Calibration and Quality Control in the Design and Manufacture of Seismic Instrumentation

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Nanometrics Inc.

INTRODUCTION AND MAIN RESULTS

Seismic instruments for test ban treaty monitoring must be precisely calibrated with verifiable accuracy. Calibration in manufacturing provides a baseline for quality assurance in a deployed network.

We describe Nanometrics' process for building and testing instruments to precise and accurately verified tolerances such as +/-0.5% for sensitivity and low-frequency response parameters. This process uses a combination of measurements at subassembly levels during manufacturing, and measurements on final assembled units. Unit testing includes (1) electrical calibration to precisely measure frequency response, and (2) Sleeman coherence measurement in side-by-side tests to verify ground motion calibration, and to measure self-noise even below the level of ground motion.

Manufacturing calibration as obtained by these methods agrees with other standard methods such as shake table testing at national laboratories.

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Calibration in Manufacturing

Three possible approaches:

1) Use components of known accuracy. Measure complete instrument response to confirm.
2) Use adjustable components. Measure and then factory-adjust for accuracy. Measure complete instrument response to confirm.
3) Build knowing that there will be instrument-to-instrument variation. Measure and publish a calibration sheet for each instrument serial number.

These are not mutually exclusive. Nanometrics uses a combination of (1) and (2). All approaches result in a known accuracy for each specific instrument. Only (1) or (2) result in a consistent spec for **all** instruments.

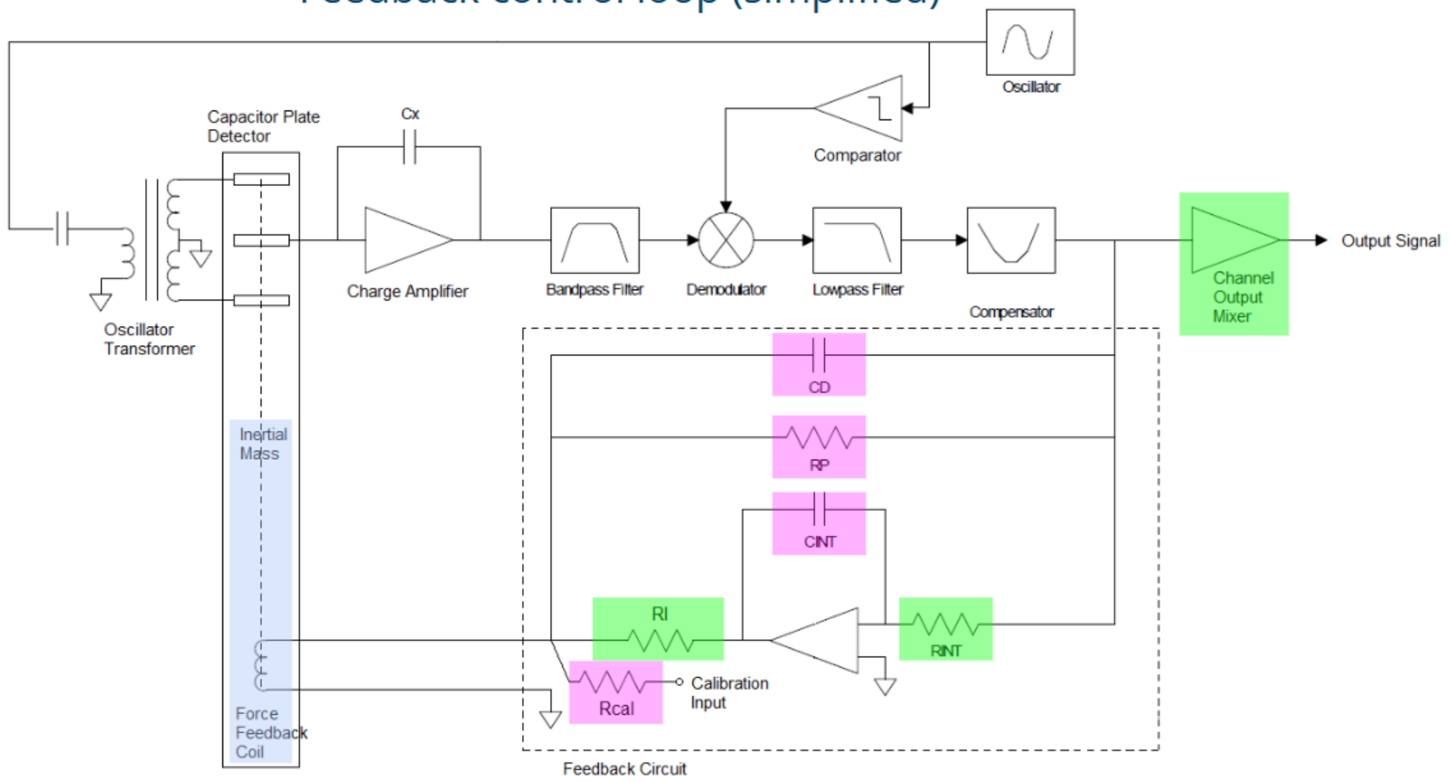
Nanometrics trim process:

- Use accurate precision resistors for RINT, RI and channel mixer
- Measure the force feedback motor constant in m/s^2 per Ampere
- Trim Cd, Rp, Cint and Rcal

Results:

- Sensitivity: function of (motor constant, Cd, mixer gain)
- Low corner freq: function of (Cd, Cint, Rint, Ri)
- Low corner damping: function of (Cd, Rp)
- Calibration input sensitivity: function of (motor constant, Rcal)

Feedback control loop (simplified)



Trillium SEISMOMETER

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Measuring the Motor Constant

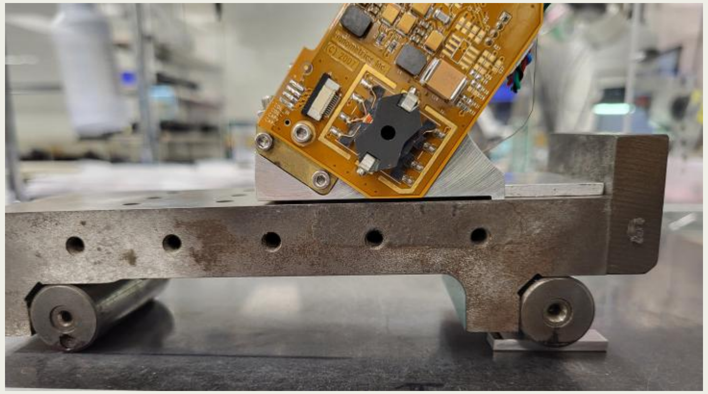
Force-feedback motor: a wire-wound coil around a permanent magnet, that applies force feedback to balance ground acceleration.

Using gravity as calibration reference, measure motor constant in m/s^2 per Ampere:
- Obtain reference value for local gravity
- Tilt the axis to a known angle
- Measure current to restore mass to center
- Knowing gravity, tilt angle and current, calculate motor constant

Need to know with sufficient accuracy:
- Tilt angle: calibrated sine block and spacers
- Local gravity: national metrology authority
- Electric current: calibrated ammeter

Manufacturing test stand is shown at right.

Close-up below shows sine bar and gauge block spacer to apply tilt.



Seismometer Unit Test Verification

Photo below shows setup for unit tests in Nanometrics manufacturing:

1) Electrical calibration testing
- Inject wide-band calibration input signal, record output
- Plot magnitude and phase of the output / input transfer function
- Verifies frequency response more precisely than ground motion or shake table test
- Does not verify sensitivity (magnet strength value cancels out)

2) Side-by-side “Huddle Test” on a pier
- All units under test measure the same background seismic signal
- Sleeman signal coherence analysis checks for
  - Sensitivity (relative to reference sensor)
  - Transfer function (relative to reference sensor)
  - Self-noise within limits (based on difference from average of group)

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