Sensor Measurement Fundamentals Series
Vibration Measurements

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Key takeaways

- Vibration fundamentals
- Vibration sensors
- Data acquisition system requirements
- Signal processing techniques
- NI’s vibration solution
Why measure vibration?

Machine Health

Noise and Vibration

Structural Health
Vibration applications

Engine NVH

Consumer Electronic Test

Road Dynamometer

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Measurement components

- Sensor
- Connectivity
- Signal Conditioning
- Analog-to-Digital Converter
- Computer

Physical Measurement

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Accelerometers

- Measure
  - Acceleration
  - Velocity and displacement (via integration versus time)
- Result is expressed in units of $g$ or $m/s^2$
  - $1 \, g = \text{acceleration at the surface of the earth}$
  - $1 \, g = 9.81 \, m/s^2$
Accelerometers use the properties of piezoelectric crystals to change force into voltage.
Vibration generates analog output voltage proportional to the acceleration of vibration.
Accelerometer materials can be oriented for different measurements:

- Compression
- Flexural
- Shear
Charge mode accelerometers are ideal for extreme temperature environments

**Advantages**

- High temperature survivability

**Disadvantages**

- External conditioning required
- Need low noise cabling
- Sensitive to environmental influences
IEPE accelerometers are easy to connect, simple to set up

Direct Connection

Advantages

• Simple and easy to use
• Built-in microelectronics

Disadvantages

• Lower temperature range
• Fixed sensitivity
Transducer Electronic Data Sheet (TEDS)

TEDS Info
- Calibration
- Sensitivity
- Sensor model
- Filter information
- And more
Accelerometer mounting options

Typical Frequency Limits for Various Mounting Options

<table>
<thead>
<tr>
<th>Method</th>
<th>Frequency Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Handheld</td>
<td>500 Hz</td>
</tr>
<tr>
<td>Magnet</td>
<td>2,000 Hz</td>
</tr>
<tr>
<td>Adhesive</td>
<td>2,500–4,000 Hz</td>
</tr>
<tr>
<td>Beeswax</td>
<td>5,000 Hz</td>
</tr>
<tr>
<td>Stud</td>
<td>6,000–10,000 Hz</td>
</tr>
</tbody>
</table>
Monitoring of roller bearings in machines is performed with accelerometers.
Proximity (eddy current) probes
Proximity (eddy current) probes
Measurement components
Measurement requirements

- Sensor excitation
- AC coupling
- Anti-aliasing
- High resolution
- Synchronous measurements
Signal conditioning removes artifacts and noise from the signal.
Powering IEPE sensors means AC coupling is needed for best measurement resolution.

- **DC Offset Due to IEPE**:
  - 27 VDC
  - 24 VDC
  - 21 VDC
  - 0 VDC

- **AC Signal (Acceleration)**:
Aliasing

- Shannon sampling theorem
  - The maximum frequency (Nyquist frequency: \( f_N \)) that can be analyzed is given by

\[
f_N = \frac{f_s}{2}
\]

\( f_s \): sampling frequency

- Improperly sampled
- Properly sampled
Anti-aliasing filter in ADCs

DSA Digital Filter vs. 8th Order Analog Bessel

Filter Response (dB)

Frequency (Hz)

0 10000 20000 30000 40000 50000 60000 70000 80000

-140 -120 -100 -80 -60 -40 -20 0

Analog Bessel Filter attenuates signals in band of interest

Signal Bandwidth

F_{Nyquist}

NI 4472 at 102.4 kS/sec

F_{Nyquist}

150 kS/sec

Bessel, Fc=15 kHz

Bessel, Fc=22.5 kHz

Bessel, Fc=30 kHz

DSA Digital Filter

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Effect of ADC resolution

With high-resolution ADCs, you can detect both strong and weak signal components at the same time.
NI synchronization technology ensures phase synchronous measurements.

0.1° Phase Mismatch
Worst Case Guaranteed
at 1 kHz

50X Magnification
NI dynamic signal acquisition devices simplify acquisition from IEPE sensors
NI has many solutions for accelerometer measurements

**Portable**
- NI 9234: WiFi, ENET, USB
- NI 443x: 24-bit analog output

- Rugged, compact
- USB, wireless, Ethernet
- Synchronized

**High Channel Count**
- NI 4498: 16 channels

- Better dynamic range
- Variable input ranges
- Highest sample rate

**High Performance**
- NI 446x analog out and in

- Best dynamic range (118)
- Best AC coupling
- PCI or PXI bus

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The Sound and Vibration Measurement Suite for LabVIEW simplifies vibration measurements
Vibration demo

Accelerometer

NI 9234 ±5 V, IEPE

cDAQ-9171 USB Chassis

Signal Processing

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Hardware Demonstration
NI hardware is frequently used in structural test

UCSD: Bridge Testbed for Health Monitoring Technologies
Continuous monitoring of seismic activity at the Beijing National Stadium and Aquatics Center