BASICS OF ACCELERATION MEASUREMENTS!

MECHANICAL FAILURE PREVENTION TECHNOLOGY
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GETTING RELIABLE AND USEFUL INFORMATION FROM YOUR ACCELEROMETER.
It is easy to get an accelerometer to measure acceleration. The problem is to keep it from measuring everything else!

Walter Kistler
Today we will Talk About:

- Some basics of your vibration measurement.
- What common industrial accelerometers are.
- Their operating characteristics.
- Some of the potential problems & error sources.

MORE IMPORTANTLY!

- Some of the information they can provide to your PdM operation.
- You may be surprised!
Why do you measure vibration?

- To establish machine condition.
- To extend the useful life of rotating machinery.
- To identify conditions that may lead to shortened life or catastrophic failure.
- Verify condition correction.
SOME IMPORTANT THINGS TO KNOW ABOUT VIBRATION MEASUREMENT!

- **DISPLACEMENT-VELOCITY-ACCELERATION? WHAT IS THE DIFFERENCE AND WHY SHOULD YOU CARE?**
VIBRATION’S FOUR RELATED CHARACTERISTICS

- **DISPLACEMENT-DISTANCE** - D or X-mil inches
- **VELOCITY-SPEED** - $\Delta D/\text{sec} = V \text{ (in/sec-cm/sec)}$
- **ACCELERATION** - $-(\Delta V/\text{sec}) = \text{in/sec}^2$
  
  In g units = multiple of gravitational acceleration = $\text{in/sec}^2 / (386.1 \text{in/sec}^2) = g$
- **FREQUENCY** (Hz or rpm)
Examples of Vibration

Period = \( T = \) Time for one cycle or revolution.

Frequency = \( \frac{1}{T (\text{seconds})} = \) Cycles / sec = Hertz (Hz)
PEAK = \frac{X}{2} \quad \text{RMS} = 0.707 \frac{X}{2} \quad \text{AVERAGE} = 0.637 \frac{X}{2} \quad \text{PEAK TO PEAK} = X

Periodic Sinusoidal Vibration
Let’s begin by looking at Frequency!

CONVERT rpm to Hz

where: Hz = cps = cycles per second
rpm = revolutions per minute
rpm/60 = Hz
rpm = Hz*60
DISPLACEMENT = X

- UNITS - Inch, mil-Inch, cm, mm
- Usually expressed as Peak to Peak
  \( (\text{mil inches} = \frac{\text{inches}}{1000} = 0.001\ \text{in.}) \)

CONVERT one inch (p-p) into mils

- ANSWER = 1000 mils
- CONVERT .005 inch (p-p) = to mils
- ANSWER five mils!
**Convert Displacement to Velocity**

\[ V = \pi f X \]

Velocity in/sec \( \approx 3.14 \) freq.(Hz)*Disp-ln(pp)

or

Velocity in/sec \( \approx 0.052\)RPM*Disp*ln(pp)

RPM = 3600, Disp. = 1 mil = Velocity?

Answer \( \approx 0.187 \) in/sec
Convert Displacement to Velocity

\[ V = \pi f X \]

Velocity in/sec = 3.14 frequency, Disp \((\text{In, } \text{p-p})\)

or

Velocity in/sec = 0.052*RPM*Disp. \((\text{in, } \text{p-p})\)

RPM = 3600, Disp. = 5 mils

Answer = 0.94 in/sec
Convert Displacement to g units

\[ g = 0.051 f^2 X \]

\[ g = 0.051 f^2 \times \text{Disp. (in-pp)} \]

or \[ = 0.051(Rpm/60)^2 \times \text{Disp.(in-pp)} \]

Let : Frequency = 61.45 Hz

\&

Displacement \approx 5.18 \text{ mils}

Answer \approx \text{approx 1 g}
Convert Velocity into g units

\[ g = \frac{(2\pi f)^2 X}{2 \times 386.1} \]

\[ \approx (6.28 f/386.1) \times \text{Velocity} \]

\[ \approx 0.0163 \times f \times \text{Velocity} \]

If \( f = 61.45 \text{ Hz} \)

\& Velocity = 1.0 in/sec

We get \( g \approx 1.0 \)

**INTERESTING!**

**AT 61.45 Hz**

**Useful Rule:** \( 1g \approx 1 \text{ in/sec} \approx 5.18 \text{ mils} \)

Easy to estimate- @ 1800 1in/sec \( \approx 10 \text{ mils} \), 0.5g, - 7200 1IPS \( \approx 2.5 \text{ mils} \), 2g, etc Easy to estimate g or Disp.
Frequency Relationship - Displacement-Velocity-Acceleration

\[ X = \text{Disp}(p-p) \]

Velocity = 3.14 \( f \) \( X \) (p-p)

\[ g = .051(f)^2 \times (p-p) \]

\[ \pi = 3.14 \]
Displacement = X
Velocity = \Pi fX
Acceleration(g) = \cdot051 f^2 X

Note: at 61.45 Hz 1g = 1 in/sec = 5.18 mils (p-p)
Why is This Relationship Important?

- Take a look at the next few slides with time history waveforms and spectrum plots shown in Disp. Velocity and Acceleration.
- Both bearing #9 and #5 are damaged.
- Displacement and Velocity suppress high frequency energy containing valuable data on bearing surface condition.
Velocity time waveform.

BRG 9, IN2, rms=0.380418

BD=3.6, HF=7.3, CF=6, KF=0.13, ED=3

RMS: 0.3

Live X1
X: 0.0799609
Y: 0.472679
Acceleration Time Waveform.  BRG 9, IN2, rms=1.08119

BD=3.6, HF=7.3, CF=6, KF=0.13, ED=3

RMS: 1.0

Live X1
X: 0.0799609
Y: -0.20284
Acceleration Time Waveform

BRG 5, OUT, rms=2.22567

BD=11, HF=12.7, CF=14, KF=10, ED=12.1

RMS: 2.2

Live X1
X: 0.0799805
Y: 0.209865
Bearing #5 - Outer Race Heavy Score

20 kHz Displacement Spectra

Low Frequency amplified

High Frequency suppressed!

MIL's

S1
X: 6600
Y: 1.57844e-005

SKF 6205
52Hz

0 5.0K 10.0K 15.0K 20.0K Hz

Na
20 kHz Velocity Spectrum

Bearing #5 - Outer Race Heavy Score

SKF 6205

Emphasis on Low Frequency

6kHz

High Frequency Reduced
Bearing #5 - Outer Race Heavy Score

20 kHz Acceleration Spectrum

Here is the bearing condition information!
The NATURE OF ACCELEROMETERS

- THE OPERATIONAL BASICS
- IMPORTANT CHARACTERISTICS
- POSSIBLE PROBLEMS?
- HOW TO SPOT & AVOID THEM
AVD CONCLUSION?

For low frequency information, Balance, Alignment, Foundation, or low end bearing fault frequencies use Velocity. (in/sec)

For sensing early degradation in rolling element bearings use acceleration. (g)
A VIBRATION TRANSDUCER

PROVIDES AN ELECTRICAL OUTPUT PROPORTIONAL TO THE INSTANTANEOUS VALUE OF THE VIBRATORY MOTION.
THE ACCELEROMETER

Produces voltage proportional to

Instantaneous acceleration.

\[ \text{Acceleration} = \frac{d}{dt} \text{Velocity} = \ddot{X} \]

(In ‘g’ units = 0.051 \( f^2 \) \( X \))

Where: \( f \) = frequency (Hz)

\( X \) = displacement (PP)

Usual output voltage units = mv/g
Figure 1a
Voltage $= \text{Force} = \text{Mass} \times \text{Acceleration} = K \times \text{Acceleration}$

**Simple Accelerometer**

Voltage follows base motion

- Positive: Upward motion
- Negative: Downward motion

Voltage = charge/xtal capacitance

Voltage $= \text{force} = \text{mass} \times \text{acceleration}$
REACTION
FORCE

SHEAR STRESS

SENSOR BASE

XSTAL

Positive Charge

Negative Charge

MOTION
Piezoelectric transducer and equivalent circuits. Charge, $q = KF$, where $K$ is piezoelectric constant, $C_a$ is transducer capacity.
Early Style Voltage Amplifier!

Simplified circuit of piezoelectric transducer in an operational voltage system.

Note: Sensitivity changes with cable length!
Simplified Charge Mode Amplifier!

Sensitive to triboelectric cable noise! Requires special low noise cable!
Low Impedance Circuit!
No ‘Tribo’ noise, long cables, low coupled noise.

Constant Current Signal Extraction Mode used in most modern industrial accelerometers!
IMPORTANT ACCELEROMETER CHARACTERISTICS

- SENSITIVITY
- NOISE DISTRIBUTION
- LOW FREQUENCY RESPONSE
- HIGH FREQUENCY RESPONSE
- FILTERED OR UNFILTERED
- BASE STRAIN
- TRANSVERSE SENSITIVITY
- TEMPERATURE
The transducer conversion constant along its major axis in Volts, or millivolts/g. Usually at specified frequency, temperature and level (1 g).
Example: 100 mv/g @ 100Hz, 1g, 720 F
The transducer sensitivity Along the axis perpendicular to the Sensitive axis. Expressed as a % of the Basic Sensitivity. For example: 3% of basic sensitivity

Triax?

View from top of accelerometer

**Transverse Sensitivity**

Rotate Machine motion

MINIMUM

5% Maximum

Expressed as % of basic sensitivity.

LATERAL MOTION CAN OFTEN BE AS HIGH AS VERTICAL MOTION!

EFFECT ON ACCURACY OF VERTICAL AXIS READING IS NEGLIGIBLE!
Sample Change in Sensitivity w/Temperature

Usual limit – 65 °F to 250 °F. Special units to 400 °F w/Electronics.
Thermal shock!

Change in Sensitivity due to temperature transient!

ANSI Standard 82.11 - thermal shock

Model X

0.14g/C°

Model Y

0.004/C°

Ambient to 32°F

10 Seconds
Linearity-Change in Sensitivity with level

Basic Sensitivity @ 100 Hz
1 g

Deviation
Level ‘g’
BASE STRAIN ERROR

Error signal introduced when sensor case or base mounting interface is mechanically strained

Specification = g/µ strain typical = 0.0003-0.001g/µ strain

µ strain= 1 µ inch/inch
µ = micro inch= 10 \(^{-6}\) inches
If large difference at 1x between magnet and hard mounted sensor check base strain.

Greased bushing will minimize effect.

BASE STRAIN ERROR

USUALLY OCCURS AT 1X IN LARGE LOW FREQUENCY MACHINERY

USE MECHANICAL ISOLATION STUD.
High Overall

- High Discrete Signal Levels

  High 1X signal levels may indicate that there is a bending mode in the machine causing base strain in the sensor. The bending mode may be decoupled by a magnet or mounting bushing placed under the sensor.

  Base strain = 0.001 g/ms × 10 ms = 0.01 g
  - 0.01 g @ 300 CPM = 0.12 in/sec ≈ 7 mils!
  - just from strain error!
High Overall

- High Discrete Signal Levels

High 1X signal levels may indicate that there is a bending mode in the machine causing base strain in the sensor. The bending mode may be decoupled by a magnet or mounting bushing placed under the sensor.

Base strain = 0.001 g/ms X 10 ms = 0.01 g

0.01 g @ 300 CPM = 0.12 in/sec
MOUNTED RESONANT FREQUENCY

The axial resonance of the mounted accelerometer’s sensing crystal and its associated mass. The frequency at which the unfiltered basic sensitivity is maximum. Usually expressed in kHz.
Vibration transmissibility ratio

\[ \text{Transmissibility} = \frac{C/C_0}{\frac{\pi}{2} \sqrt{\frac{K}{M}}} \]

vs. frequency ratio

\[ \text{Ratio} = \frac{\text{Forcing Frequency}}{\text{Natural Frequency}} \]
Useful frequency response range

Accelerometer Sensitivity vs. Freq.

Typical
Specified
Range
5-10kHz
+/- 5%

Useable range
½ fn

10kHz
+/- 5%

Resonance range 15 to 25kHz
+/-3dB

Low
But
Useable

Typical 3-5 Hz

10 –15 kHz

Useable for high frequency

Internal Filter
Mounting - High Frequency Effects

Mounting

A - Stud Mounting
B - Adhesive Mounting
C - Magnetic Mounting
D - Hand Held

Minimum effect at low frequency!
Resonances modify your spectrum!
Mount to solid surfaces - near load zone
avoid brackets!

Bracket resonance can modify machine spectrum!
SURFACE PREPARATION

Thin film
Silicon grease.

Accelerometer mounting surfaces shall be flat within 700 micro inches Rms

Drilled and tapped holes shall be perpendicular to the finished surfaces within ±1 degree

Surface finish of 125 microinches or better

Mounting holes shall be drilled and tapped to a depth sufficient to accommodate the mounting stud.

Chamfer
Remove burrs
Suggestions regarding frequency response.

- If you have something specific to measure such as 3rd gear mesh and know the expected frequency, select sensor with fn at least 2/3x expected frequency.
- For bearing measurements mount sensor close to load zone. This can usually be visually estimated.
- General vibration energy up to 10/13 kHz. Select unit with 25 kHz fn.
- If you need to measure important information above 2/5 kHz pay special attention to method of mounting. Use flush (not horseshoe) super magnets, rigid epoxy bonds. Do not use hand held stinger probe.
- Above 8kHz hard mount to flush flat surface with thin film of silicon grease.
MOUNTING & PROBES

- MOUNTING-HARD, ADHESIVES
- MAGNETS
- HAND PROBES
USE OF MAGNETS!

TEST ACCEL
WITH FLAT +/- 5% RESPONSE TO 10KHz

INTERFACE #1
SUPER MAGNET
INTERFACE #2
HIGH FREQUENCY REFERENCE ACCEL.

Sweeping sinusoidal vibration Input motion generated from high frequency vibration exciter.
Thick film of grease.\([+20\%]\)

Frequency response:

- +10\% @ 6kHz
- +20\% @ 10kHz

Model 1030 accelerometer
Super magnet model H100 1030.
SUPER MAGNET W/ OILED SURFACE (+10%)
Thin film of grease-best (+5%)

The grease tends to fill the voids and provide better interface coupling!
Super magnet on dry surface @ 5 g.
Conclusion on Magnet?

- Use rare earth super magnets with machined contact surface.
- Use smooth machined bushing for attachment.
- Thin film of grease or oil gives good results to 10 kHz.
- More is not better! Do not use excessive Coating of grease.
- Thin film of silicone grease on both mating surfaces is best.
- Consider the expected g level!
- Over 5/10 g use grease on both surfaces, high strength 25 lb magnet or hard mount if possible.
Use of a Hand Held Probe?
Be Aware!

Frequency response

Good grade 100mv/g accel!

AVG= 10

XFR FN MAG :

SPAN: 0.000000HZ–10.0000KHZ

FS: 40.00dB

N: 16 P: 50HZ

5dB/
Hand Held Probe- 4 1/2 in stinger

500 Hz
Up 5 dB

2300 Hz
Data attenuated

700 Hz
Down 8 dB

Up 4 dB

XFR FN MAG
SPAN: 0.000000HZ-5.000000KHZ
FS: 41.00dB
AVG= 32
N: 32 P: 25HZ
5dB/
SUGGESTION:
ONLY USE HANDHELD PROBES FOR CHECKING LOW FREQUENCY BALANCE AND ALIGNMENT ABOVE 1200 CPM!

Bearing information

20 dB Attenuation!

NADA!

Fn est. ≈ 0.16√(AE/L(m_s+0.3m_r))
Conclusion on hand probe!

- Be cautious in using hand probes in general.
- Tests indicate that they are best used above 20 Hz and below 500 Hz.
- For checking imbalance and misalignment.
- Not recommended for use in detecting bearing faults.
NOISE SOURCES!

- GENERAL
- GROUNDING NOISE
- BASE COUPLED NOISE
- EFFECTS OF INTEGRATION
- LOW FREQUENCY NOISE!
High Output- Ground Loop Noise
*keep connectors and sensors off ground!*

Case Grounded

Line Powered Analysis Equipment

Current flow through ground loop

Machine Surface

Noise capacitively couples into signal!

noise voltage on ground
Internal or external isolation could be a problem!

- **Accel.**
- **Vibration Signal**
- **Data System**
- **0 Vdc**
- **24 Vdc**
- **12 Vdc**
- **2mA constant current**
- **Bias Level**
- **Capacitively Coupled Noise Foils**
- **Internal Isolation**
- **Contamination**
- **Shorts Out External Isolation**

**Ground Noise**
High Output-Ground Loop Noise
or Base Coupled Noise!

- IsoShield™

Glass Isolated outputs.

Internal Faraday Shield
Good solution!

Thin film Isolation

Noise is shunted to ground!

Trademark Vibra-Metrics Inc.
Another Isoshield™ Design.
High level at line frequency

- Zoom in to check actual frequency. Should be exactly at power line.
- Try power turn off- If it disappears instantly - it’s electrical!
  If not - it’s from other source.
- Check for single System ground.
  Remember ground noise can be from adjacent machine or source!
High Output - Ground loop noise

- Loss of Isolation

Conductive materials at the accelerometer, cable, or connections are common cause of ground loops!
Most Common Noise Problems:

- **Noise -Integration-Low Frequency**
- **Clipping** [May be high frequency-above analysis range!]
  - Bias Instability-square wave FFT causes odd harmonics.
- **Turn-on Time, Base Strain, Cable Sensitivity**
- **Loss of Isolation-60 Hz noise**
- **Use Time Domain as a diagnostic tool.**
- **See strange peak? Change resolution.**
- **High frequency-VFD, Gear noise, line coupled noise from other electrical signals.**
COMMON SOURCES OF LOW FREQUENCY NOISE!
High Output - Ski slope

Problem-suppresses real signal!

Frequency

OA = 0.8

Ski-slope

$1x = 0.19$
Understand INTEGRATION!
Amplifies low frequency noise.

- FFT of Acceleration
- FFT integrated to Velocity

Velocity ≈ $\frac{g}{0.0163f}$ or $1/f$
High Overall-SKI SLOPE

USE HIGH PASS FILTER IN DATA COLLECTOR.

This will drop the overall component levels due to noise or unwanted foundation motion!
High Output: ski-slope (Low Frequency Measurements)

- **Sensor / Power Supply 1/f Noise (In Velocity)**

Velocity noise. Velocity signal

Velocity = \( \frac{61.5 \times g}{F} \)

Note that HP filter will not help here! Why?

May need higher Sensitivity

Very low frequency SIGNAL. Frequency
High Overall - SKI SLOPE

- **Sensor Turn-on Time**

Looks like Low Frequency

Some sensors can take 8 to 10 secs! Allow time before collecting data.
Real Motion?
Structural / support motion is usually discrete frequency. Increase analysis resolution. Look for distinct peaks that relate to floor or structural resonance. Otherwise it’s probably noise!

Put sensor on floor or structure!
Other Diagnostic Tricks!

- Changing FFT resolution to check for discrete structural frequencies.

High Resolution

Low resolution
High Ski Slope

Possible Causes:

1) Could be real motion of floor or supporting Structure?
2) Sensor turn on time?
3) Sensor 1/f noise?
4) Integration processing noise?
6) Clipping Saturation products?
7) Aliasing signal processing errors?
8) Wrong high pass filter?
Signal Level Dropping!
Trouble Level Dropping!
Low Frequency Noise Increasing!

- Random Noise = \[ g_{\text{rms}} = \left( \frac{g^2}{\text{Hz}} \times Bw \right)^{1/2} \]
  
  \[ = \frac{g}{\sqrt{\text{Hz}}} \times (Bw)^{1/2} \]

Where:

- \( g^2/ \text{Hz} \) = spectral density factor
- and \( \frac{g}{\sqrt{\text{Hz}}} = \) is the spectral noise factor.

- Caused by the internal electronics in the sensor. Random thermal noise and 1/f low frequency random noise.
- It is not constant with frequency!
Trouble level dropping!

0.001g = 100 μ volts!
Signal Level out of sensor dropping!

Select Sensor with prop low frequency response corner!
Electronic noise Increasing!
Signal to Noise Ratio

Periodic signal in random noise @ 90 %.

- Ratio = signal/noise Minimum 3:1
- Example: Signal = 3, noise = 1
  \[ = \sqrt{3^2 + 1^2} = 3.16 \approx 5.3\% \]
- Signal = 2, noise = 1 error \( \approx 12 \% \)
- At 10 DOF (5 aver.) error up to 35%
- At 20(10aver.) error range up to 28%.
- At 40(20 aver.) error 25%
- Need 500 averages to approach 12%
Reduce Noise by:

- Most vibration sources in rotating machinery are periodic. Therefore the information exists at discrete frequencies.
- Need for bandwidth in making measurements is to accommodate normal variation in the machines rotational frequency.
- Unwanted random noise may be reduced when necessary by reducing the analysis bandwidth.
- $\text{Rms noise} = \sqrt{g^2/Hz \times BW}$
- Reducing a 5 Hz band to 1 Hz will cause a $\sqrt{5}$ or 2.24 reduction-increases the sample time by 5.
- Purchasing low frequency sensor with higher sensitivity!
Ref: Tony Keller, Spectral Dynamics, CA.
Degrees of Freedom, Bandwidth & Averaging time?

- $DOF = n = 2bT = \text{degrees of freedom, } b = \text{bandwidth, } T = \text{Averaging time, } t = \text{sample time for one block} = \frac{1}{b}$.
- $T = \text{sample time} * N (\text{number of block averages})$
- $n = 2bT = 2/t*T = 2/t* N \ t = 2N$
- $DOF = 2N(\text{number of block averages})$
A Better Way: Synchronous Averaging.

Averages out random noise signals!

\[ S/N = 10 \log_{10} q \]

Signal-to-Noise Level Enhancement for Synchronous Averaging.
Figure 6-10. Percent magnitude differences resulting from measurements taken by five people manually holding a Wilcoxon 726 accelerometer onto a rotating machine.
Figure 6-4. Percent magnitude differences of four major frequencies calculated from measurements taken by seven people using a CSI 310 handheld probe with a pointed two-inch steel stinger attachment.
Figure 6-6. Percent magnitude differences of measurements taken by five individuals using a CSI 310 handheld probe with a pointed two-inch steel stinger attachment.
Figure 4-2. Spectra ranging from 0 to 400 Hz for reference (top graph – part a) and test measurements (bottom graph – part b) corresponding to data taken from the negative side of the bearing housing (see Figure 4-1(a)).
ERROR SOURCE

SIGNAL CLIPPING!
SENSOR SYSTEM REVISITED

Dynamic Range? Maximum g w/o clipping. (Not Damage!)

- Power supply
- Vibration Signal>
- Data System >

Accel.

2ma constant current

12 +/- 2 Vdc

Bias Level

0 Vdc

24 Vdc
DYNAMIC RANGE

Dynamic Range = \text{max peak voltage w/o clipping} \quad 3 \times \text{rms band limited noise floor.}

Factors:
> Bias level determines +/- allowable voltage swing.
> Bias level varies +/- around 10volts.
> Rms noise is random with 3 sigma peaks
> Noise varies as $\sqrt{\text{bandwidth}}$.
> Power supply allows uniform +/- voltage swing.
> Sensitivity 10, 100, 250, or 500 mV/g?
w/ 24v supply +/- 10 VOLT LIMIT

Most power now +/- 12 volts
Bias +/- 2v

Note:
10 volt peak =
100 g – 100mv/g
10 g - 1volt/g
2 g – 5volt/g
1g – 10volt/g

Input Voltage Swing from Accelerometer Crystal Assuming Power Supply at 24V But Bias level at 14 volts.

14 volt bias
Also Remember!

- **Time Domain**
  - Peak values can be many times higher than single spectral components in the **Frequency Domain**

![Spectrum](image)

- 100 g
- 80 µ sec
- peak

Spectrum w/10 g bins.
BIAS VOLT

Time Domain Voltages Add!
Erratic Data - clipping

- Clipping - Strange components?
  - The FFT of a square wave consists of the fundamental frequency and all odd harmonics.
SENSOR - Clipping

- **Sensor Sensitivity**!
  - 10, 100, 250, or 500 mV/g?

- **Dynamic Range**

- Supply voltage normally 24 VDC

- Bias Voltage
  - 12 VDC nominal
Clipping causes DC offsets!

Clipping shifts ref up causing DC component.

Zero ref.

Off set looks like low frequency and takes RC to settle down.

\[ T = RC \]
\[ T = \frac{1}{6.28f_L} \]

Low frequency corner 3 Hz

\[ T = 0.05 \text{ sec.} \]

Where:
- \( R \) = input z
- \( C \) = capacity of xstal
- \( f_L \) = Low frequency corner

Cause of ski slope - low frequency noise?
Erratic Data - clipping

- Time Domain Data

Note exponential offsets!

What effect will this produce?

Low Frequency Noise and sum/difference frequencies!
Erratic Data - clipping

- Clipping - Strange components?
  - The FFT of a square wave consists of the fundamental frequency and all odd harmonics.

![Graph showing FFT of a square wave with fundamental and odd harmonics marked at 1, 3, 5, 7, 9, 11, 13.](image-url)
Signal Clipping Modulation

Dynamic Output (volts)

Input Volts

+12 Power Supply

12 Volt Bias Level

Power Supply Voltage

$e^{j\omega T}$ modulates input

$e_1 + e_2 + e_3$
False Spectral Components Caused by Clipping
Erratic Data - other places to look!

- **Clipping**

  Look for g levels beyond the dynamic range of the sensor. There may be clipping beyond the frequency range being viewed.
Most Common!

- Noise -Integration-Low Frequency
- Clipping-bouncy-bias Instability-odd harmonics-clipping beyond analysis frequency
- Low frequency-high pass filter-integration-turn-on time.
- 1/rev-Base Strain-Cable Sensitivity, increase resolution.
- 60 Hz noise-Loss of Isolation-ground loop!
- Signal loss-check bias voltage
- Change resolution-If amplitude changes it is Random noise and not a discrete frequency.
ERROR SOURCE

SLEW RATE LIMITING
THE HIGHER THE VOLTAGE SWING- THE LOWER THE FREQUENCY AT WHICH SLEWING ERROR OCCURS.

Gain change due to slew rate limiting!
Effect of slew limiting!

IDEAL

Slew limited.
Slew Limiting causes reduction in high frequency gain and peaky signal!
Example of distortion due to slow rate limiting when frequency is 25
Can cause DC offset after signal burst!
SLEWING RATE INCREASES WITH FREQUENCY

REQUIRED CURRENT = I = C de/dt

SR = 6.28 frequency Emax

\[ \frac{de}{dt} = \frac{\text{volts}}{\text{sec}} \] (or \( \frac{\text{volts}}{\mu\text{sec}} \))

\[ e = E_{\text{max}} \sin(\omega t) \]

\[ \frac{de}{dt} = E_{\text{max}} \omega \cos(\omega t) \]

\[ \frac{de}{dt} \text{(max)} = (\omega) E_{\text{max}} \]
<table>
<thead>
<tr>
<th>Frequency</th>
<th>Sensitivity</th>
<th>E_max</th>
<th>Slew Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>10,000 Hz</td>
<td>100mv/g</td>
<td>100</td>
<td>6.28 x 10,000 x 10</td>
</tr>
<tr>
<td></td>
<td>0.1 VOLS/g</td>
<td></td>
<td>628,000 volts/sec</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.628volts / micro- sec</td>
<td></td>
</tr>
</tbody>
</table>
Power Supply Current Required

\[ I = C \frac{de}{dt} \]

Where:

- \( I \) = current
- \( C \) = capacitance = 15pf/ft
- \( \frac{de}{dt} \) = Slew Rate \( 0.628 \text{V/}\mu\text{sec} \)

\[ I = 1000(15 \times 10^{-12}) \times 0.638 \text{V/}10^{-6} \]

\[ I = 9 \text{mA} \]
CABLE LENGTH @ CURRENT @ 10kHz-15pfd/ft-5volts

Approximate cc power supply current:

- 0.6 ma ≈ 125 ft.
- 1.2 ma ≈ 250 ft.
- 2.4 ma ≈ 500 ft.
- 4.8 ma ≈ 1000 ft.
- 9.6 ma ≈ 2000 ft.
### Sensor High - Low Frequency Measurements?

#### STRANGE SIGNALS ?
- BELOW 500 RPM – LF NOISE, FLOOR/MOUNTING
- AROUND 60 Hz (1x) GROUND NOISE/STRAIN!
- ABOVE 5/10 kHz- MOUNTING, CLIPPING, VFD, OR GEAR MESH!

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Accel.</th>
<th>Output</th>
<th>Volts</th>
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</thead>
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<td></td>
<td>+5%</td>
<td>+5%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-5%</td>
<td>-5%</td>
<td></td>
</tr>
</tbody>
</table>

#### Usable Frequency Range

![Graph showing frequency range and output voltage range](fn)
Error Sources!

Measuring Shock or Transient Impulse with accelerometer.
To avoid accelerometer ringing in an impact test:

\[ f_n > \frac{10}{T} \& f_{lp} = 0.5 f_n \]

Where: \( f_n \) is mounted resonance.
Shock & Vibration Handbook 3rd Edition

Eller & Whittier
Endevco Corp. Chap. 12
Droop Error!
To avoid low frequency error and zero shift:

Low frequency response < 0.008/T
Where: T = pulse duration.

Shock & Vibration Handbook 3rd Edition
Shock & Vibration Handbook 3rd Edition

Eller & Whittier

Endevco Corp. Chap. 12
Key Items to Observe for Impact

- To minimize Amplitude Errors & Undershoot
  Low Frequency Corner < .008/ T[Pulse duration.]
  Ex. T=0.2 sec. Low corner =0.04 Hz.

- To minimize Ringing
  Resonance Fn must be > 10/T and Low Pass Filter less than 0.5 Fn
  Ex. T= 1millisecond, Fn => 10 kHz.
GETTING USEFUL INFORMATION FROM YOUR ACCELEROMETER?

[See session on Bearing Lifeguard™ Multiple Discriminant Analysis.]
## Newark Campus

### DENTAL SCHOOL

**PD-RAD 2**

| Probability of failure within 90 days is: | 0.75 |
| Life Expectancy Factor (LEF): | 11.00 |
| Bearing Degradation Factor (BDF): | 13.00 |
| Dynamic Force Factor (DFF): | 3.00 |

<table>
<thead>
<tr>
<th>Cycle</th>
<th>Date</th>
<th>Condition</th>
<th>Prob of Failure (90)</th>
<th>LEF</th>
<th>BDF</th>
<th>DFF</th>
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<td>14</td>
<td>0.75</td>
<td>11.00</td>
<td>13.00</td>
<td>3.00</td>
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</tbody>
</table>

**Recommendation(s):**
- Rebuild/replace motor
- Replace bearings

**Est. Repair Cost:** $2,200

**Est. Avoided Cost:** $22,000
MAIN CAMPUS LIFE FACTOR DISTRIBUTION

144 MACHINES HAVE REDUCED BEARING LIFE!

NUMBER OF MACHINES BY LIFE FACTOR
CHANGE IN EXPECTED BEARING LIFE WITH CHANGE IN MACHINE SPEED

DROP IN LEF VS. SPEED

% L 10

1  1080
2  1800
3  3600  RPM
BEARING LIFE FACTOR DISTRIBUTION

SAMPLE

NUMBER OF MACHINES BY LIFE FACTOR

L-FACTOR  1-3  3-7  7-10

MACHINES

BAD

BAD MOTORS

AHU

PUMPS

MOTORS

0  10  20  30  40  50  60

0  10  20  30  40  50  60

0  10  20  30  40  50  60
Questions?
Where to get more information?

- Contact your sensor manufacturer!
- Contact the Vibration Institute!
- Dynamic Measurement Consultants!

jejvibes@aol.com