# Vibration Data collection
# (การเก็บข้อมูลการสั่นสะเทือน)

SCHOOL OF MECHANICAL ENGINEERING
SURANAREE UNIVERSITY OF TECHNOLOGY

Mr. Autsadayut Rodpai

## Vibration data collection.


- Vibration Sensors & Transducers
  - Selection
  - Location
  - Mounting
  - Etc.

- Frequency Span
- Line of resolution
- Aliasing filter
- Window filter etc.

- Waveform
- Spectrum

etc.

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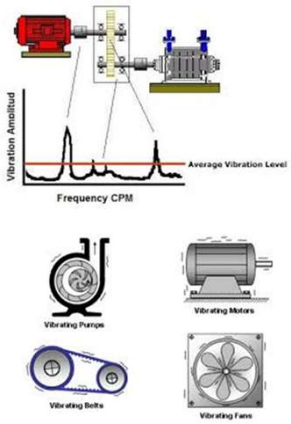
## What do you want to measure ?

- Machine vibration
- Structural vibration
- Building or Ambient vibration
- Human vibration

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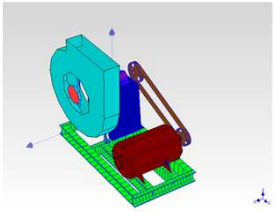
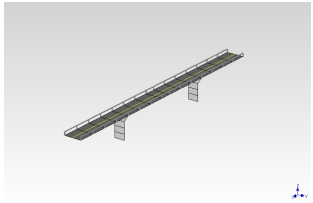


Blower structure



Bridge

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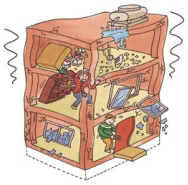
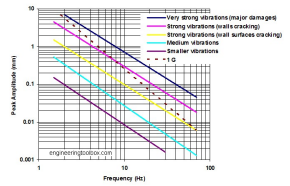


Ref: http://www.jssi.or.jp/english/eng-sib/e-sib-source.htm




The effects of low-frequency vibration on building constructions are indicated in the diagram

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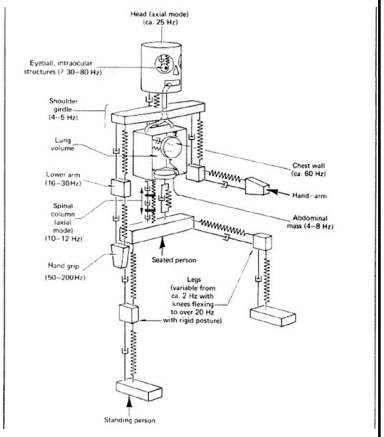


Ref: http://www.jssi.or.jp/english/eng-sib/e-sib-source.htm

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## Vibration Transducers

*Definition, by Vibration Institute, USA*

Any device that translates the magnitude of one quantity into another quantity.

Three of the most common measure in vibration measurements are

1) Displacement

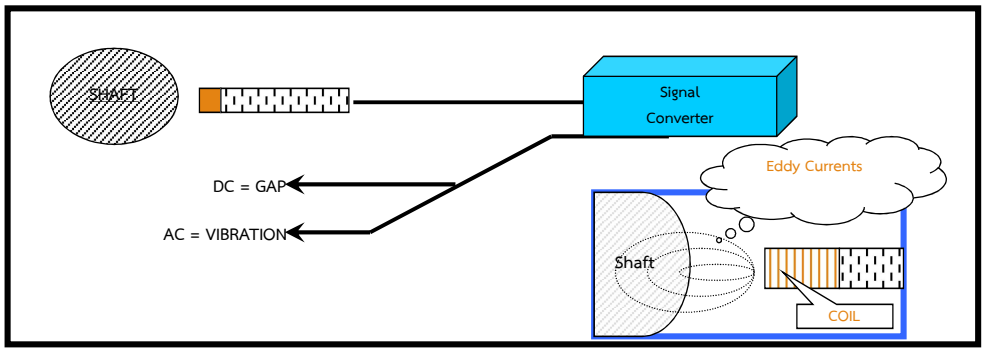
2) Velocity

3) Acceleration

*ที่มา www.Vibinst.org*

## Transducers

Proximity / Eddy Current Sensors

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# Proximity Probe

Advantages

- Measures Displacement Directly
- Best for Low Speed Equipment
- Best for Journal Type Bearings
- Good Signal Strength at Low Frequencies
- Can Measure Vibration
- Can Measure Distance – Thrust Position
- Excellent for Turbo Machinery

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# Proximity Probe

Disadvantages

- Expensive to Install
- Expensive to Purchase
- Requires fixed Cable Length from Proximity Probe to Proximiter
- Mostly Limited to Applications Measuring a Gap
- Poor High Frequency Signal Strength
- Not Good at Measuring Rolling Element Bearings
- Very Sensitive to Surface Material
- Only Good for Ferrous Materials

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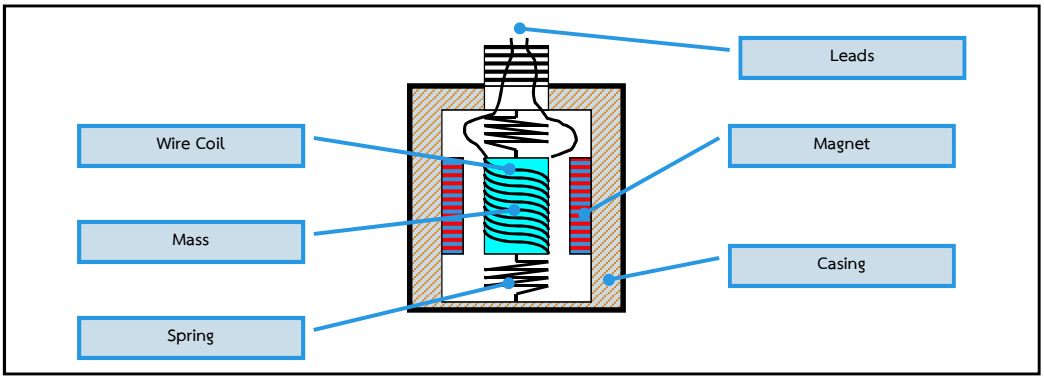
# Transducers

Velocity Sensor

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# Velocity Sensor

Advantages

- Easy to Install – Case Mount
- Not Sensitive to Mounting Surface
- Large Signal Output
  - 1000 mV per Inch / Sec.
- Rugged Design Can be Dropped
- Self Generates Signal Requiring No Power Supply
- Good for General Vibration Measurement
- Good Temperature Range
  - Up to 600 Degrees F

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# Velocity Sensor

Disadvantages

- Limited Life - Spring Design will Wear Out
- Limited Frequency Range Due to Resonance of Spring
  - Low Frequency 600 CPM
  - High Frequency 60,000 CPM
- More Expensive than Most Accelerometers
- Sensitive to Magnetic Fields
- Large Cross Axis Vibration Can Destroy
- Spring Develops Frequency Memory
- Not Good for Early Bearing Detection
- Slightly Large in Size

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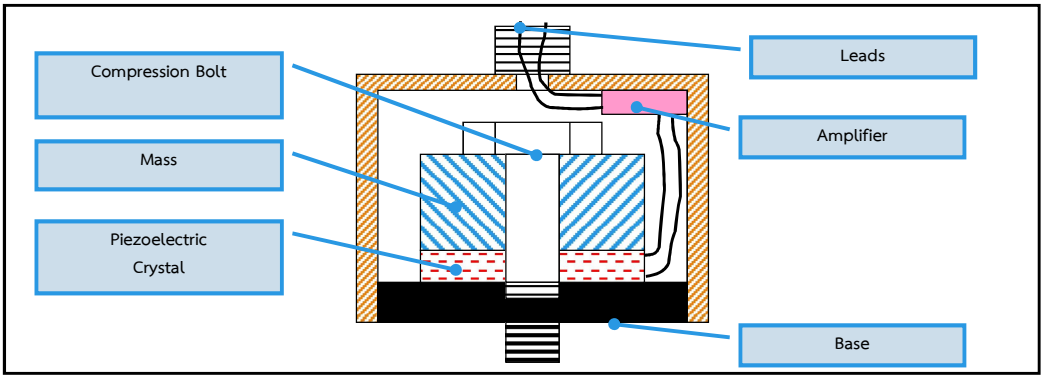
# Transducers

Compression Accelerometers

- แข็งแรง
- ทนทาน
- ความถี่ รีโซแนนซ์ สูง

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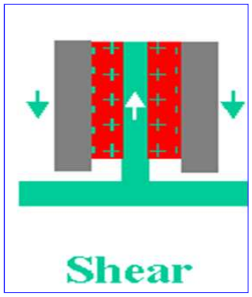
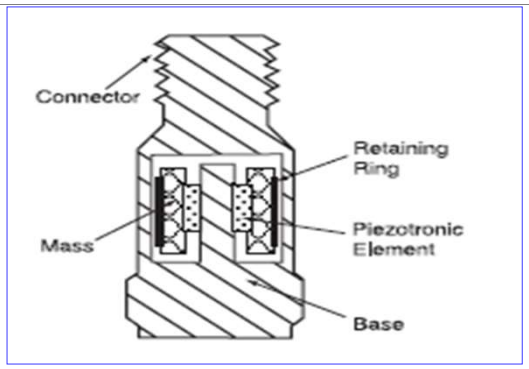
# Accelerometer types

Shear mode Accelerometer




- Good stiffness
- Good durability
- Reasonable resonant frequency
- Less susceptible to inputs from base strain by thermal transient

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# Accelerometer

Advantages

- Large Frequency Range
  - Low Frequency – 10 CPM
  - High Frequency – 600,000 CPM +
- High Temperature Units Available
  - Natural Crystal 1,200 Degrees F $$$$$$$
- Small Design
- Not Sensitive to Magnetic Fields
- Long Life Expectancy – 10+ Years
- Excellent for Bearing and Gear Detection as well as General Vibration

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# Accelerometer

Disadvantages

- Low Voltage Signal !!!
- Sensitive to Mounting Surface
  - Perpendicular to 2%
  - Base Strain and Mounted Resonance Frequency Limits
- Do Not Drop !
- Requires External Power
- Signal Sensitive to:
  - Cable in Magnetic Fields
  - Variable Frequency Drives
  - Improper Cable Shield Grounding
- Requires Twisted Shielded Pair Wiring
- Requires Military Type Connectors

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# Other Transducers

Modified Accelerometer Outputs

- **Acceleration Integrated to Velocity**
  - Good Velocity Signal
  - Bad High Frequency Roll Off
  - No Shock Pulse
- **Acceleration Modified to 4-20 mA**
  - Good for PLC / DCS Direct Connection
  - No Dynamic Data to Analyze
  - No Shock Pulse

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# *Accelerometer* Selection Guidelines

**1.Measurement Range/Sensitivity**

Determine the maximum peak vibration amplitude that
will be measured and select a sensor with an appropriate measurement range.

The maximum measurement range=+/- 5V divided by
the sensitivity

## Accelerometer Selection Guidelines

| Sensitivity | ± 5 VDC output range |
|---|---|
| 1 mV/g | ± 5000 g |
| 10 mV/g | ± 500 g |
| 100 mV/g | ± 50 g |
| 1000 mV/g | ± 5 g |
| 10,000 mV/g | ± 0.5 g |

## Accelerometer Selection Guidelines

**2.Frequency Range**

Determine the lowest and highest frequency to be analyzed.

## Accelerometer Selection Guidelines

Recommended Frequency Spans for rotating machines (Lower to Upper Frequency), speed up to 600 rpm

| Fault | Lower frequency | Upper frequecy |
|---|---|---|
| Shaft Vibration | Up to 2 Hz | 10 x RPM |
| Rolling Element Bearings | Up to 2 Hz | 40-50 x RPM |

## Accelerometer Selection Guidelines

Recommended Frequency Spans for Structural, Building and Ambient vibration (Lower to Upper Frequency)

| Fault | Lower frequency | Upper frequency |
|---|---|---|
| Structural vibration | Up to 0.5 Hz | 4-5 kHz |
| Building and Ambient | Up to 1 Hz | 80 Hz (ref. ISO 2631) |
| Human vibration | Up to 0.1 Hz | 45 Hz |

## Accelerometer Selection Guidelines

**3.Temperature Range**

Determine the highest and lowest temperatures that the sensor will be subjected to and verify that they are within the specified range for the sensor.

| Accelerometer Type | Temperature Range |
|---|---|
| Normal temperature | 90 – 140 C |
| High Temperature | Up to 140 C |
| | |

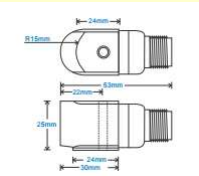
## Accelerometer Selection Guidelines

**4.Size**

Two parameters to be considered, footprint and clearance.

**Footprint** – area covered by the base of sensor

**Clearance** – the height above the surface required to fit the sensor and cable.

Side Exit :

## Accelerometer Selection Guidelines

**5. Cable**

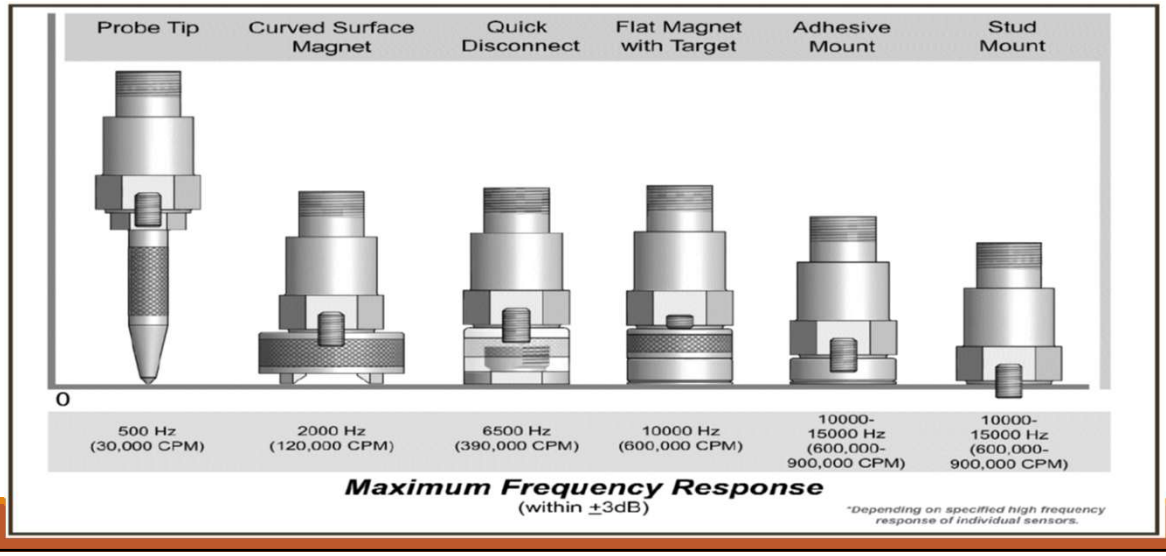
- Silicon Cable

| Physical Properties | | | | |
|---|---|---|---|---|
| Summary | | Cores | Jacket | Finished Cable |
| Flame retardant | | IEC 60332-3-24 | TBA | TBA |
| Fluids | Acid resistance | Excellent | Good | Good |
| | Base resistance | Excellent | Good | Good |
| | Fuel resistance | Excellent | Good | Good |
| | Oil resistance | Excellent | Good | Good |
| | Water resistance | Excellent | Good | Good |
| Halogen free | | - | - | - |
| Low smoke | | IEC 61034-2 | IEC 61034-2 | IEC 61034-2 |
| Radiation tolerance | | 2x 10^5 Gy | 6x 10^5 Gy | 2x 10^5 Gy |
| Weight | | N/A | N/A | 46 g/m |
| Temperature | | -65ºC +150ºC | -50ºC +150ºC | -50ºC +150ºC |

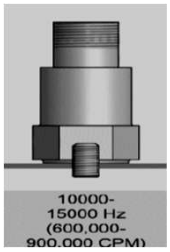
- Braided Screened & Drain Wire Cable

| Physical Properties | | | | |
|---|---|---|---|---|
| Summary | | Cores | Jacket | Finished Cable |
| Flame retardant | | IEC 60332-3-24 | IEC 60332-1 | IEC 60332-1 |
| Fluids | Acid resistance | Excellent | Good | Good |
| | Base resistance | Excellent | Fair | Fair |
| | Fuel resistance | Excellent | Good | Good |
| | Oil resistance | Excellent | Excellent | Excellent |
| | Water resistance | Excellent | Excellent | Excellent |
| Halogen free | | - | IEC 60754-2 | - |
| Low smoke | | IEC 61034-2 | - | - |
| Radiation tolerance | | 2x 10^5 Gy | 10^6 Gy | 2x 10^5 Gy |
| Weight | | N/A | N/A | 28 g/m |
| Temperature | | -65ºC +150ºC | -40ºC +100ºC | -40ºC +100ºC |

# Sensor Mounting Techniques




## 1. การยึดโดยใช้สลักเกลียว (Stud Mount)



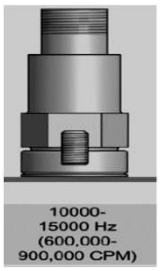

ข้อดี

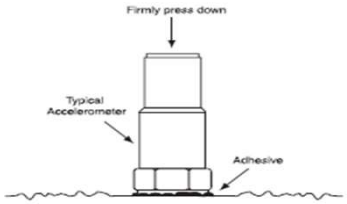
เป็นการยึดที่แน่นหนามั่นคงจึงมีความถี่ตอบสนองที่สามารถใช้งานได้สูง

## ข้อเสีย

1. ไม่สะดวกถ้าต้องการตรวจวัดการสั่นสะเทือนเป็นครั้งคราว
2. ง่ายต่อการเกิด Ground effect ถ้าติดตั้งไม่ดีพอ

## 2. Adhesive Mount (การยึดโดยใช้กาว)




Mounting Pad


Epoxy

Motor Fin Mounting Stem

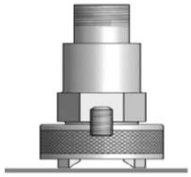
### 3. การยึดโดยการใช้แม่เหล็ก (Magnetic Mount )

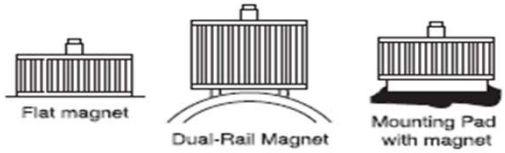

**ข้อดี**

สะดวกและรวดเร็ว เหมาะสำหรับการตรวจวัดเป็นครั้งคราว

**ข้อเสีย**

1. ชิ้นส่วนที่จะวัดการสั่นสะเทือนจะต้องเป็นเหล็ก
2. ควรใช้วิธีนี้เมื่อความถี่ใช้งานไม่เกิน 2.5 kHz
3. ควรใช้ที่อุณหภูมิต่ำกว่า 150 องศาเซลเซียส

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# 4. Hand-held Probe Tip

**ข้อดี**

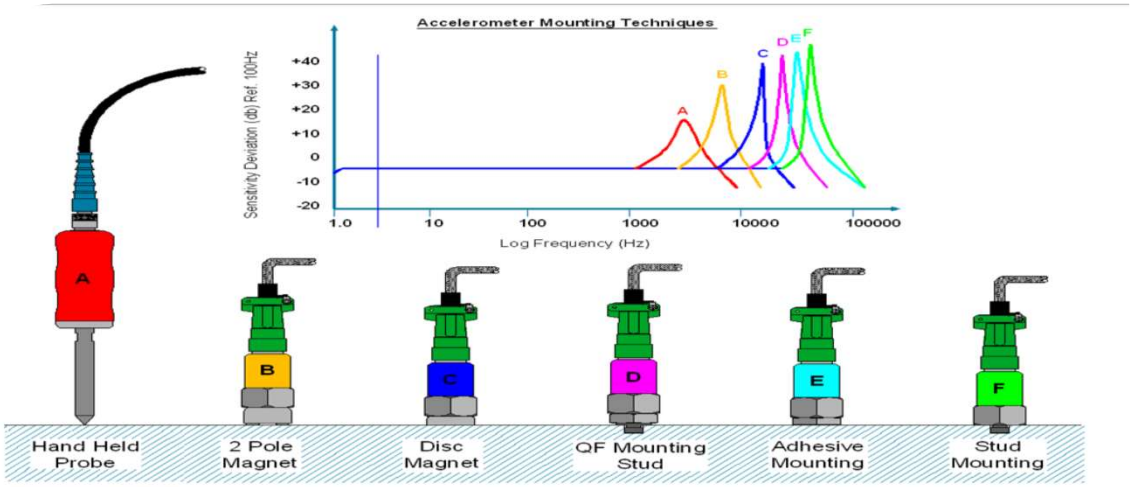
เป็นวิธีการที่ง่าย สามารถวัดในที่แคบๆได้ดี

**ข้อเสีย**

1 มีข้อจำกัดด้านความถี่มาก โดยใช้งานได้ที่ความถี่ไม่เกิน 1 kHz

2 การอ่านค่าไม่ค่อยมีเสถียรภาพ เนื่องมาจากความแข็งแรงโดยรวมมีค่าต่ำ

## Accelerometer Mounting Techniques - Practical Tips



## Vibration Instrumentation

There are different types of instruments for collecting data.

*Meters*

*Oscilloscopes*

*FFT Analyzers*

*Data collectors*

*Virtual instruments*

- *The oscilloscope - analog or digital - shows the time waveform only and is used for screening and analysis of waveform shape and frequencies.*
- *The oscilloscope can be used to evaluate phase and orbits.*
- *The FFT and electronic data collector are used for time waveform and spectrum analysis is used to track rapidly occurring transient events.*
- *Computer based virtual instruments provide an opportunity for the analyst to create an instrument for almost any task.*

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## Vibration Instrumentation

*Meters*

- *Vibration meters that measure voltage serve to make direct overall readings from the output of*
- *a transducer.*
- *In many cases the meter will read out volts directly.*
- *By dividing the measured voltage (peak or rms) by the transducer scale value in millivolts*
- *per engineering unit, the overall peak or rms value of the signal can be found.*

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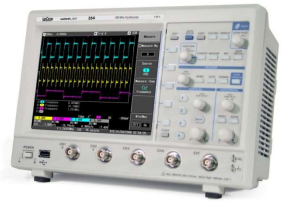
# Vibration Instrumentation

## *Oscilloscope*

*Analog Oscilloscope*



*Digital Oscilloscope*

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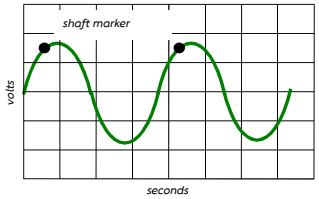
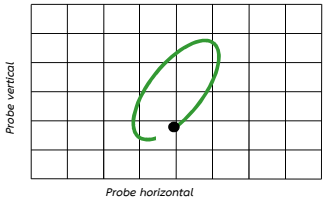
# Vibration Instrumentation

## *Oscilloscope*




*Waveform*




- *Orbit plot*

- *Good for viewing time waveforms and orbits*
- *Can display markers for phase*
- *Triggers can be used for initiating data acquisition*
- *Horizontal (time) and vertical (amplitude) scales are adjusted to show desired range of data*
- *May be digital (discrete values) or analog (continuous values)*

## Vibration Instrumentation

### *FFT Analyzers*

*Analyzer*

*Portable vibration analysis*
*With Ethernet connection*

- *Digital device that samples value to make a digitized block of waveforms data from which A spectrum can be calculate*
- *Ability to see spectrum key advantage over an oscilloscope*
- *These days, often PC card or USB based for use with laptop*

## Vibration Instrumentation

### *Electronic Data Collectors*

*DLI*


*LUCEDA*

*MaintTech(CXM)*

*CSI*

- *Acquires and stores a range of vibration data types*
- *Interact with a database to allow trending of vibration*
- *May use a route to allow simple data collection*
- *May perform many of the functions of an FFT analyzer*

| Common Instrument Systems | | |
|---|---|---|
| *Description* | *Component* | *Capabilities* |
| *Simple Meter* | *Transducer and Meter* | *Overall vibration amplitude peak, average or rms* |
| *Oscilloscope* | *Transducer and Oscilloscope* | *Overall vibration, amplitude and frequency, pulse shape, and frequency* |
| *Single and Dual Channel FFT Analyzer* | *Transducer, Reference Signal, FFT Analyzer, Plotter* | *average or instantaneous spectrum and time waveform for selected frequency span, phase, orbit, transfer function and coherence, real and imaginary plots.* |
| *Virtual Instrument* | *Transducers, Laptop computer, Data Acquisition Box, Printer, Reference Signal* | *simulated instruments of any type* |
| *Electronic Data Logger* | *Transducer, Reference Signal, FFT Analyzer, Computer, Printer* | *data acquisition, limited spectrum analysis, data storage, trending, and display* |

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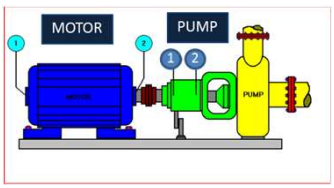
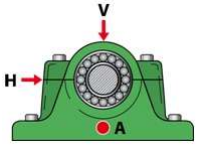
# Measurement points

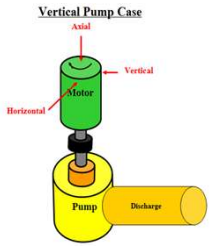
การกำหนดจุดวัดสำหรับวัดการสั่นสะเทือนนั้น พิจารณาดังนี้

1. วัดใกล้แหล่งกำเนิดการสั่นสะเทือน
2. ถ้าต้องวัดค่าแบบ Route ต้องทำการวัดค่าการสั่นสะเทือนที่ตำแหน่งเดิมทุกครั้ง

Rotating Machines : ISO 10816

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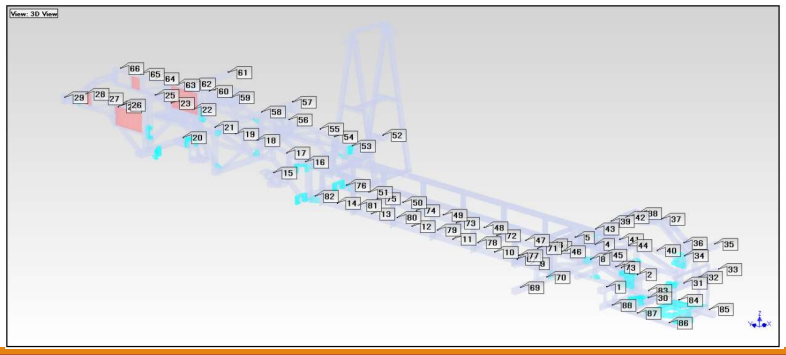
# Measurement points

**Structural vibration**

1. Reference point : At High vibration or source of vibration
2. Response point :

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# Vibration excitation:

Impulse Hammer : Impulse hammer system may be used in conjunction with a spectrum analyzer

| | Sensitivity (±15%) | Measurement Range | Resonant Frequency |
|---|---|---|---|
| Printed Circuit Boards & Hard Drives | 100 mV/lbf(±20%) | 50 lbf pk | ≥100 kHz |
| Lightly Damped Panels & Frames | 50 mV/lbf | ±100 lbf pk | >=15 kHz |
| Medium sized structures such as Car Frames, Engines, & Machined Parts | 50 mV/lbf | ±100 lbf pk | >=22 kHz |
| | 10 mV/lbf | ±500 lbf pk | |
| | 5 mV/lbf | ±1000 lbf pk | |
| Heavier sized components such as Pumps & Compressors | 1 mV/lbf | ±5000 lbf pk | >=22 kHz |
| Heavy Structures such as Tool Foundations & Storage Tanks | 1 mV/lbf | ±5000 lbf pk | >=12 kHz |
| Large Structures such as Buildings, Bridges, & Ships | 1 mV/lbf | ±5000 lbf pk | >=5 kHz |

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# Vibration excitation:

Impulse Hammer : Application

- Structure Health Testing
- Resonance Determination
- Modal Analysis

Structure Health Testing

**Structure Health Testing:**

- Crack
- Porosity
- Nodularity
- Hardness/ Density
- Etc.

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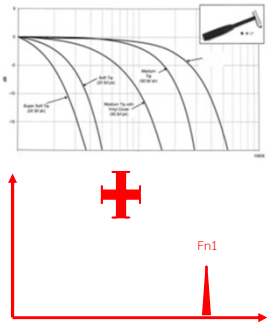
# Vibration excitation:

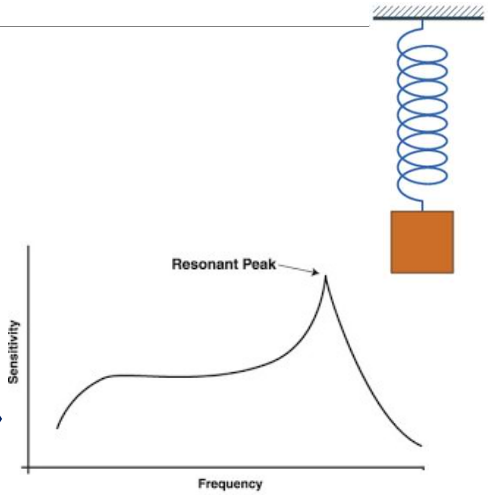
$$\text{Natural frequency (fn)} = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$$

Impulse Hammer : Application

- Structure Health Testing
- Resonance Determination
- Modal Analysis

Resonance Determination

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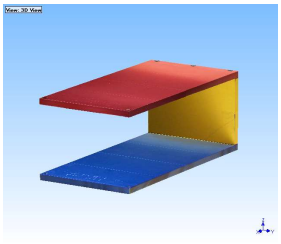
# Vibration excitation:

Impulse Hammer : Application

- Structure Health Testing
- Resonance Determination
- Modal Analysis

- Frequency (Natural frequency)
- Damping
- % Damping
- Animation (Mode shape)



Modal Analysis

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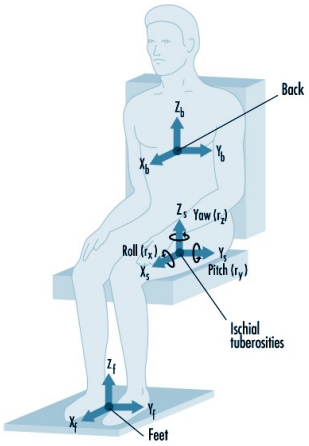
# Measurement points

Human vibration

1. **Whole-body vibration** is transmitted to the body as a whole, mainly through the supporting surface (that is, feet, buttocks, back, etc.). Prolonged exposure to whole-body vibration can either cause permanent physical damage or disturb the nervous system

2. **Hand-arm vibration** is experienced through the hand and arm. Daily exposure to hand-arm vibration over a number of years can cause permanent physical damage, usually resulting in what is commonly known as "white-finger syndrome", or it can damage the joints and muscles of the wrist and/or elbow.

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# Vibration data collection : Case

VB Transducers

Processing

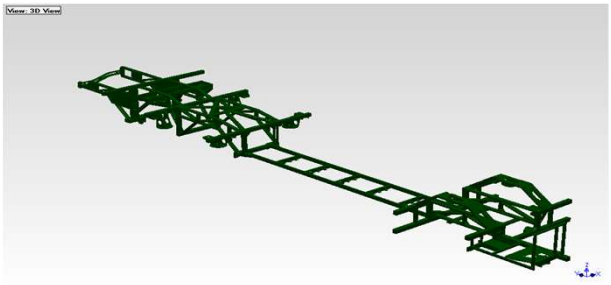
10 Channels - Iotech 655U

**Signal:** Amplitude
Phase

**Case: Vibration data collection for chassis bus.**

Vibration Transducer: Acceleration range ± 50 g ,
Frequency Range: 0.5 – 5kHz ±5%

Mounting : Magnet



Structural vibration analysis for Chassis Bus at 553 CPM

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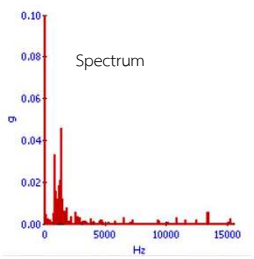
# Vibration data collection : Case

VB Transducers

Processing

4 channel portable vibration analyzers




Spectrum

**Case: Vibration data collection for Cooling pump**

Vibration Transducer: Acceleration range ± 50 g ,
Frequency Range: 2 – 10 kHz ±10%

Mounting : Magnet

**Diagnostics:**

- Machine fault : Unbalance, Misalignment, Mechanical looseness, Bearing fault, Gear fault etc.

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# Vibration data collection : Case

VB Transducers + Impact Hammer

**Case: Vibration data collection for Cooling pump**

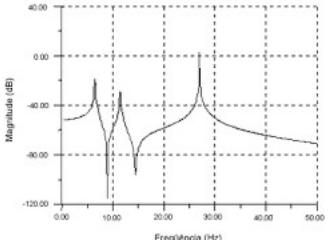
Vibration Transducer: Triaxial Acceleration range ± 50 g , Frequency Range: 2 – 10 kHz ±10%

Impact Hammer: 10 mV/lbf , ± 500 lbf pk

Mounting : Beewax

Processing

4 channel portable vibration analyzers




**Testing:**

- Frequency Response Function (FRF)
- Natural frequency

etc.

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# DATA PROCESSING

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Input → Signal Processing → Output & Post processing

- Frequency Span
- Line of resolution
- Aliasing filter
- Window filter etc.

- Waveform
- Spectrum

etc.

## Recommended Frequency span setting

| Component | Frequency Span |
|---|---|
| shaft vibration | 10x RPM |
| gear box | 3x, 3.5x GMF (Gear Mesh Frequency) |
| rolling element bearings | 10x BPFI (Ball Pass Frequency, Inner race) |
| pumps | 3x VP (Vane Pass frequency) |
| Motors/generators | 3x 2LF (2 Lines Frequency) |
| fans | 3x BP (Blade Pass frequency) |
| sleeve bearings | 10x – 16x RPM |

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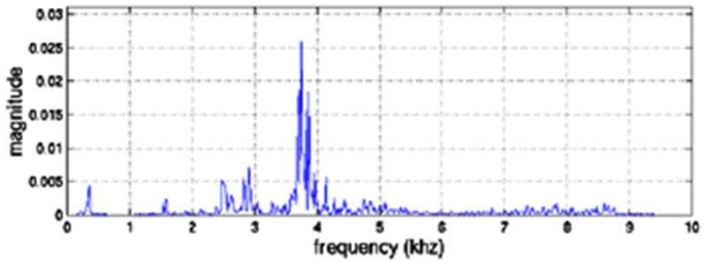
# Line of Resolution

The FFT always has a defined number of lines of resolution.

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

This spectrum has 800 lines, or the X scale is broken down into 800 points.

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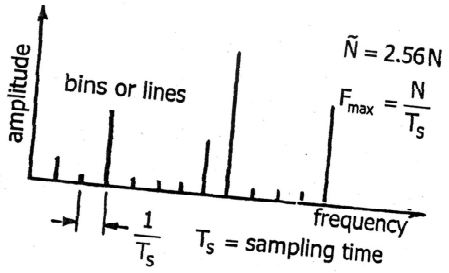
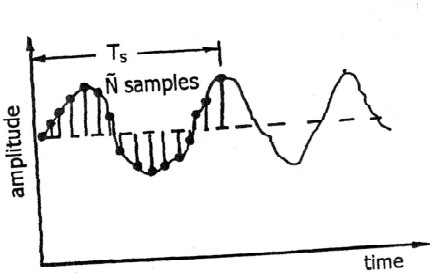
# Data Sampling

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# Nyquist theorem for Sampling

The Nyquest rate is the mininum sampling rate required to avoid aliasing, equals to twice the highest frequency contained within the signal

$$f_s > 2 f_{\max}$$

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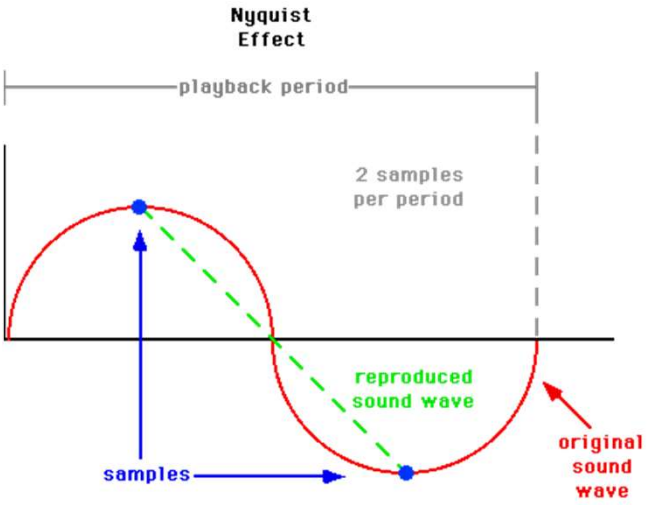


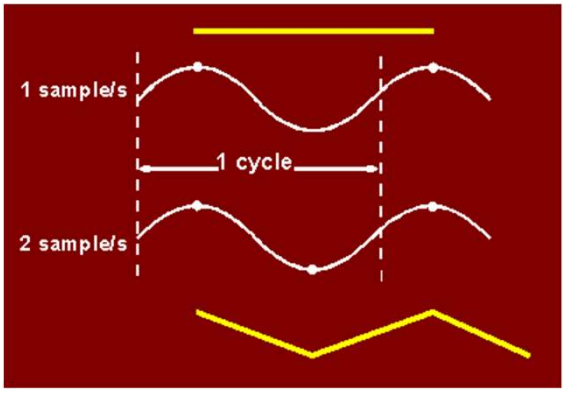


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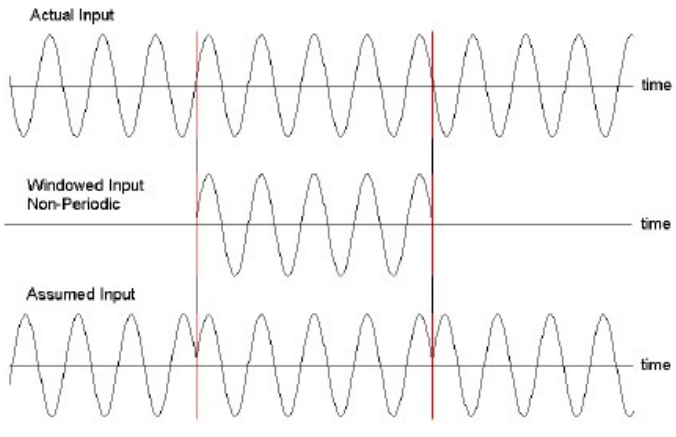
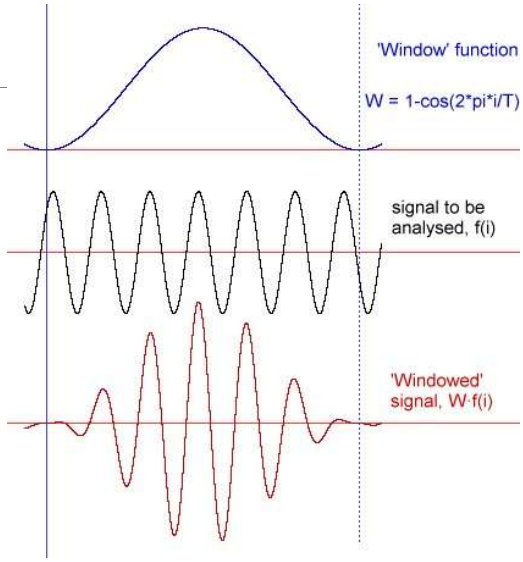
# Windowing

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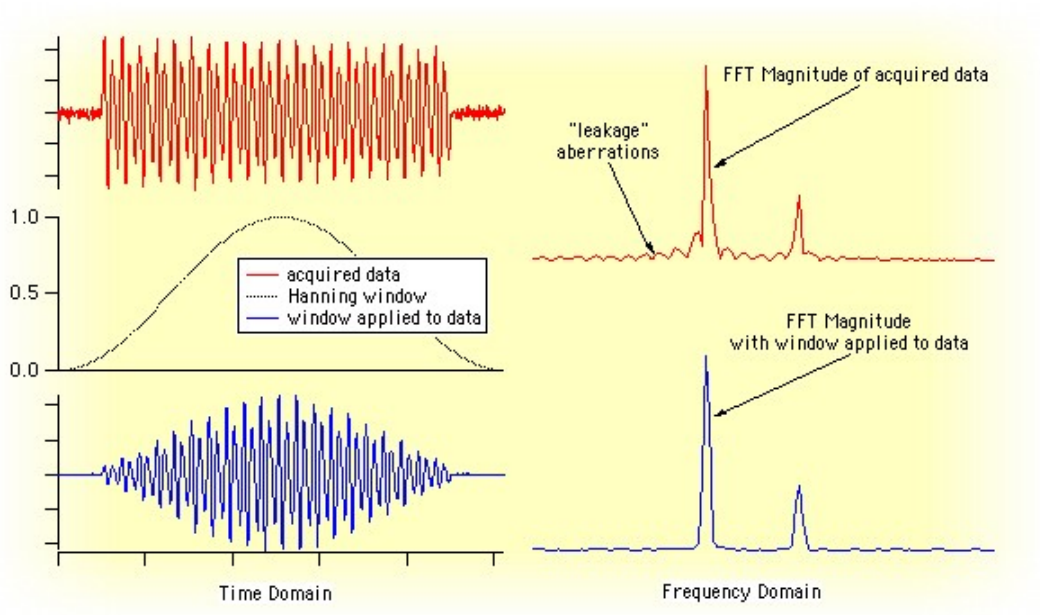


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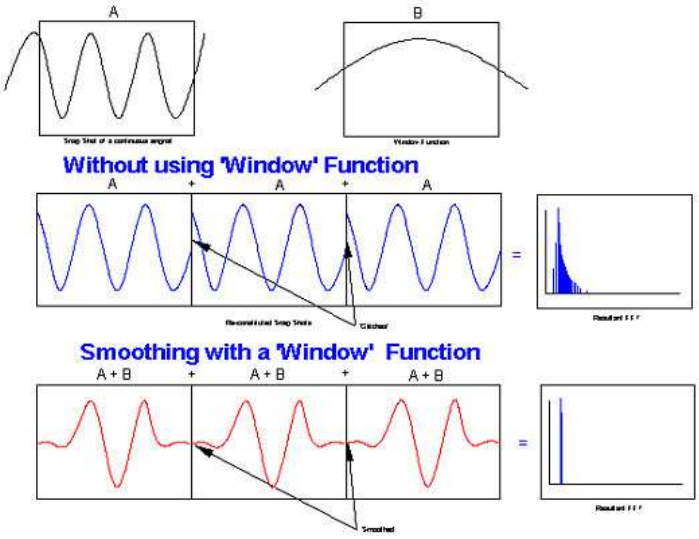
## Aspects of Windowing

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| Window | Purpose | Amplitude Uncertainty | Window Factor(WF) |
|---|---|---|---|
| Uniform | Impact test | 56.5% | 1 |
| Hanning | Fault analysis | 16% | 1.5 |
| Flat top | Condition evaluation | 1% | 3.8 |

- Use the Uniform Window for impact tests and resonance checks(No Window).
- Use the Hanning Window for normal vibration monitoring (Frequency).
- Use the Flat Top Window for calibration and accuracy (Amplitude).

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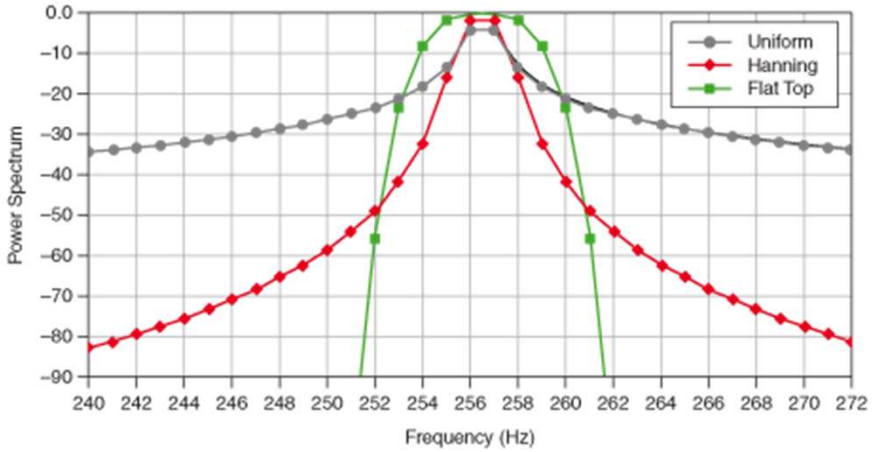


| | 254 Hz | 255 Hz | 256 Hz | 257 Hz | 258 Hz | |
|---|---|---|---|---|---|---|
| Uniform | 0.0162 | 0.0450 | 0.4053 | 0.4053 | 0.0450 | $Vrms^2$ |
| Hann | 0.0006 | 0.0288 | 0.7205 | 0.7205 | 0.0288 | $Vrms^2$ |
| Flat Top | 0.1591 | 0.7235 | 0.9978 | 0.9978 | 0.7235 | $Vrms^2$ |

| Amplitude Error 256 Hz (dB) |
|---|
| –3.9224 |
| –1.4236 |
| –0.0098 |

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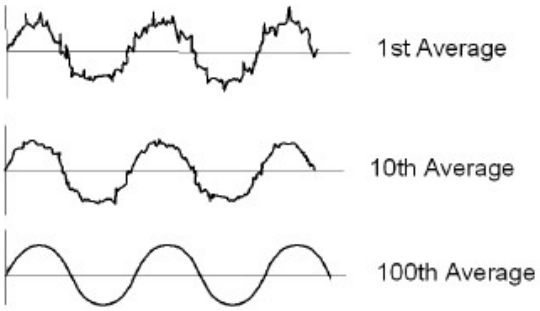
# Averaging

The FFT analyzer can be used in a number of averaging modes other than instantaneous display of the FFT after the data are acquired. These averaging modes include Linear, Exponential, Peak Hold, etc.. Noise is smoothed, but not eliminated, and discrete signals are reinforced in the display.

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# Averaging

Linear : All blocks of data are treated equally in terms of their effect on the averaged result.

Exponential : Similar to linear averaging, Exponential requires a weighting factor that either increases or decreases the effect of each new data block on the resultant average.

Peak Hold : The resultant block of data is a collection of points that represent the peak amplitude for each point in the block. The highest amplitude for each point in the block is retained. Therefore, it does not actually do any averaging.

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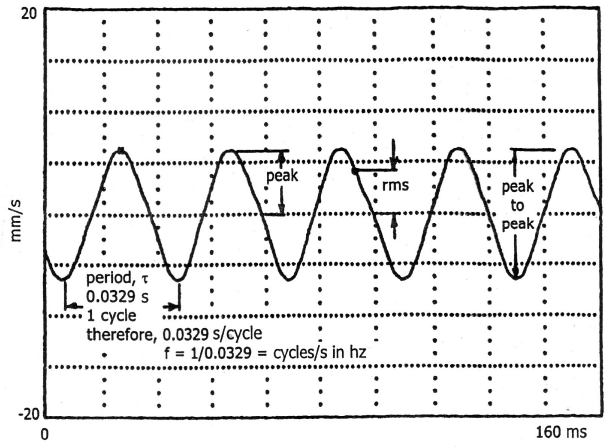
# Amplitude

Pk – Pk / 2 = Peak

Peak x 0.707 = RMS

RMS x 1.414 = Peak

Peak x 2 = Pk - Pk

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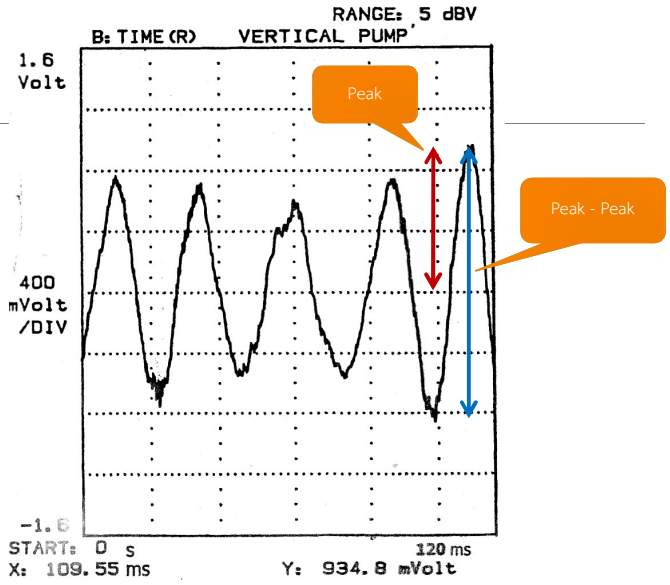
# Amplitude

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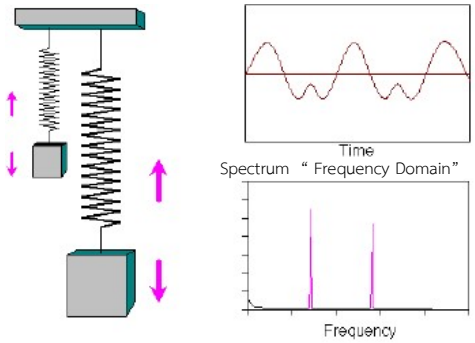
# Output & Post processing

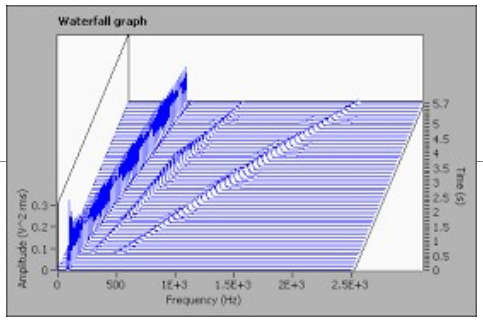

- Waveform
- Spectrum

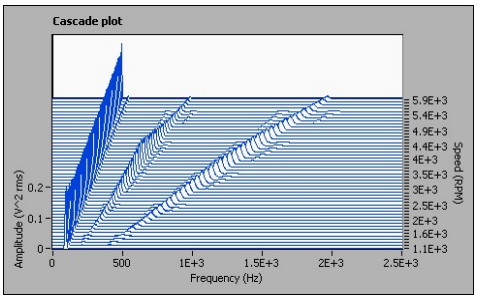
etc.

Rotating machine Diagnostics




Time Domain vs Frequency Domain

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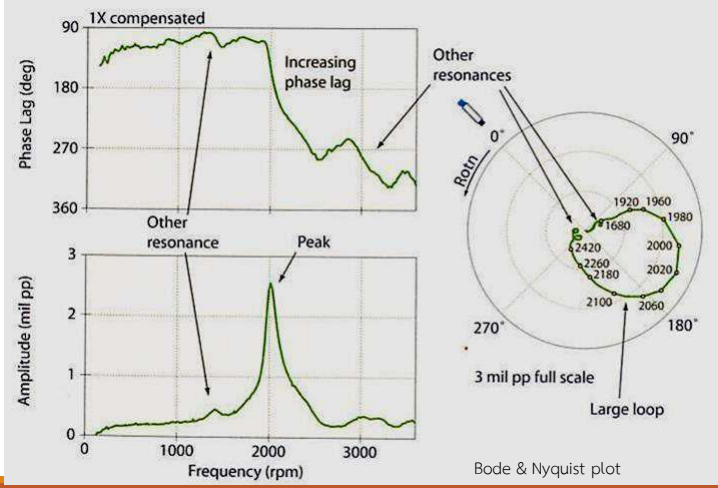
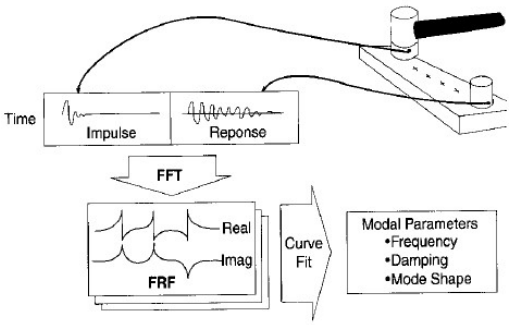
Resonance testing




Bode & Nyquist plot




Frequency Response Function (FRF)

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# Thank you for your attention

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