Vibration Monitoring Training Modules

Beginning Vibration Analysis

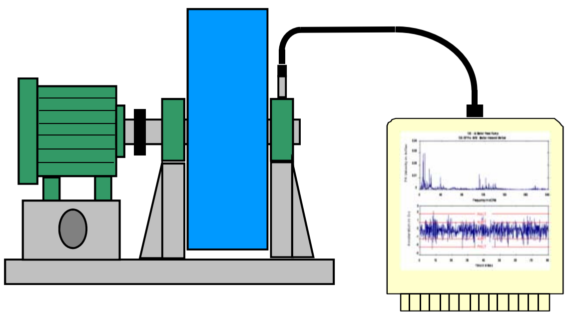
Connection Technology Center, Inc
7939 Rae Boulevard
Victor, New York 14564

www.ctconline.com

Connection Technology Center, Inc.

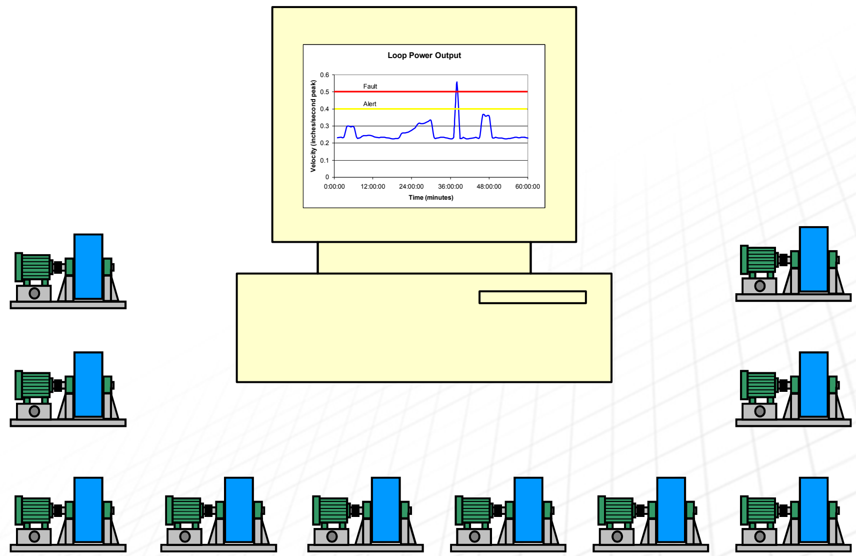
Data Collection

Data Collection



Portable

Route Based



Permanent, Continuous, On-line

Portable Data Collectors

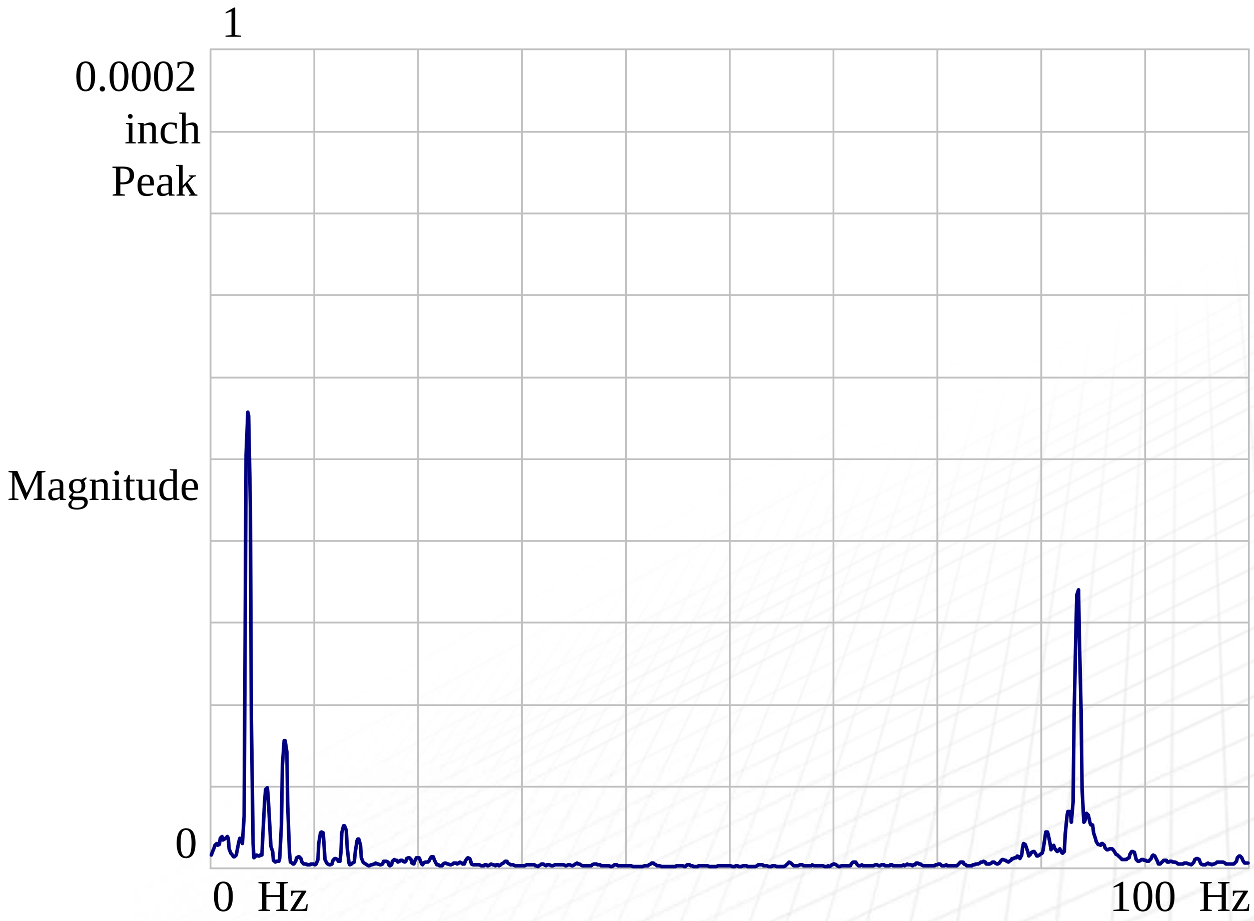
- ✓ Route Based
- ✓ Frequency Spectrum
- ✓ Time Waveform
- ✓ Orbits
- ✓ Balancing
- ✓ Alignment
- ✓ Data Analysis
- ✓ History
- ✓ Trending
- ✓ Download Data
- ✓ Upload Routes
- ✓ Alarms
- ✓ "Smart" algorithms

Permanent Monitoring

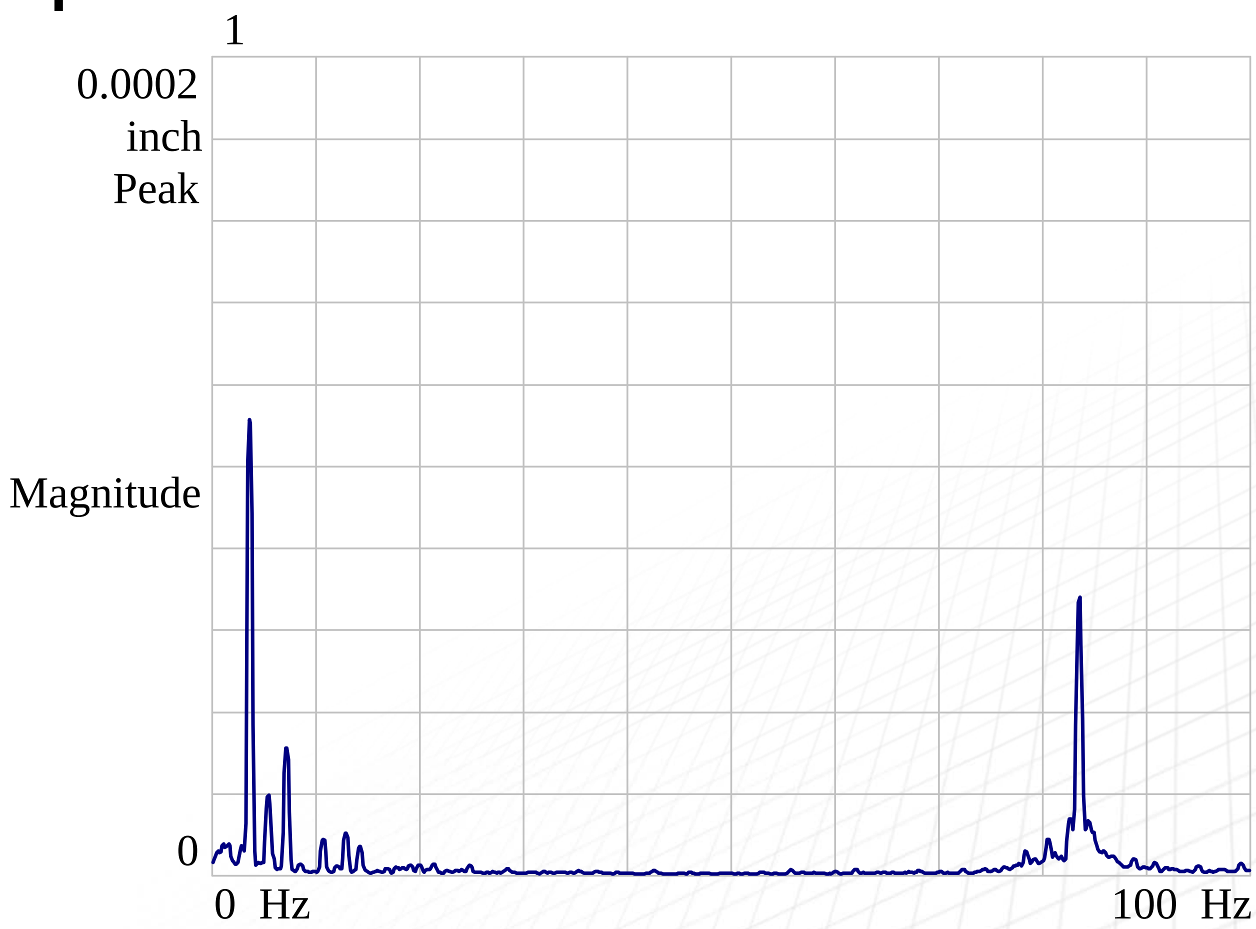
- ✓ **Continuous Measurement**
- ✓ **Permanent Sensors**
- ✓ **Frequency Spectrum**
- ✓ **Time Waveform**
- ✓ **Orbits**
- ✓ **Data Analysis**
- ✓ **History**
- ✓ **Trending**
- ✓ **Ethernet Connection**
- ✓ **Alarms**
- ✓ **"Smart" Algorithms**

FFT & Time Waveform

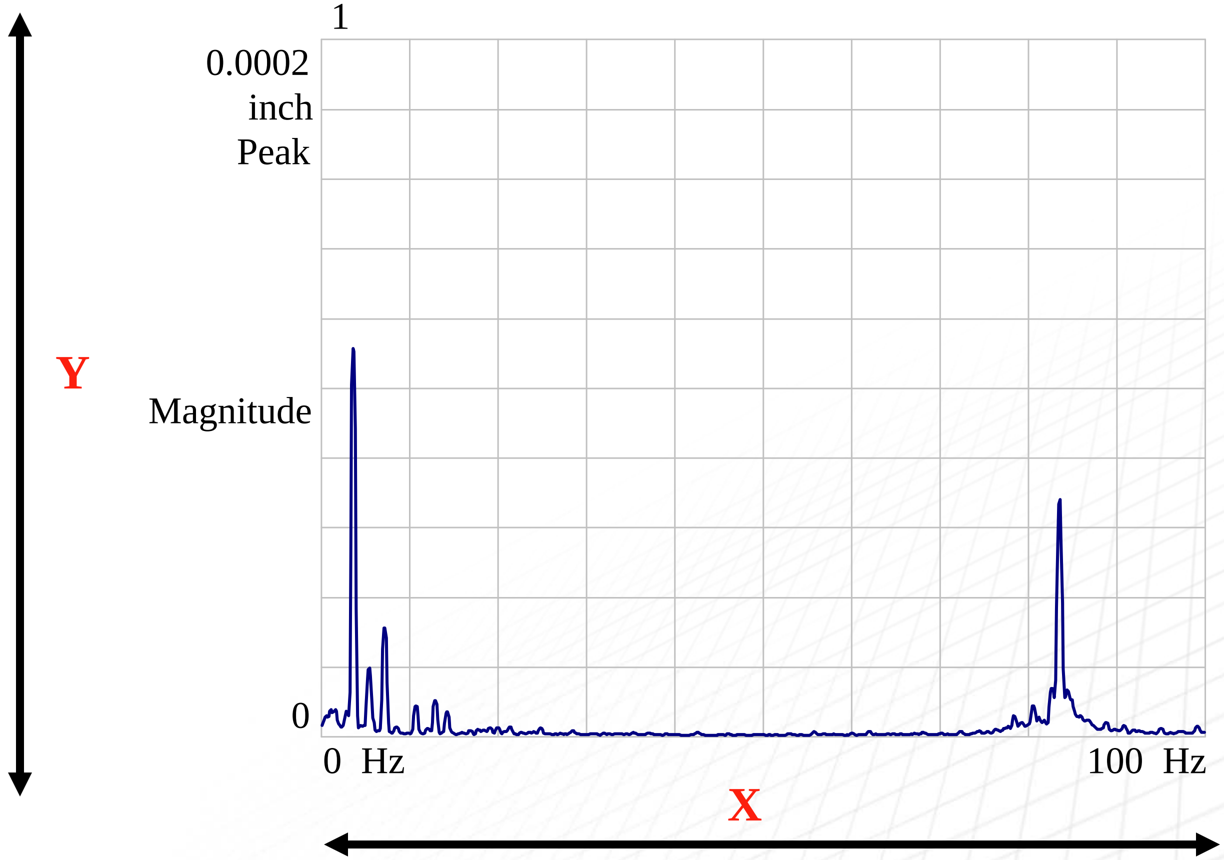
What's This ?



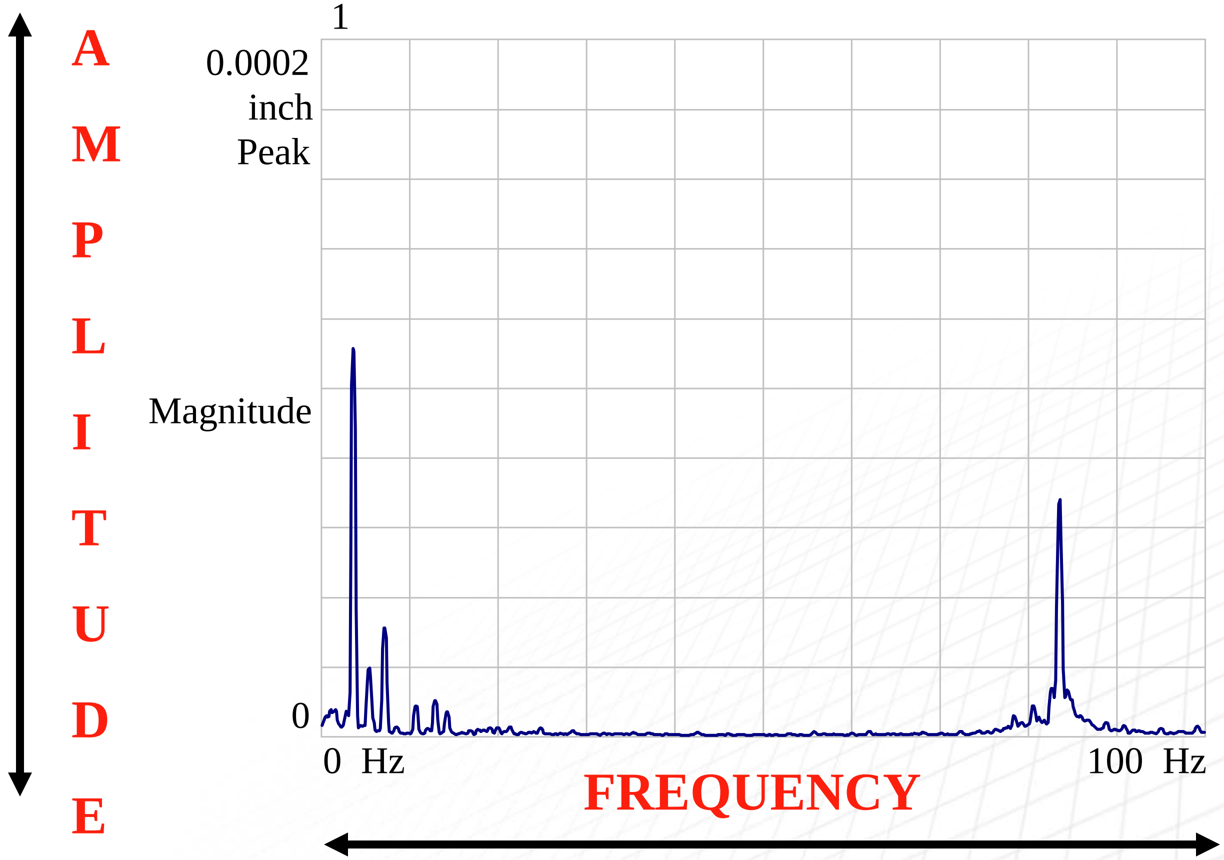
FFT, Frequency Spectrum, Power Spectrum



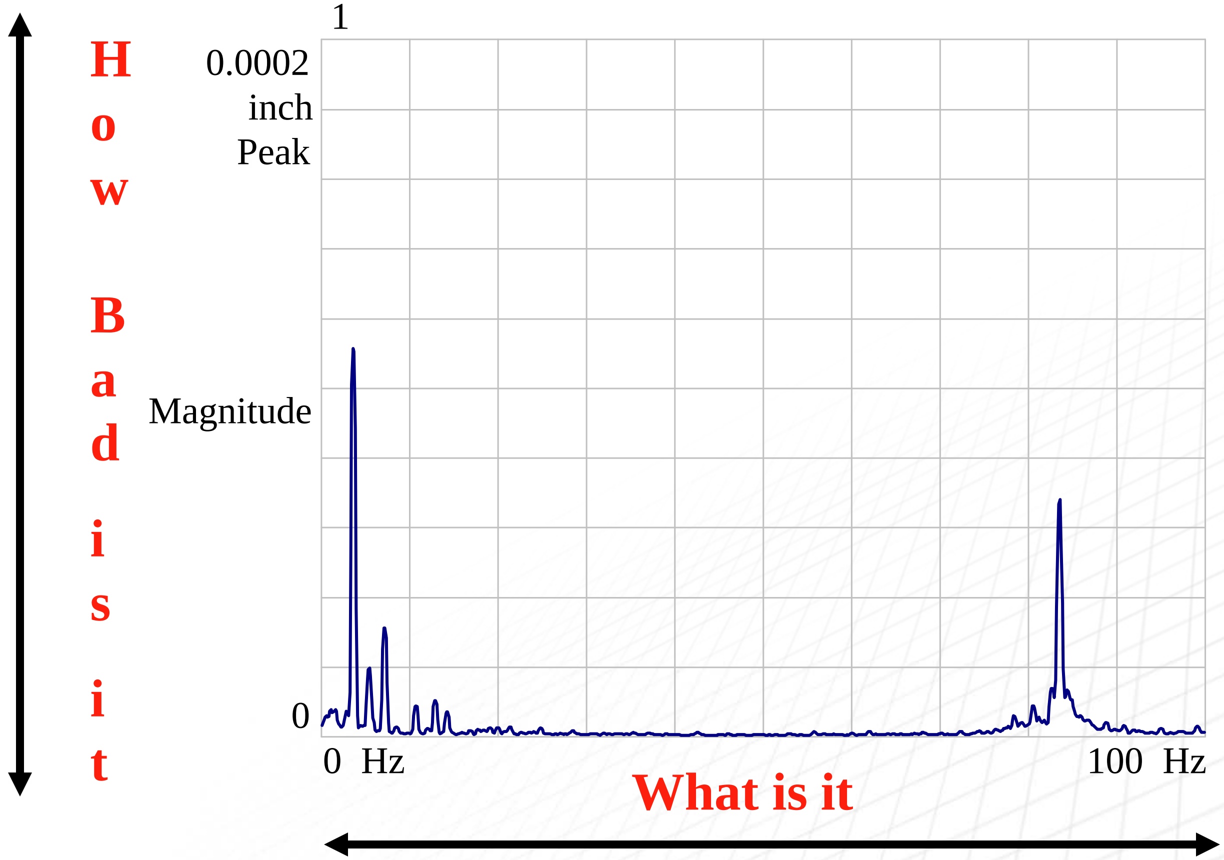
Scaling X & Y



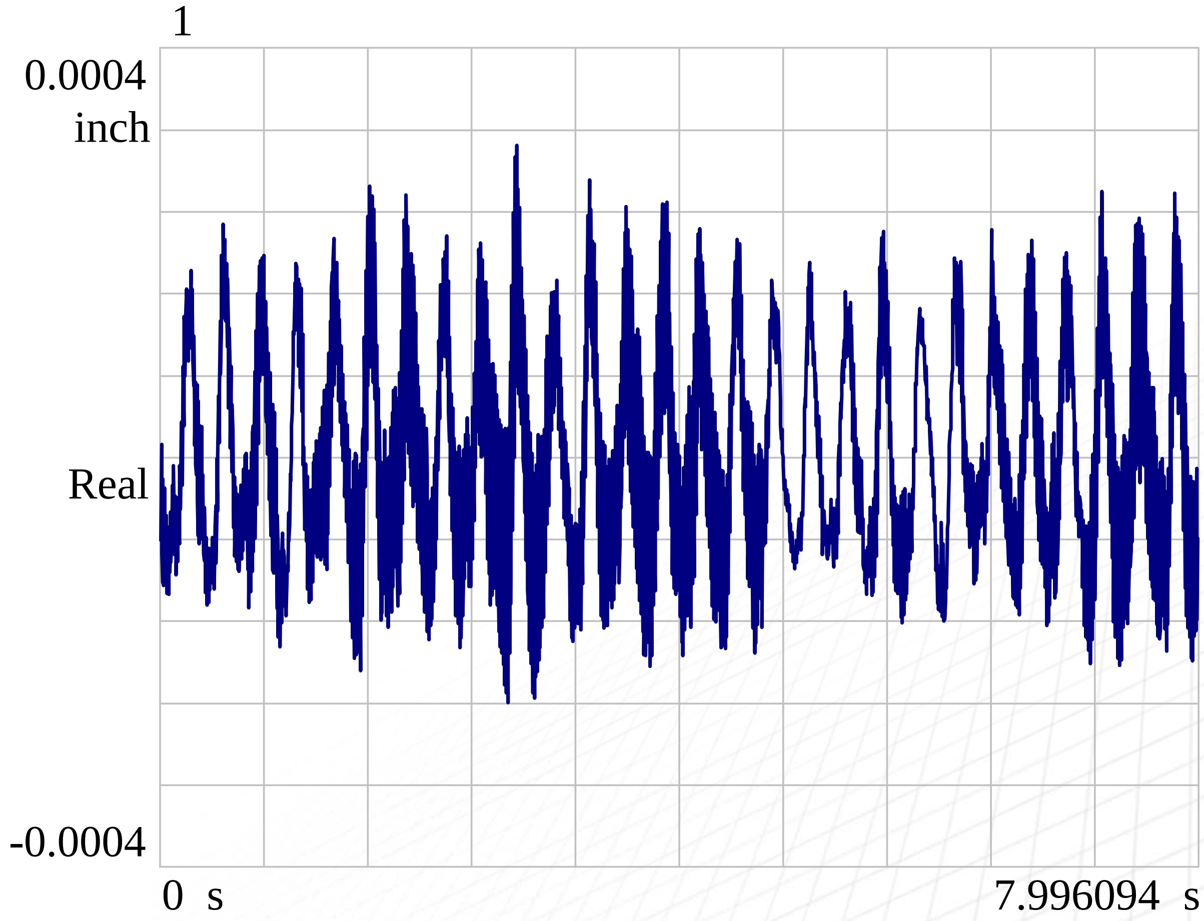
Scaling X & Y


AMPLITUDE
1
0.0002
inch
Peak
Magnitude
0
0 Hz
100 Hz
FREQUENCY

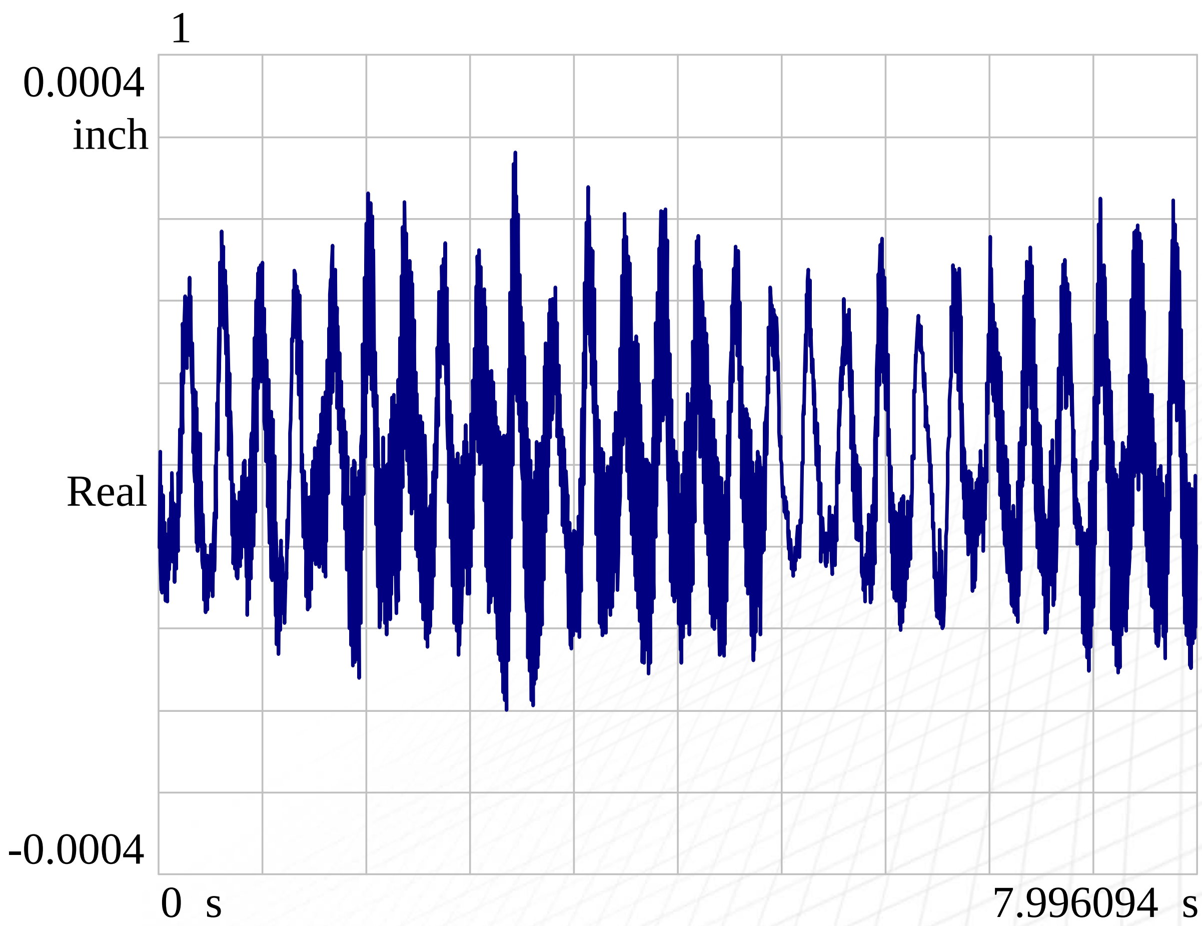
Scaling X & Y


How Bad is it
1
0.0002
inch
Peak
Magnitude
0
0 Hz
100 Hz
What is it

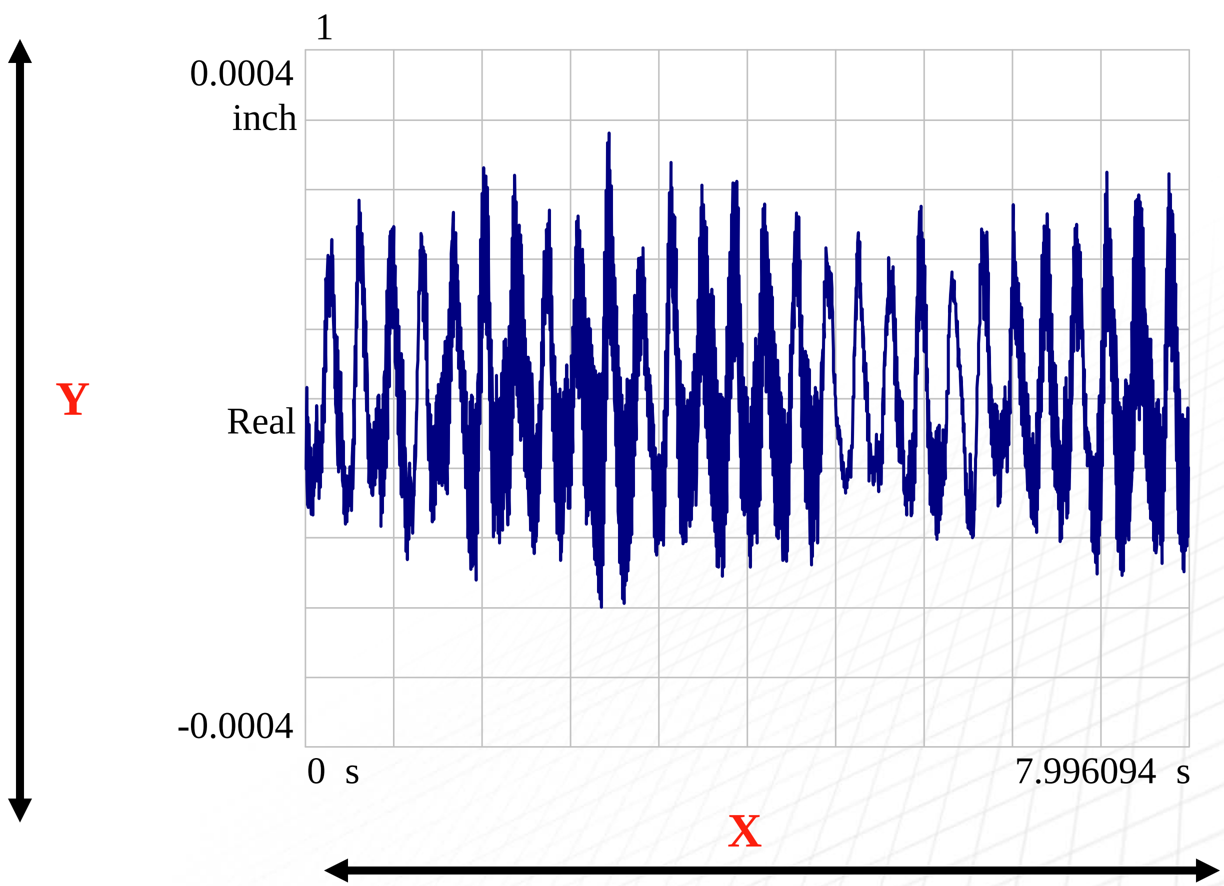
What's That ?



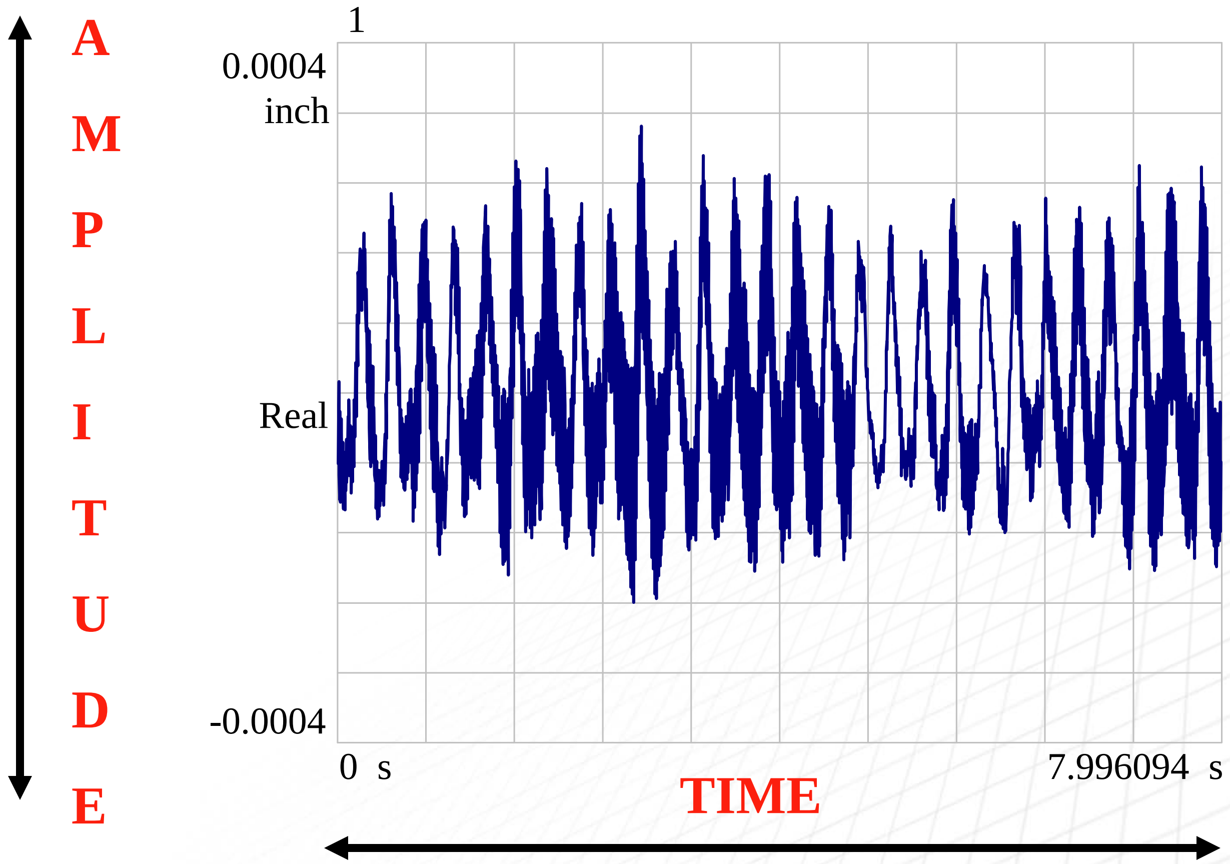
Time Waveform



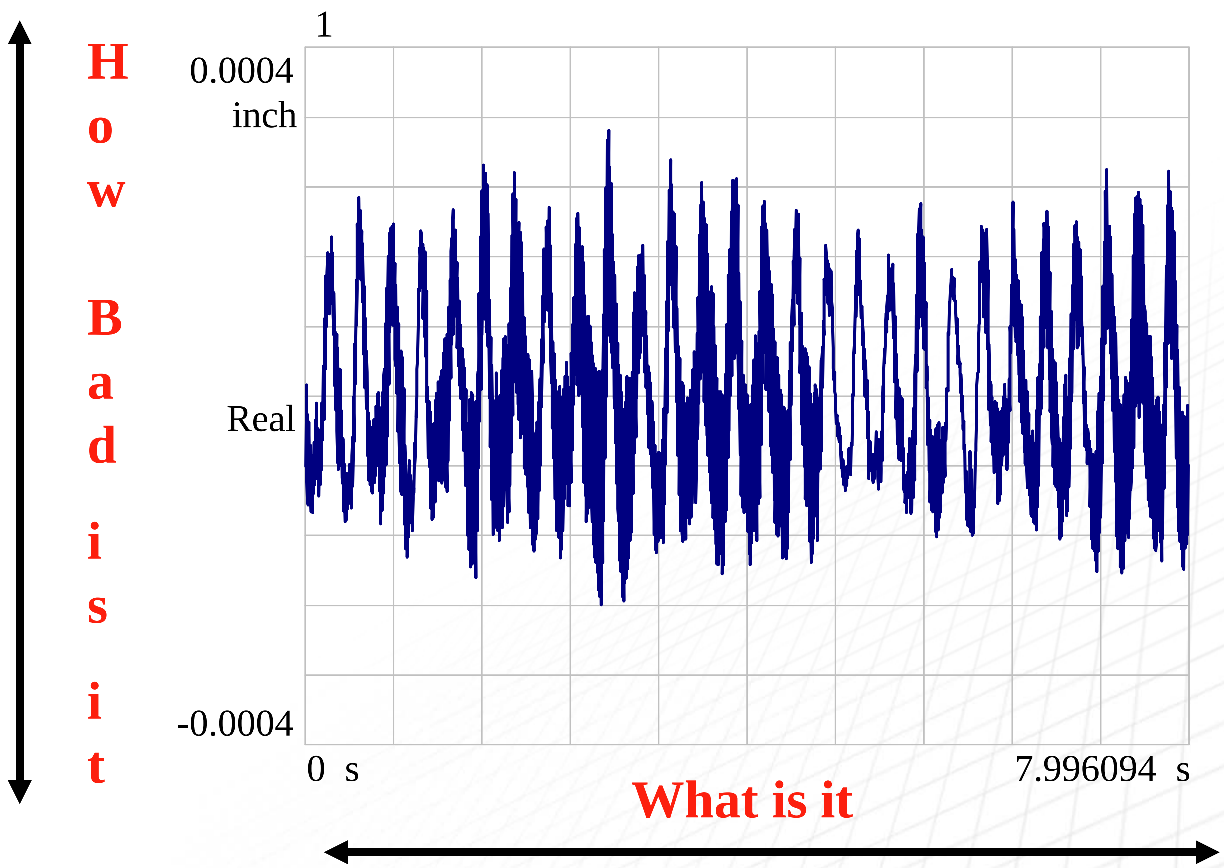
Scaling X & Y



Scaling X & Y



Scaling X & Y

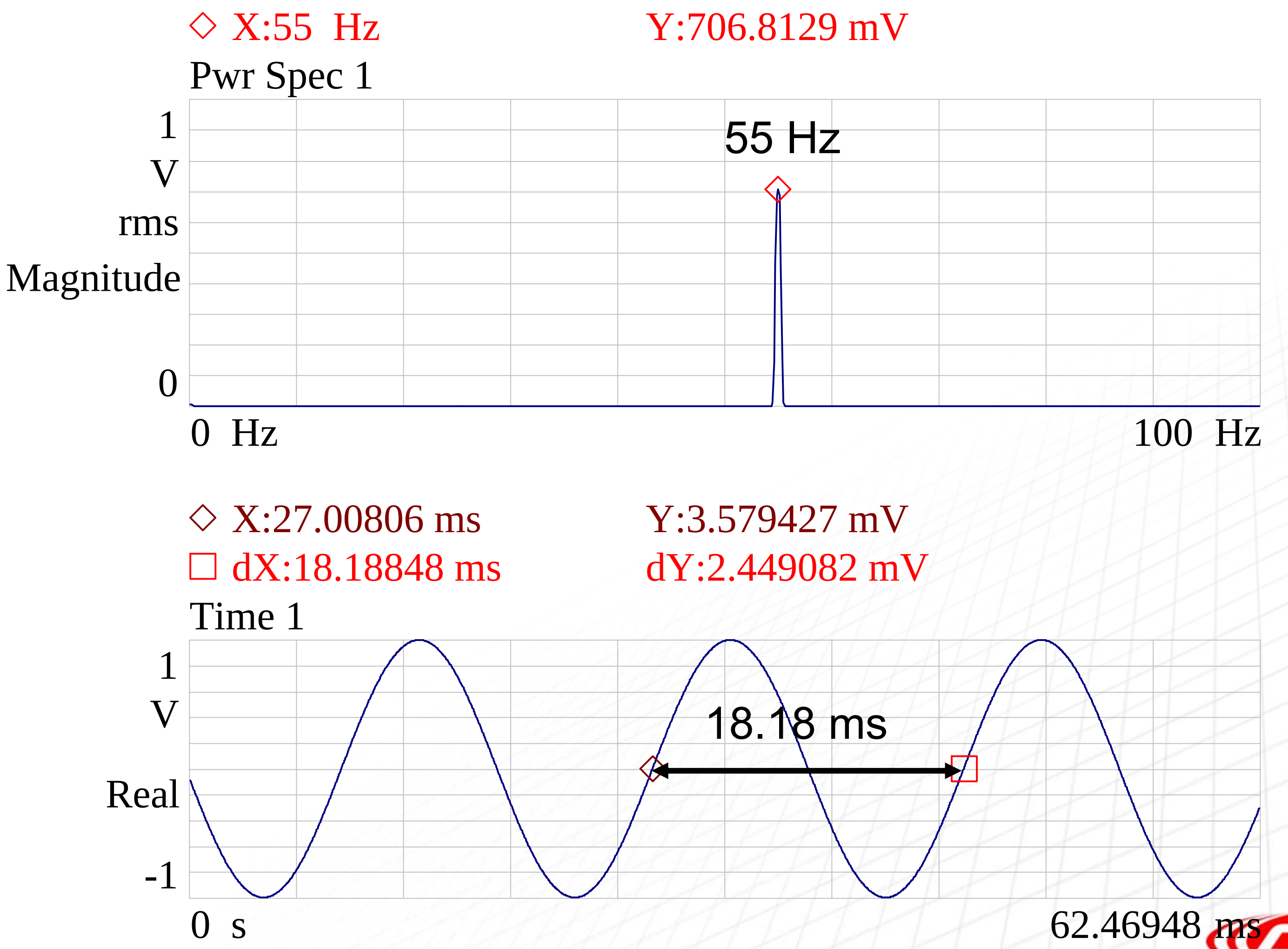


The X Scale

What is it ?

X

Single Frequency



Frequency & Time

$$f_{Hz} = 1/t_{Sec}$$

$$t_{Sec} = 1/f_{Hz}$$

Frequency & Time

FT = 1

If: F = 1/T and T = 1/F

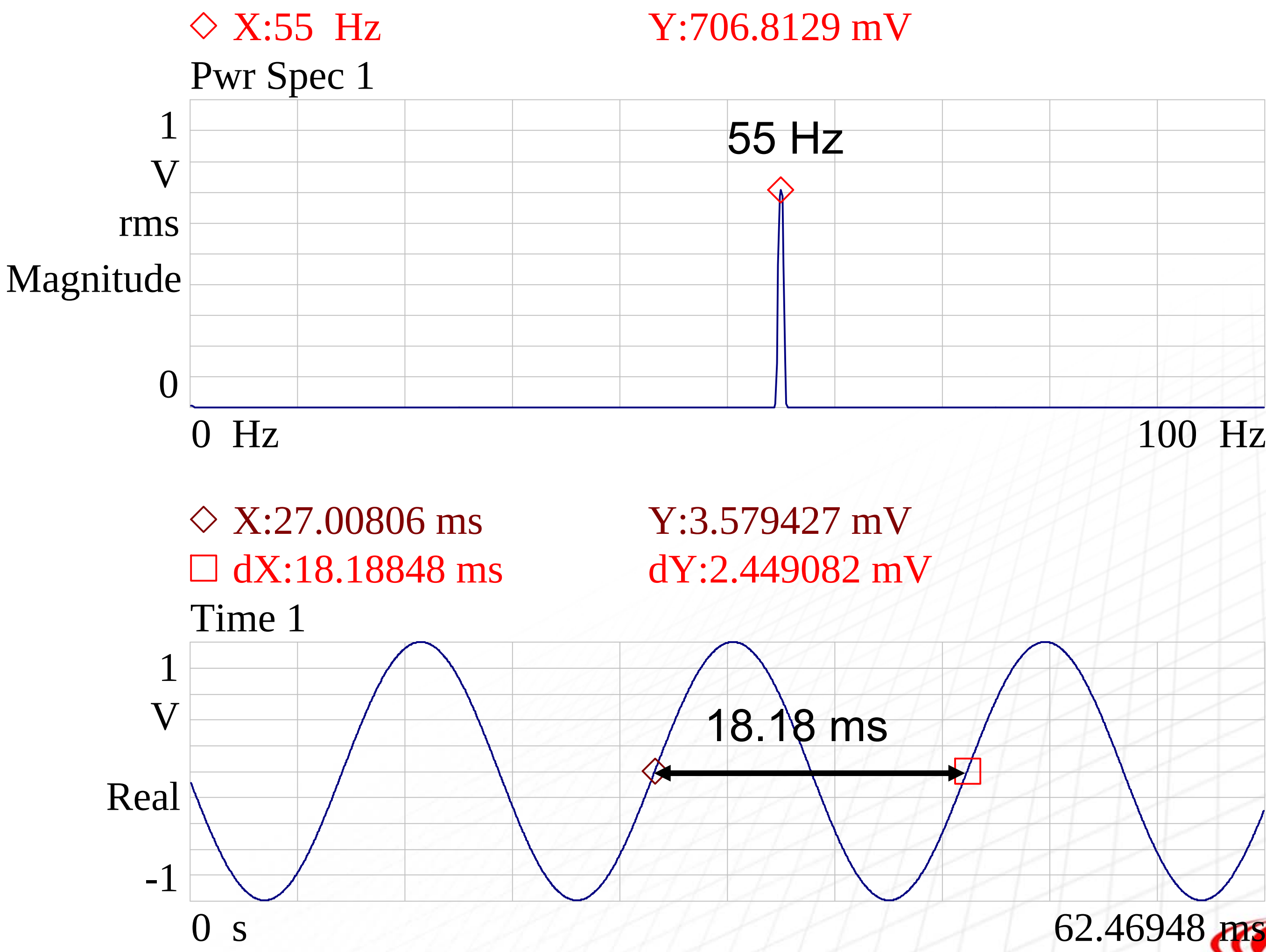
Then: FT = 1

Concept !

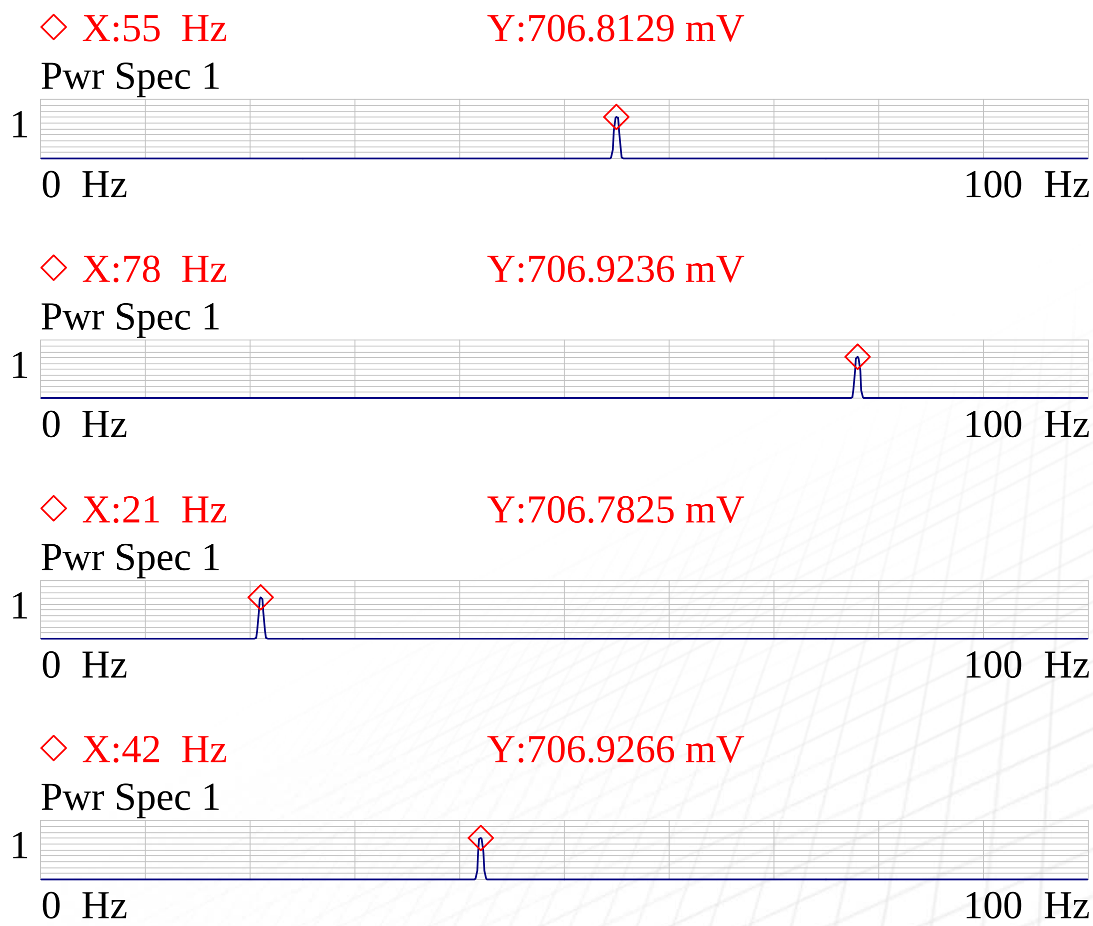
FT = 1

If:	**F increases**
Then:	**t decreases**
If:	**T increases**
Then:	**f decreases**

Single Frequency

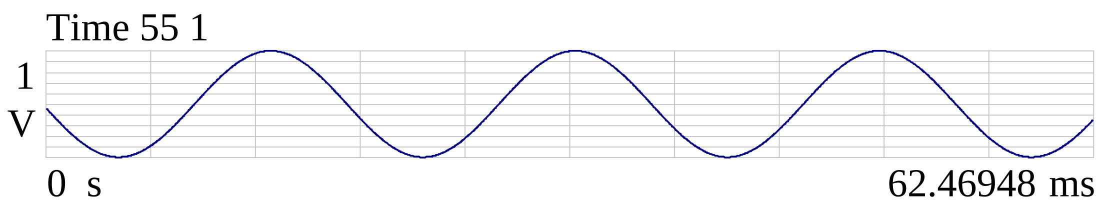


Multiple Frequencies

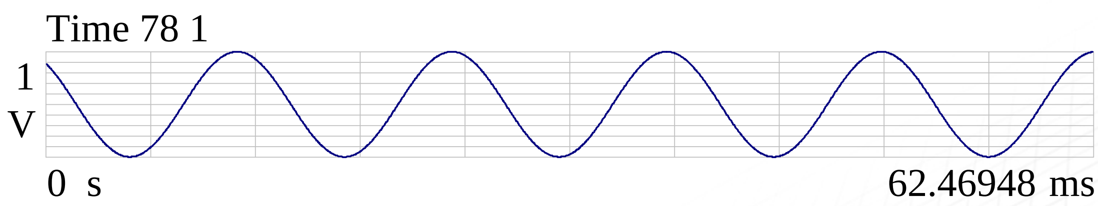


Multiple Waveforms

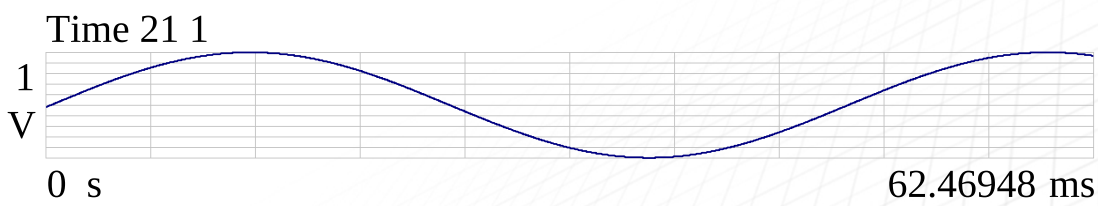
55 Hz



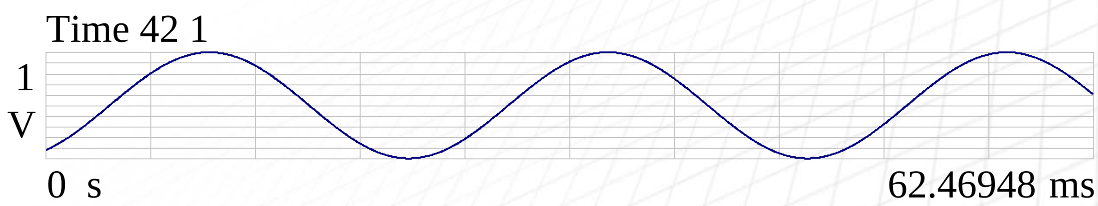
78 Hz



21 Hz

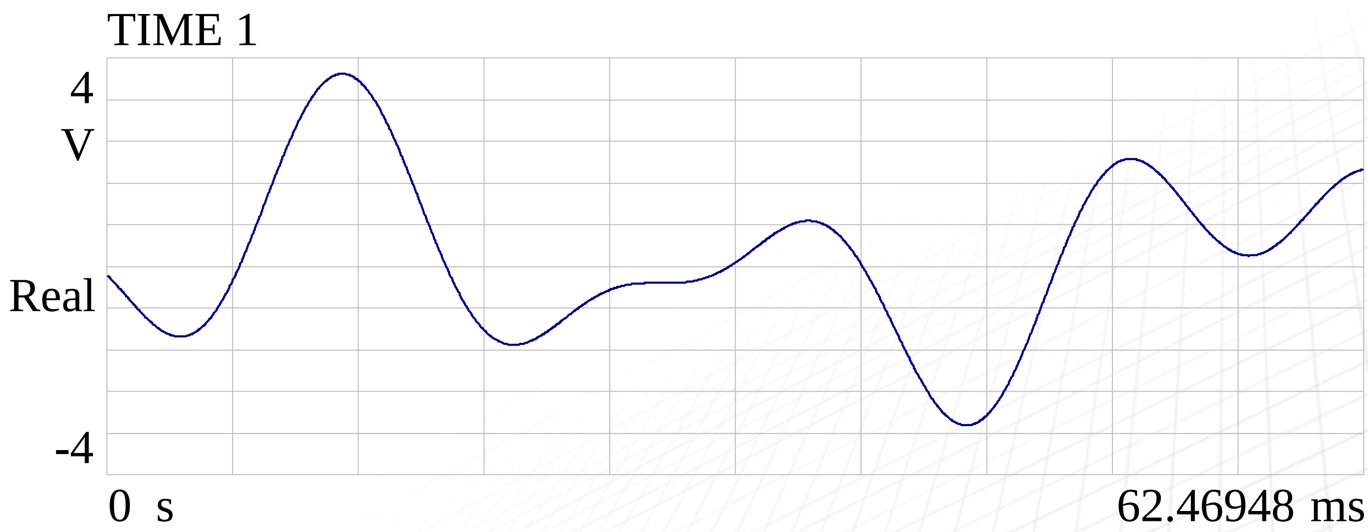


42 Hz

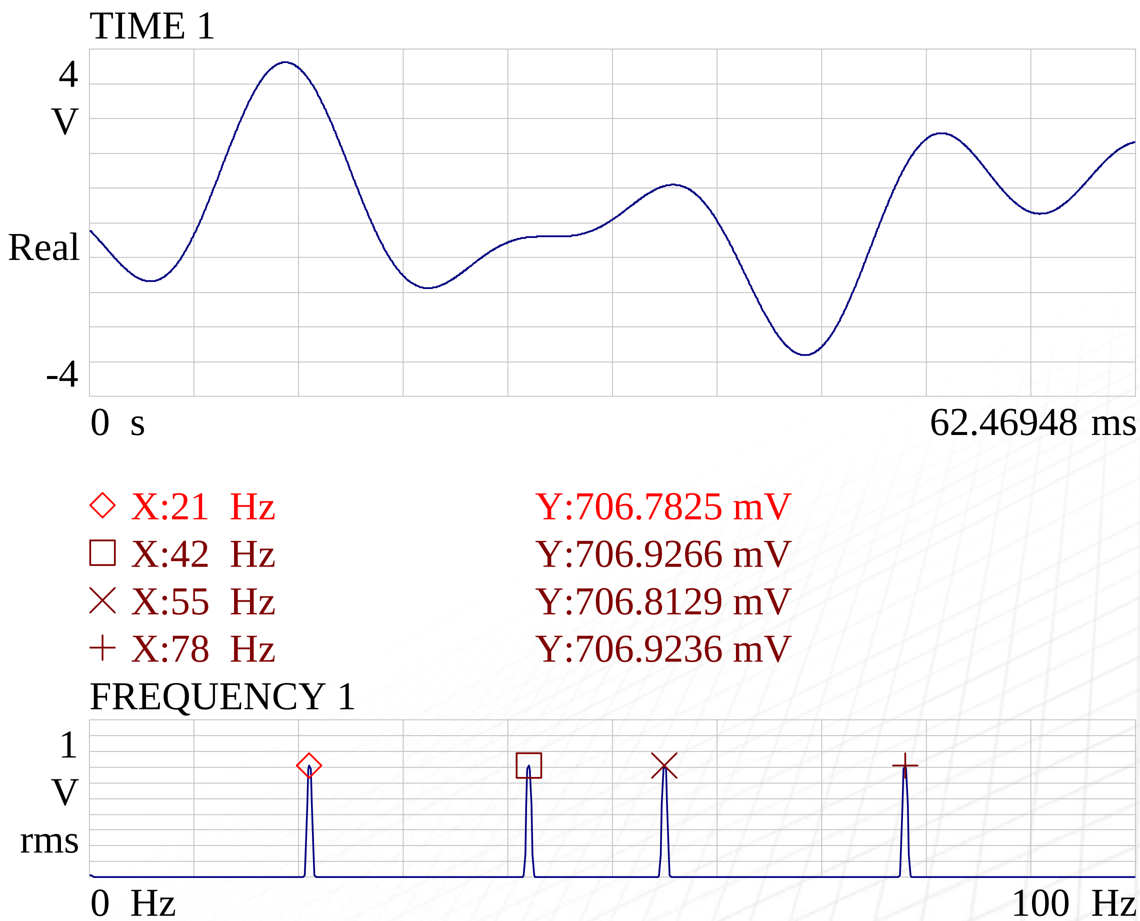


Real Life Waveform

55 Hz + 78 Hz + 21 Hz + 42 Hz = Trouble !



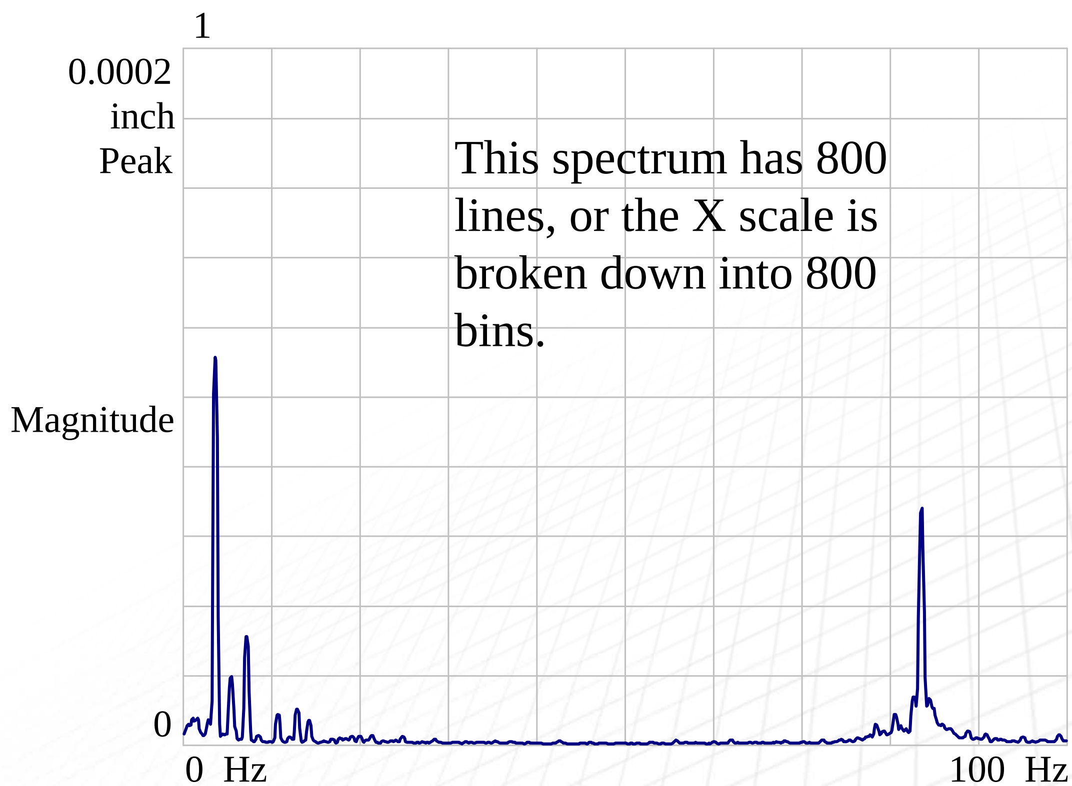
FFT Capabilities



Lines or Bins

The FFT always has a defined number of lines or Bins.

100, 200, 400, 800, 1600, and 3200 lines are common choices.



LRF

The **L**owest **R**esolvable **F**requency is determined by:

Frequency Span / Number of Analyzer Lines

The frequency span is calculated as the ending frequency minus the starting frequency.

The number of analyzer lines depends on the analyzer and how the operator has set it up.

Typically, this is the value that can be measured by the cursor

Example: 0 to 400 Hz using 800 lines

Answer = (400 - 0) / 800 = 0.5 Hz / Line

Bandwidth

The Bandwidth can be defined by:

(Frequency Span / Analyzer Lines) Window Function

Uniform Window Function = 1.0

Hanning Window Function = 1.5

Flat Top Window Function = 3.8

Example: 0 to 400 Hz using 800 Lines & Hanning Window

Answer = (400 / 800) 1.5 = 0.75 Hz / Line

Resolution

The frequency resolution is defined in the following manner:

2 (Frequency Span / Analyzer Lines) Window Function

or

Resolution = 2 (Bandwidth)

Example: 0 to 400 Hz using 800 Lines & Hanning Window

Answer = 2 (400 / 800) 1.5 = 1.5 Hz / Line

Using Resolution

The analyst wishes to measure two frequency disturbances that are very close together.

Frequency #1 = 29.5 Hz.

Frequency #2 = 30 Hz.

A hanning window and 800 lines will be used.

What frequency span is required to accurately measure these two frequency disturbances ?

Using Resolution

Resolution Required = 30 - 29.5 = 0.5 Hz

Resolution = 2 (Frequency Span / 800) 1.5

0.5 = 2 (Frequency Span / 800) 1.5

0.5 = 3 (Frequency Span) / 800

400 = 3 (Frequency Span)

133 Hz = Frequency Span

Therefore, the frequency span must be 133 Hz or less to measure the desired resolution of 0.5 Hz.

Data Sampling Time

Data sampling time is the amount of time required to take one record or sample of data. It is dependent on the frequency span and the number of analyzer lines being used.

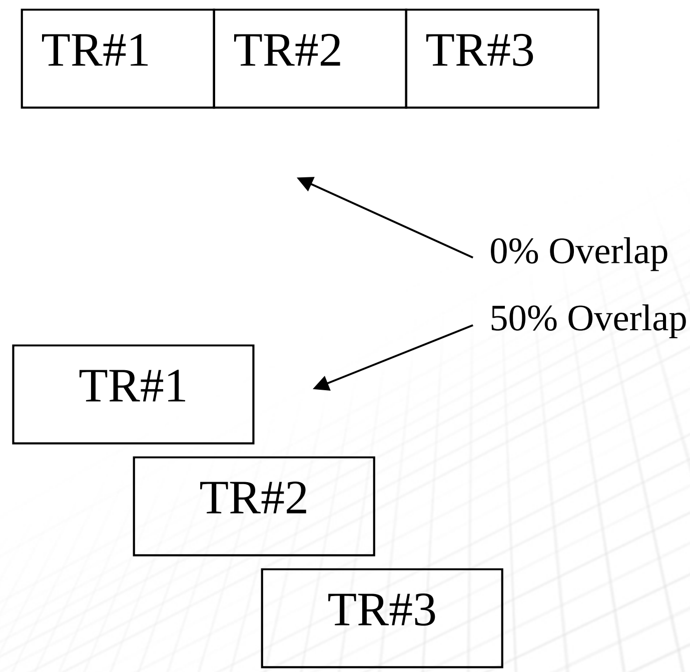
$$T_{Sample} = N_{lines} / F_{span}$$

Using 400 lines with a 800 Hz frequency span will require:

400 / 800 = 0.5 seconds

Average & Overlap

- ✓ **Average - On**
- ✓ **Overlap Percent - 50%**
- ✓ **Overlap is the amount of old data that is used**



How long will it take for 10 averages at 75% overlap using a 800 line analyzer and a 200 Hz frequency span?

75% Overlap ?

- ✓ 10 Averages
- ✓ 75% Overlap
- ✓ 800 Lines
- ✓ 200 Hz

Average #1 = 800 / 200

Average #1 = 4 seconds

Average #2 - #10 = (4 x 0.25)

Average #2 - #10 = 1 second each

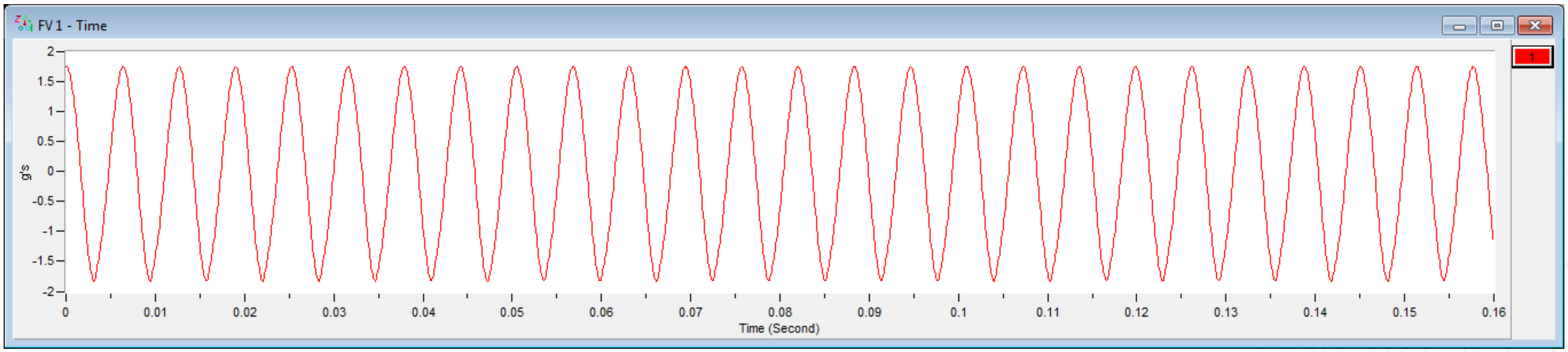
Total time = 4 + (1 x 9)

Total time = 13 seconds

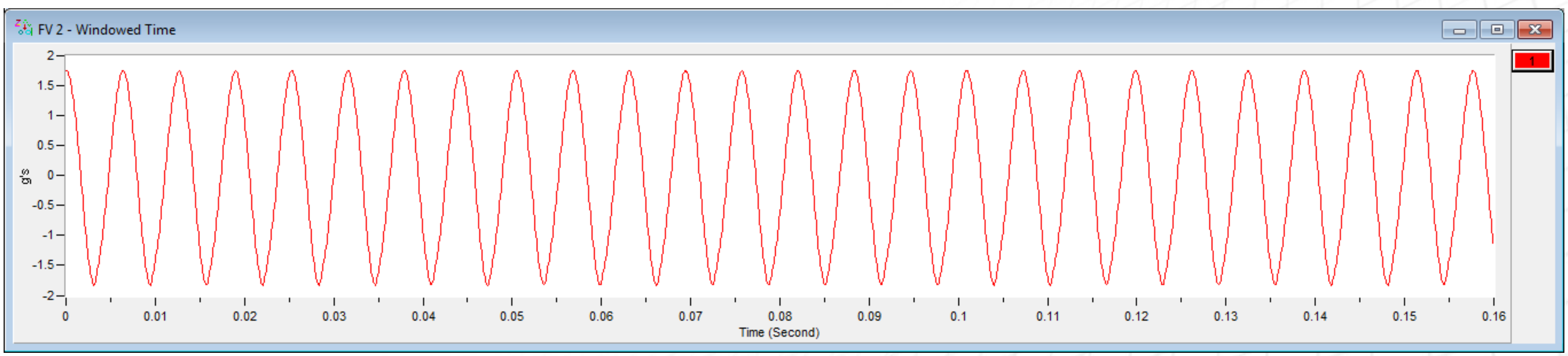
Filter Windows

- ✓ Window filters are applied to the time waveform data to simulate data that starts and stops at zero.
- ✓ They will cause errors in the time waveform and frequency spectrum.
- ✓ We still like window filters !

Window Comparisons

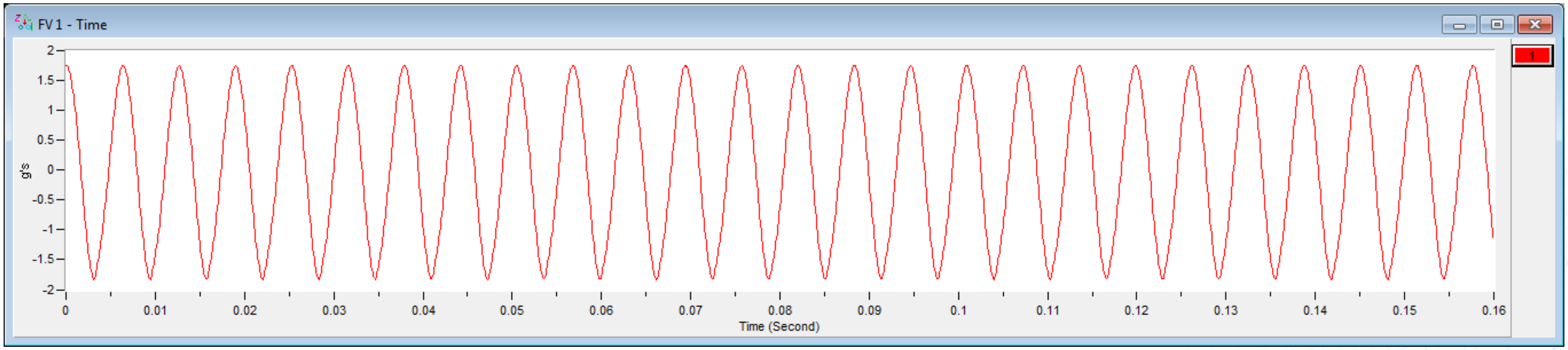


Real Time

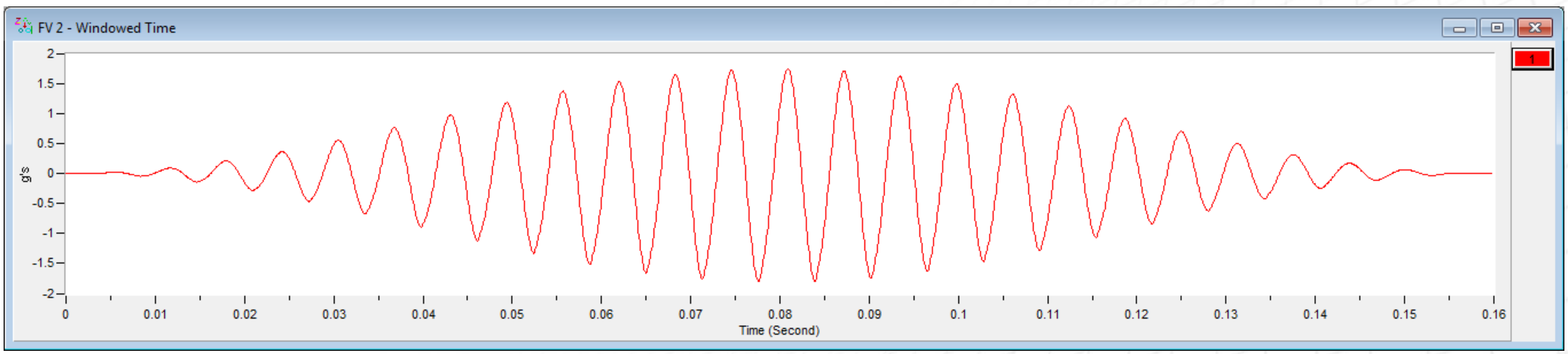


No Window

Window Comparisons

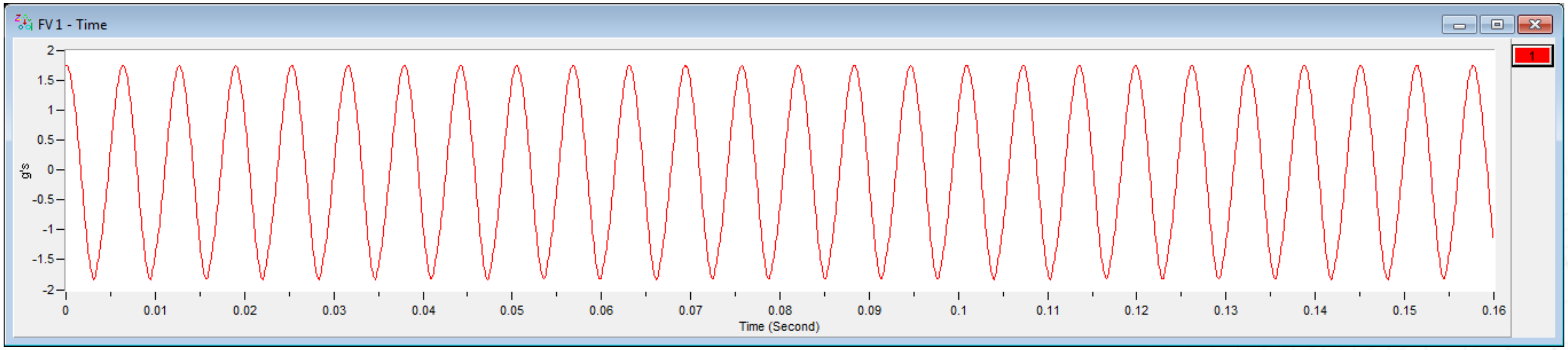


Real Time

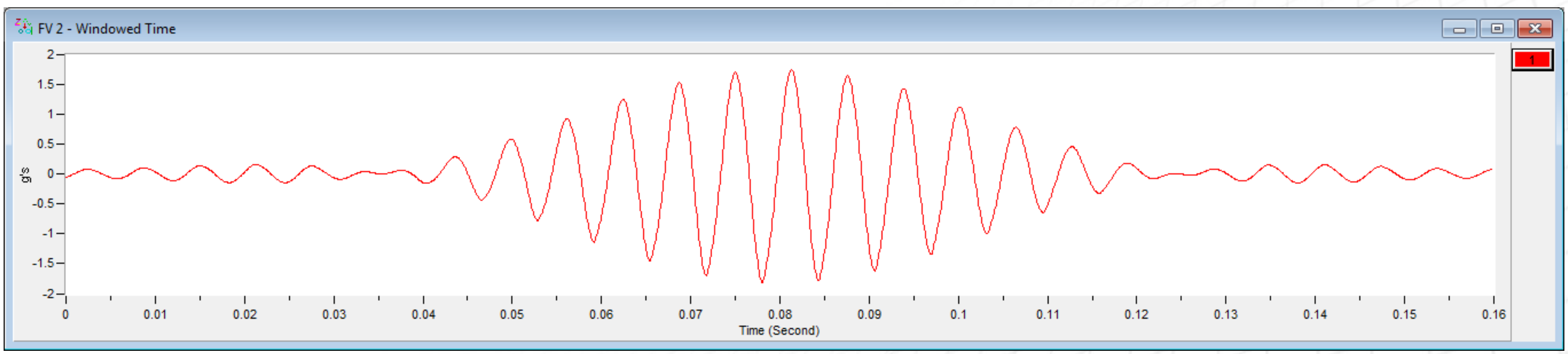


Hanning Window

Window Comparisons



Real Time



Flat Top Window

Window Filters

- ✓ **Hanning (Frequency)**
  - **Window Factor 1.5**
  - **Amplitude Accuracy ≈ 18%**
- ✓ **Flat Top (Amplitude)**
  - **Window Factor 3.8**
  - **Amplitude Accuracy ≈ 1%**
- ✓ **Uniform (Impacts)**
  - **Window Factor 1.0**
  - **Amplitude Accuracy ≈ 56%**
- ✓ **Force Exponential**
  - **Force/Expo Set-up**
  - **Requires Channel 1 Input Force (Hammer)**
  - **Requires Channel 2 Response (Sensor)**
  - **Response/Force (Channel 2/Channel 1)**
  - **Normalizes data based on response to force**

Filter Windows

- ✓ Use the Hanning Window for normal vibration monitoring (Frequency)
- ✓ Use the Flat Top Window for calibration and accuracy (Amplitude)
- ✓ Use the Uniform Window for bump testing and resonance checks (No Window)

The Y Scale

Y

How bad is it ?

Amplitude

Acceleration = g's rms. or peak

Velocity = inch/s rms. or peak

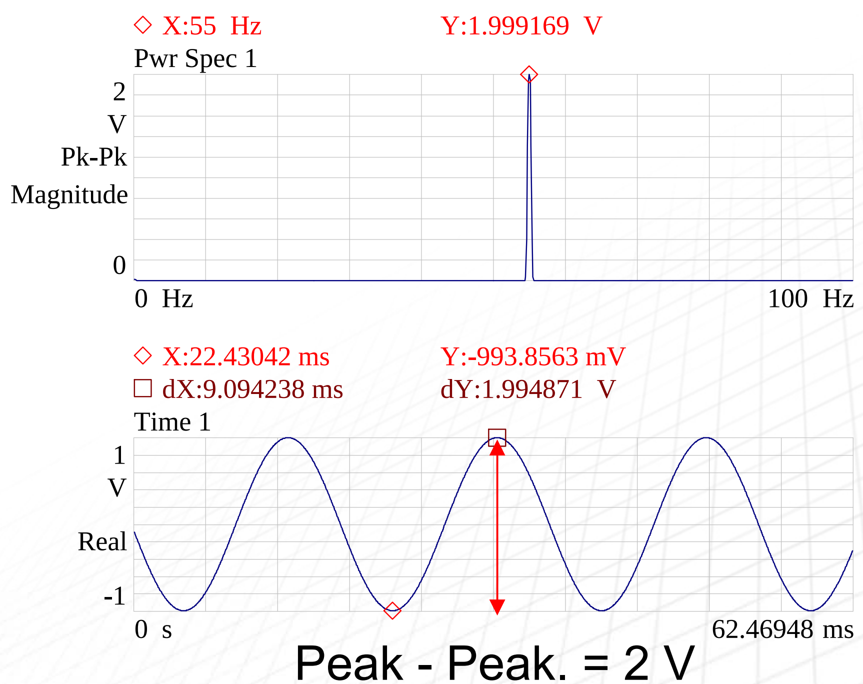
Displacement = mils peak to peak

Note: 1 mil = 0.001 inches

Pk-Pk (Peak - Peak)

The Peak - Peak value is expressed from the peak to peak amplitude.

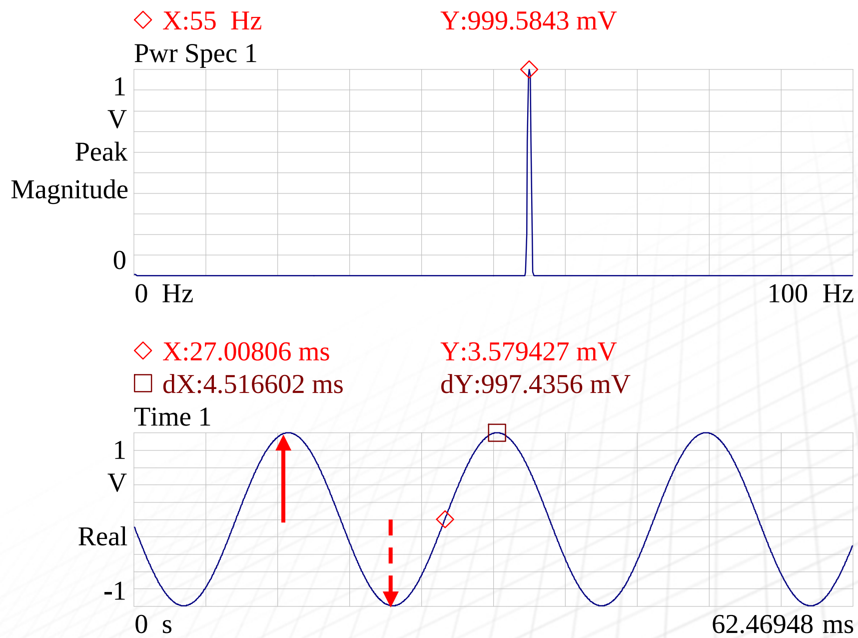
The peak to peak value is measured in the time waveform.



Pk (Peak)

The time wave has not changed. The Peak value is expressed from zero to the largest positive or negative peak amplitude.

The peak value is measured in the time waveform.



Peak. = 1 V

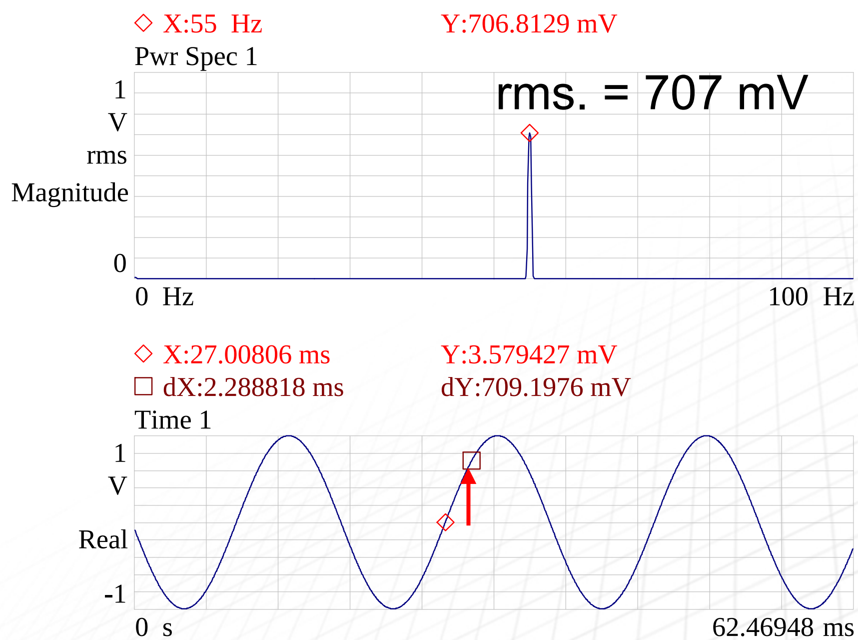
RMS (Root Mean Square)

The time wave has not changed.

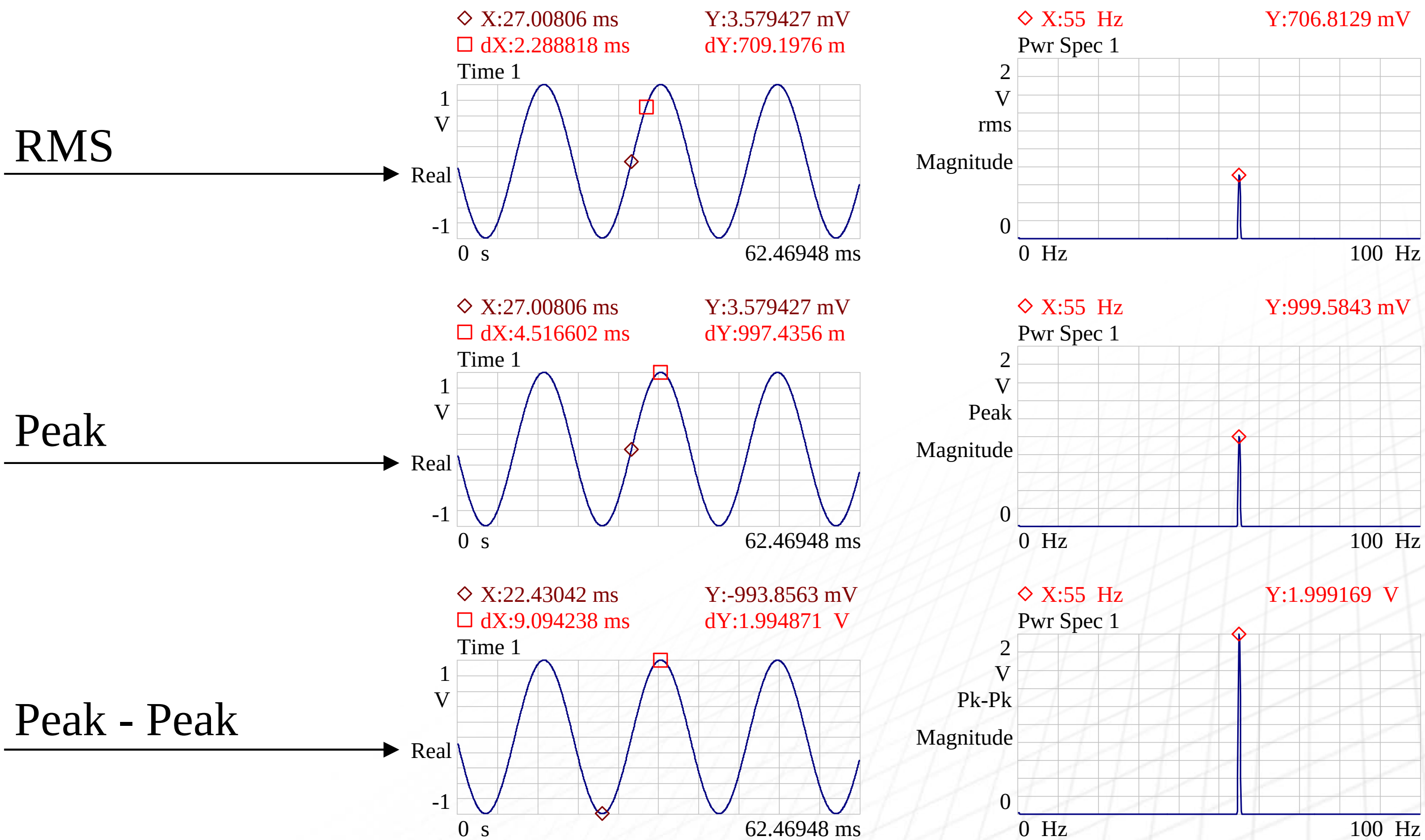
The rms. value is expressed from zero to 70.7% of the peak amplitude for a single frequency.

The rms. value is calculated for the spectrum.

In a periodic time wave, the rms. value must be calculated in the FFT. It will represent the overall energy of the FFT.



Unit Comparison



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Changing Units

Many times it is necessary to change between units.

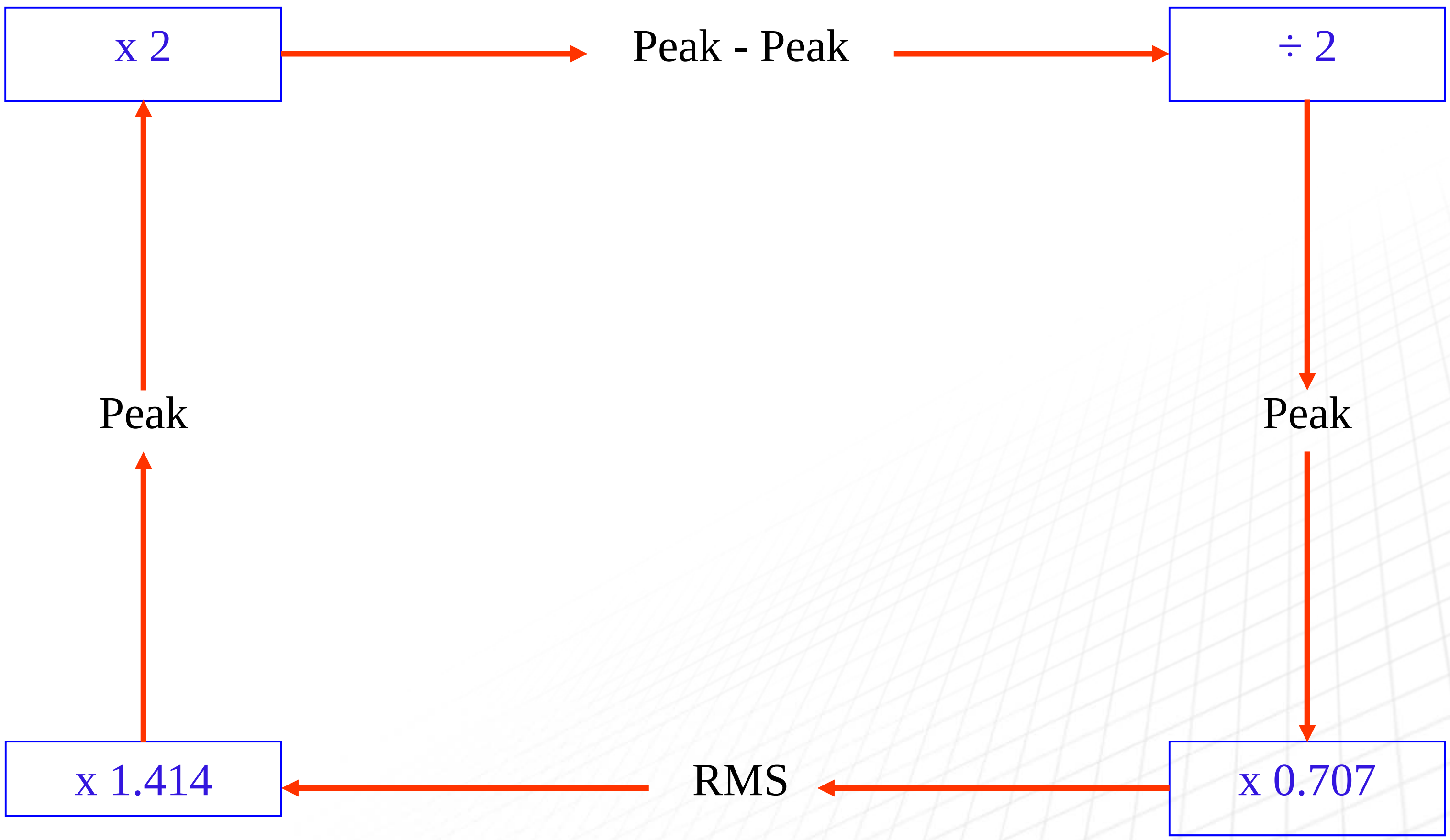
Pk-Pk / 2 = Peak

Peak x 0.707 = RMS **(Peak / 1.414 = RMS)**

RMS x 1.414 = Peak **(RMS / 0.707 = Peak)**

Peak x 2 = Pk-Pk

Convert the Unit



Engineering Units (EU)

Engineering units are used to give meaning to the amplitude of the measurement.

Instead of the default "volts", it is possible to incorporate a unit proportional to volts that will have greater meaning to the user.

Examples:	**100 mV / g**	**20 mV / Pa**
	1 V / in/s	**200 mV / mil**
	50 mV / psi	**10 mV / fpm**
	33 mV / %	**10 mV / V**

EU's the Hard Way

Sometimes we forget to use EU's, or just don't understand how to set up the analyzer. The measurement is in volts!

There is no immediate need to panic if ????

You know what the EU is for the sensor you are using.

Example: An accelerometer outputs 100 mV / g and there is a 10 mV peak in the frequency spectrum.

What is the amplitude in g's ?

Answer = 10 mV / 100 mV = 0.1 g

Three Measures

- ✓ **Acceleration**
- ✓ **Velocity**
- ✓ **Displacement**

Converting Measures

In many cases we are confronted with Acceleration, Velocity, or Displacement, but are not happy with it.

Maybe we have taken the measurement in acceleration, but the model calls for displacement.

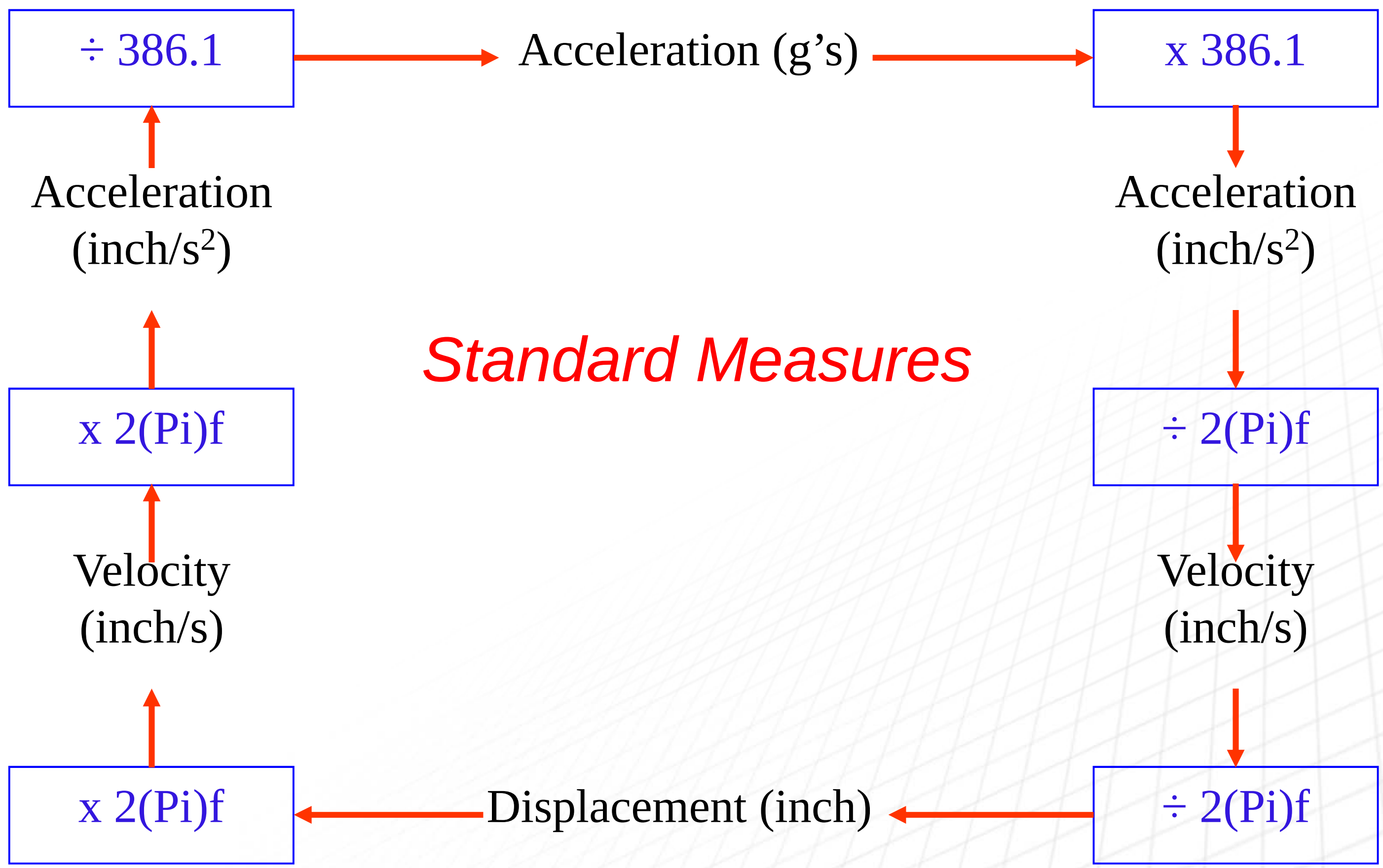
Maybe we have taken the data in displacement, but the manufacturer quoted the equipment specifications in velocity.

How do we change between these measures ?

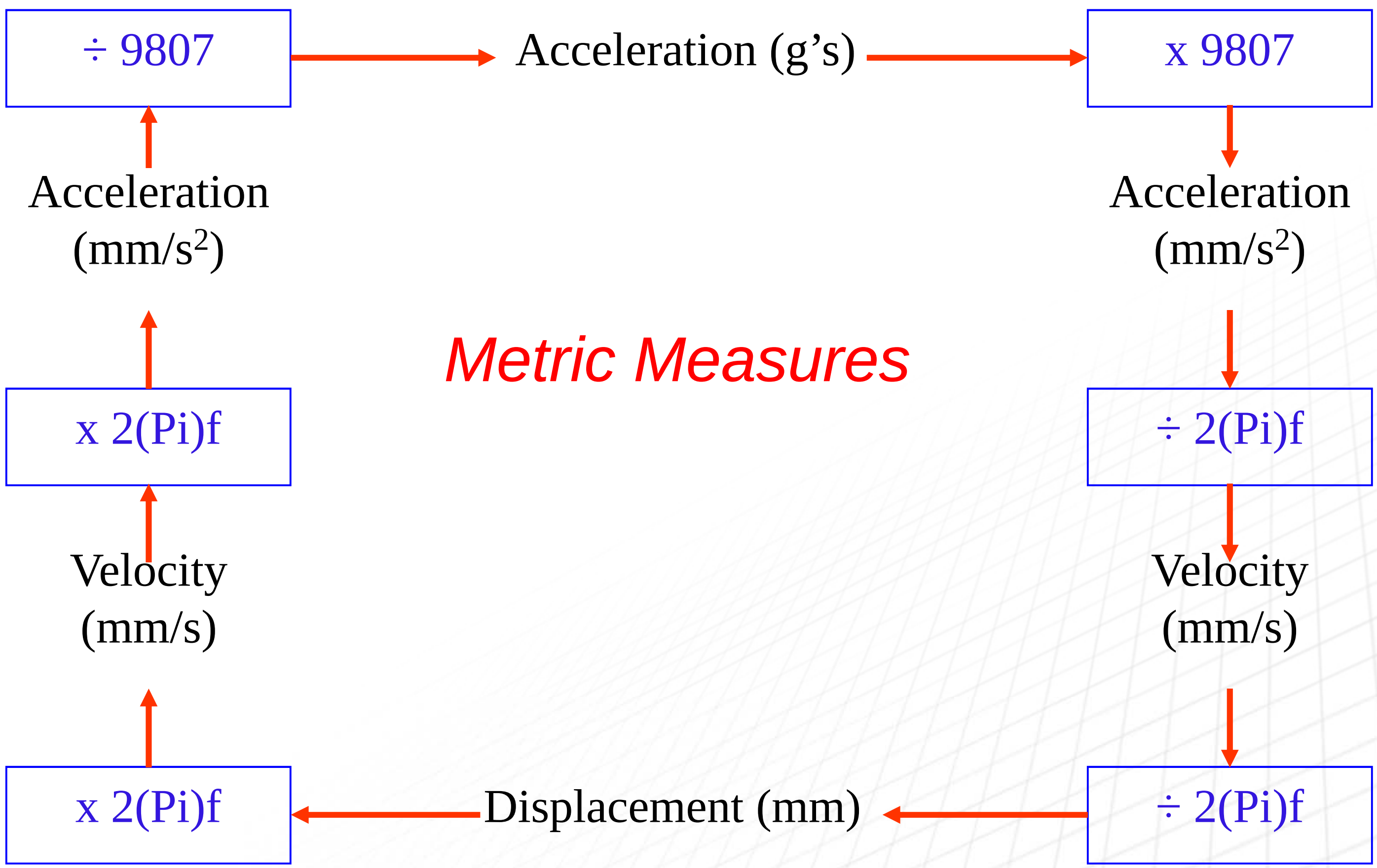
Converting Measures

- ✓ *Velocity = Acceleration / 2πf*
- ✓ *Displacement = Velocity / 2πf*
- ✓ *Displacement = Acceleration / $(2\pi f)^2$*
  - *Where:*
    - *Acceleration = g's*
      - *Multiply acceleration in g's by (386.1 inches/second ^{2})/g*
      - *Multiply acceleration in g's by (9807 mm/second ^{2})/g*
    - *Velocity = inches/second or mm/second*
    - *Displacement = inches or mm*
    - *f = frequency in Hz. (cycles/second)*

Converting Measures



Converting Measures



Acceleration - Velocity

Example: Find the equivalent Peak velocity for a 25 Hz vibration at 7 mg rms.

Velocity = (g x 386.1) / (2 π f)

Velocity = (0.007 x 386.1) / (6.28 x 25)

Velocity = 0.017 inches / second RMS

Answer = 0.017 x 1.414 = 0.024 inches / second Peak

Velocity - Displacement

Example: Find the equivalent peak-peak displacement for a 25 Hz vibration at 0.024 in/s Peak ?

Displacement = Velocity / (2 π x f)

Displacement = 0.024 / (6.28 x 25)

Displacement = 0.000153 inches Peak

Answer = 0.000153 x 2 = 0.000306 inches Peak – Peak

or 0.3 mils Peak - Peak

Acceleration - Displacement

Example: Find the equivalent Peak-Peak displacement for a 52 Hz vibration at 15 mg rms.

Displacement = (g x 386.1) / $(2\pi \text{ x f })^2$

Displacement = (0.015 x 386.1) / $(6.28 \text{ x } 52)^2$

Displacement = 0.000054 inches rms.

Answer = (0.000054 x 1.414) 2 = 0.000154 inches Peak-Peak

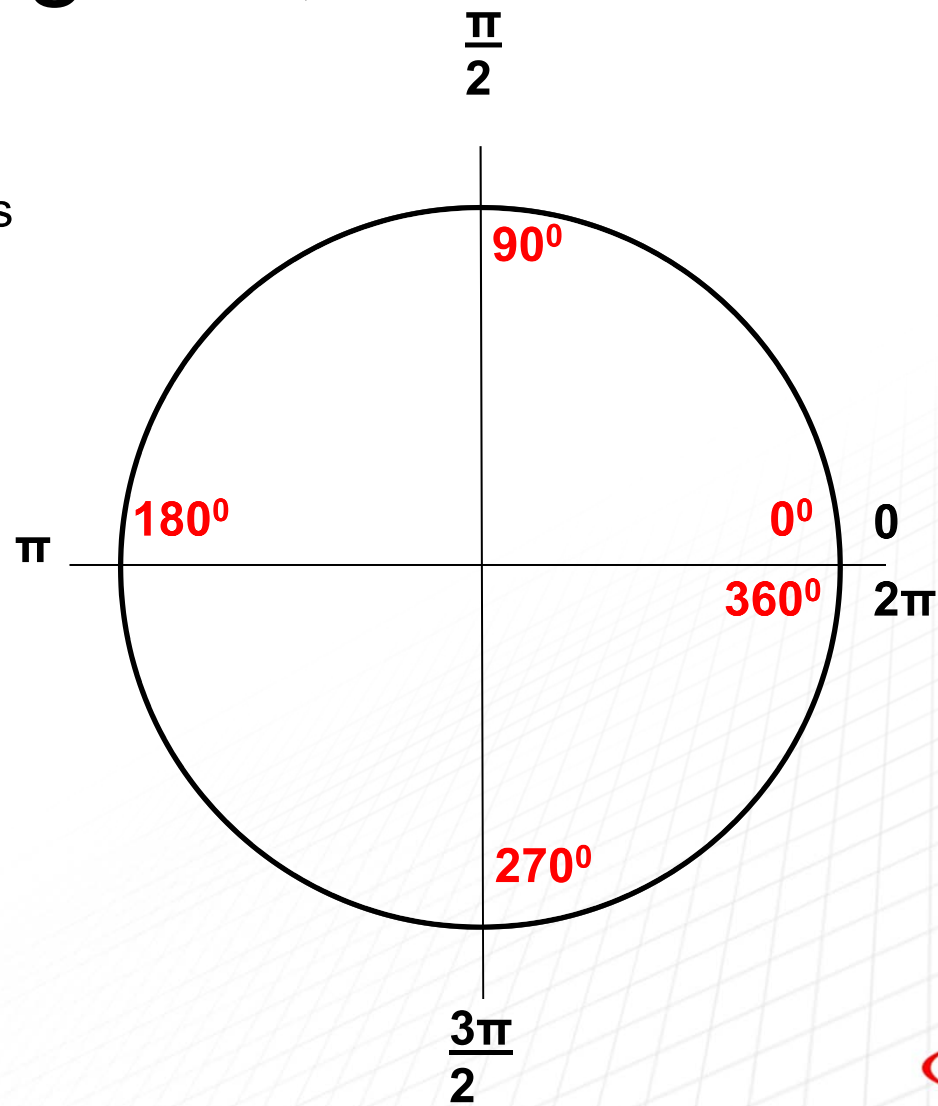
or 0.154 mils Peak - Peak

Radians, Degrees, or Time

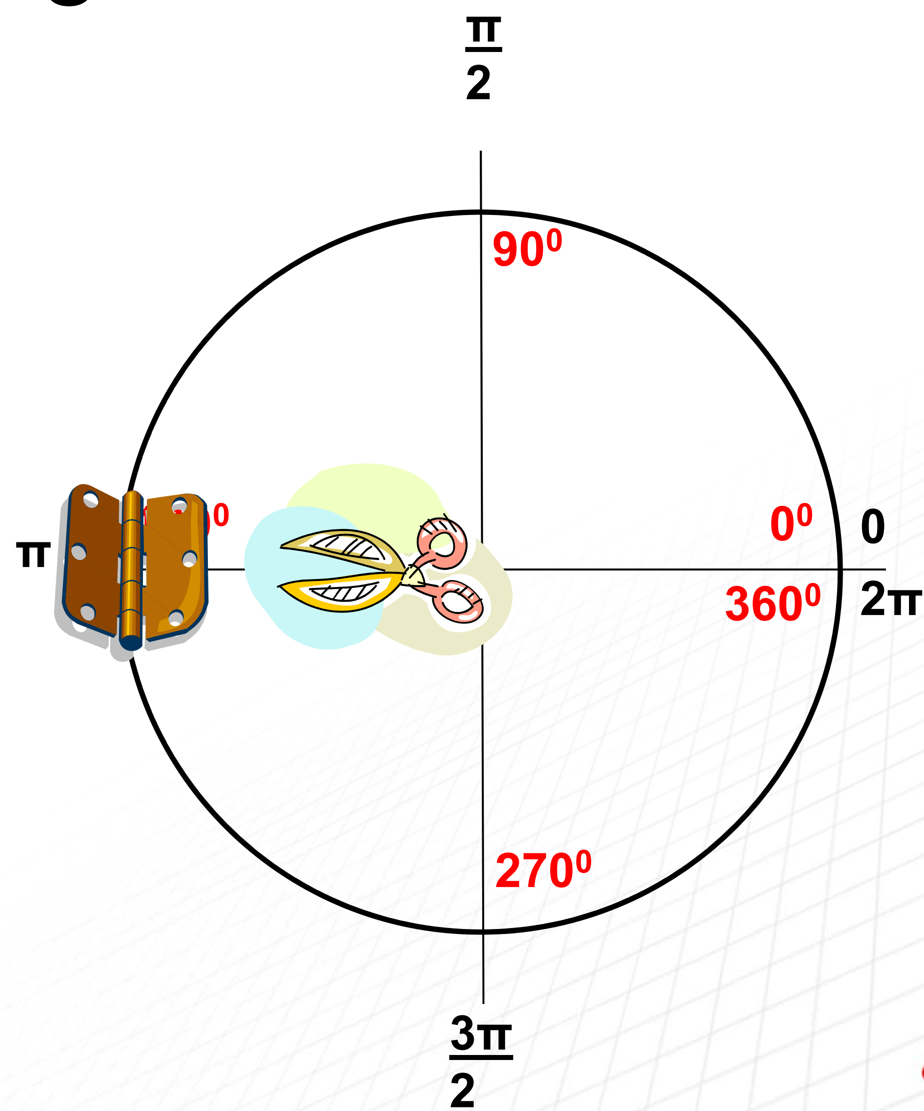
$360^0 = 2\pi$ Radians

$360^0 / 2\pi$ Radians

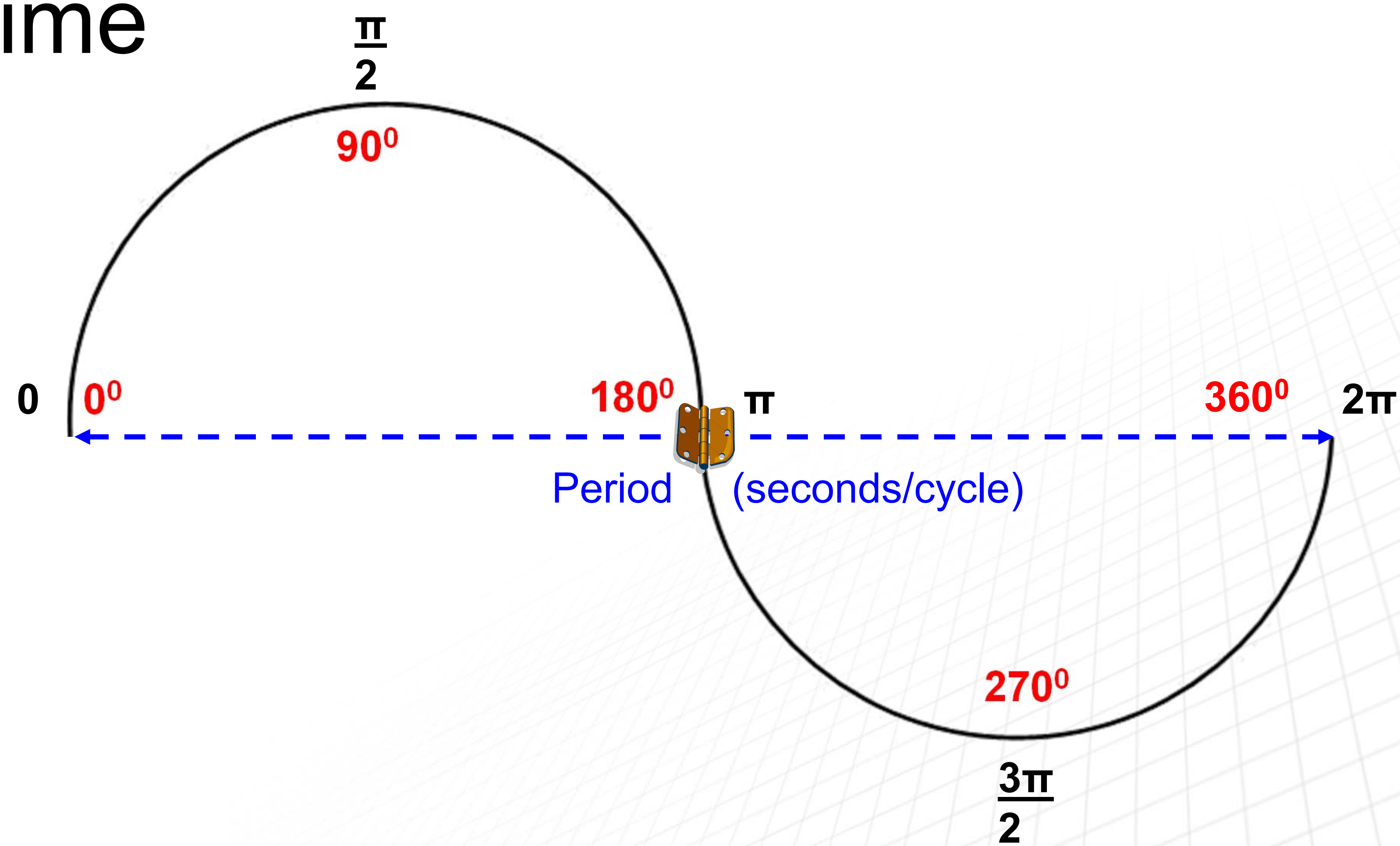
57.325^0 / Radian



Radians, Degrees, or Time

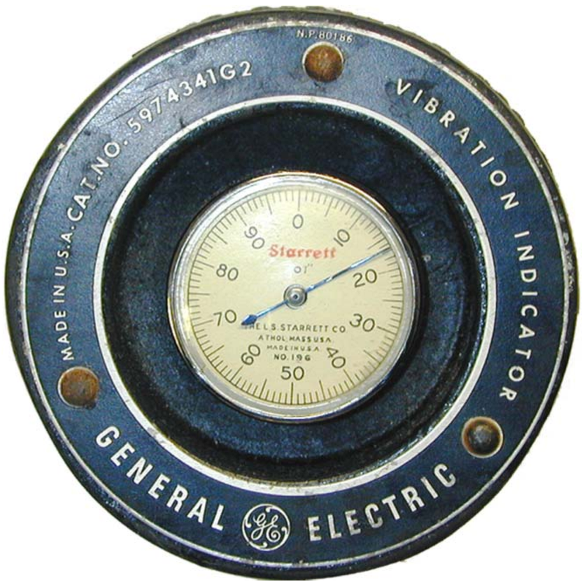


Radians, Degrees, or Time



Vibration Sensors

Sensors



Displacement

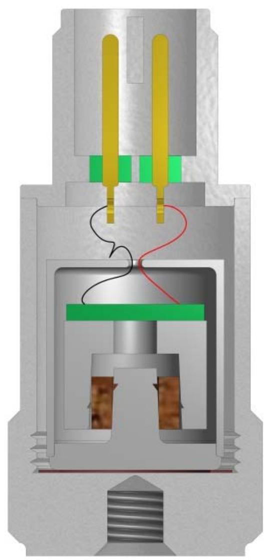
Frequency

Accelerometers

Accelerometers

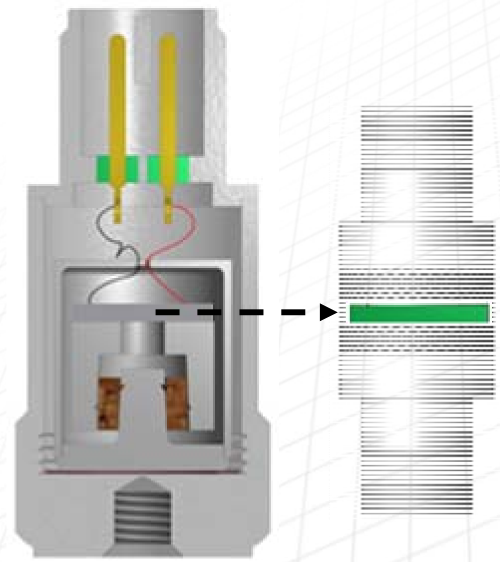
✓IEPE

- Internal Amplifier
- Industrial



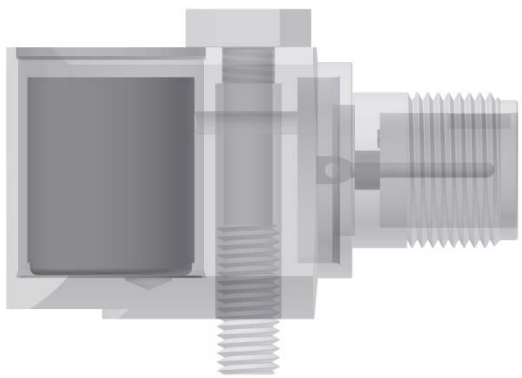
✓Charge Mode

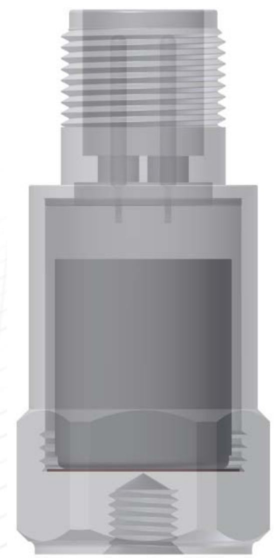
- External Amplifier
- High Temperature



Accelerometer Requirements and Applications

- ✓ Requirements
  - Functionality
  - Durability
  - Affordability
- ✓ Applications
  - Trending
  - Alarming
  - Diagnostics
- ✓ Remember
  - One sensor does not fit all applications
  - Fit, Form & Function





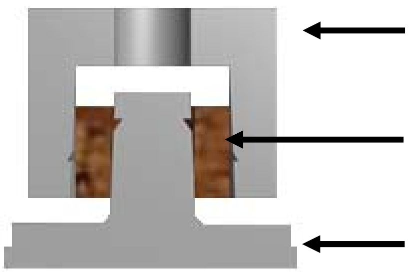
Accelerometer Advantages

- ✓Measures casing vibration
- ✓Measures absolute vibration
- ✓Integrate to Velocity
- ✓Easy to mount
- ✓Large range of frequency response
- ✓Available in many configurations

Accelerometer Disadvantages

- ✓ Does not measure shaft vibration
- ✓ Sensitive to mounting techniques and surface conditions
- ✓ Difficult to perform calibration check
- ✓ One accelerometer does not fit all applications

Mass & Charge

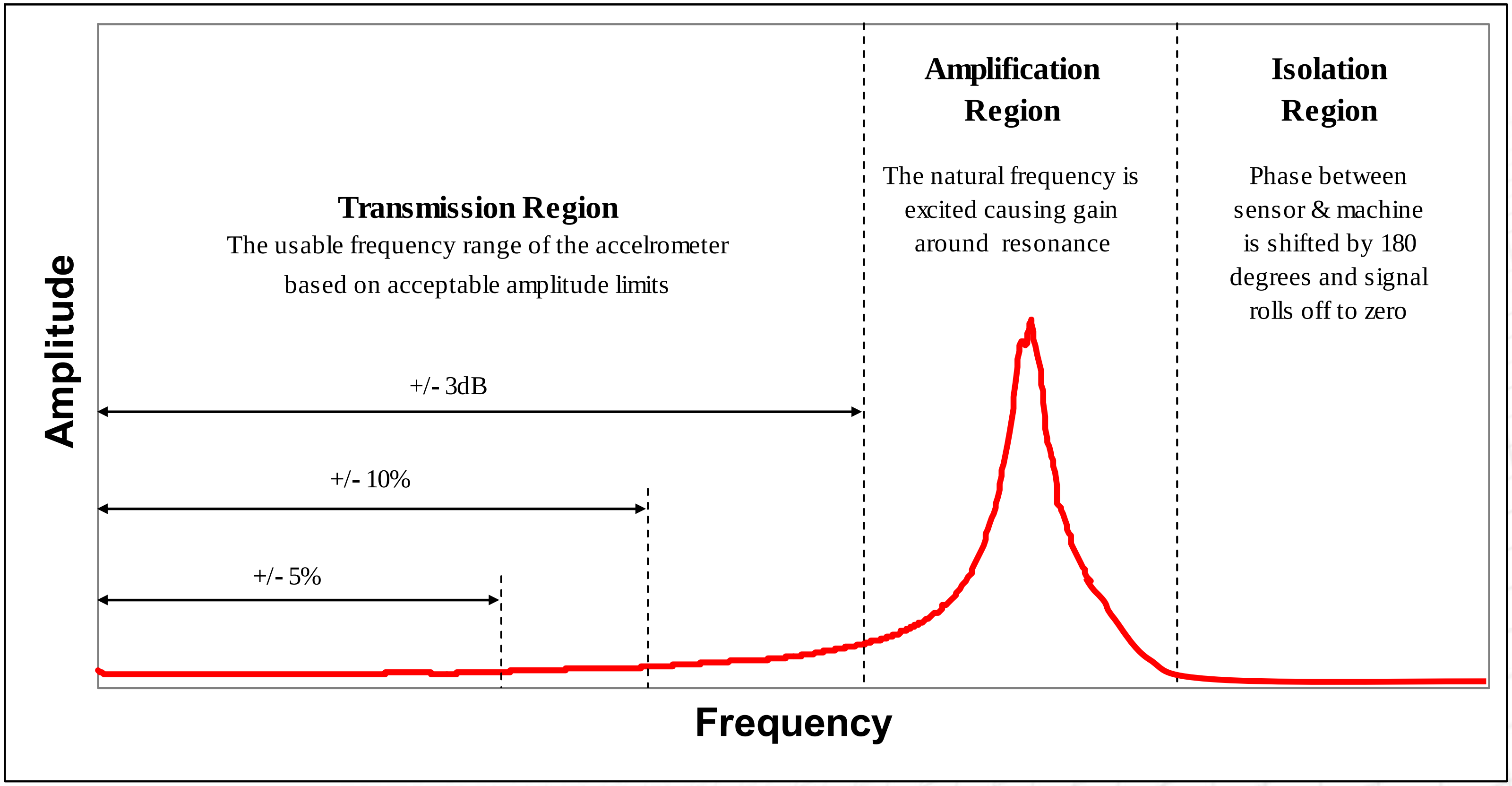


Relative movement between base & mass creates shear in ceramic producing charge.

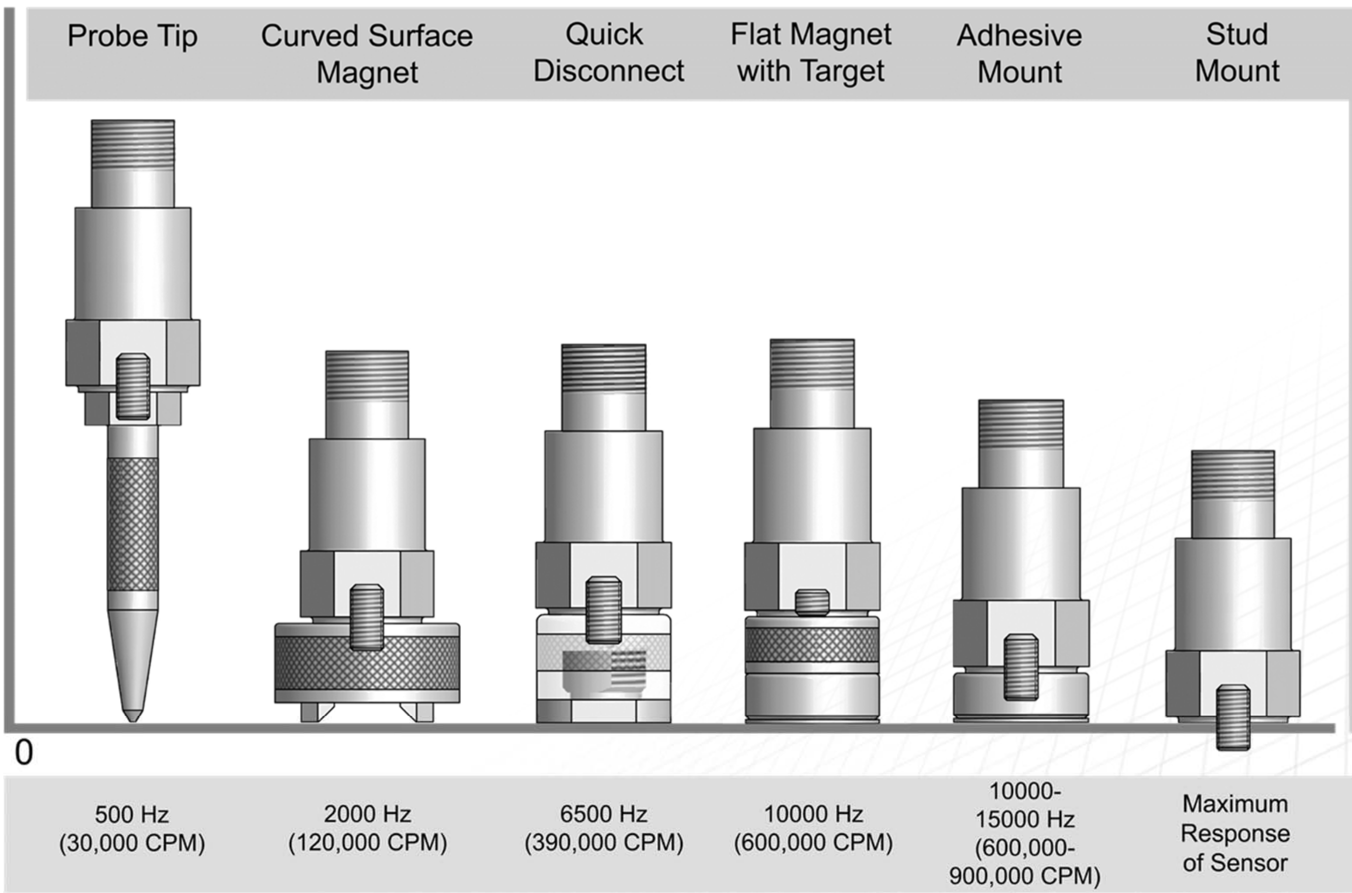
Typical Accelerometer Parameters/Specifications

Specification	Value	Alternate Value
Sensitivity	100 mV/g +/-5%	
Frequency Response +/-3dB	30 – 900,000 CPM	0.5 – 15,000 Hz
Frequency Response +/-10%	60 – 420,000 CPM	1.0 – 7,000 Hz
Frequency Response +/-5%	120 – 240,000 CPM	2.0 – 4,000 Hz
Dynamic Range	+/- 80 g peak	
Resonant Frequency	1,560,000 CPM	26,000 Hz

Typical Accelerometer Frequency Response



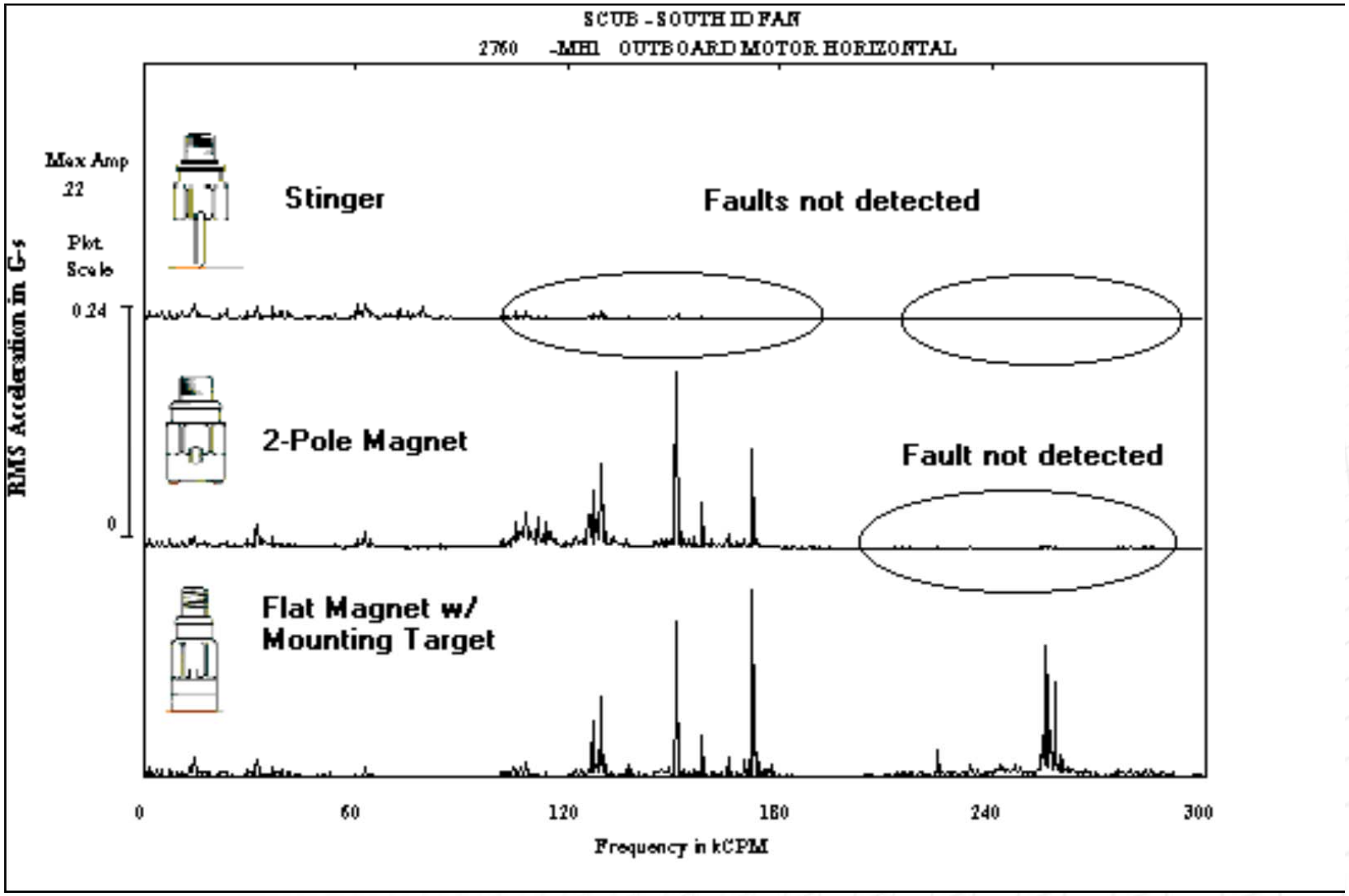
Accelerometer Mounts



Maximum Frequency Response
(within ±3dB)

**Depending on specified high frequency response of individual sensors.*

Realistic Mounting



Connection Technology Center, Inc.

Sensitivity, Range & Application

Sensitivity	Range	Output	Application
10 mV/g	**+/- 500 g**	**+/- 5 VAC**	A 10 mV/g accelerometer will have a dynamic range of +/- 500 g's, and a dynamic output of +/- 5 volts AC. They are typically used for machinery that is generating high amplitude vibrations. With the large dynamic range, they are much less likely to become saturated as a result of the high amplitude vibrations.
50 mV/g	+/- 100 g	+/- 5 VAC	
100 mV/g	+/- 50 g	+/- 5 VAC	
500 mV/g	+/- 10 g	+/- 5 VAC	

Sensitivity, Range & Application

Sensitivity	Range	Output	Application
10 mV/g	**+/- 500 g**	**+/- 5 VAC**	A 50 mV/g accelerometer will have a dynamic range of +/- 100 g's, and a dynamic output of +/- 5 volts AC. They are typically used for general purpose machinery measurements, and are sometimes offered as standard sensors for data collectors.
50 mV/g	+/- 100 g	+/- 5 VAC	
100 mV/g	+/- 50 g	+/- 5 VAC	
500 mV/g	+/- 10 g	+/- 5 VAC	

Sensitivity, Range & Application

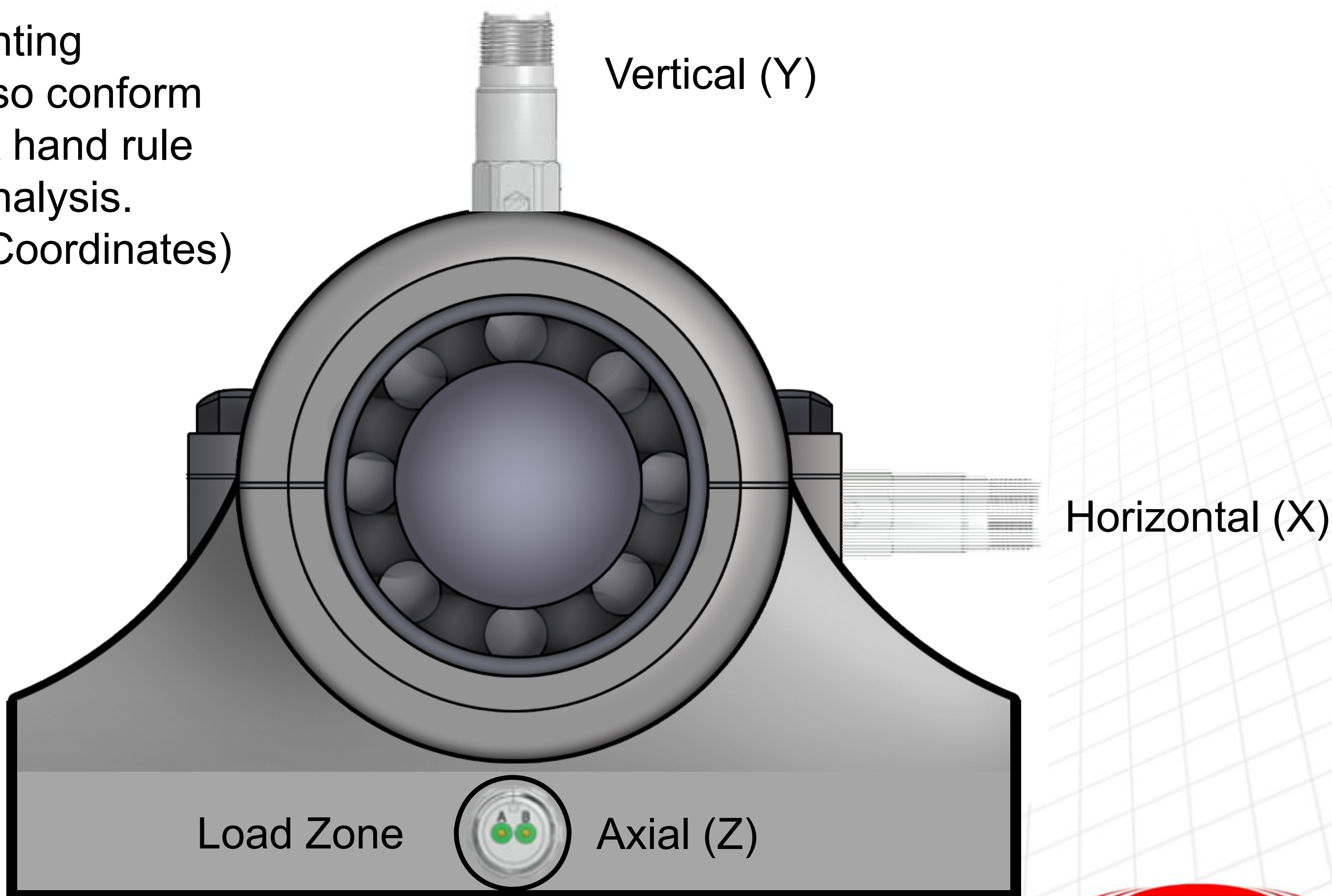
Sensitivity	Range	Output	Application
10 mV/g	**+/- 500 g**	**+/- 5 VAC**	A 100 mV/g accelerometer will have a dynamic range of +/- 50 g's, and a dynamic output of +/- 5 volts AC. Approximately 90% of all vibration analysis and data collection is accomplished with a 100 mV/g accelerometer. Some sensors are also available with a +/- 80g dynamic range for measuring larger signal amplitudes.
50 mV/g	+/- 100 g	+/- 5 VAC	
100 mV/g	+/- 50 g	+/- 5 VAC	
500 mV/g	+/- 10 g	+/- 5 VAC	

Sensitivity, Range & Application

Sensitivity	Range	Output	Application
10 mV/g	**+/- 500 g**	**+/- 5 VAC**	A 500 mV/g accelerometer will have a dynamic range of +/- 10 g's, and a dynamic output of +/- 5 volts AC. This high output sensor is typically used for low speed equipment, low frequency measurements, and low amplitude analysis. The high output provides a much better signal to noise ratio for low amplitude signals.
50 mV/g	+/- 100 g	+/- 5 VAC	
100 mV/g	+/- 50 g	+/- 5 VAC	
500 mV/g	+/- 10 g	+/- 5 VAC	

Mounting Locations

These mounting locations also conform the the right hand rule for phase analysis. (Cartesian Coordinates)



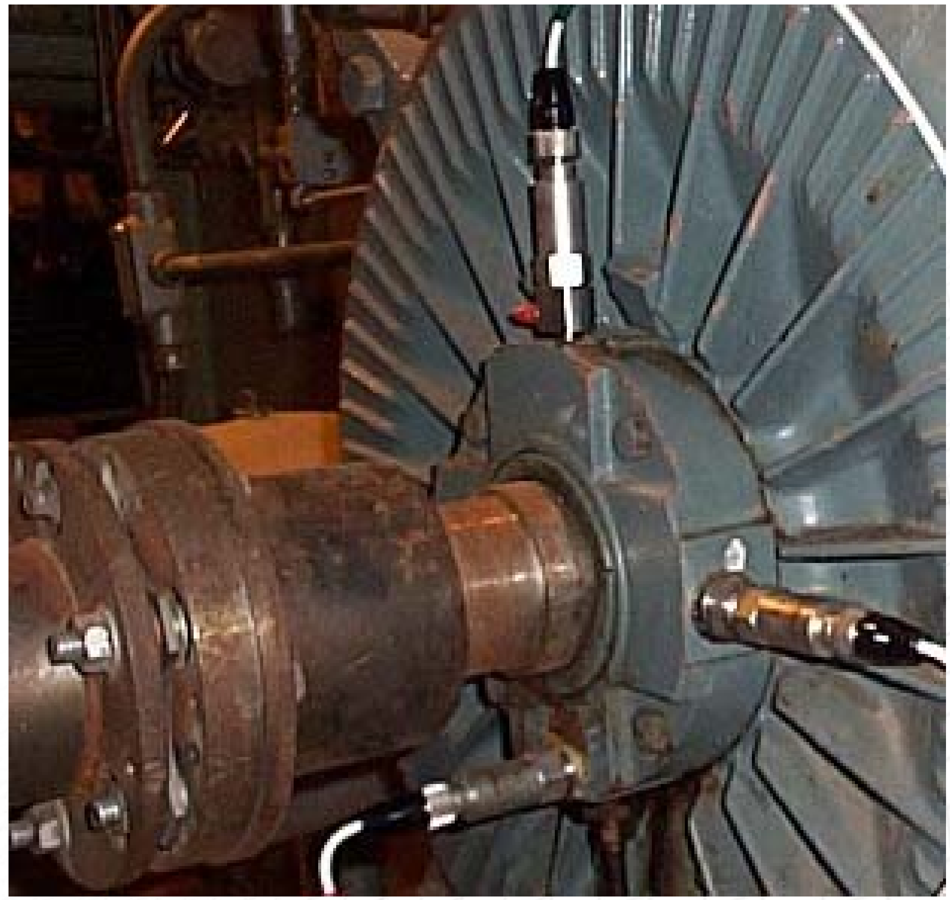
Mounting Locations

✓Load Zone

- Axial (Z)

✓Radial

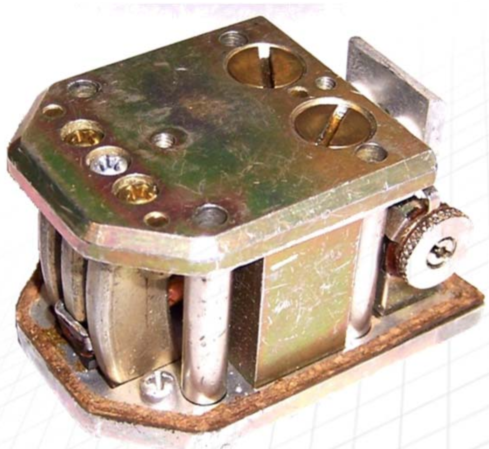
- Vertical (Y)
- Horizontal (X)



Velocity Sensors

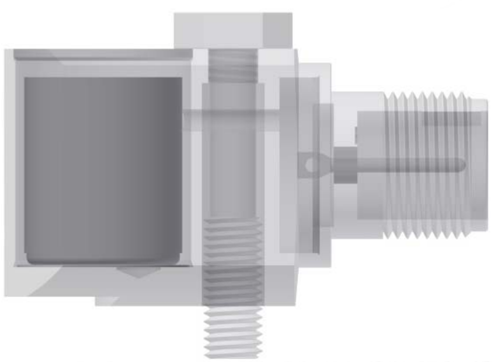
Velocity Sensors

- ✓ Self Generating – no power supply required
- ✓ Magnet inside coil generates velocity proportional to vibration
- ✓ Spring mass system
- ✓ 10 Hz. to 1000 Hz.
- ✓ Phase change 90^0
- ✓ Directional mounting
- ✓ Large & Heavy
- ✓ Output = mV/inch/sec
- ✓ Wide range of available outputs



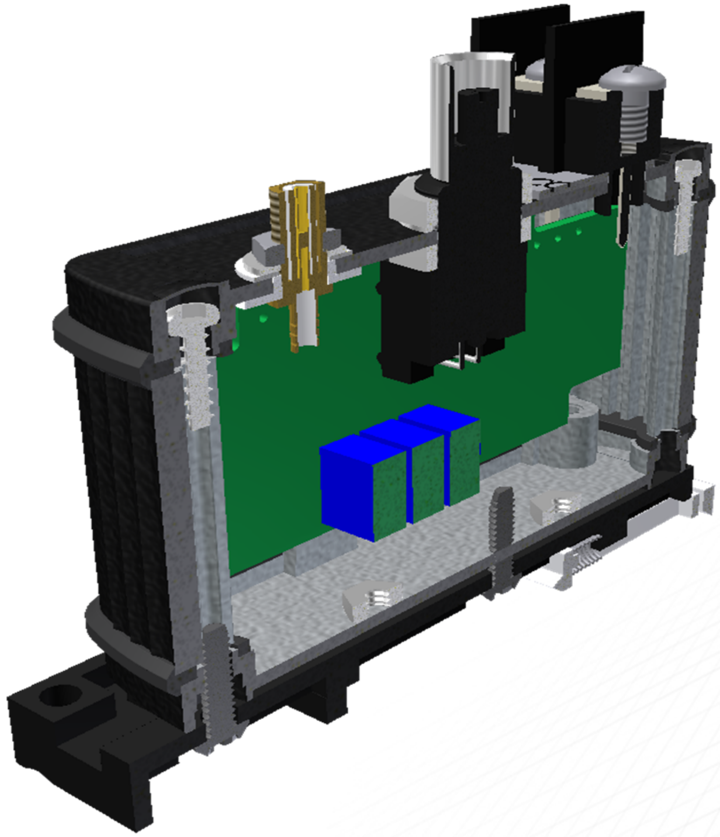
Piezo Velocity Sensors

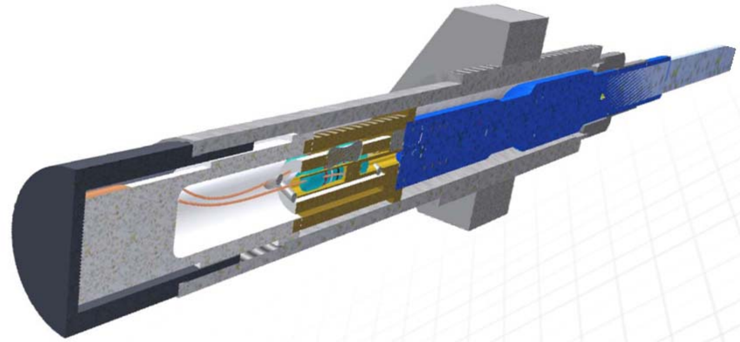
- ✓ Remember everything that you just learned about an accelerometer
- ✓ The output of the accelerometer has been integrated to velocity and has a 90^0 phase change
- ✓ 100 mV/inch/sec (4 mV/mm/sec)
- ✓ 500 mV/inch/sec (20 mV/mm/sec)

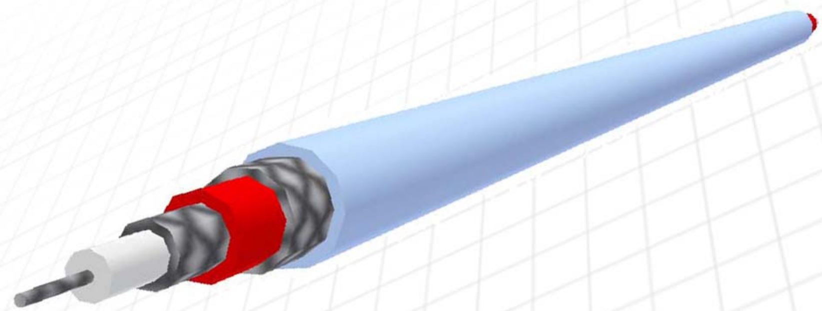


Proximity Probes

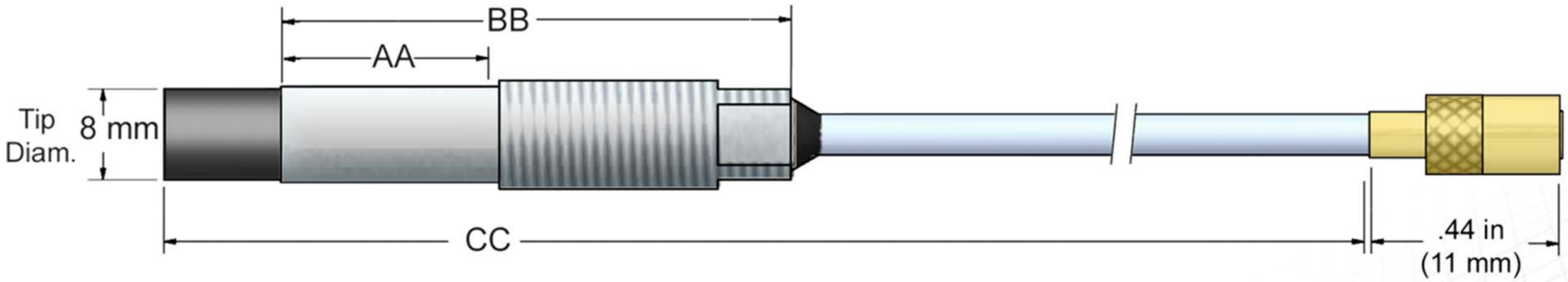
Proximity Probes, Cables, & Drivers







5, 7 and 9 Meter Systems



AA = No Thread Length

BB = Case Length

CC = Total Length

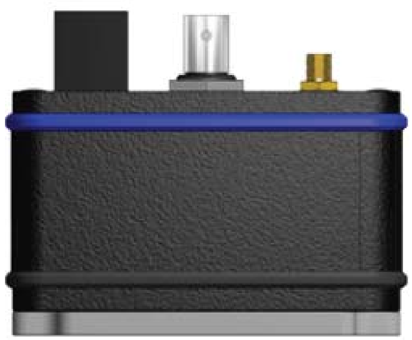
5, 7 & 9 Meter Systems

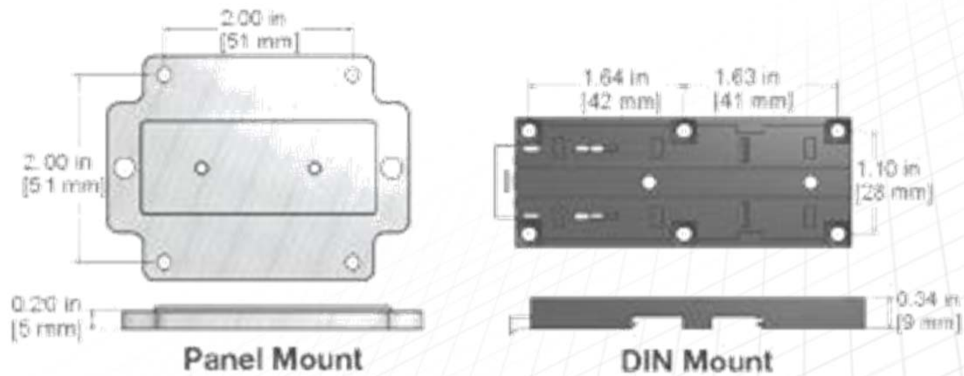
Extension Cable

Probe Length + Extension Cable Length must equal 5, 7 or 9 meters in system length

5, 7 and 9 Meter Systems

Driver

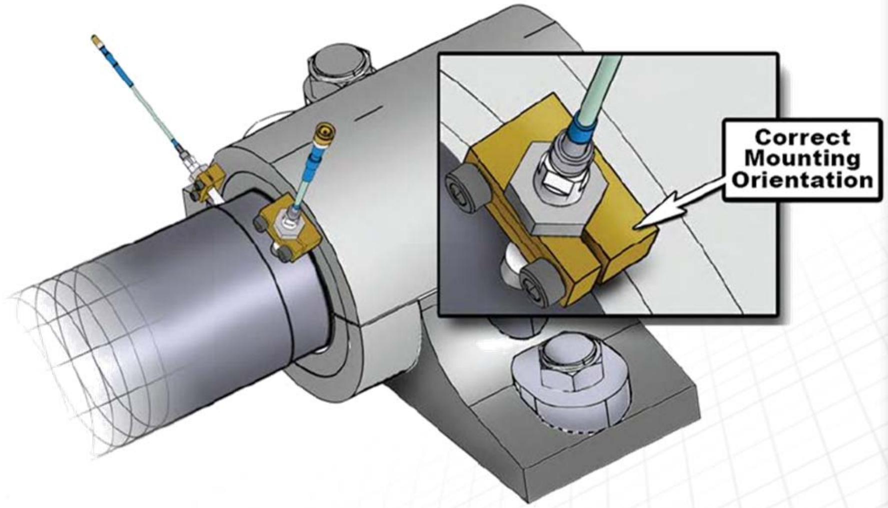


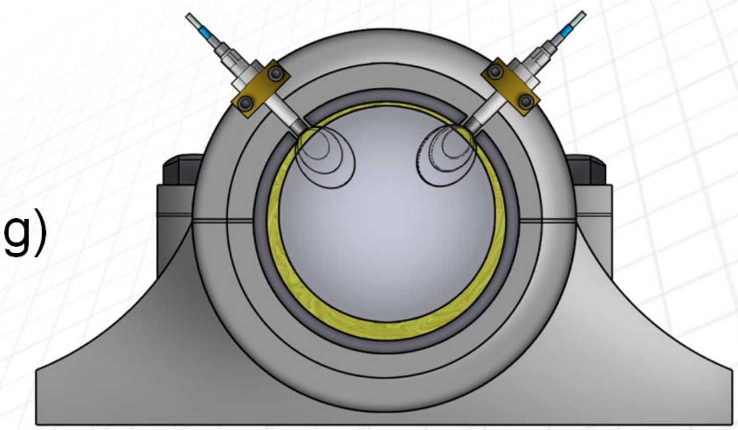


Electronics tuned for 5, 7 or 9 meter systems

Application

- ✓ Measure Displacement
  - ✓ Plain bearing applications
  - ✓ Non Contact Sensor
  - ✓ Ideal for measuring:
    - ✓ Shaft vibration
    - ✓ Shaft centerline position (Gap)
    - ✓ Shaft axial position (Thrust Bearing)
    - ✓ Rod drop
    - ✓ Speed (Gear)
    - ✓ Trigger (Key or Keyway)





Common Applications

- ✓Compressors
- ✓Steam Turbines
- ✓Pumps
- ✓Fans
- ✓Blowers
- ✓Generators
- ✓Gear Boxes

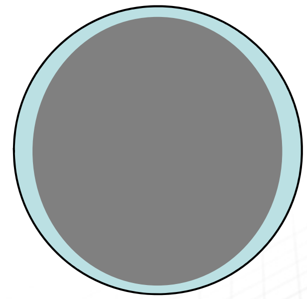
- ✓ **Plain Bearings**
- ✓ **Journal Bearings**
- ✓ **Fluid Film Bearings**
- ✓ **Babbitt Bearings**
- ✓ **Sleeve Bearings**
- ✓ **Tilting Pad Bearings**
- ✓ **Recip's (cross head)**

Displacement Probes Advantages

- ✓ Non-contact
- ✓ **Measure relative shaft vibration**
- ✓ **Measure shaft centerline position (DC gap)**
- ✓ **Measure axial position (Thrust)**
- ✓ **Provide Speed or Trigger**
- ✓ Flat frequency response dc – 10KHz
- ✓ Simple calibration
- ✓ Suitable for harsh environments

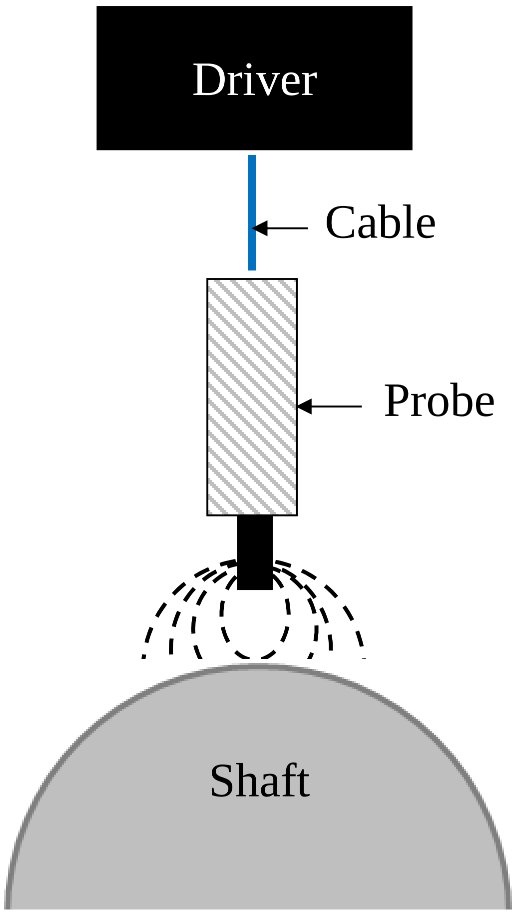
Displacement Probes Disadvantages

- ✓ **Probe can move (vibrate)**
- ✓ **Doesn't work on all metals**
- ✓ Plated shafts may give false measurement
- ✓ Measurement is affected by scratches & tool marks in shaft
- ✓ Available system lengths (probe, cable & driver) 5 meter or 9 meter are standard
- ✓ Must have relief at sensing tip from surrounding metal (counter bore)



Plated shaft is round, but core material is not..

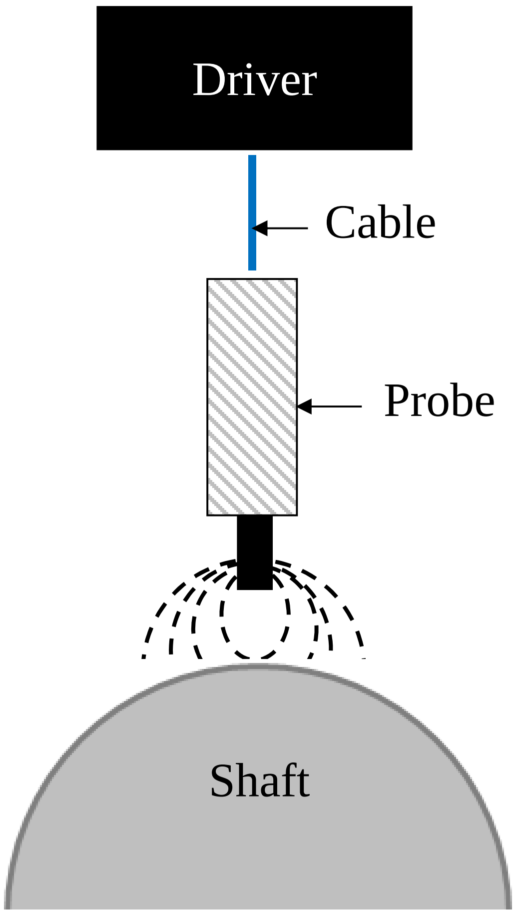
Technical Background



- **The tip of the probe emits a radio frequency signal into the surrounding area as a magnetic field**

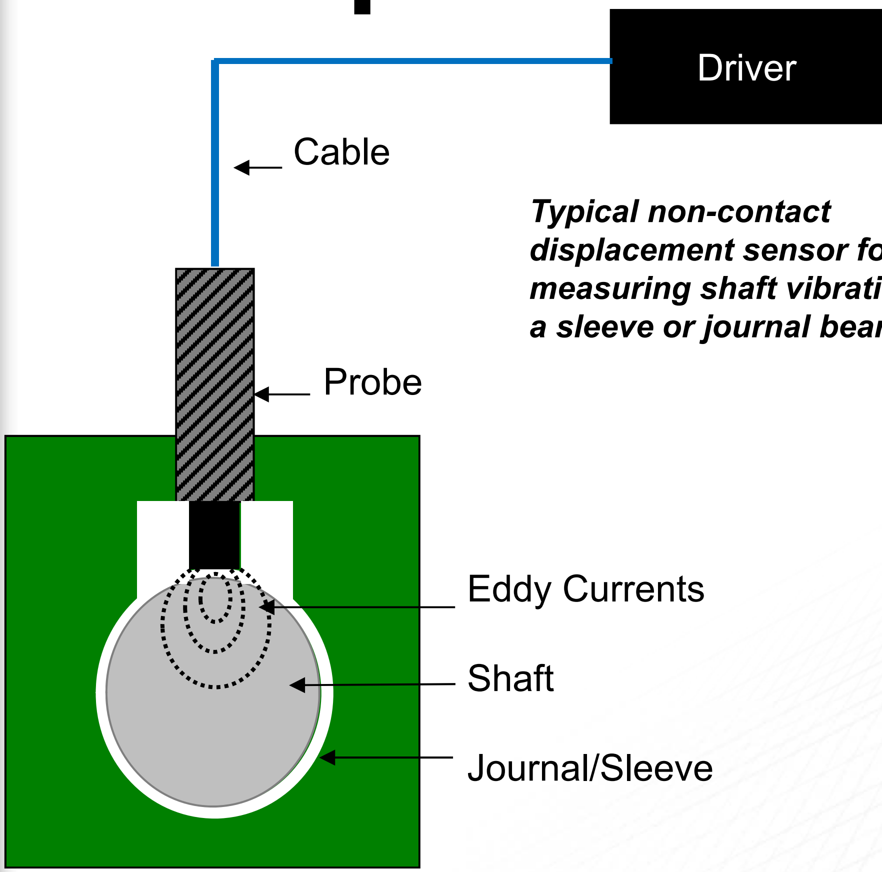
- **As a conductive target intercepts the magnetic field, eddy currents are generated on the surface of the target, and power is drained from the radio frequency signal**

Technical Background

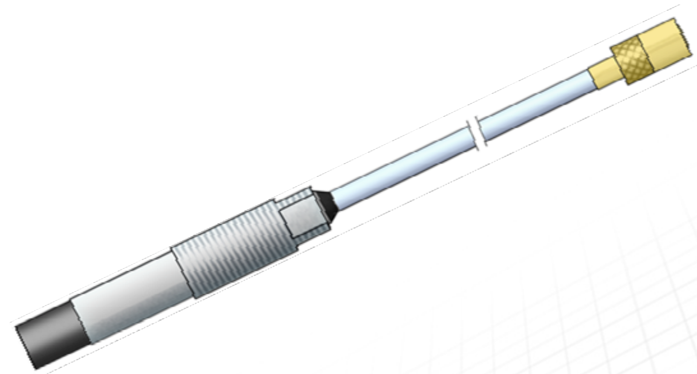


- **Power varies with target movement in the radio frequency field creating a variation in the output voltage of the driver**
  - **A small DC voltage indicates that the target is close to the probe tip**
  - **A large DC voltage indicates that the target is far away from the probe tip**
  - **The variation of DC voltage is the AC dynamic signal indicating the vibration (displacement)**

Sensitivity, Range, & Response

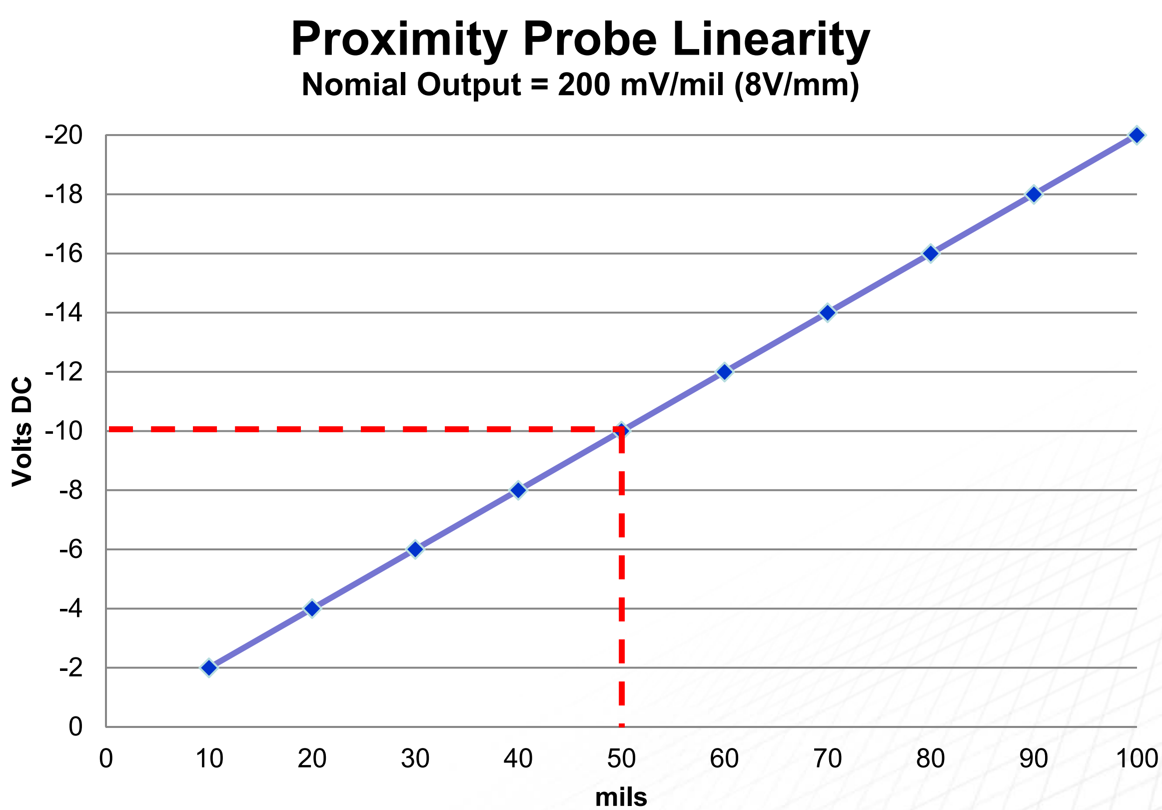


Typical non-contact displacement sensor for measuring shaft vibration on a sleeve or journal bearing.



Sensitivity	**200 mV/mil (8 V/mm)**
Dynamic Range	**10 – 90 mils (.25 – 2.3 mm)**
Frequency Response	**DC – 10 kHz**

Linearity



Gap	Gap	Output
mils	mm	VDC
10	0.25	-2.00
20	0.51	-4.00
30	0.76	-6.00
40	1.02	-8.00
50	**1.27**	**-10.00**
60	1.52	-12.00
70	1.78	-14.00
80	2.03	-16.00
90	2.29	-18.00
100	2.54	-20.00

Materials & Sensitivity

- ✓Typical
  - ✓200 mv/mil
  - ✓(8 V/mm)
  - ✓4140 Steel
- ✓Depends on probe, cable (length), and driver.
- ✓Target material varies output.

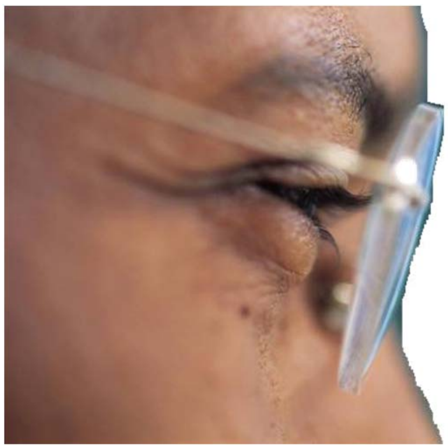
Note:

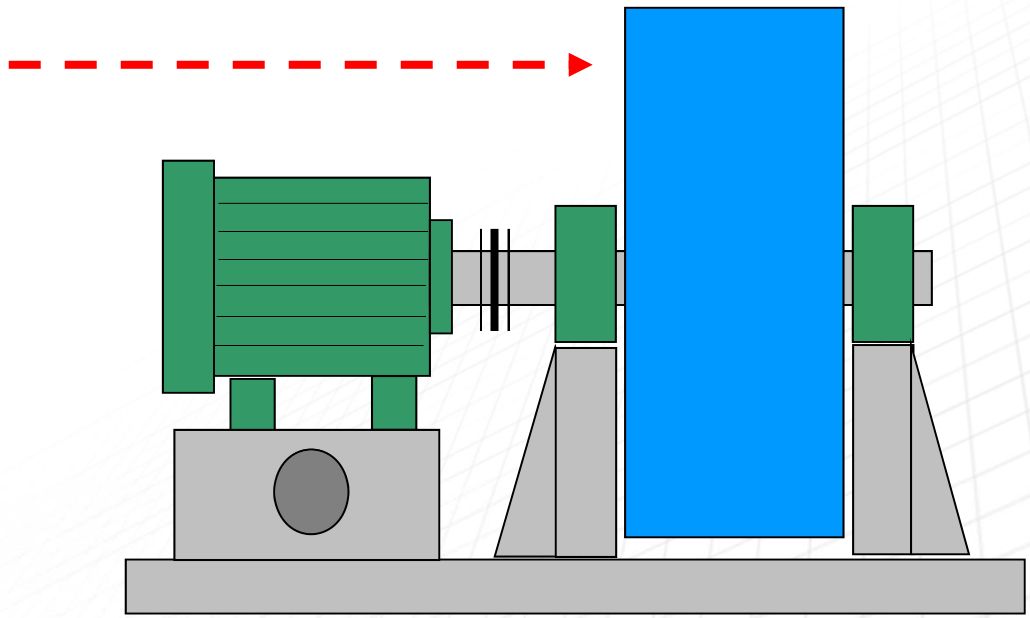
If the shaft or target material is not 4140 steel, then a test should be run to determine the sensitivity of the material being measured.

Durability is Required

Proximity probes lead a rough life. Installation, maintenance and overhauls require trained analysts, technicians, or mechanics to properly install and remove the probes. Some probes are actually encapsulated inside the fluid film bearing, and are exposed to the lubrication and heat generated by the bearing. Proper handling and durability are key performance factors.

Driver to Driven

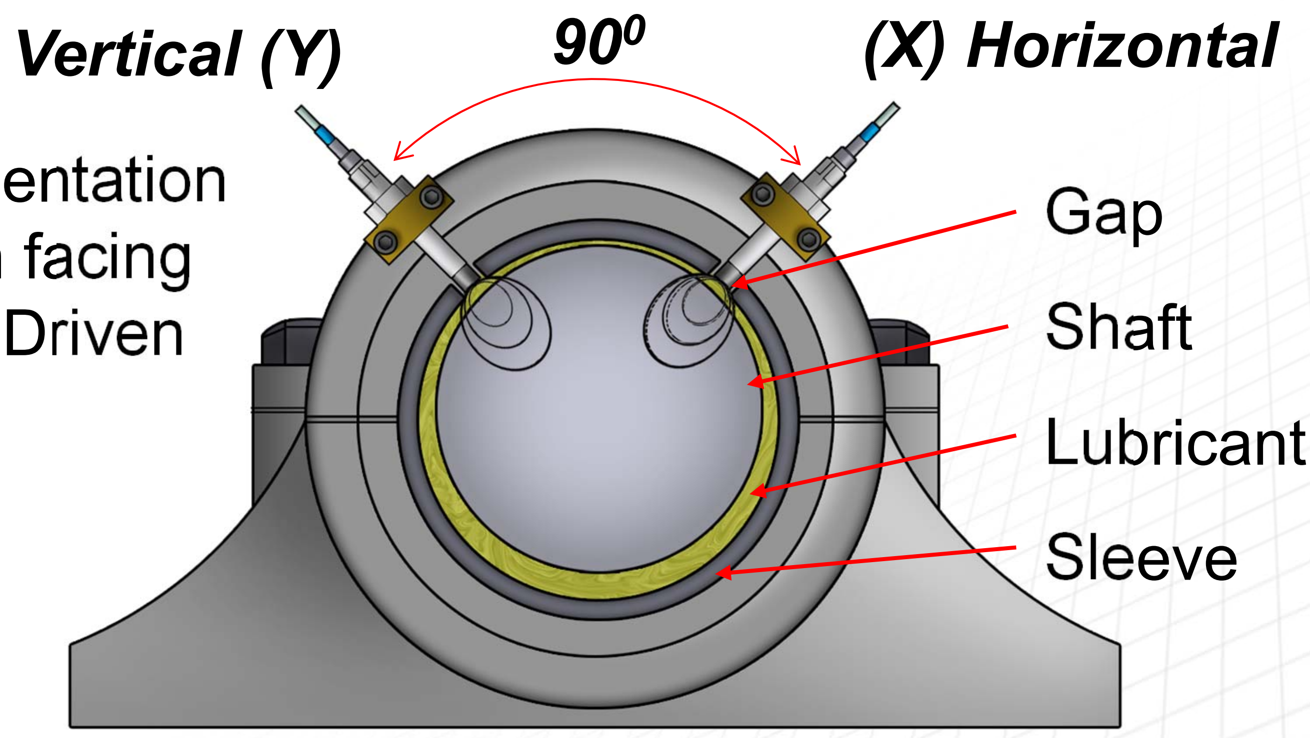




API Standard 670

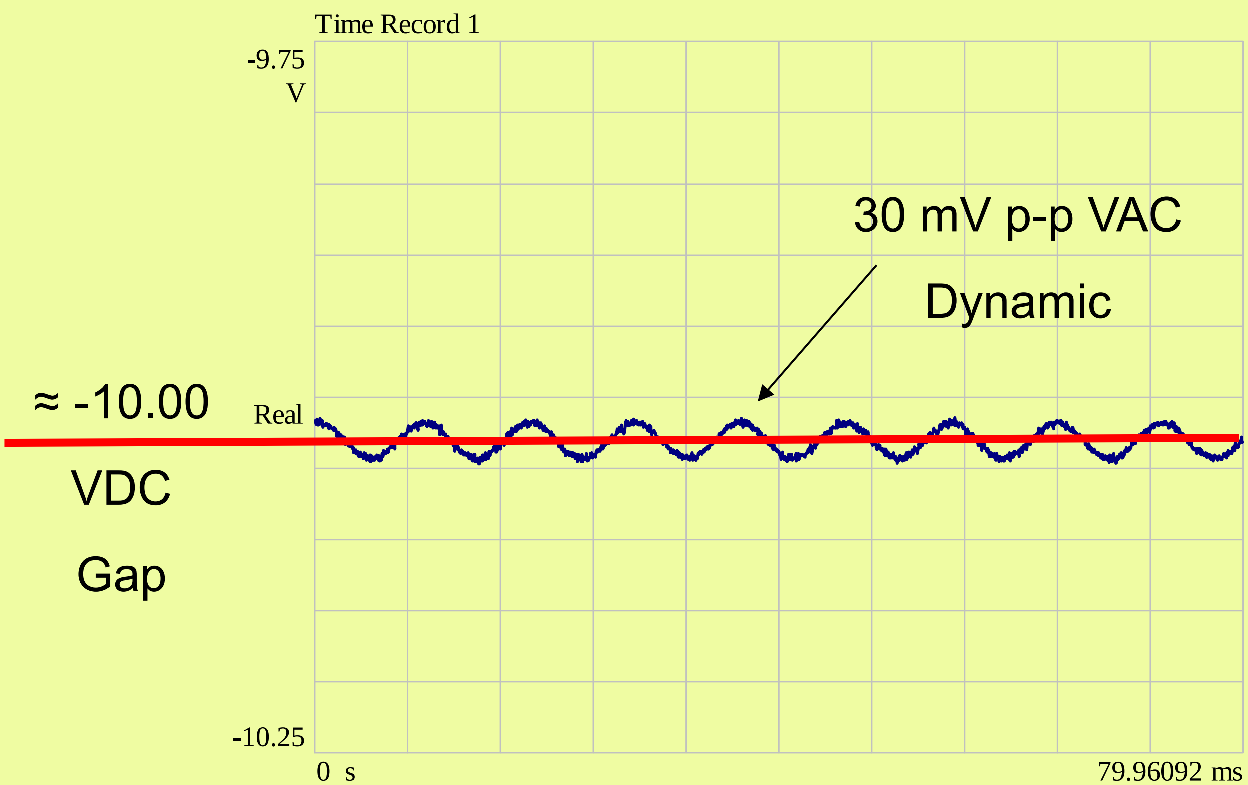
- Industry Standard for Proximity Probes
  - American Petroleum Institute
  - 4th Edition, December 01, 2000
  - (5th Edition Pending Release)
  - www.techstreet.com ≈ $200.00 USD/copy

Probe Orientation



Probe orientation based on facing Driver to Driven

DC Gap & Dynamic AC



DC Gap

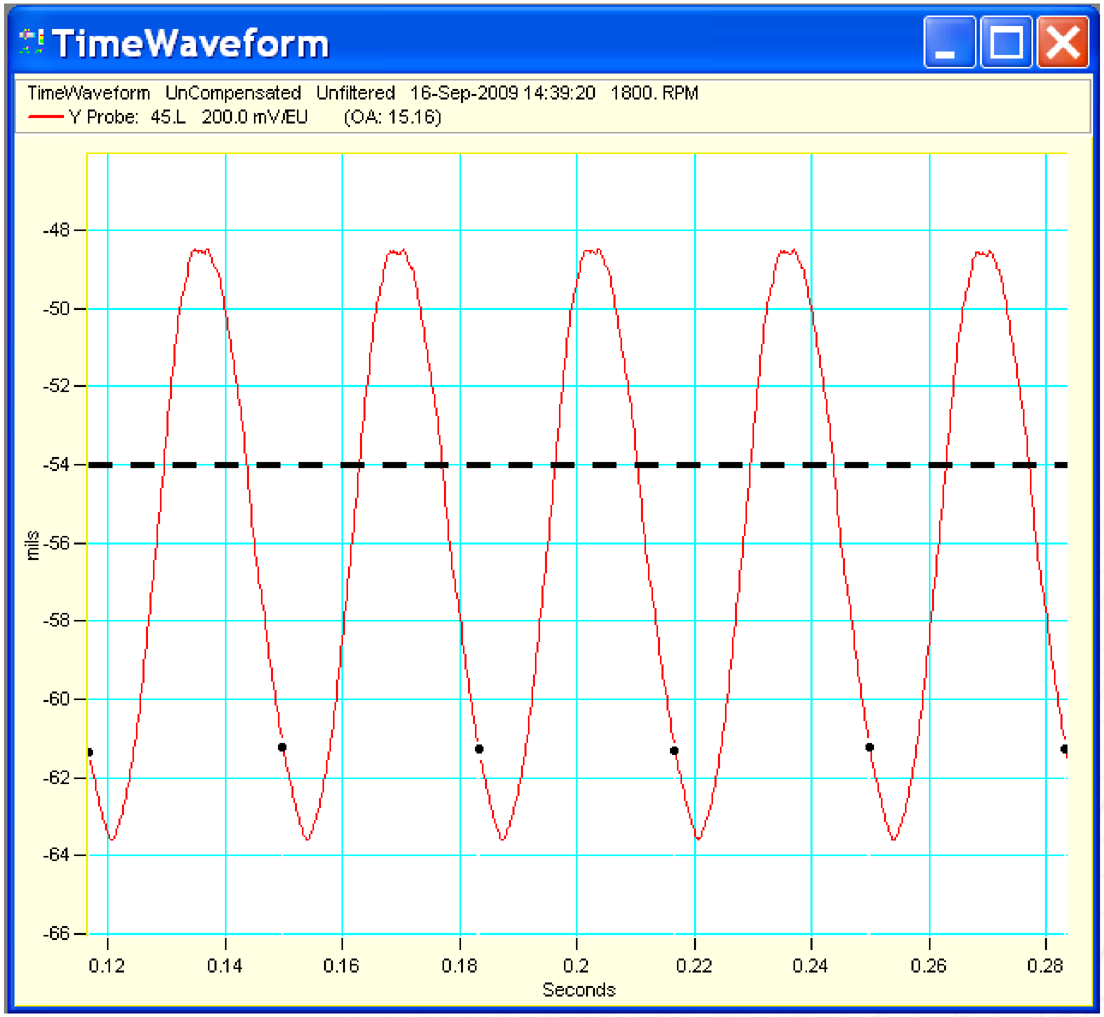
A negative voltage level proportional to the gap spacing

Dynamic AC

Varying DC voltage simulates dynamic AC voltage for vibration output

30 mV/(200 mV/mil) = 0.15 mil's p-p

DC Gap & Dynamic AC



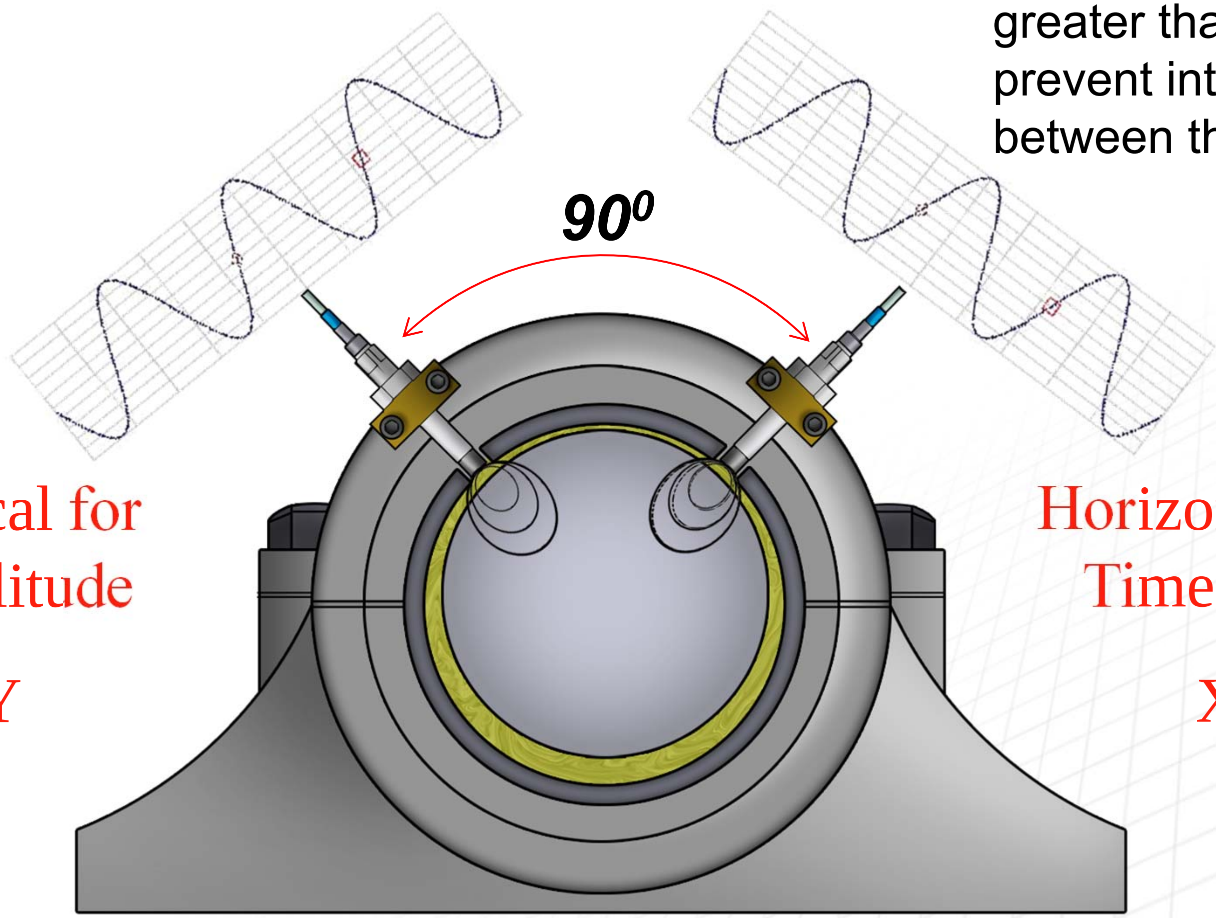
Positive Peak = - 48.57 mils

DC Gap = - 56.08 mils

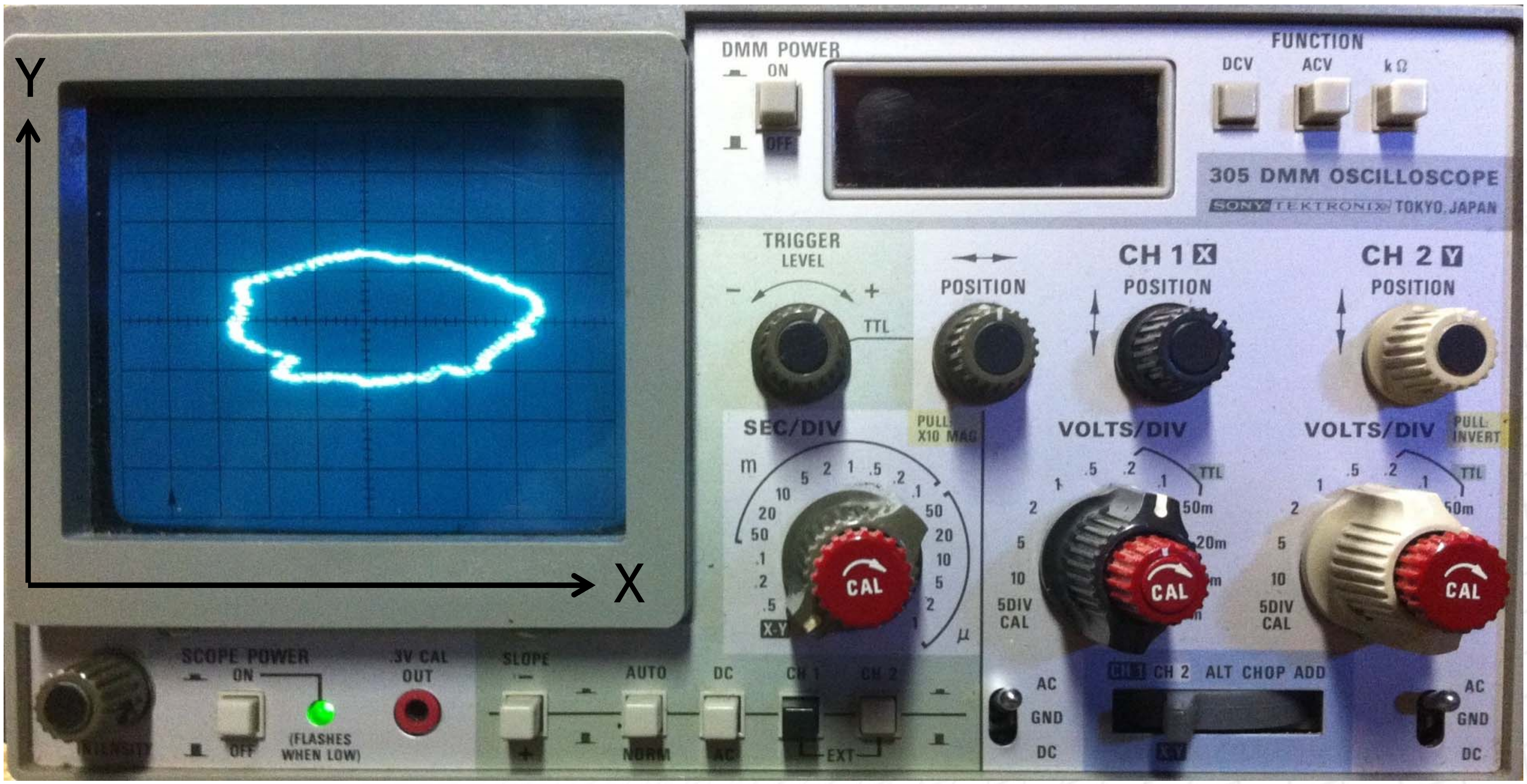
Negative Peak = - 63.59 mils

Dynamic Outputs

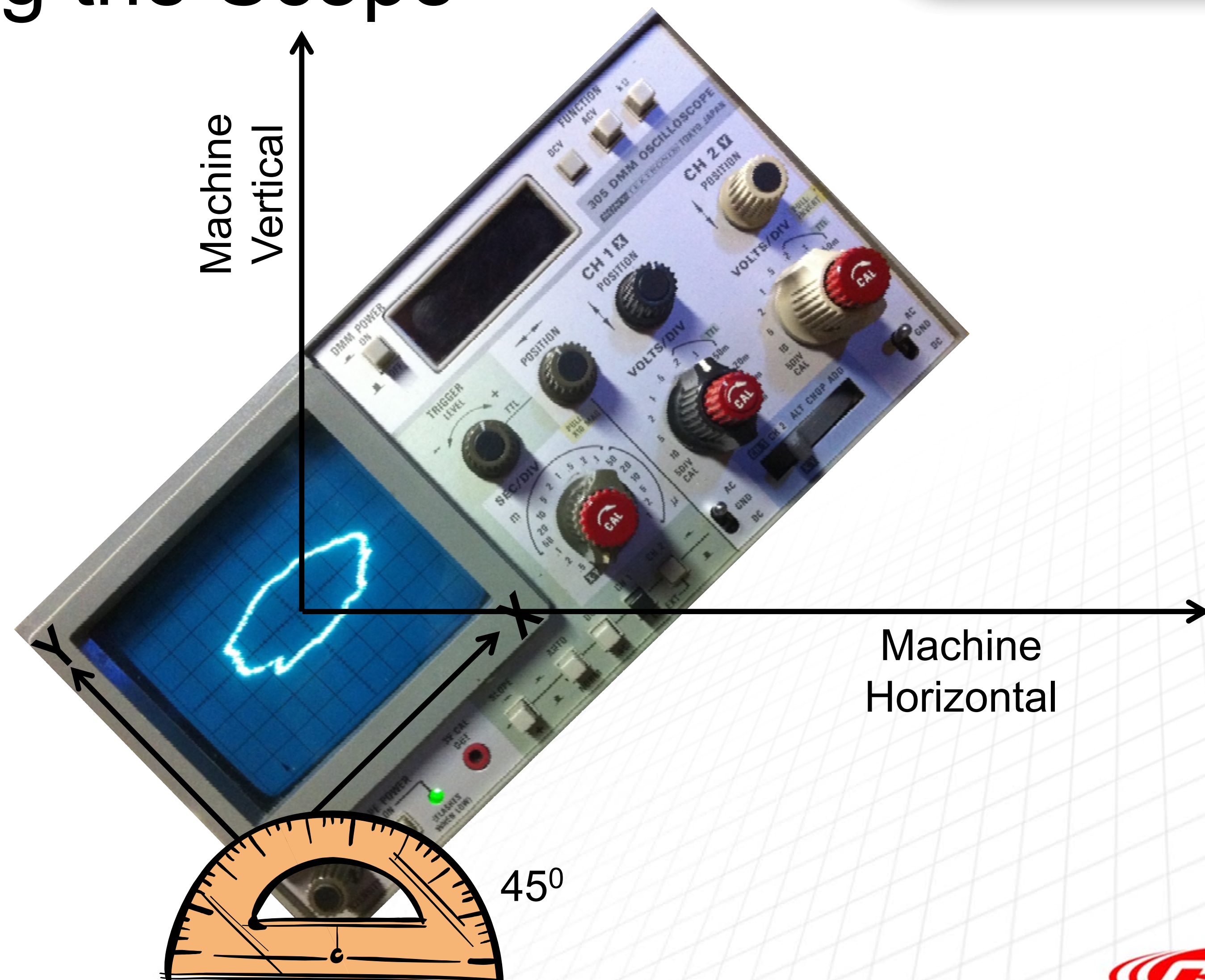
Note: The shaft diameter needs to be greater than 2 inches to prevent interference between the two probes.



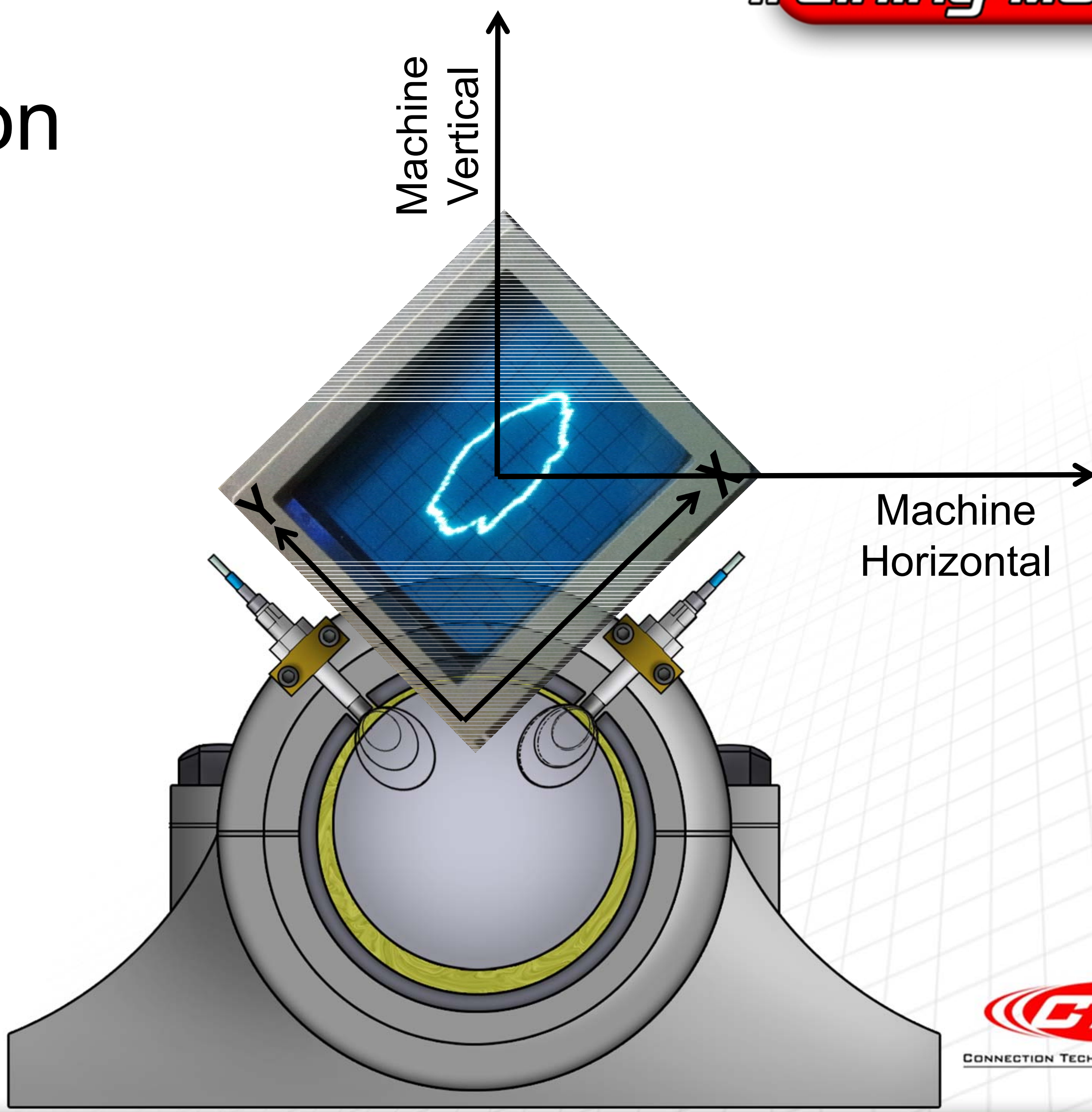
The Orbit Display



Rolling the Scope

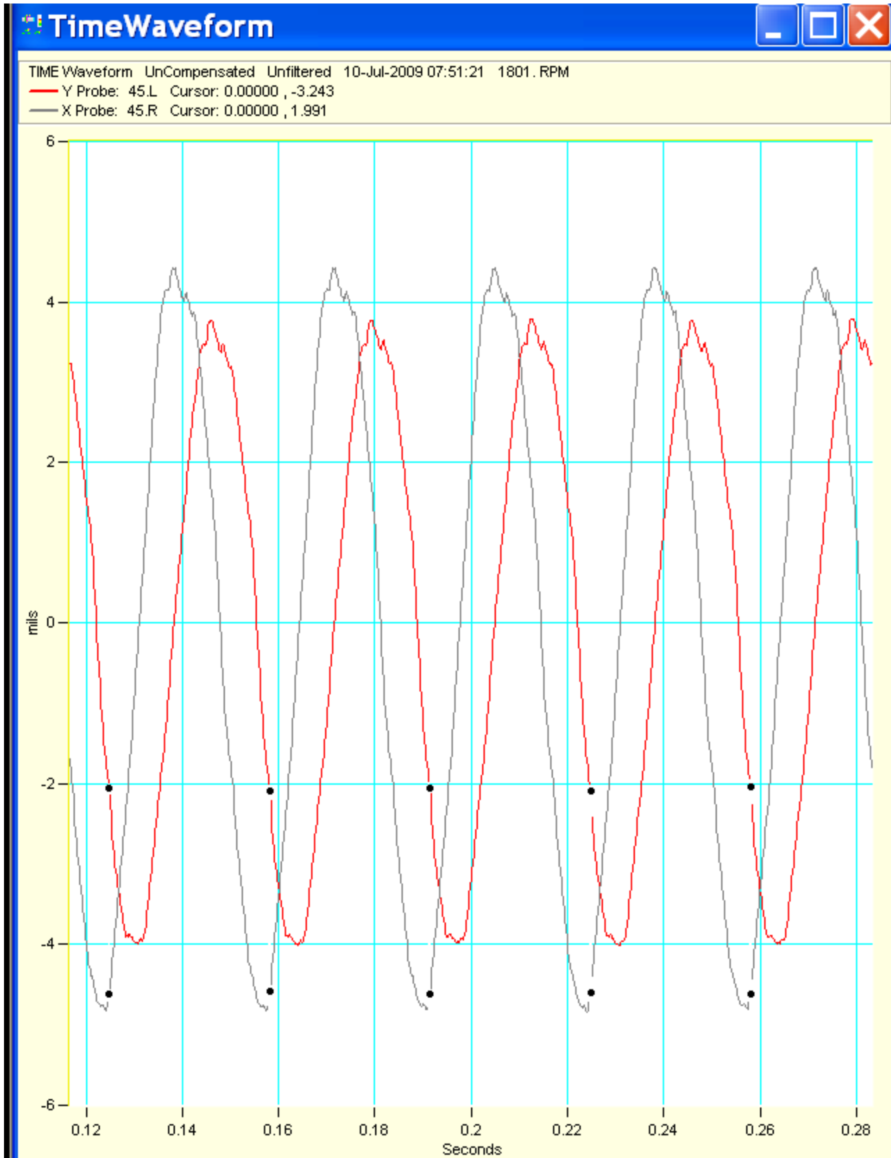


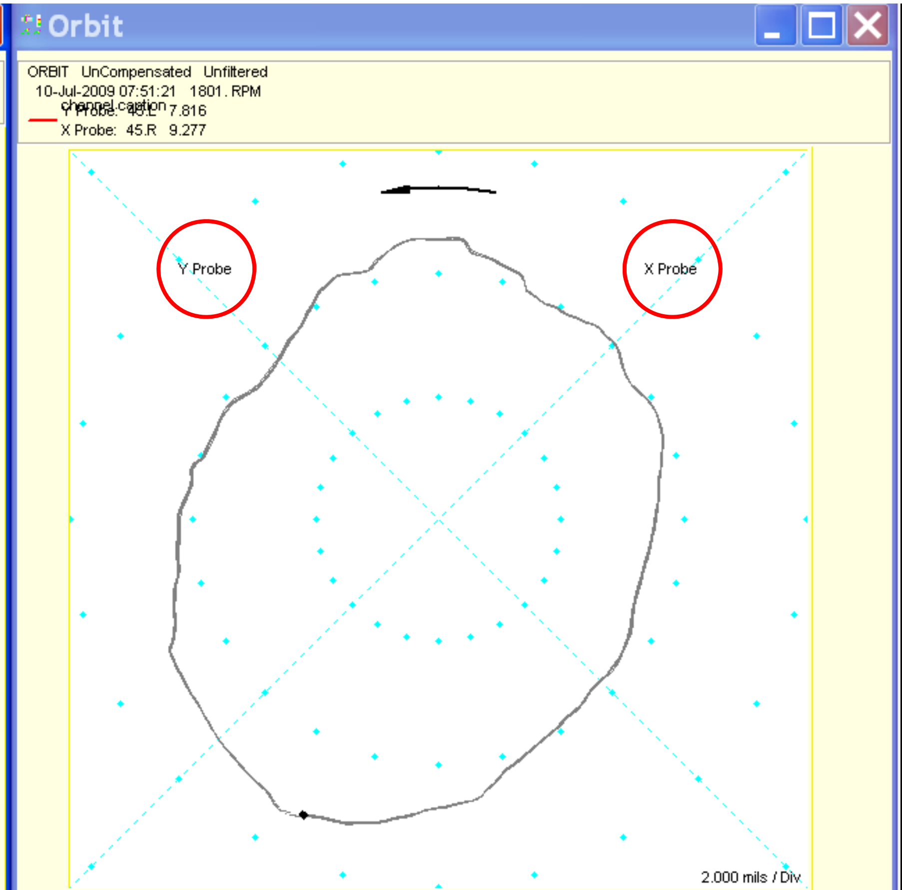
Orbit Correction



2013

Modern Orbits

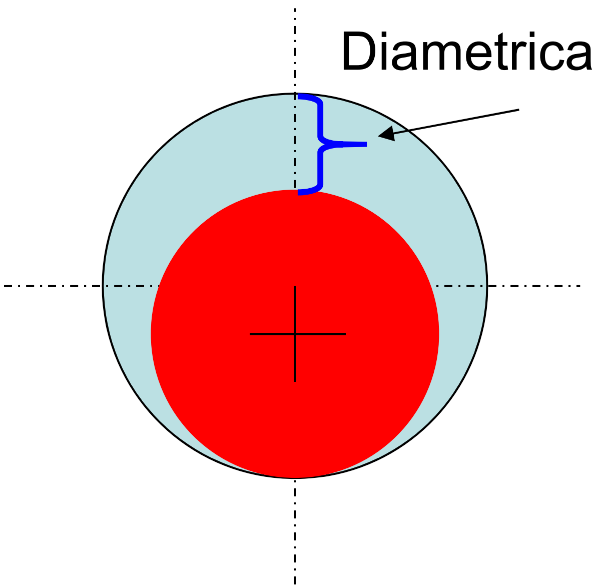


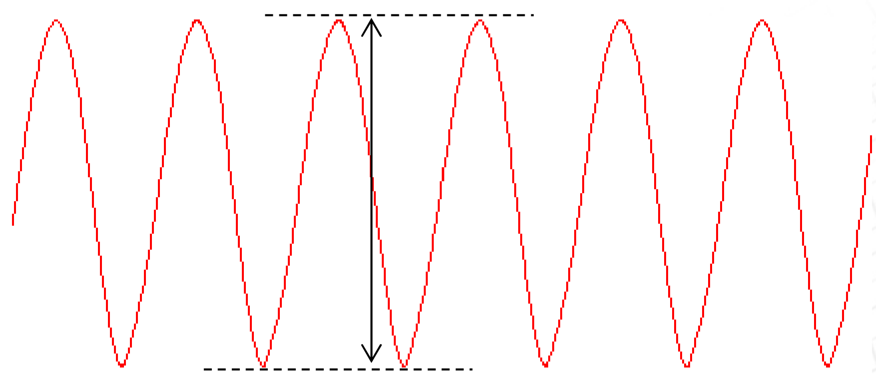


Modern instrumentation can compensate for the location of the X and Y probes providing a true machine vertical and horizontal measurement.

Vibration Monitoring Training Modules

Clearance vs. Vibration

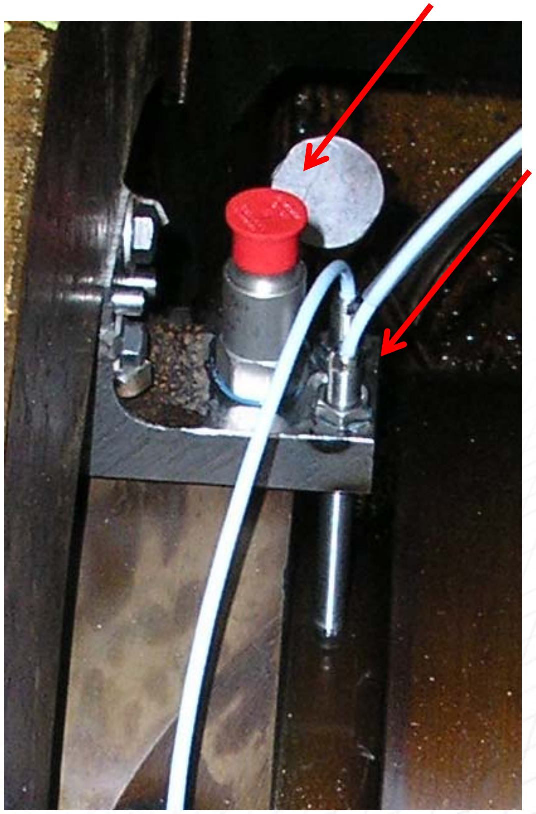




If the (Peak – Peak Displacement / Diametrical Clearance) x 100% > 50% then the vibration of the shaft is using more than half of the bearing clearance and additional analysis may be required to identify and reduce the vibration amplitude.

Absolute Shaft Displacement

1. Measure the vertical shaft displacement.
2. Measure the vertical casing velocity.
3. Include phase



Vertical Measures

D = 2.85 $mils_{p-p}$ @165^0

V = 0.24 IPS_{pk} @ 211^0

3600 RPM

Graphical Addition

Vertical Measures

D = 2.85 mils$_{p\text{-}p}$ @165^0

V = 0.24 IPS$_p$ @ 211^0

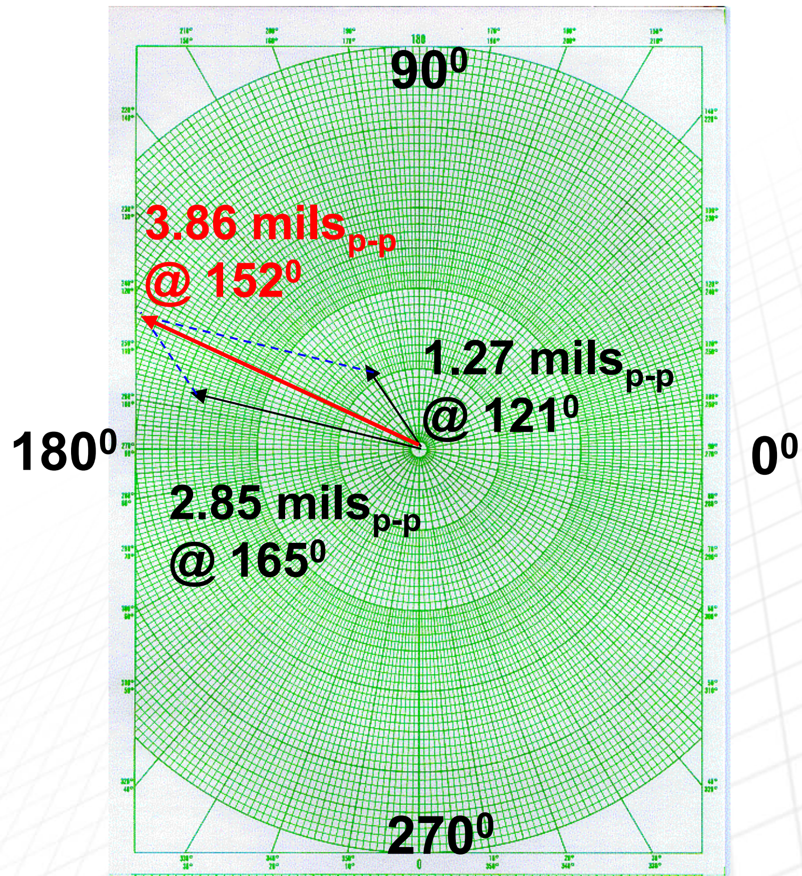
Velocity leads displacement by 90^0

211^0 - 90^0 = 121^0

$D_{p\text{-}p} = 2[0.24/(2\pi f)]$

$D_{p\text{-}p} = 2[0.24/(6.28x60)]$

D = 1.27 mils$_{p\text{-}p}$ @ 121^0



Mathematical Addition

$D = 2.85\ \text{mils}_{p\text{-}p}\ @165^0$

$D = 1.27\ \text{mils}_{p\text{-}p}\ @\ 121^0$

$y = 2.85\ \text{mils}_{p\text{-}p} \times \sin 165^0$

$y = 0.74\ \text{mils}_{p\text{-}p}$

$y = 1.27\ \text{mils}_{p\text{-}p} \times \sin 121^0$

$y = 1.09\ \text{mils}_{p\text{-}p}$

$y = 0.74 + 1.09 = 1.83\ \text{mils}_{p\text{-}p}$

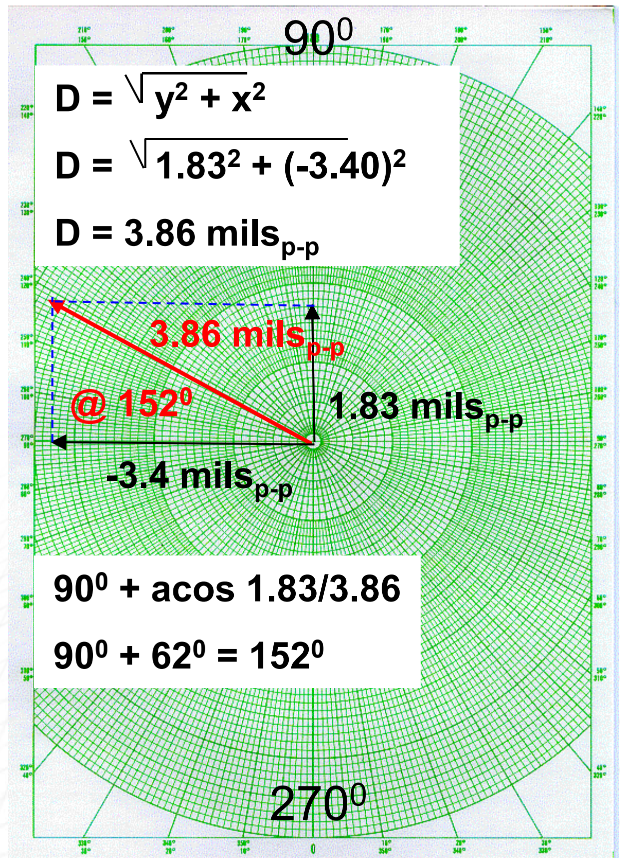
$x = 2.85\ \text{mils}_{p\text{-}p} \times \cos 165^0$

$x = -2.75\ \text{mils}_{p\text{-}p}$

$x = 1.27\ \text{mils}_{p\text{-}p} \times \cos 121^0$

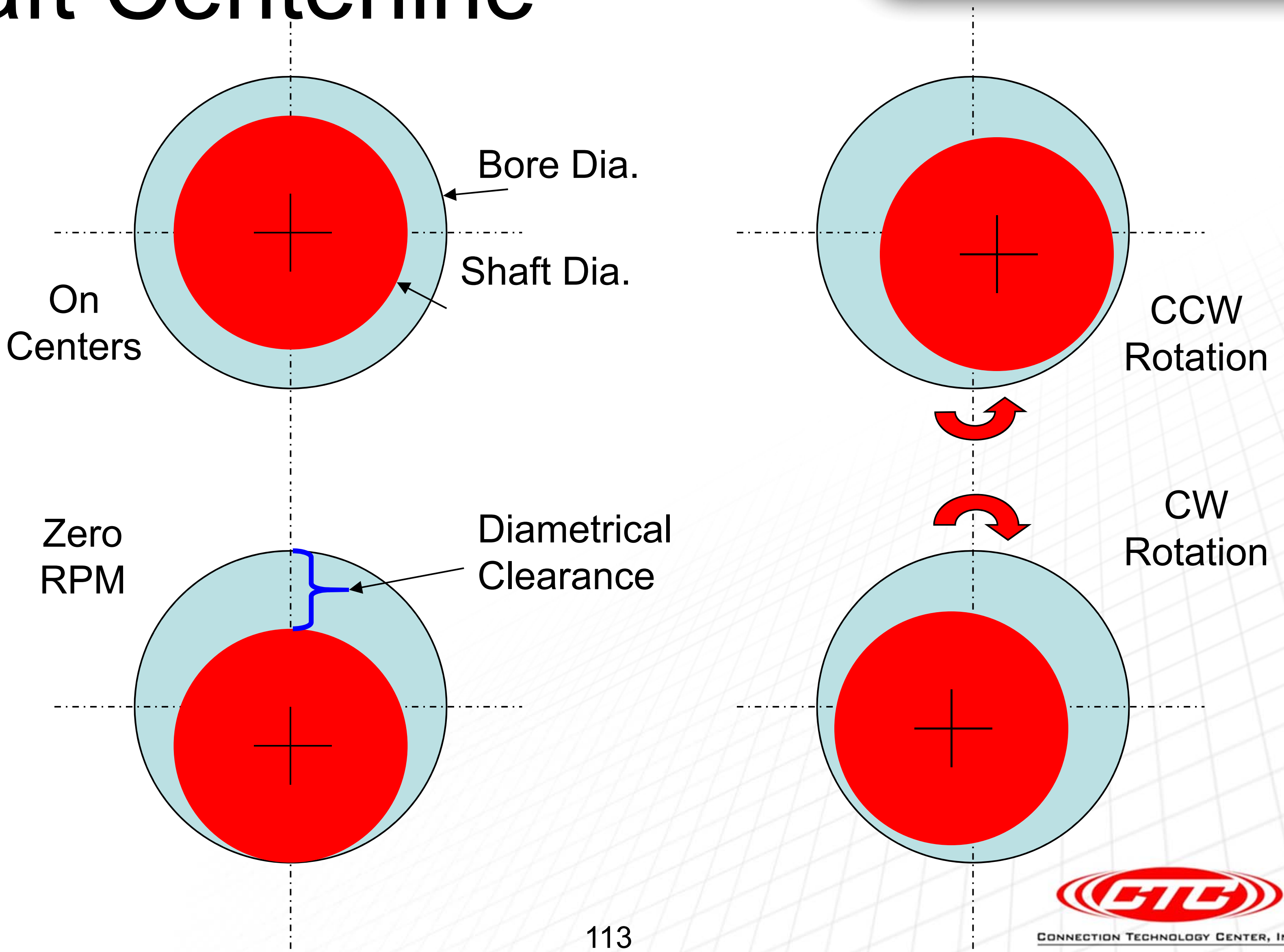
$x = -0.65\ \text{mils}_{p\text{-}p}$

$x = -2.75 + -0.65 = -3.40\ \text{mils}_{p\text{-}p}$

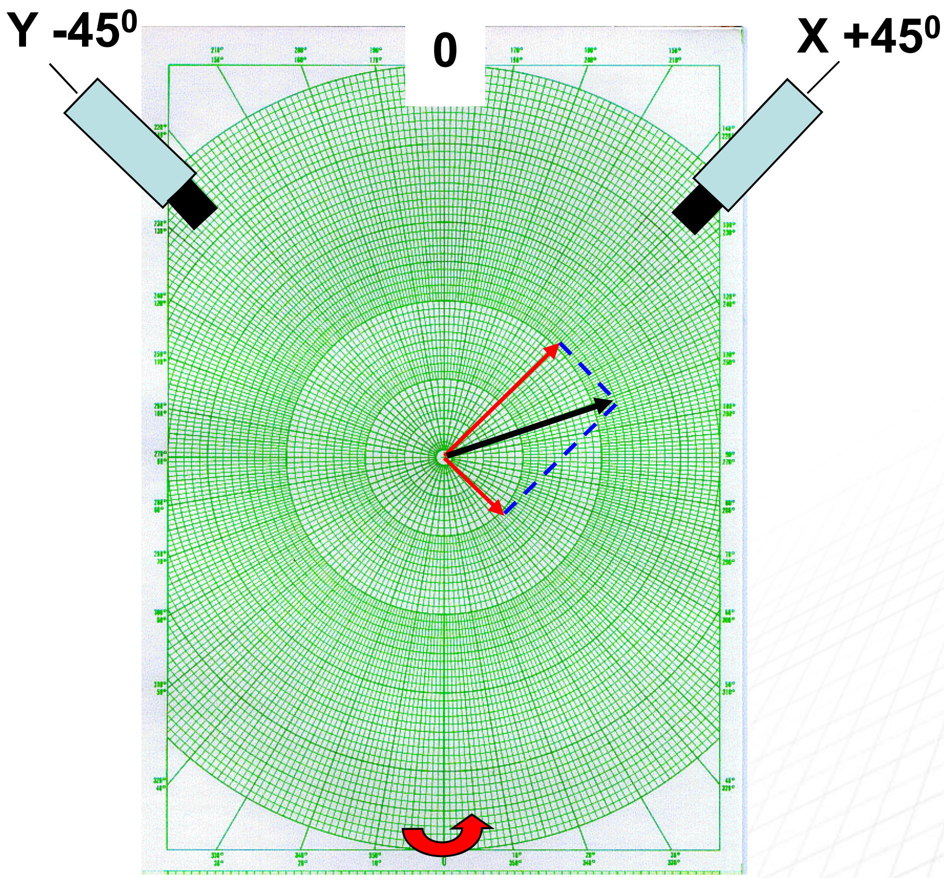


180^0 0^0

Shaft Centerline



Plotting Shaft Position



At Running Speed

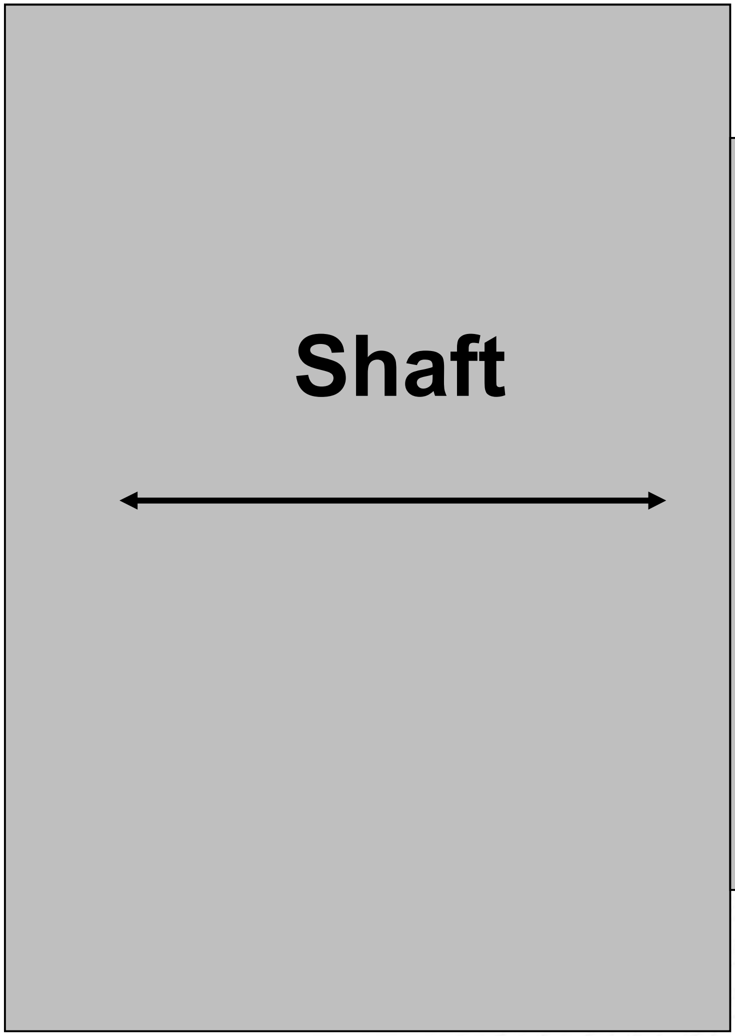
CCW Rotation

Y = -1 mil

X = +2 mils

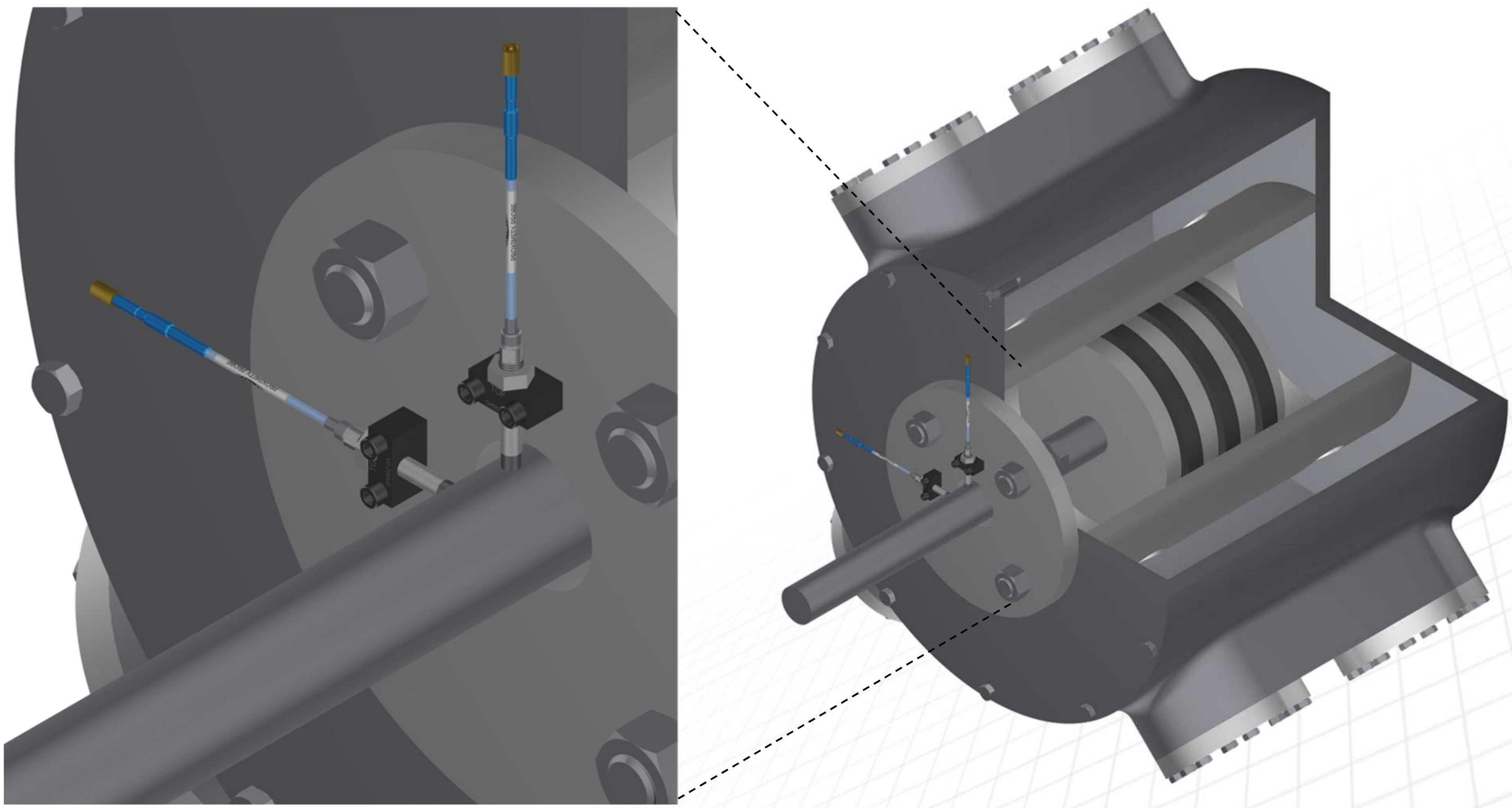
Shaft Change = 2.24 mils @ 71.6^0

Axial Thrust or Position



Two axial oriented probes are used for redundancy to monitor the axial movement of the shaft or thrust collar.

Rod Drop

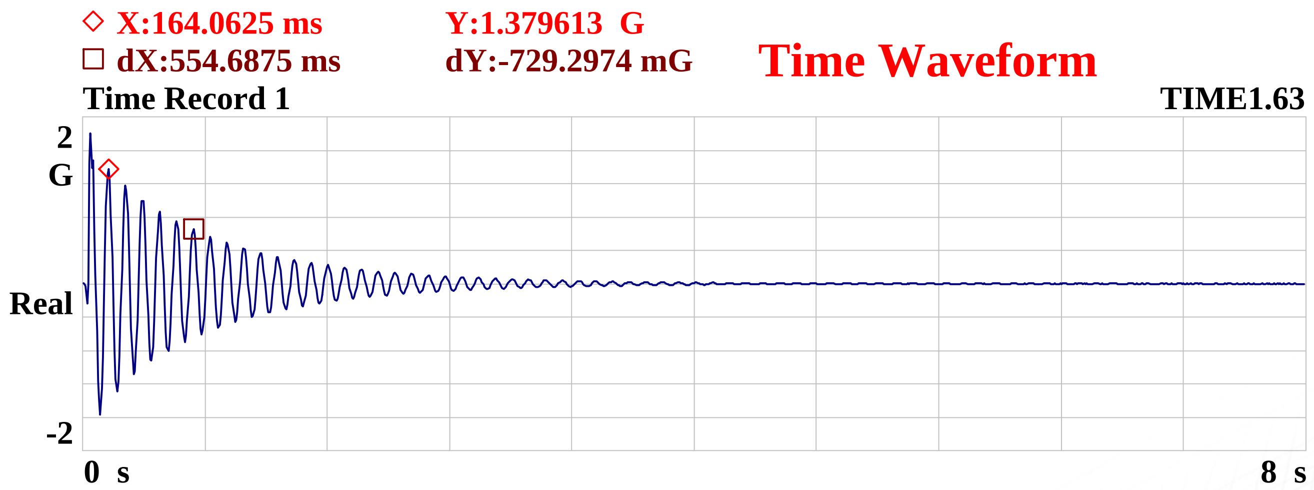


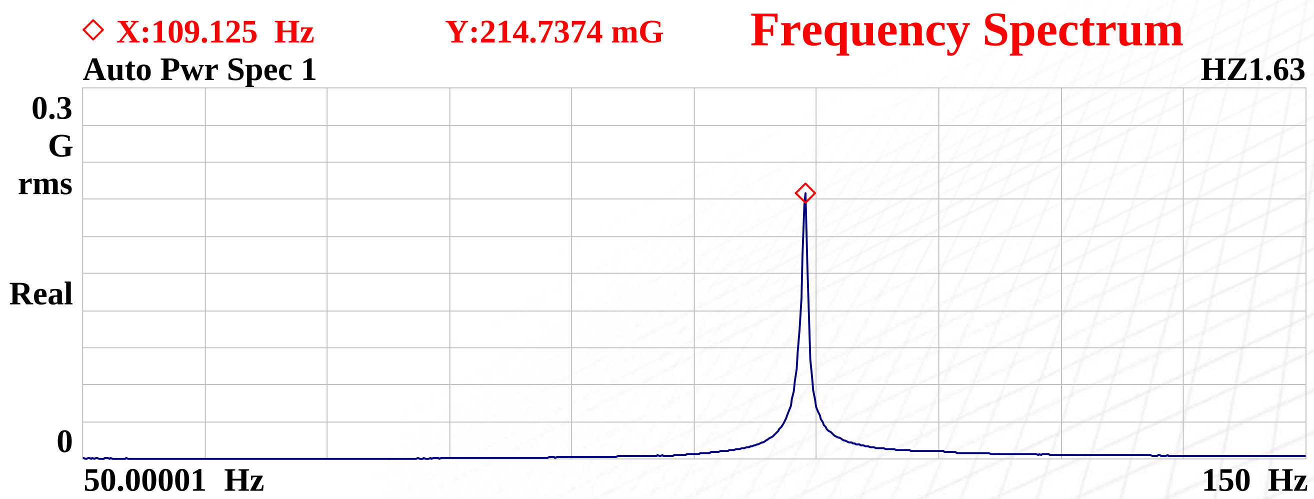
Machinery Fault Frequencies

Natural Frequency

- ✓ A result of the Mass (m) and Stiffness (k) of the machine design
- ✓ Resonance occurs when a natural frequency is excited by a force
- ✓ Critical speed occurs when the machine speed matches the natural frequency and creates resonance

Natural Frequency





$$f_n = (1/2\pi)\sqrt{k/m}$$

▲ INCREASE the stiffness (k) ▲ INCREASE the frequency (f)	▲ INCREASE the mass (m) ▼ DECREASE the frequency (f)

Natural Frequency

$$f_n = (1/2\pi)\sqrt{k/m}$$

10 lbs. **30 lbs.** **50 lbs.** **95 lbs.**

Pull Strength

Frequency Response ≈ 2000 Hz.

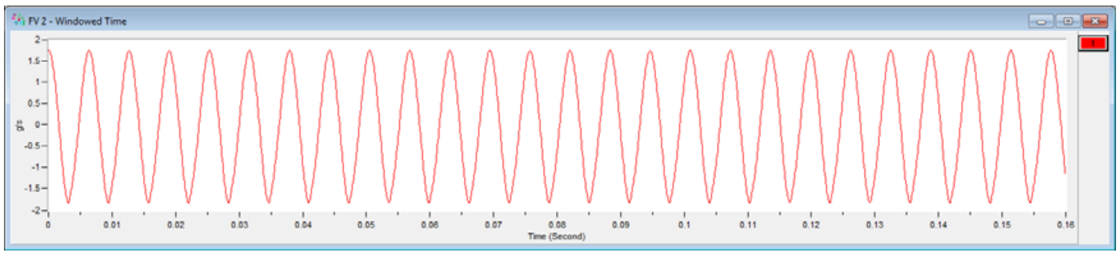
k/m ≈ k/m ≈ k/m ≈ k/m

Bump Testing Set-up

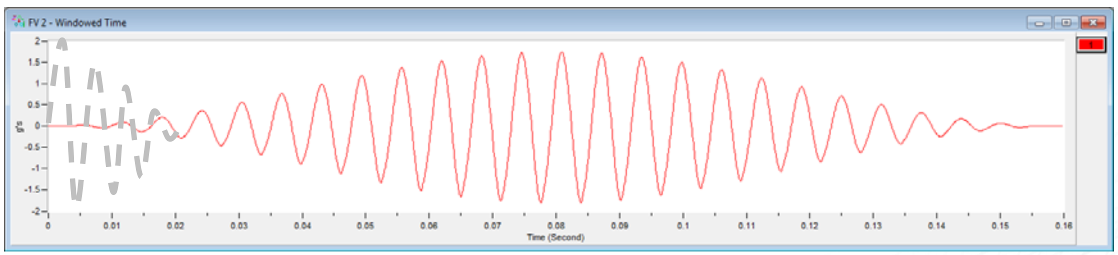
UNIFORM WINDOW

- ✓ Take your time – Bump around
- ✓ Do not over range or clip the input signal
- ✓ 800 – 1600 lines of resolution
- ✓ Try some different frequency spans
- ✓ Only 1 bump for each time record
- ✓ About 4 averages (depends on noise)

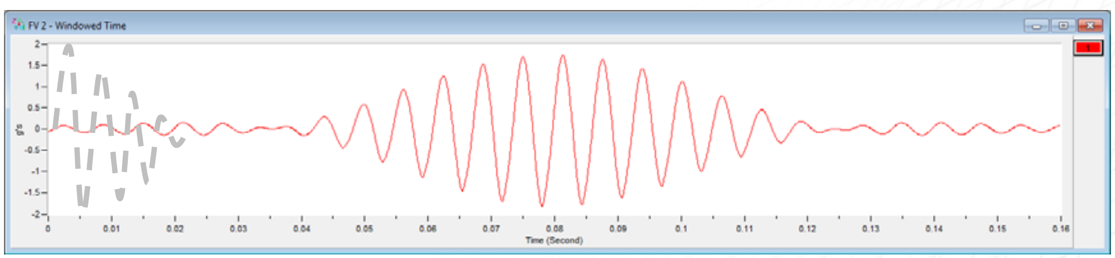
Uniform Window



Uniform



Hanning



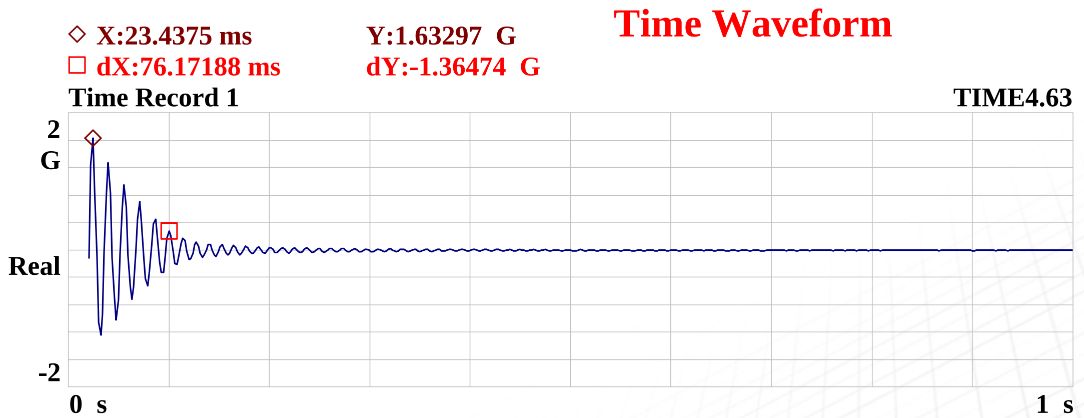
Flat Top

The Uniform window should be used for bump testing.

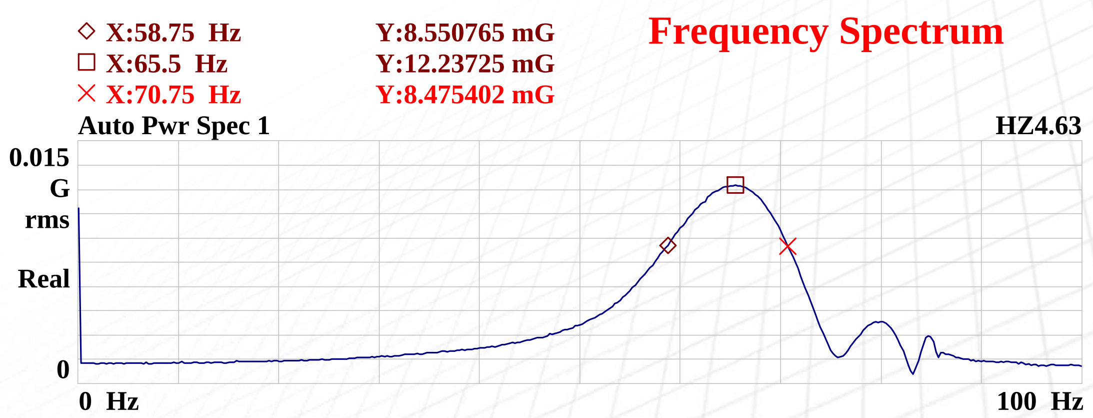
If you use the Hanning or Flat Top windows, they will filter out the response from the impact

Bump It !

TIME

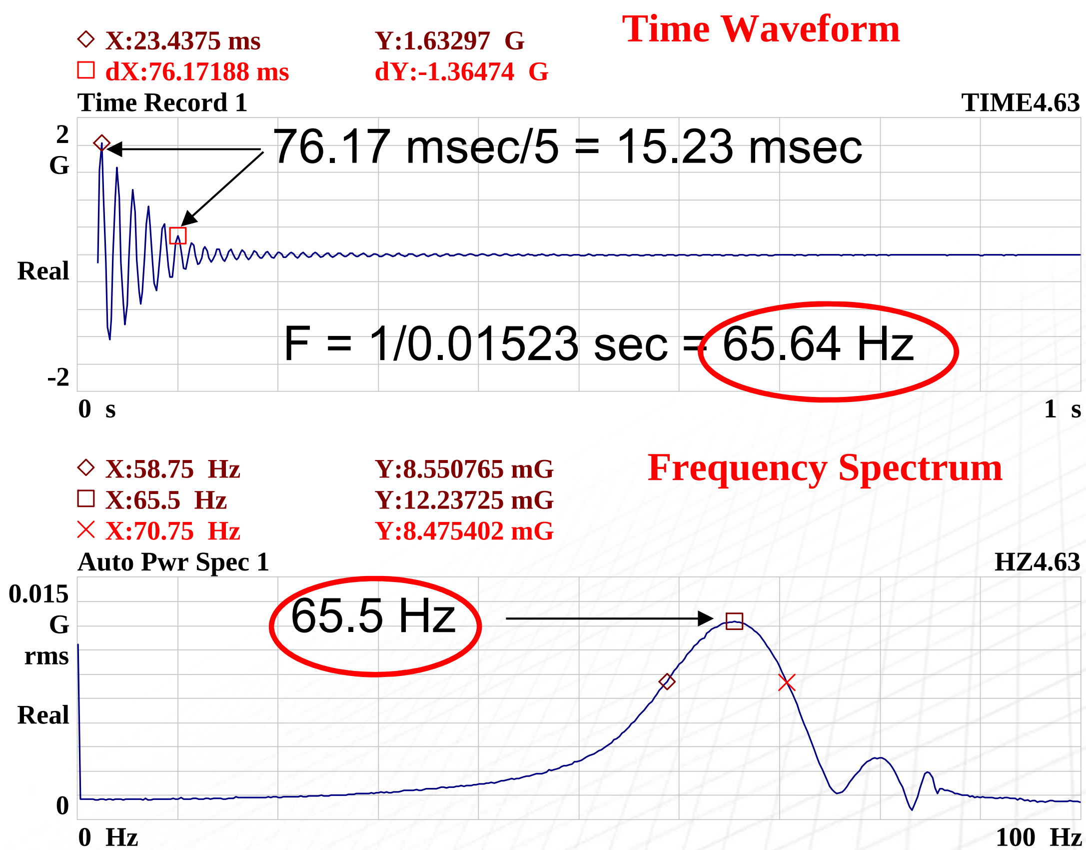


FREQUENCY

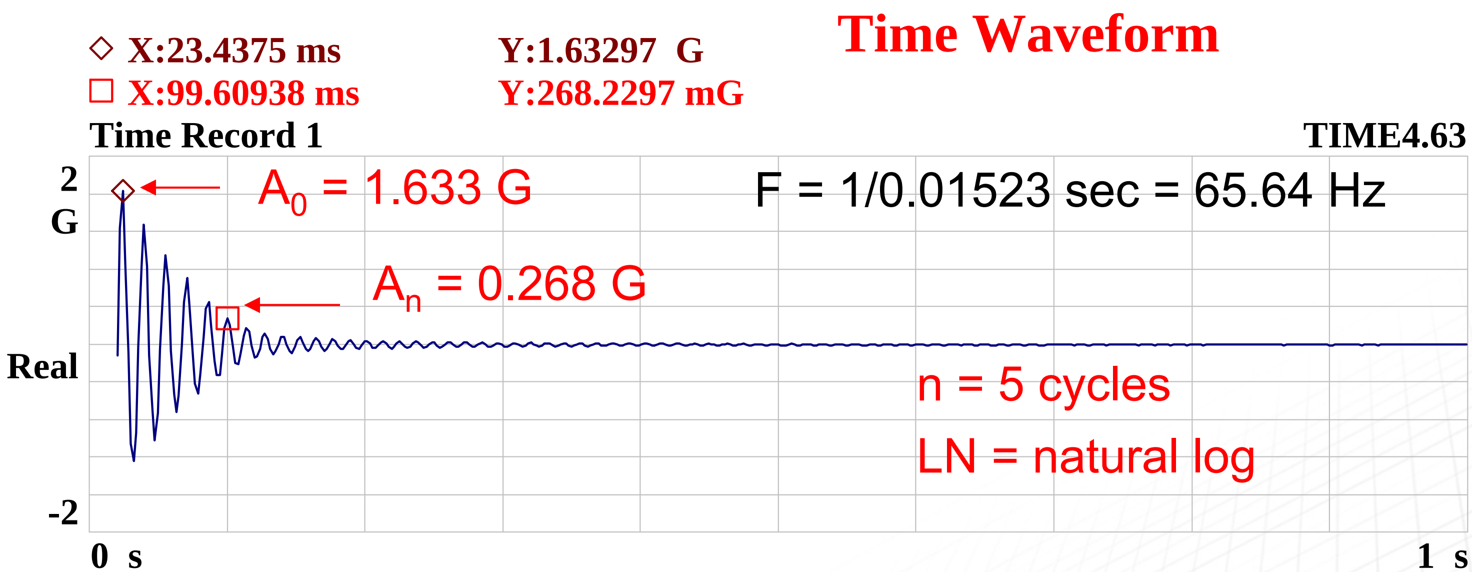


Mental Health Check !

The frequency measured in the time waveform should be the same frequency in the FFT.

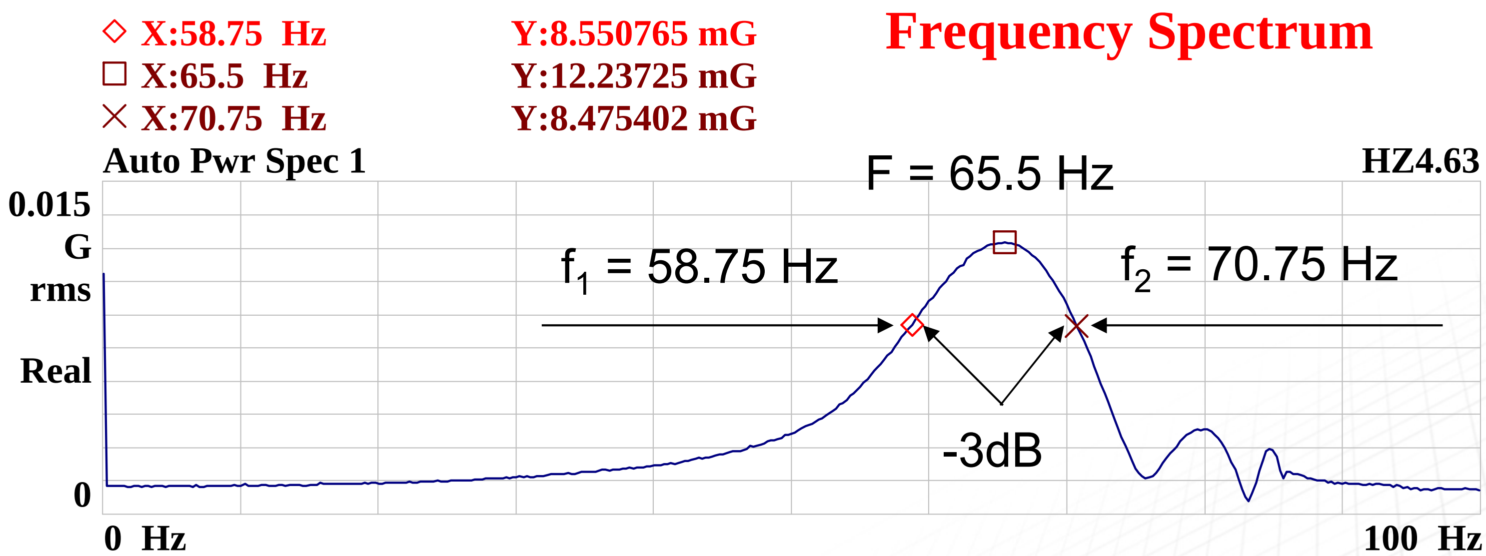


Time Waveform



1. **Log decrement = (1/n)[LN(A_0/A_n)] = (1/5)[LN(1.633/0.268)] = 0.36**
2. **Damping ratio = Log dec/2Pi = 0.36/2Pi = 0.36/6.28 = 0.057**
3. **Amplification factor = 1/(2*Damping) = 1/(2*0.057) = 8.68**

FFT or Spectrum



1. Find the –3dB points = A_F * .707 = 12.24 mG * .707 = 8.65 mG
2. Find the frequencies at the –3dB points (f_1 and f_2)
3. Amplification factor = F/ (f_2 - f_1) = 65.5/(70.75 – 58.75) = 5.46

Bump Testing Summary

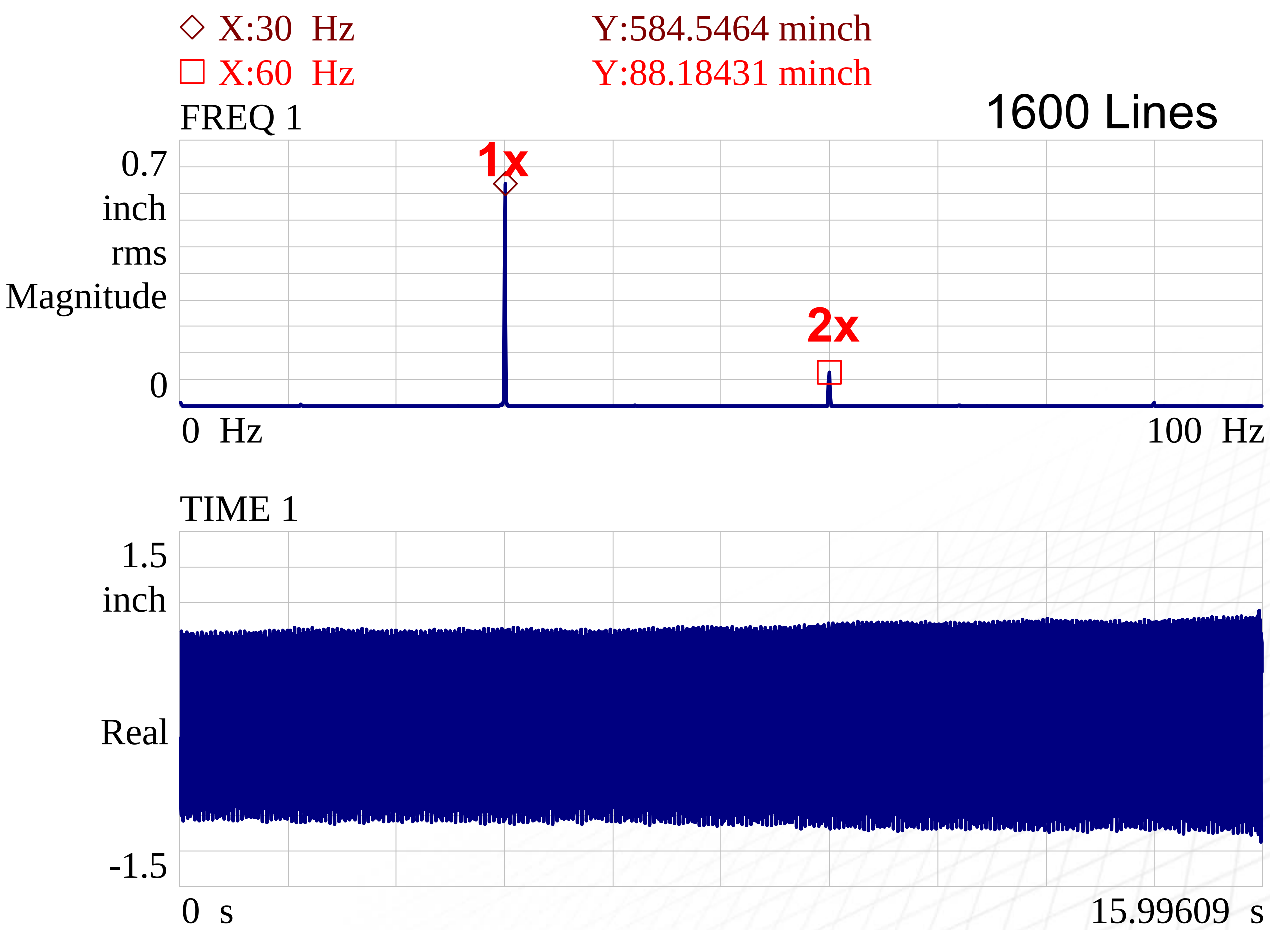
- ✓ Take your time
- ✓ Choose your weapon
- ✓ Bump around
- ✓ Uniform Window
- ✓ Look at the time waveform
- ✓ Look at the frequency spectrum
- ✓ Do a mental health check
- ✓ Calculate the amplification factor
- ✓ Change the mass
- ✓ Change the stiffness
- ✓ Add damping
- ✓ Bump around
- ✓ Compare and verify results after changes to the machine

1x (Running Speed)

✓ Mass Unbalance 1x

- Critical Speed 1x
- Misalignment 1x, 2x, 3x
- Looseness 1x, 2x, 3x, 4x, 5x, ….
- Runout 1x

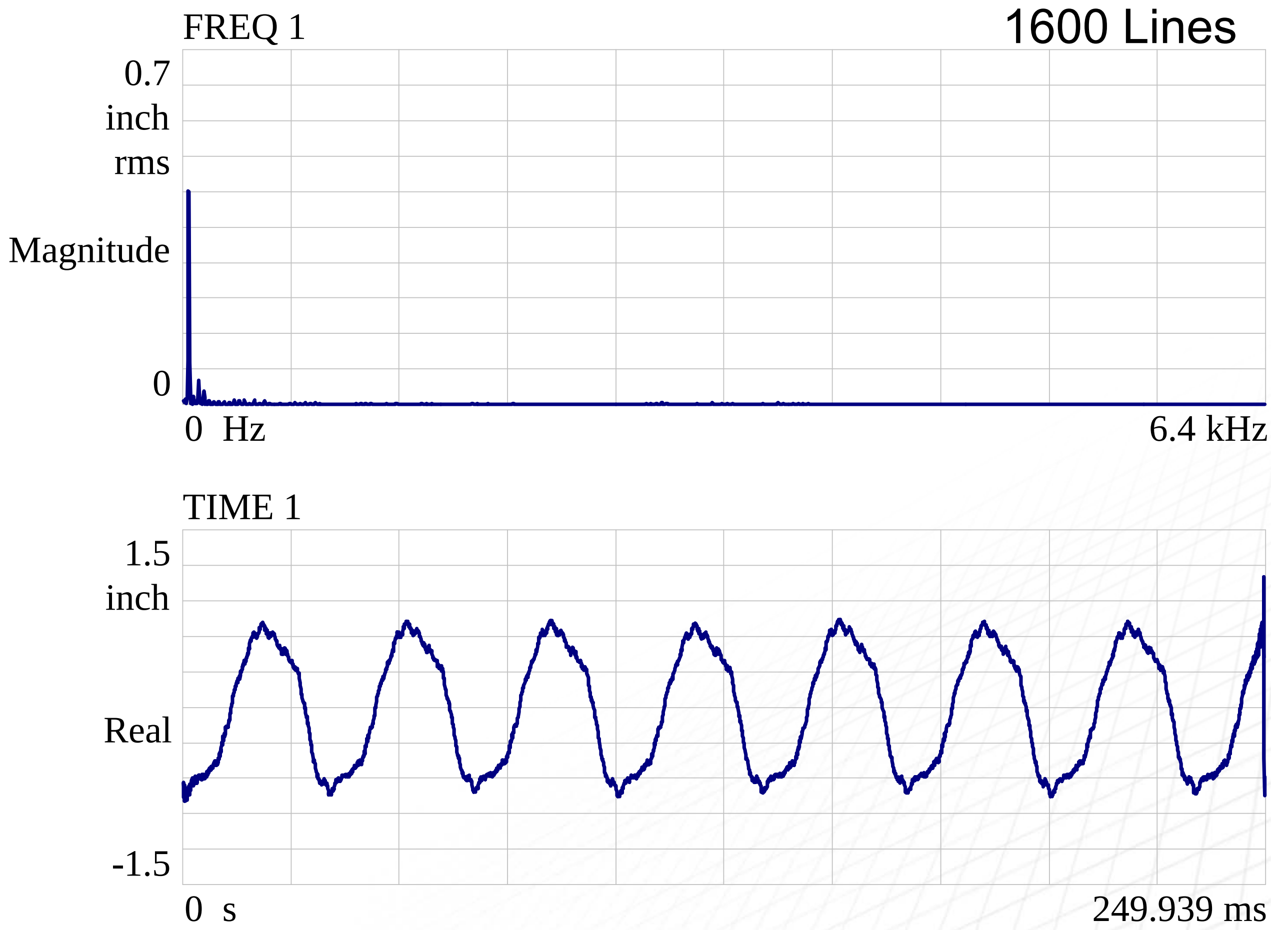
1x Mass Unbalance



fT = 1 ?

Usable FFT

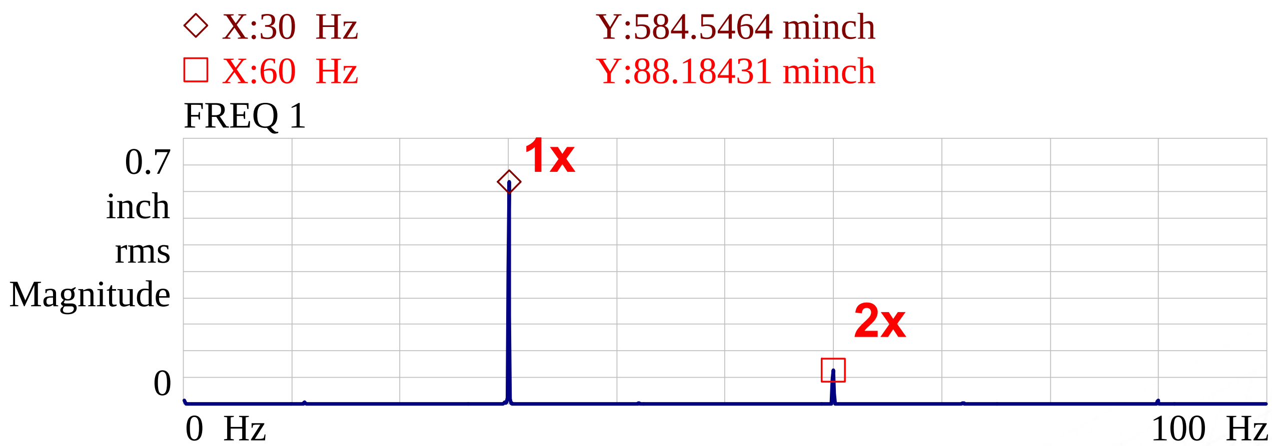
1x Mass Unbalance

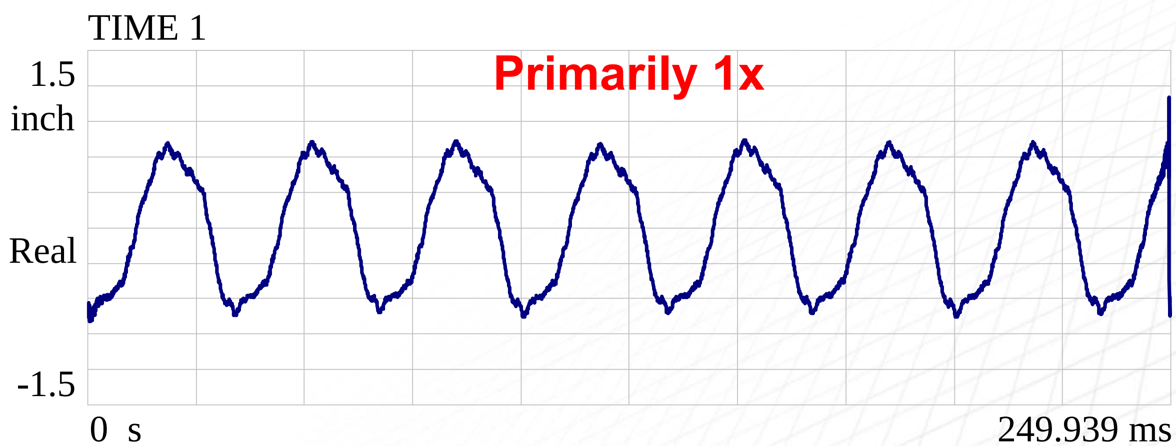


Ft = 1 ?

Usable Time Waveform

1x Mass Unbalance

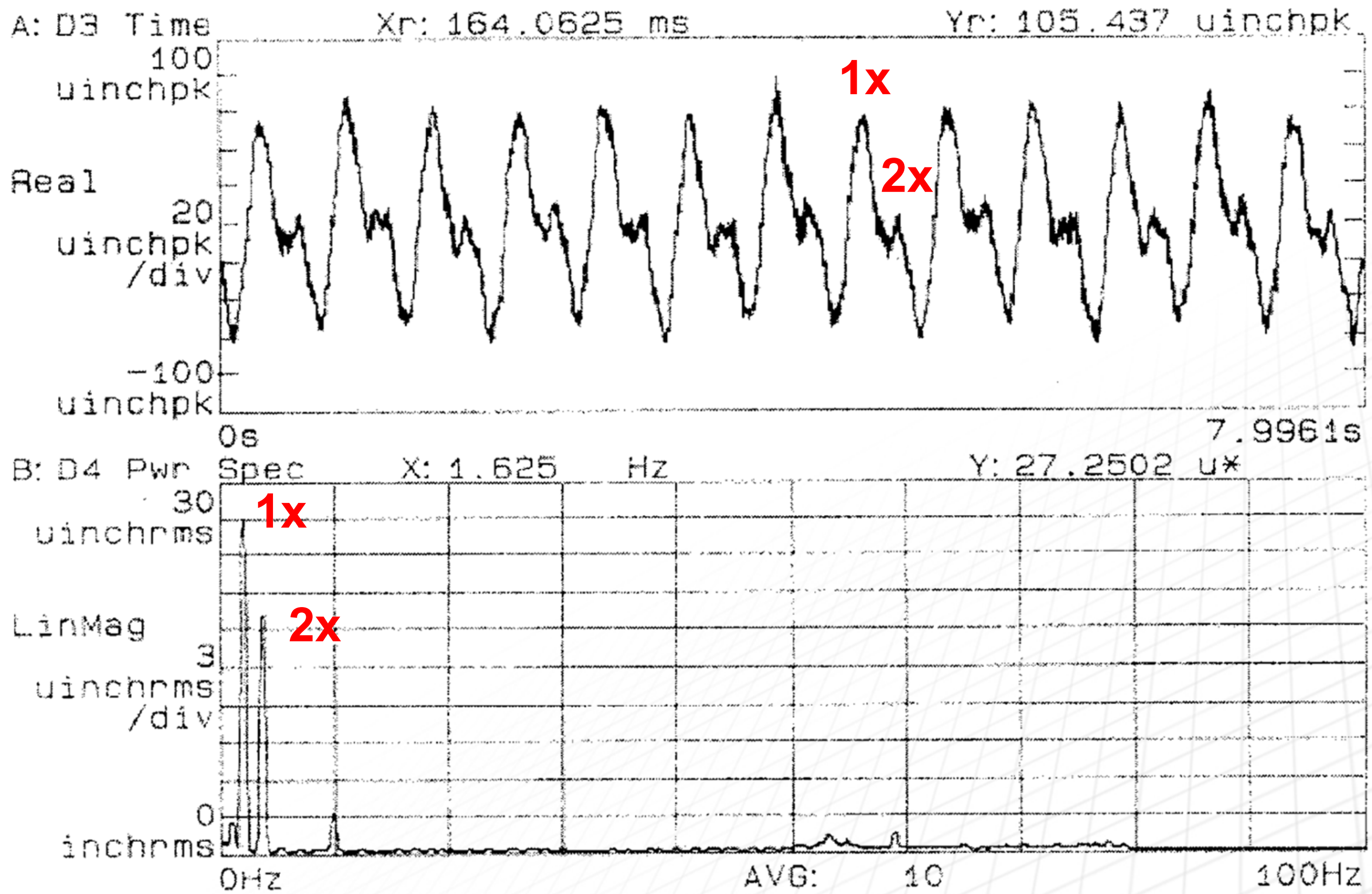




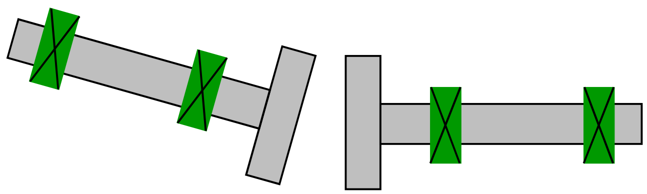
FT ≠ 1 !

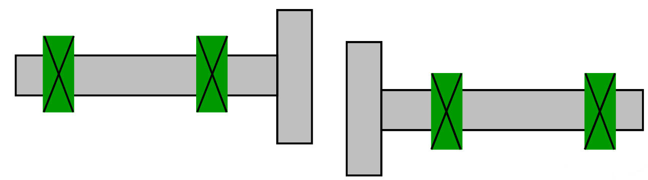
But it makes a nice set of plots to analyze !

1x, 2x, 3x Misalignment



1x, 2x, 3x Misalignment





1x

Angular

Misalignment

2x

Offset

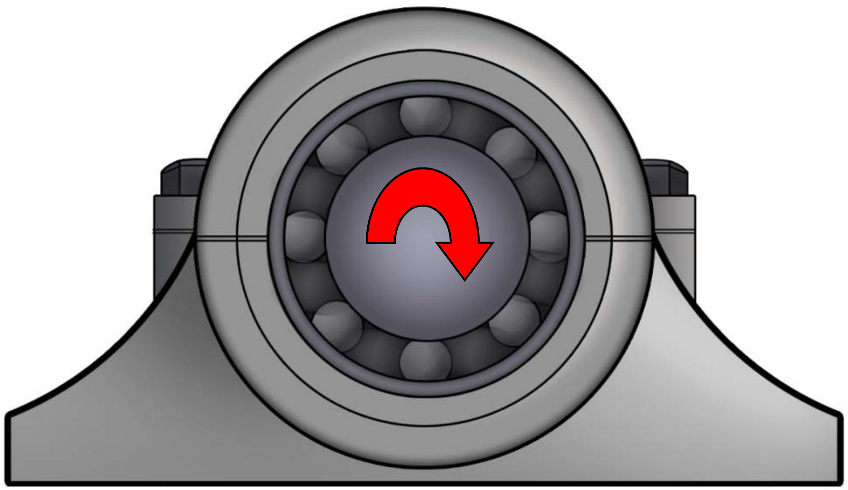
Misalignment

Look for a 180^0 phase shift across the coupling in axial vibration measurements. Be careful with the way you mount the accelerometer. Don't create the 180^0 phase shift by flipping the accelerometer around.

Rolling Element Bearings

- ✓ Rolling element bearings will not generate frequencies that are even multiples of running speed. They are non-synchronous.
- ✓ They often generate low amplitudes
- ✓ They have stages of failure starting with high frequency stress waves deteriorating to low frequency components.
- ✓ When the vibration gets better – shut the machine off immediately!

Rolling Element Bearing Frequencies *"Inner Race Rotates"*



Inner race and shaft rotate.

Outer race is held or fixed.

FTF = (Hz/2)[1-(B/P)cosCA]

BPFO = (N/2)Hz[1-(B/P)cosCA]

BPFI = (N/2)Hz[1+(B/P)cosCA]

BSF = (PHz/2B){1-[(B/P)cosCA]^2}

Where:

Hz. = shaft speed in cps

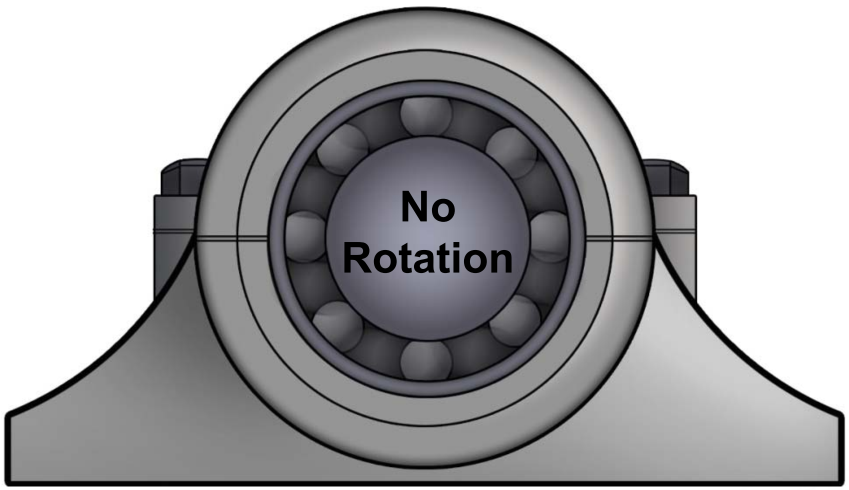
N = number of rolling elements

B = ball diameter

P = pitch diameter

CA = contact angle

Rolling Element Bearing Frequencies *"Outer Race Rotates"*



Inner race and shaft fixed.

Outer race rotates.

FTF = (Hz/2)[1+(B/P)cosCA]

BPFO = (N/2)Hz[1+(B/P)cosCA]

BPFI = (N/2)Hz[1-(B/P)cosCA]

BSF = (PHz/2B){1-[(B/P)cosCA]^2}

Where:

Hz. = shaft speed in cps

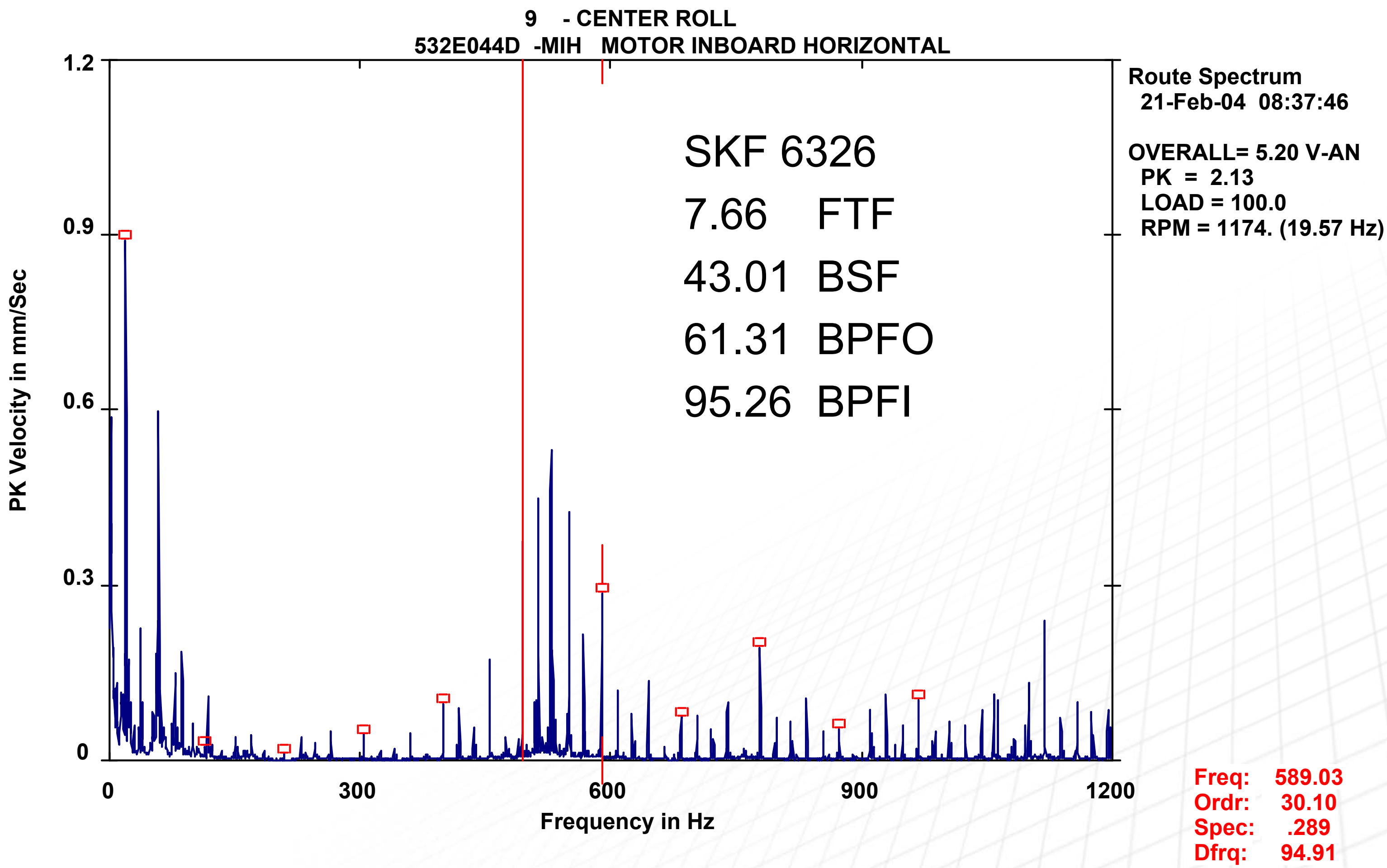
N = number of rolling elements

B = ball diameter

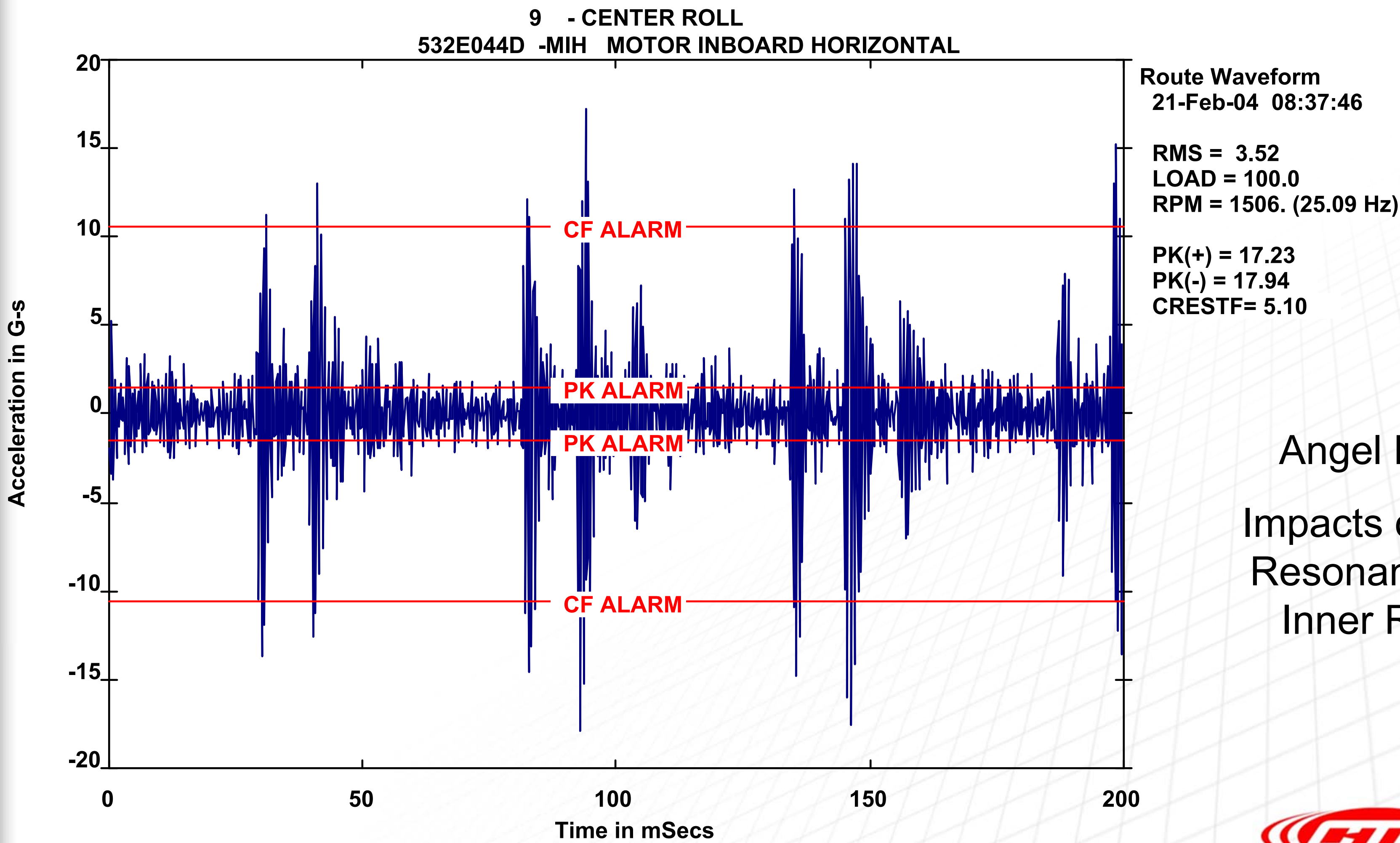
P = pitch diameter

CA = contact angle

Rolling Element Bearings (BPFI)



Rolling Element Bearings (BPFI)



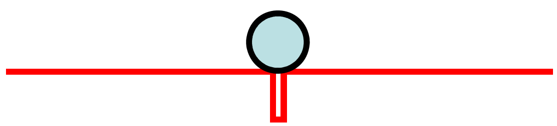
Angel Fish

Impacts create Resonance of Inner Ring

Rolling Element Bearings

ft = 1 ?

t is very small

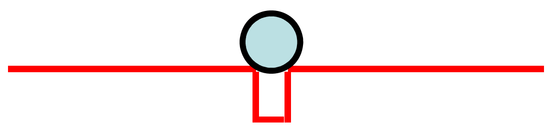


F is very high

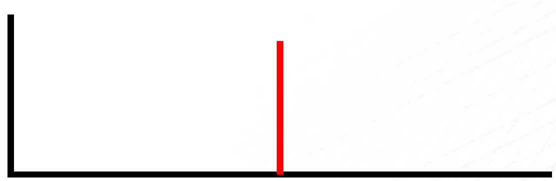
Rolling Element Bearings

ft = 1 ?

t is longer



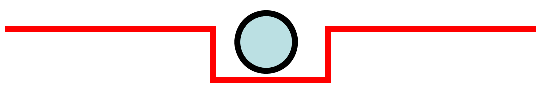
f is lower



Rolling Element Bearings

ft = 1 ?

T is really long



f is really low

Rolling Element Bearings ?

As the frequency gets lower bad things are happening !

CTC
Connection Technology Center, Inc.

Rolling Element Bearings ?

No vibration program?

No Reliability!

Rolling Element Bearings ?

You need all of the rolling elements, a good cage, and a solid inner race to have a quality bearing and low vibration measurment!

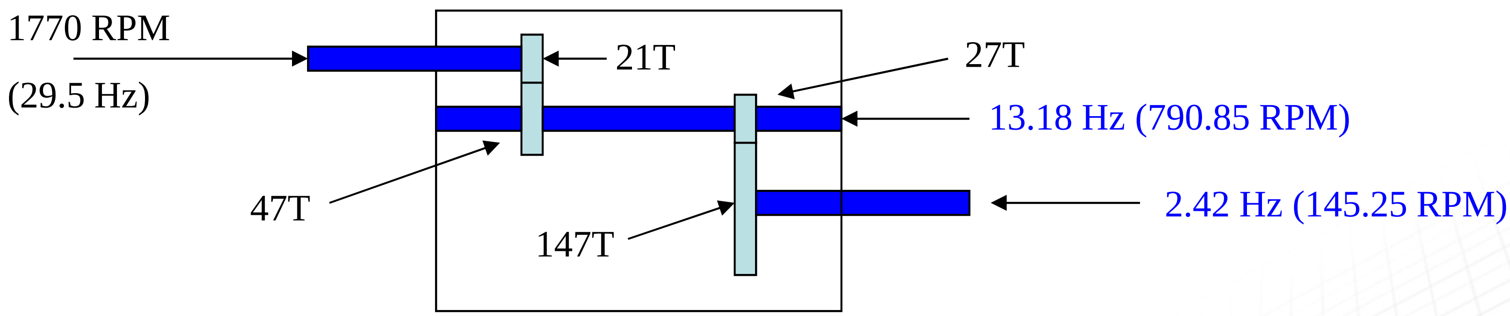
Rolling Element Bearings

Electrifying!

Gear Mesh

- ✓ Number of Teeth x Speed of the Shaft it is mounted on.
- ✓ Sidebands around gear mesh will be spaced at the shaft speed the gear is mounted on.
- ✓ Typically the vibration will be in the axial direction

Gear Mesh & Shaft Speeds



Shaft Speeds

Inter Speed = 29.5(21/47) = 13.18 Hz

13.18 x 60 = 790.85 CPM

Output Speed = 13.18(27/147) = 2.42 Hz

2.42 x 60 = 145.25 CPM

Gear Mesh

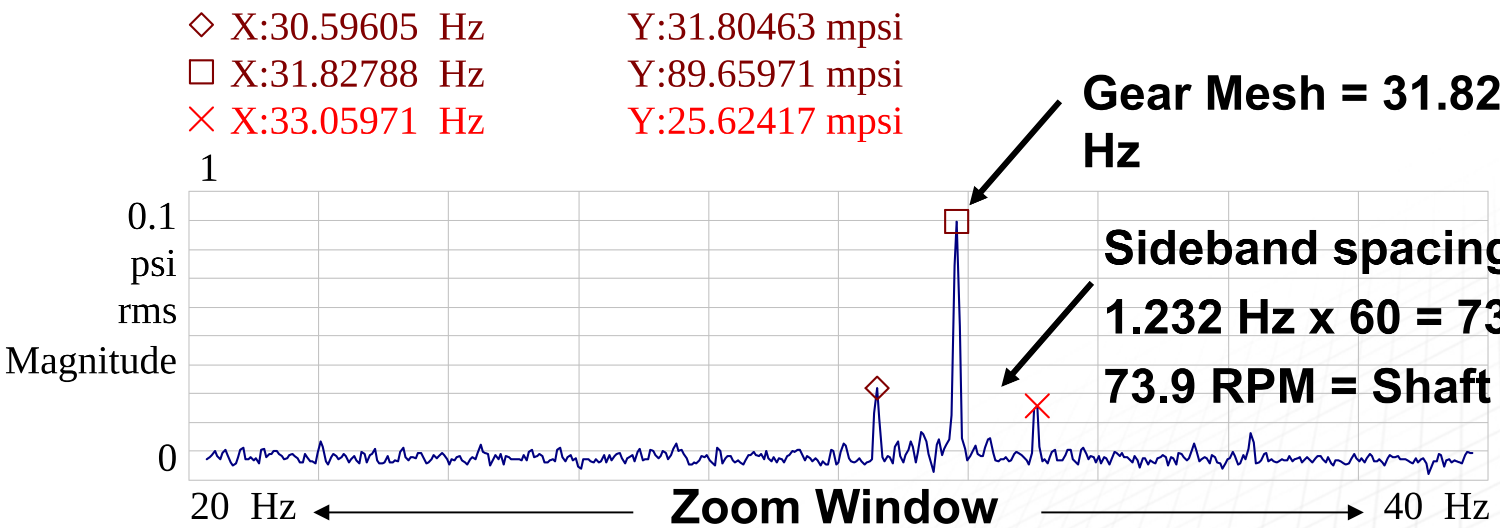
GMH = 29.5 x 21 = 619.5 Hz

619.5 x 60 = 37,170 CPM

GML = 13.18 x 27 = 355.88 Hz

355.88 x 60 = 21,352 CPM

Gear Mesh with Sidebands of Shaft Speed



Gear Mesh = 31.828 Hz

Sideband spacing = 1.232 Hz

1.232 Hz x 60 = 73.9 CPM

73.9 RPM = Shaft Speed

Fans

- ✓ Blade Pass
  - Number of Blades x Speed of the Shaft the rotor is mounted on.
  - Look at the damper and duct work for flow and restrictions.
  - Blade clearance, discharge angle, wear & tear
- ✓ Unbalance, misalignment, bearings

Pumps

- Vane Pass
  - Number of Vanes x Speed of the Shaft the rotor is mounted on.
  - Look at the input and output pressures
  - Vane clearance, discharge angle, wear & tear
- Recirculation
  - Random noise in FFT & Time Waveform
  - Axial shuttling, High back pressure, Low flow rate
  - Fluid being forced back into pump
- Cavitation
  - Random noise in the FFT & Time Waveform
  - Audible noise, Low back pressure, High flow rate
  - Air entrained in fluid
- Unbalance, misalignment, bearings

Motors (synchronous)

- ✓ Synchronous Speed
  - (2 x Line Frequency)/number of poles
- ✓ Stator
  - 2 x Line Frequency and Multiples
- ✓ Rotor
  - Sidebands Around Running Speed = Slip Frequency x Number of Poles with Multiples
- ✓ Unbalance, Misalignment, Bearings

Thank You !

You can find technical papers on this and other subjects at

www.ctconline.com

in the "*Technical Resources*" section

Connection Technology Center, Inc.
7939 Rae Boulevard
Victor, New York 14564
Tel: +1-585-924-5900
Fax: +1-585-924-4680