Automated Test Solution for Automotive Six-Axis IMU ICs

A Complete Test System for Six-Position Orientation, Steady Angular Rate, High-g Acceleration and Dynamic Frequency Response

Complete DAQ Solutions from DOEWE

DOEWE Application Notes-084-V1.2

https://www.doewe.com

1. Solution Overview

An inertial measurement unit (IMU) typically integrates a three-axis accelerometer, a three-axis gyroscope and a temperature sensor in a single device, continuously reporting vehicle linear acceleration and angular rate along three axes. These measurements support vehicle stability control, integrated navigation, driver assistance, crash recording and attitude compensation. The accuracy and stability of IMU outputs affect the quality of the resulting state estimates, making device testing an important part of development and application verification. Testing therefore checks both the availability of six-axis data and the relationship between device outputs and actual orientation, angular rate, acceleration, temperature and vibration inputs.

IMU testing typically covers three areas. Static and steady-state performance includes bias, scale factor, nonlinearity, range and cross-axis response. Temperature, noise and dynamic performance includes bias temperature drift, noise density, frequency response and digital-filter bandwidth. Supply, communication and functional checks include startup, operating current, SPI/I²C access, self-test, data-ready interrupts and FIFO operation. These tests require different physical inputs, so a single instrument cannot perform all verification tasks.

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 these motion and environmental test rigs, the six-face indexing fixture, IMU test boards, synchronous acquisition and host software into an automated platform for automotive six-axis IMU ICs. Each rig independently produces its mechanical or thermal input. A common carrier allows the device under test to move efficiently between rigs, while shared control and acquisition equipment coordinate rig operation, time synchronization and data management.

The solution supports multiple measurement ranges found in common six-axis IMUs. For example, a device family may offer accelerometer ranges from ±2 g to ±16 g and gyroscope ranges from ±250 °/s to ±2000 °/s. Six-position tests use gravity to apply approximately +1 g and −1 g static inputs to each accelerometer axis in turn. A precision centrifuge provides multipoint acceleration above 1 g, a single-axis rate table provides positive and negative steady angular rates, and linear and angular vibration systems evaluate accelerometer and gyroscope dynamic response respectively. The specific ranges, temperatures, frequencies and acceptance limits follow the device datasheet and the agreed test conditions.

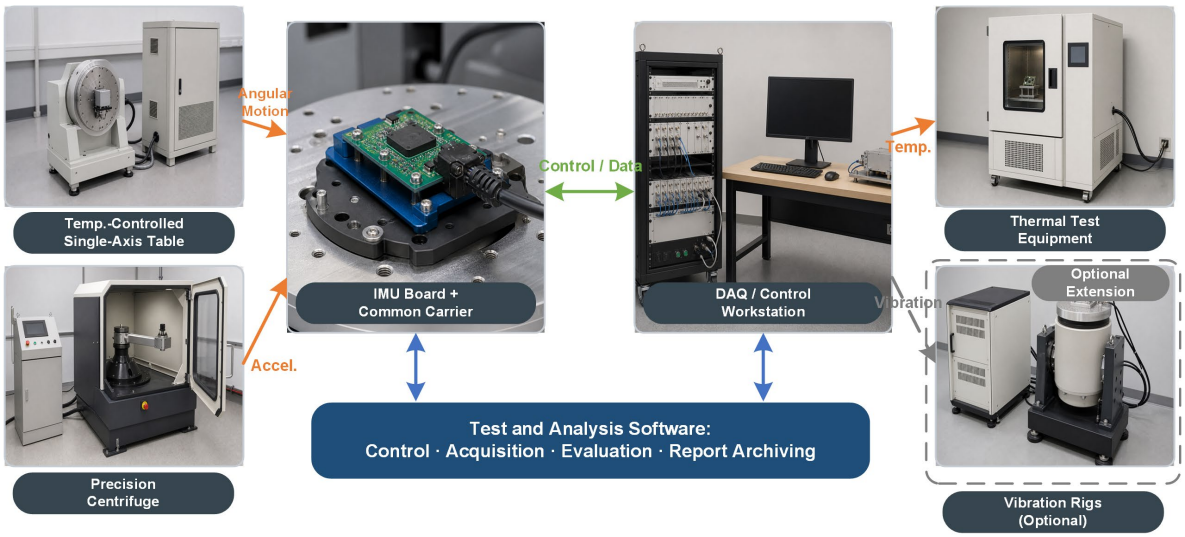

Figure 1. Automotive six-axis IMU IC automated test system

2. Overall Test Workflow

The host software creates and manages the test task. The operator enters the sample ID, device type, package, mounting orientation and test-board revision, selects accelerometer or gyroscope tests, and loads the corresponding supply, range, output data rate, temperature and mechanical-input settings. The software generates the execution sequence and identifies the rigs, fixtures and reference sensors required 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.

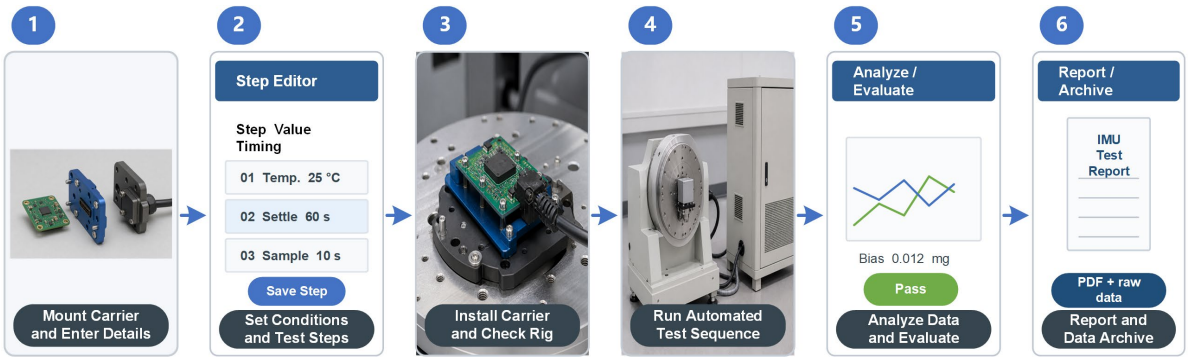

Figure 2. Automotive six-axis IMU IC automated test workflow

Table 1 summarizes common 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 automotive 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
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

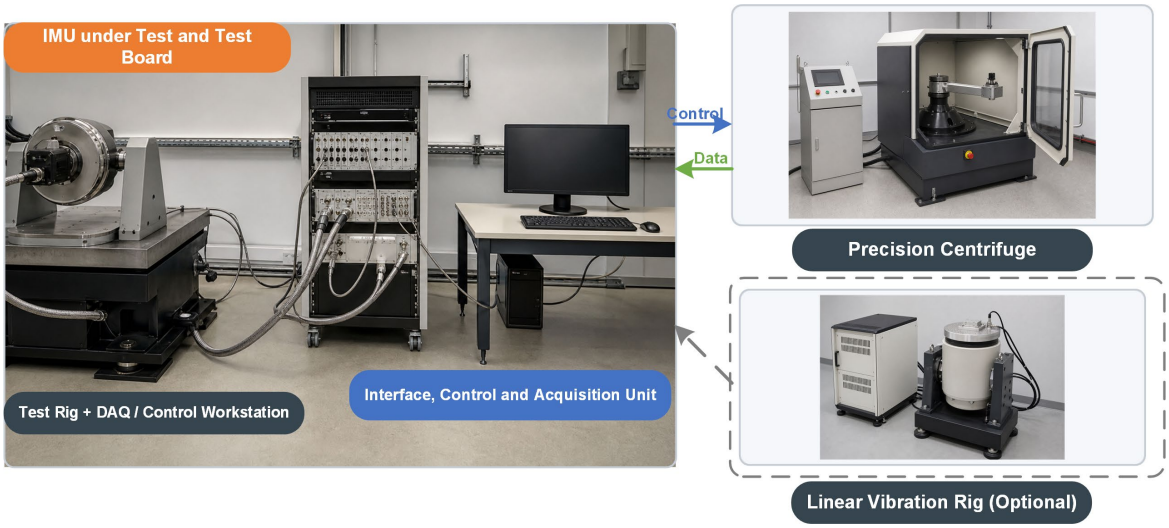

Figure 3. Architecture of the automotive six-axis IMU IC test system

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.

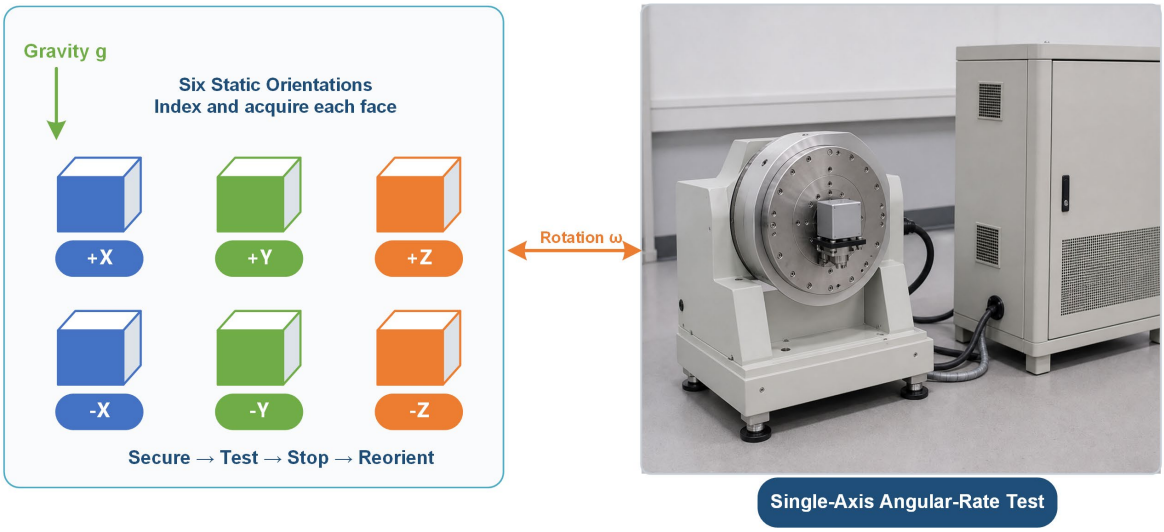

Figure 4. Six-position orientation and single-axis angular-rate test methods

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 be transmitted in real time through a slip ring or buffered on the rotating assembly, depending on the rig design. Vibration testing requires control of the mass and stiffness of the board, carrier and cables so that added structural resonances do not distort the reference input. In either case, the test-board revision, fixture orientation and mounting condition are recorded to distinguish reorientation or mounting errors from device performance.

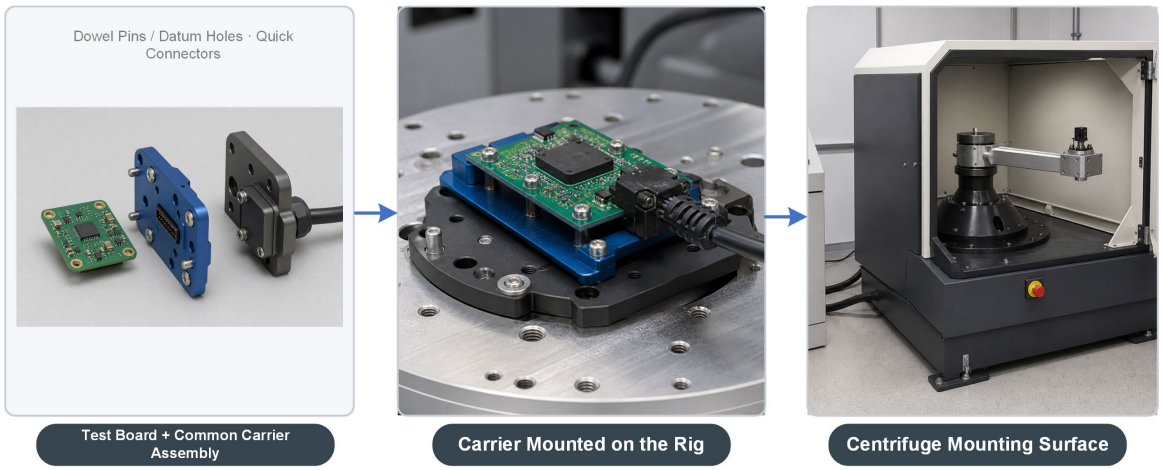

Figure 5. IMU test board and common carrier for changing test rigs

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.

The system associates the data using a common trigger, hardware timestamps or explicit test-point IDs. Steady-state measurements are taken after the rig reaches the target and stabilizes. Sweeps and continuous-motion tests retain the reference waveforms and raw IMU sequences for subsequent timestamp alignment. Raw device output is preserved throughout acquisition, and noise and frequency-response analysis use the raw sequences directly. Rig calibration information, sampling rates, filter settings and coordinate transformation parameters are saved with the results for error-source review.

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.

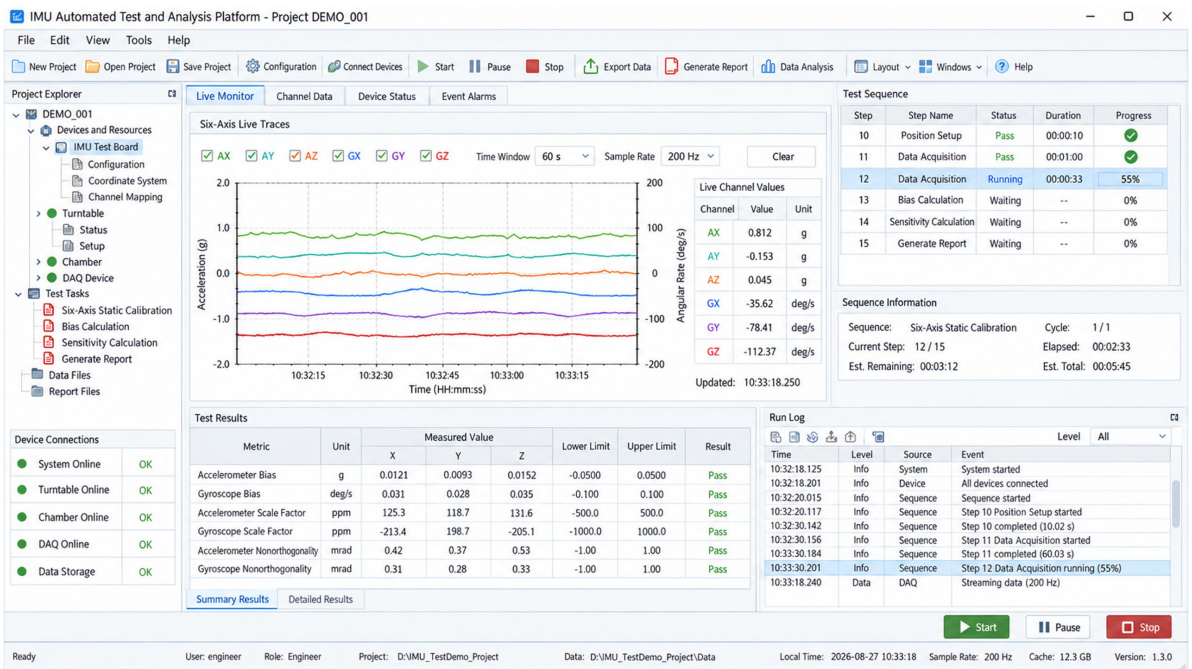

Figure 6. Illustrative IMU automated test and analysis interface

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 rate testing first aligns the sensitive axis under test with the table's rotation axis. The sequence includes zero, several positive and negative intermediate rates, and points near full scale for each range. Encoder-measured angular rate provides the reference at each point, with acquisition starting after the rate stabilizes. The software fits reference rate against digital output to calculate scale factor and nonlinearity. It also compares equal-magnitude positive and negative rates, increasing and decreasing rates, and zero-rate outputs before and after the test. After one axis is complete, the table stops and the fixture is reoriented to test the other two axes.

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 7. Precision centrifuge and temperature test methods

Temperature testing starts with a reference temperature sensor placed near the IC. Acquisition begins after the reference temperature and equipment status stabilize. For the gyroscope, zero-rate output and noise can be calculated at each temperature while stationary. For the accelerometer, fixed-orientation data show changes in static output, noise, current, communication and startup over temperature. Multiple orientations at each temperature are used to calculate three-axis zero-g bias and scale factor as functions of temperature.

4.3 Linear and Angular Vibration Tests

Linear vibration tests evaluate accelerometer dynamic sensitivity, amplitude and phase response, digital low-pass filter bandwidth and dynamic cross-axis response. The reference accelerometer and IMU are mounted close together on the same rigid fixture. A low-amplitude preliminary sweep checks fixture fastening and resonances in the target frequency band. Fixed-frequency or sweep tests are then performed with the selected filter settings. The software calculates the amplitude ratio and phase difference of the IMU axis under test relative to the reference acceleration and records the responses of the other two axes.

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 8. Linear and angular vibration tests for dynamic response

For dynamic testing, the reference-channel sampling rate and device output data rate must exceed twice the highest test frequency, with additional margin for anti-aliasing. Each digital filter setting is paired with its permitted output data rate to obtain separate amplitude and phase responses. If the −3 dB cutoff is defined as the frequency at which the amplitude ratio falls to 0.707 of its low-frequency value, the sweep must extend above the target cutoff. Structural endurance and random vibration tests are optional extensions, with spectra, levels and durations configured according to the applicable product standard.

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 six-axis IMU IC test solution connects rigs based on different physical principles to a common power, acquisition, synchronization and software system. Each rig retains independent calibration and protection, while the device moves between rigs on a common carrier. This reduces duplicate equipment and avoids the additional eccentricity, resonance and heat-transfer effects that can arise from combining rate-table, centrifuge and vibration mechanisms into one structure. 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.
- A precision centrifuge extends acceleration testing beyond the 1 g limit of the six-position method. Linear and angular vibration systems evaluate accelerometer and gyroscope dynamic amplitude, phase and filter response respectively, forming an optional combination of static, steady-state and dynamic tests.
- 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

Six-axis IMU ICs combine acceleration, angular-rate, temperature and digital communication functions, and their verification requires several types of excitation equipment. Six-position orientation supports bias and scale-factor measurements around ±1 g. A single-axis table provides steady angular rate, a precision centrifuge provides high-g acceleration, and linear and angular vibration systems provide dynamic inputs. Temperature-controlled tables and temperature chambers support different thermal tests. Recording external references and raw IMU outputs together allows device performance, mounting errors and rig conditions to be distinguished.

DOEWE can configure rigs, fixtures, test boards, synchronous acquisition and automated software according to the IMU package, ranges, interfaces and test objectives. When devices change, the existing rigs and data paths can be reused by adapting the board, fixture and software configuration. The solution supports development verification, sample comparison and standardization of test methods. Contact DOEWE for further information.