Y, −Y, +Z and −Z directions with gravity in turn. The aligned sensitive axis receives approximately +1 g or −1 g, while the theoretical inputs to the other two axes are close to 0 g. For a given axis, averaging the outputs in the two opposite orientations estimates zero-g bias. Dividing the output difference by the difference in measured gravity inputs gives the scale factor. Fixture tilt, mounting-angle errors and axis nonorthogonality also project onto the other axes. Results are first expressed as total cross-axis response, then corrected for orientation and mounting errors to further assess the device's cross-axis sensitivity.

Gyroscope testing aligns the sensitive axis with the table axis and applies zero, positive and negative intermediate rates, and high points within range. Additional low-rate points can cover slow turning or balance applications, provided the table's reference capability is verified in that region. Stabilized encoder rate and device output are recorded to calculate scale factor, nonlinearity and directional consistency. The table stops for reorientation before the other axes are tested, and zero-rate output is rechecked.

4.2 High-g Acceleration and Temperature Tests

The six-position method provides only approximately ±1 g. To verify higher ranges, the precision centrifuge calculates acceleration from $a = \omega^2 r$, where ω is the encoder-measured angular velocity converted to rad/s and r is the calibrated effective radius from the rotation center to the IC's sensitive center. The gravity component is corrected for the mounting orientation. At each stable acceleration point, rotational speed, fixture position, equipment status and IMU output are recorded together. Reversing the fixture provides the negative direction. Sensitive-center location and dynamic balance are checked again after changing axes.

Multipoint loading is used to calculate scale factor and nonlinearity in the high-g range. Repeating the same points during loading and unloading also reveals return-path differences. The highest test point remains below the equipment's rated limit with a suitable safety margin. Point count, hold times, reference acceleration accuracy and measurement uncertainty are defined from the device specification and the test objectives.

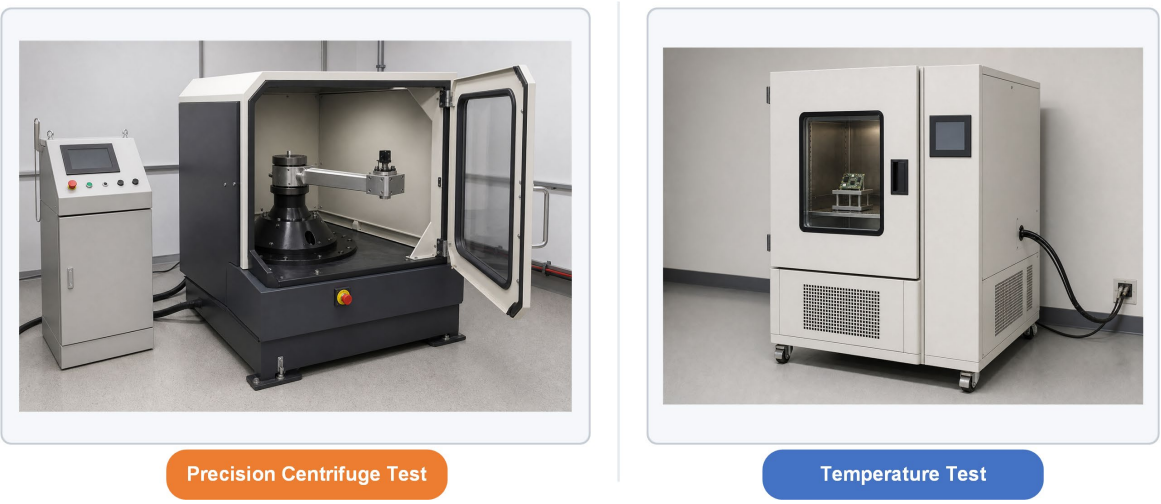

Figure 8. Precision centrifuge and temperature test methods

A reference temperature sensor is placed near the IC. At each stable temperature, zero-rate output, noise and current are recorded, and multiple orientations provide accelerometer zero-g bias and scale factor. Fixed-orientation warm-up and temperature-transition records can be added to study heating during sustained robot operation, retaining both internal temperature codes and the external reference. Repeated thermal cycles use consistent mounting and sampling conditions to compare drift and repeatability.

4.3 Linear and Angular Vibration Tests

Linear vibration tests use available measurements from the robot body, motors and transmission, or an agreed frequency band. The reference accelerometer and IMU are mounted close together on a rigid fixture, checked with a low-amplitude sweep before measuring sensitivity, amplitude and phase response, filter bandwidth and cross-axis response. Pronounced peaks in the operating band are retained in the raw records and compared across filter settings. System structural resonances are analyzed separately using mounting information and reference measurements.

Angular vibration tests evaluate gyroscope dynamic angular-rate response and filter bandwidth. The rig oscillates the device about the rotation axis in both directions. Reference angular rate can be obtained by differentiating angular position measured by a high-resolution encoder or by direct measurement with an independent angular-rate sensor. For sinusoidal motion, peak angular rate depends on frequency and angular displacement amplitude. Sweep settings therefore account for angular displacement, angular rate, drive capacity and device range, with frequency adjusted within the limits of both the rig and the device.



Figure 9. Linear and angular vibration tests for dynamic response

Reference sampling, device output rate and filter settings are selected for the mechanism's motion band with anti-aliasing margin. The software reports amplitude and phase curves and compares the effects of filtering on noise, usable bandwidth and delay. Linear and angular vibration characterize the IC's dynamics. Gait, impact or prolonged structural-endurance tests can be added for a particular robot and project, with their conditions archived separately.

4.4 Power Supply, Communication and Functional Tests

Supply tests use the device's specified low, nominal and high voltages. Voltage, current, reset, first communication, data-ready and the first valid data frame are recorded to distinguish register accessibility from stable sensor-data updates. Steady-state current is measured separately in each operating mode. Current transients and digital output are retained during mode changes and wake-up from sleep.

SPI and I²C tests cover register access, continuous data reads, clock-rate changes and recovery from abnormal conditions. Data-ready interrupts are used to measure the actual update interval and jitter. FIFO tests check byte counts, data order, overflow and missing samples against the current sample layout. The actual update interval for each frame is determined from DATA_RDY or in-frame timing information; the interval between host FIFO block reads is recorded separately as communication scheduling information. Self-test compares each axis with self-test disabled and enabled, using the device's specified factory reference values or evaluation method.

5. Solution Features

DOEWE's robot MEMS six-axis IMU IC solution integrates static, temperature and dynamic tests through common power, acquisition and software. Independent rigs provide verifiable reference inputs, and a common carrier reduces connection work when changing devices or rigs. Axis mapping and device settings are stored with results, supporting progression from IC evaluation to comparisons under the intended robot mounting conditions. The main features are as follows:

- A single-axis temperature-controlled rate table and six-face indexing fixture support approximately ±1 g six-position tests, steady angular-rate testing of all three axes, and temperature testing. The table stops for each reorientation, and the sensitive axes are tested in turn.
- Linear and angular vibration tests evaluate accelerometer and gyroscope bandwidth, phase and cross-axis response. Filters can be compared over motor and transmission frequency bands, with a precision centrifuge added for high-g range verification.

- Separate test-board, common-carrier and adapter levels simplify changes to packages, interfaces and fixtures.
- External references, raw six-axis data, voltage, current, temperature and equipment status are associated through common triggers, timestamps or test-point IDs. Calculated results can be traced to the original data and test conditions.
- Device configurations manage registers, scale factors, filters, sampling rates and acceptance limits. Software automatically performs equipment checks, acquisition, retests, calculations and report export, while retaining manual point control and waveform review.

6. Conclusion

Robot IMU testing relates device errors to the intended mechanism's motion, temperature and mounting conditions. Orientation and rate tests establish baseline performance, thermal tests examine operating changes, and vibration and timing tests inform bandwidth and filter choices. Reference inputs, raw six-axis data, coordinate mappings and device settings provide a consistent, reviewable basis for sensor selection, control development and fault analysis.

DOEWE can provide rigs, dedicated fixtures, test boards, synchronous acquisition and automated software for IMU applications in mobile, legged and manipulator robots. Tests are selected from the device specification and mechanism dynamics. Contact DOEWE to discuss robot inertial-device verification, sample comparison or an automated test platform.