Signal processing: chapter One:

1st the data collector take analog Signal and record it from the sensor and provide us with data we can use and analyze. Such as spectrum, wave form ems readings and more.

Step One: we power the Sensor (ICP) accelerometer, that Signal from the sensor is electrical analog Signal. we Convert this Signal to somthing that we can Read, Step two: degtize the Signal to no. which we can Read. and that will help data Collector to work with.

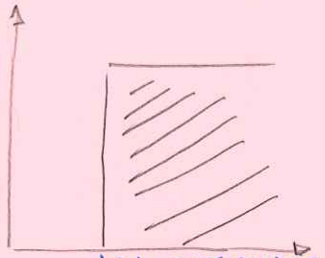
3 important chalnges, does the voltage from the sensor macth the input Range of the data collector?, How Quickly we should Sample?, How many Sample do we keep? we need to create data to work with so, we go to step three: Signal processing, filtring, avging, sampling, windowing and integration.

1. Filters:

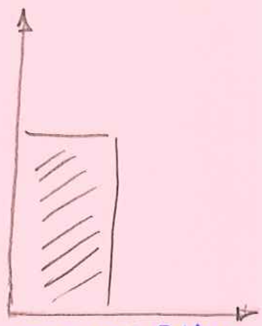
filters types are Five, low pass filter Band pass filter, Band stop filter, high pass filter, and limited freq. filter.

the filter Could be analog filter designed from capacitors, resistors and inductors. which treat the Signal as it Comes From the Sensor, many data collector still using analog filters. settling time is very important.

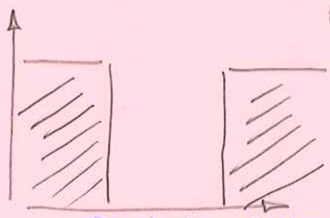
digital filters: computer software or DSP chip. deal with digtized data which may pass through analog filter before. they have better roll off than analog filter but still not ideal.



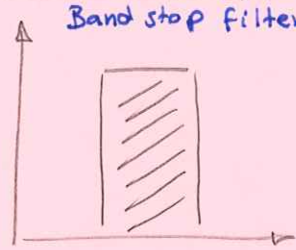
high pass filter



low pass filter



Band stop filter



Band pass filter.

Application:

- anti aliasing filter by using searis of analog fiter or two analog filter and one digital filter to reSample the data.
- Integration: convert acc. to velocity and from AC/DC copled.
- peakvue, demodulation, enveloping.

2. Integration and S/N Ratio:

The analog Signal from acc. is porportional to acc. we typically view the data in velocity or acceleration. , convert data from acceleration to velocity is called integration and from velocity to disp. called integration too, & from acceleration to disp. called douple integration. that process can be done by analog circuit or digital integration reduce high Freq. vibration and amplifies low Freq. vib. and change phase by 90° degree.

(S/N) Ratio:

it is very importatnt to have high S/N ratio we don't want Noise to mask important vibration signal., also Noise can come from No. of Sources such as process or external machines or from electronics and transducers.

digital Integration:

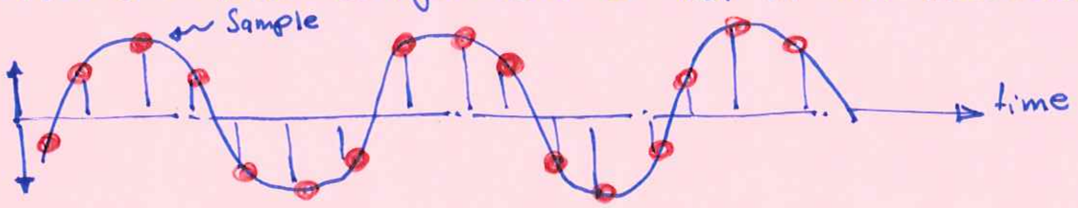
A. Signal is digitezed while still in acceleration.
B. Converted to velocity or displacement on the Software.
C. Spectrum and optionaly TWF.

Low Speed machines:

A. High senstivity Sensor.
B. Be aware of thermal and physhical transient.
C. Mount the Sensor on the Load zone.
D. Be carful with mounting method.

Sampling process:

we have electrical voltage from the sensor which convert to analog Signal but our data collecter can't deal with analog Signal he need Numbers to deal with so. we digitize the Signal into numbers he can work with and we have individual points or readings. at discrete time intervals. the rate of Sampling called Sampling rate which is no. of Samples per sec. the result will be aseries of Nmber or points when we join them togther we could have oor time domain. or TWF. and we can store that (TWF) and use (FFT) to see or convert it to Spectrum. and event happen bet. those Sample will be lost or not recorded



Triggering:

Time sync. Avg. , impact test. , Run up & coast down test. , Order trac... phase measurement. ODS and modal analysis's.

Normaly we use pretrigier with certain % as we need to record all data with respect to trigger pulse. and the datal collector could start to Sample the data and finish record before trigger pulse arrive. and pre trigger is a % of time record.

FFT:

the (twF) known with time record which have defined No. of Sample (N) the (FFT) spectrum has no. of lines (N/2) (bins)

N (No. of Sample) 2^9 = 512 Sample → N/2 256 lines on Spect.

N (No. of Sample) 2^{10} = 1024 Sample → N/2 512 lines on Spect.

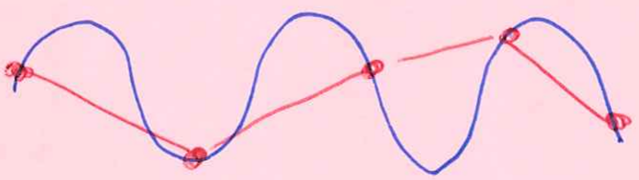
↓

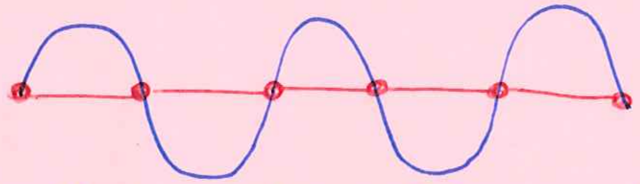
N (No. of Sample) 2^{13} = 8192 Sample → N/2 4096 line on Spect.

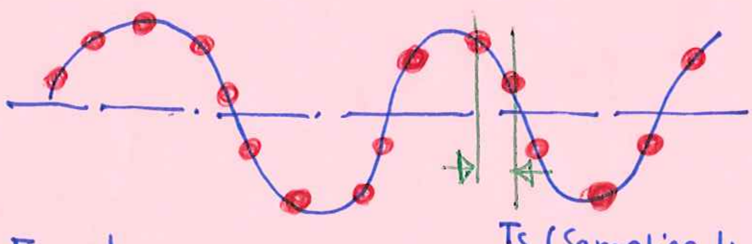
For the FFt to work correctly we have 3 problems to deal with

A. Aliasing:

we need at least two Sample per cycle to resolve that Freq. and be able to draw Freq. cycle so, sampling rate must be at least greater than (F_{max}) For the freq. of intersit Sample rate > 2.56 F_{max}.







Ts (Sampling time)

$F_s = \frac{1}{T_s}$ Sampling rate.

$F_s > 2\ F_{max}$ (Nyquist Criterion)

without antialiasing Filter only what you will see is aflat line (anti-aliasing filter is alow pass filter which fiter out all those high Freq. which higher than Sampling Rate and that will stop the appearnce of non true Freq. on the Spectrum on the other hand we should take more than two Sample per cycle to be able to draw it.

Resolution :

$$R = 2 \frac{Fmax}{No. of lines} \times W.F = 2 \times BW.$$

dynamic Range:

dynamic Range is ameasure of the ability of the data collector to see Small Amp. vibration in the precense of higher Amp. vibration.

$$\left(dB = 20 \log \frac{Vm}{Vr}\right) = 20 \log \left(\frac{Small}{Biggest}\right)$$

Windowing:

as the way to resolve with (fft) and be able to re construct the Signal we must start and end at zero that's why we use window to distortion the Signal. and that will help us to avoid leakge on the Signal.

		Amp. uncertainty	WF
Uniform	impact test	56.5 %	1
Hanning	Fault analysis	15.0 %	1.5
Flat top	Condition evaloation	1.0 %	3.8

Averaging:

it is the best way to reduce the noise on the sys. Not Remove it we should take from (4-10) No. of avg. for better data and be able to reduce Noise as mush as we can.

Rms or liner averaging, over Lap averaging, Exponational avging peak hold averaging, TSA averaging.

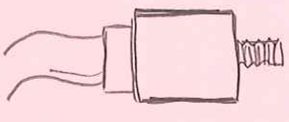
sensor Mounting:

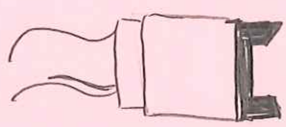
Stud Mount
6 - 10 KHZ

Bees Wax
5 KHZ

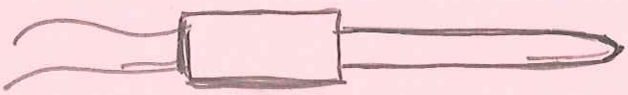
Adhesive
2.5 - 4 KHZ

Magnet Mount
2 KHZ





Hand held
500 HZ



Time wave form Analysis

Chapter TWO:

Time wave form is avery important Analysis tool. that we can detect many usful information such as (impacts, true (p-p) Meas.), transient events, phase, Beat Modualation (Amp, Freq.), truncation, Asymmetrical and more.

Constraction of tWF:

A. Analog Signal from the Sensor B. digital dots on wave form (Sampling)

c. join dots to plot wave form.

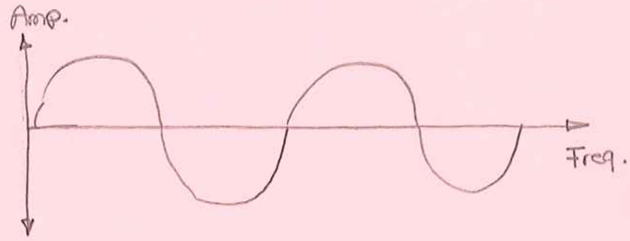
NotE as per Nyquist creation theory Sampling rate must be greater than twice Fmax of intersit Sample Rate = 2.56 Fmax.

Not always high Fmax or v. long time form is good you should see only what you need Note that ($T = \frac{N}{F_{max}}$) if Fmax ↑ means shorter time But missing info. and v. low Fmax means v. long time which could be not usfuel that thing you have to mange yourself.

Time wave form types:

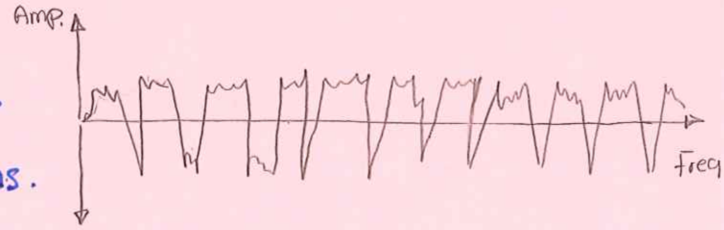
(1.) Harmonics (Sinusoidal):

very Simple (twF), Could by imbalance or bent shaft, or Soft foot, Somthing cause only pure (1X) on Spectrum.



(2.) Truncation:

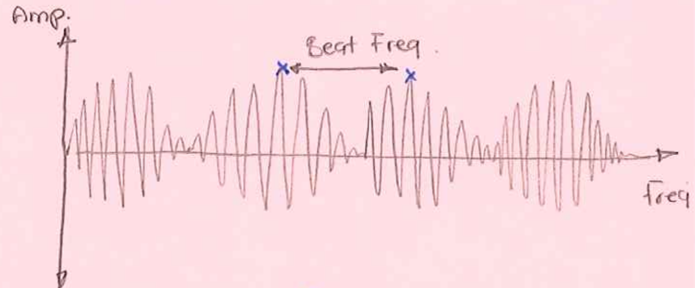
usoaly caused by Motion restrication like Misalignment or Coupling lockup problems.



(3.) Beats:

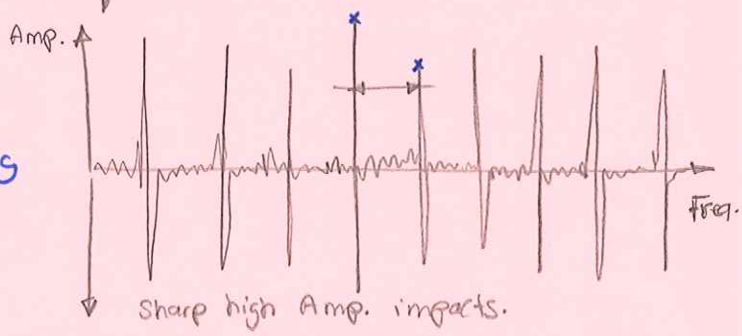
very close two Freq. move in and out of phase amp. always or mostly are Similar so, beats almost goes to zero.

Beat Freq = diff. bet. two Freqs.



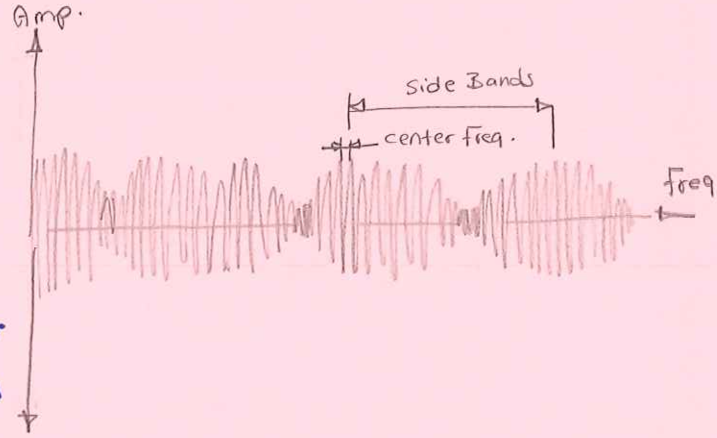
(4.) Impacts:

Sharp high Amp. impacts Repeated not Random such as gear Bracken or Bearing defect. or belt Condition



(5.) Amp. Modulation:

Two Sparate components multiplied rater than added. Not going to zero on the wave form. very Similer to Beating. normaly Side Bands around centeral Freq. on the spect. Could be Bearing defect or gear wear or Rotor bar problem, all according to Freq? calculations.



also you can see many other types of wave form such as Freq Modualtion or Random impacts on wave form which caused by looseness. Asymmetric wave form, Clipped.

chapter six:

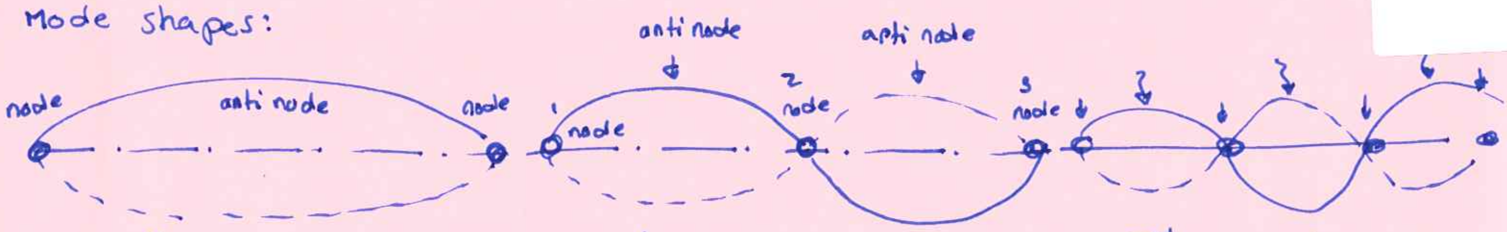
Reasonance and Critical Speed testing:

Reasonance is acondition on machine or structure where freq. of vibrotary force is near or equal to Natural Freq. if that vibratory Force was Runnig Speed then we call it critical speed. , Natural freq. can by controled by design. Natural Freq. can be exited by impact, Random Force and Harmomic or vibrating Freqs. usualy Natural freq are not harmonics from the 1st Nf. phase at Natural Freq. (critical speed) = 90° and phase shifted by 180° bet. After & Before Nf.

deflection shape: it is represent how the machine vibrating (shap) at Nf and it is called (mode Shape).

Mode Shapes: it is determined by Modal Analysis we can creat 3D Anamation of the sys. or (structureal) showing How It is Moving when it is excited @ certain Natural Freq. and the Modal Analysis Require Forcing input (known) to excite the sys. we can use Roving sensor and stationry hammer or statrnary sensor and roving hammer.

Mode shapes:



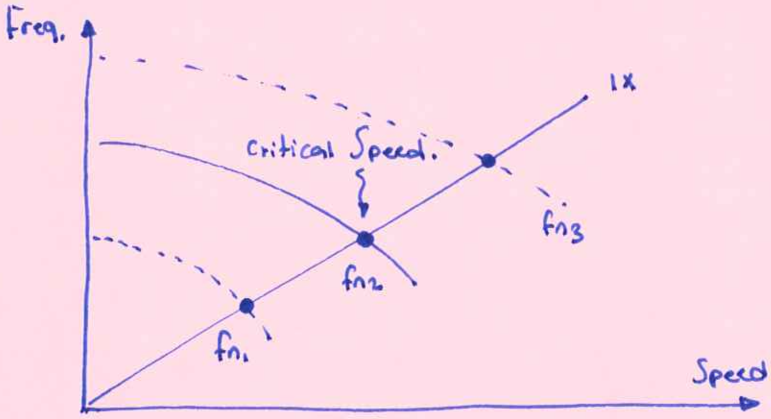
1st mode shape 2nd mode shape 3rd mode shape

operating deflection Shape: ODS analysis used to determine a 3D anamation showing the motion and deflection shape with max and min divation but on that case no need to determine (Nf) by using (shaker or hammer force) it can by careid out at the suspect (Nf) of interst. but we don't excite the sys. with external force and no need to stop the machine to carry out the meas. could be done in two ways. (ODS) Bade on (TWF) which can animate at all Freq. of interst and show M/C movemont (moment to moment) or at aspecific freq only one of interst. also could be done using dual channel or depend on a tacho ref. But on that case we will need to stop the M/C.

coherance: is Function from (0-1) to represent the relation ship bet. input & out put (1) is Ecxllent. (0.9 -> 0.7) good less than (0.6 - 0.5) is poor coherance which could be due to cracks or sensor problems or non linearty cause on the sys.

Interferance diagram:

Interferance diagram is adigram of Freq. Vs Speed & Natural Freq. on that diagram which could be created manualy or model test data on PC. we can detect critical speed and avoid to run. the M/C. near to that Speed.



So, we should solve that problem by Runnis the M/C away from the NF. and that could be done by changing (NF) by adding or removing mass also by stiffen supports.

$\omega_n = \frac{1}{2\pi}\sqrt{\frac{K}{m}}$ where (K) is stiff. and m (mass) or by damping or using Vib. absorber.

Freq. Responce function (FRF):

(FRF) represent the Relation ship bet. input and out put bet. two points on a structure as both are functions of Freq. also very important to determine How the sys. will responce to excitation Force means how much (disp, velocity and acceleration) has as a out put.

① **Compliance** $= \frac{\text{displacement}}{\text{Force}}$

① **Dynamic Stiffnece** $= \frac{1}{\text{Compliance}}$

② **Mobility** $= \frac{\text{Velocity}}{\text{Force}}$

② **Impedance** $= \frac{1}{\text{Mobility}}$

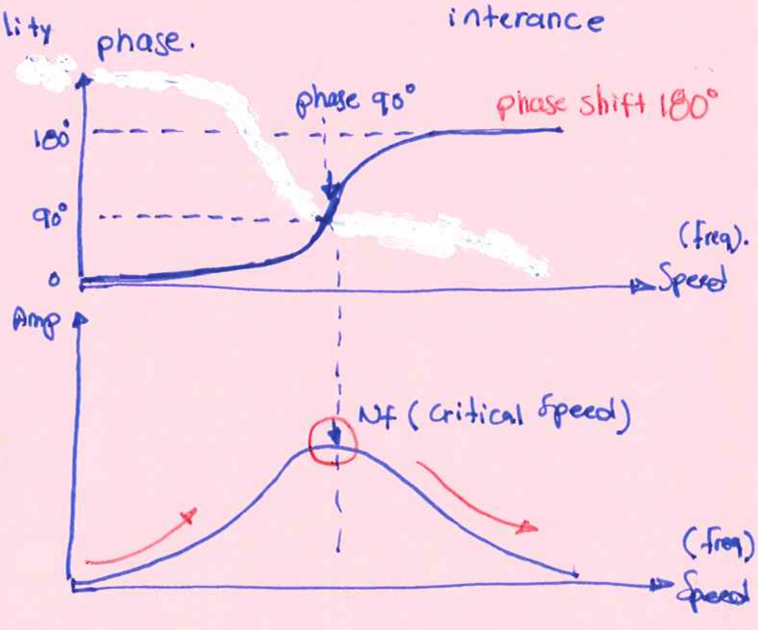
③ **Interance** $= \frac{\text{acceleration}}{\text{Force}}$

③ **Dynamic Mass** $= \frac{1}{\text{interance}}$

Bode' digrama:

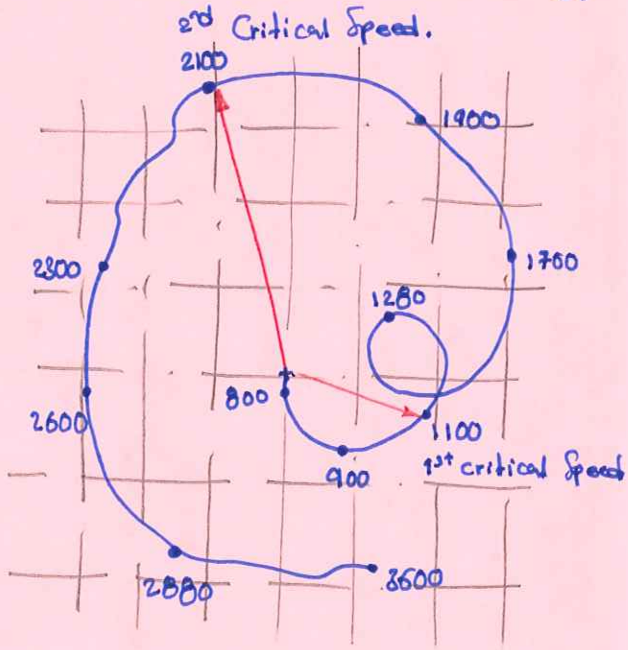
Two plots one for speed with Amp. and 2^{nd} for Speed with phase you can notice that at Critical Speed or NF phase $= 90°$ and phase shift before and after Critical Speed is $180°$.

one of the most porful tool, Run up and coast dowen test.



polar plot (Nyquist plot):

Same as Bode'/plolar plot But on that case you can find speed and Amp & phase on the Same plot 3 of them also you can see internal loops on the polar plot and after each one new mode Shape start and at the max peak you can detect your critical speed. which will creat resonance.



NotE: other plots to detemine (NF) or critical speed such as campeble diagram or water fall or (cascade) plots.

Reasonance Correction. (chapter Seven 7 :)

1. damping

- (A) Viscous damping
- (B) Coloumb or fractional damping
- (C) Structural or Hysteresis damping (Molcular motion)

ON damping

- **Transmissibility (τ)**: Ration bet. input and out put vibration and how much Really transmit. ($TR = F_T/F$) =1 for hard mounted M/Cs.
- **Amplifcation Factor (Q)**: How much magntuide the sys. will be Amplifed at excat force
  - half power method
  - phase angle method

  $= \frac{f_n}{f_H - f_L}$

  $C/C_c = \frac{1}{2Q}$

  mech. gain from the sys. @ natural freq.
- **damping Ratio (ξ)**: Ratio bet. damping on sys. and C_c
  - >1 over damping
  - =1 critical damp.
  - <1 under damp.

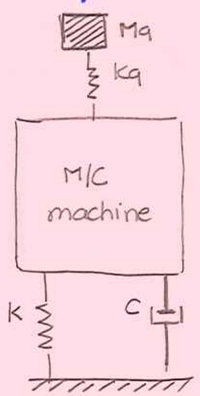
(A) Free layer damping
extentional damping
two layer slides against each other and convert vib. to friction bet. them or heat energy

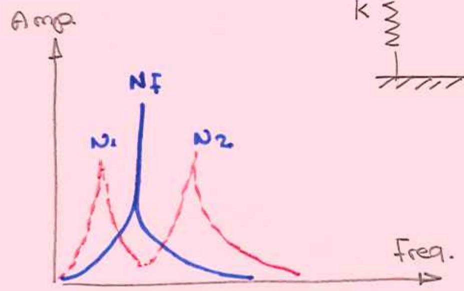
(B) Constraind layer damping
sandwich if lamnting layer the base to damp. energy. deformation rather than extenstion.

2. Vibration absorbers

(A) **Tuned Mass absorber**
Creat absorber has natural freq. equal to freq of interst at the sys that absorber will vibrate instead of M/C. and split Nf to 2 freq. after and before. and also it will damp the vib. levels.
(visco elastic damp.)

(B) **Tuned absorber**
Same as tuned Mass absorber but will not increase damping on the sys.





$w_n = \sqrt{\frac{k}{m}}$

$m\uparrow \quad w_n\downarrow$

$k\uparrow \quad w_n\uparrow$

3. Isolators

used to isolated vib. from machine to the ground. for isolator to work the natural freq. of the isolators should be 70% less than the max excitation force on the sys. or it will not work.

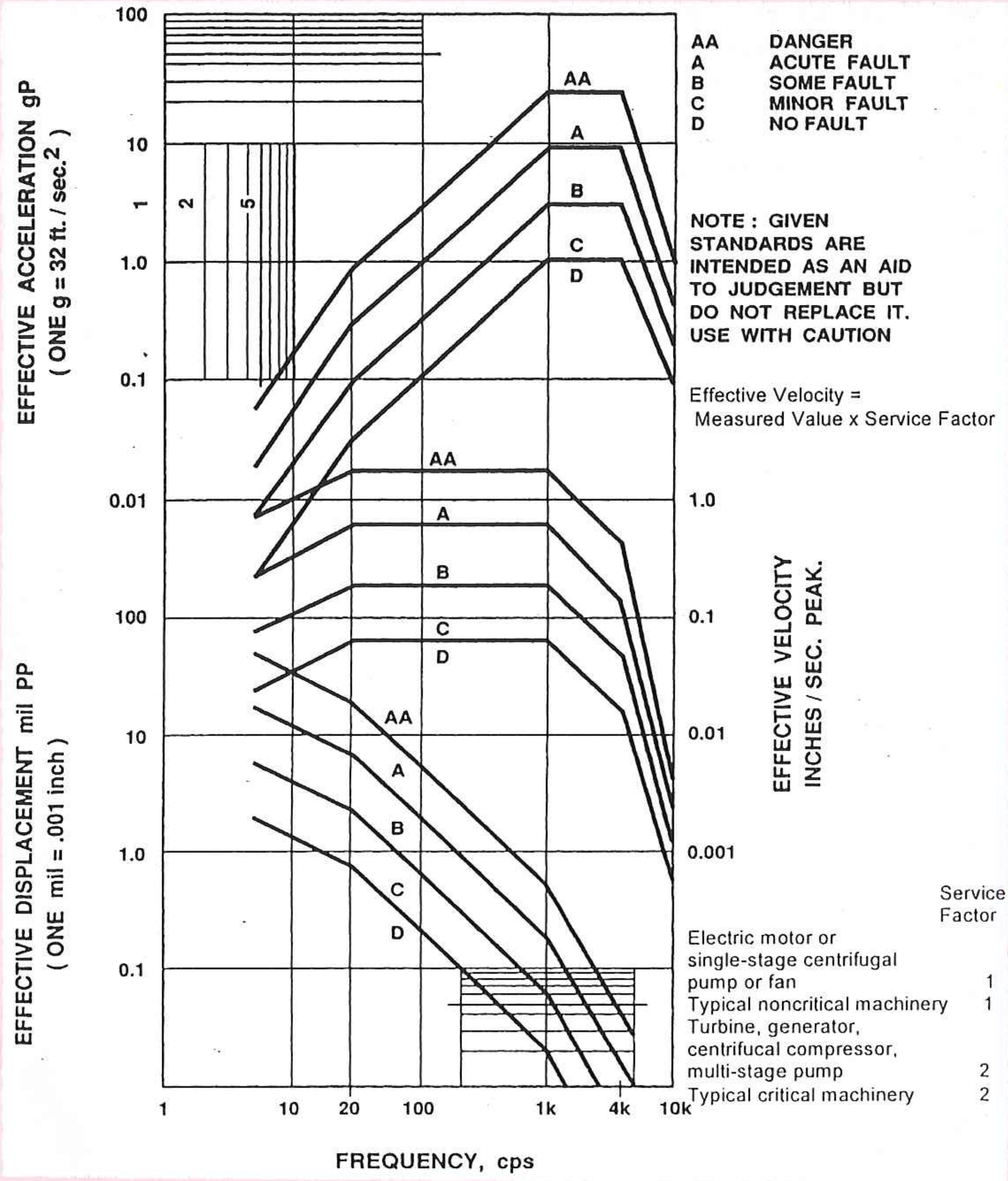
$\frac{f}{f_n} > 1.414$.

NotES:

1. mass of foundation must be from 4-5 times mass of the M/C (Reciprocating M/C.)
2. C_c: critical damping is just enough damping to prevent vib.
3. For isolators to work the Nf of the sys. must be 70% less than the main excitation freq.
4. damping only work when Nf is very close to excitation freq.

Condition Evaluation NOTES.

Blake Chart.



1. plot Machine Speed in Hz first.
2. only used with peak value from (wave form).
3. multiply by service factor
4. letters (e.g) AA should refer to a certain region.
5. watch out for Log Scale.

Journal Bearing Vibration Evaluation:

Table 7.16. Evaluation of Journal Vibration in Fluid Film Bearings

Maintenance	R/C	
	3,600 RPM	10,000 RPM
Normal	under 0.3	under 0.2
Surveillance	0.3-0.5	0.2-0.4
Shut down when convenient	0.5-0.7	0.4-0.6
Shut down immediately	above 0.7	above 0.6

R = Shaft Vibration, C = Diametral Bearing Clearance

a good way to evaluate journal Bearing vibration is to compare the levels of the Brg. clearnce, R/C, where R: is vibration Amp. in disp. (P-P) and C: is diamtrical clearnce in the Bearing.

Table 7.5. Vibration Guidelines for Condition Evaluation*[7.16]			
Condition	Limits (IPS)		
	rms Velocity	peak velocity	code
Acceptance of new or repaired equipment	<0.08	<0.16	A
Unrestricted operation — normal	<0.12	<0.24	N
Surveillance	0.12-0.28	0.24-0.7	S
Unsuitable for operation	>0.28	>0.7	U

- These values should be adjusted to reflect the condition of the machine. Service factors may be necessary for some special equipment, depending on design, speed, and/or process.

important note in cond. evaluation when we use those 3 charts always rem. that (RMS) value From Spectrum & (peak) value from (TWF).

(chapter eight 8 :)

Balancing:

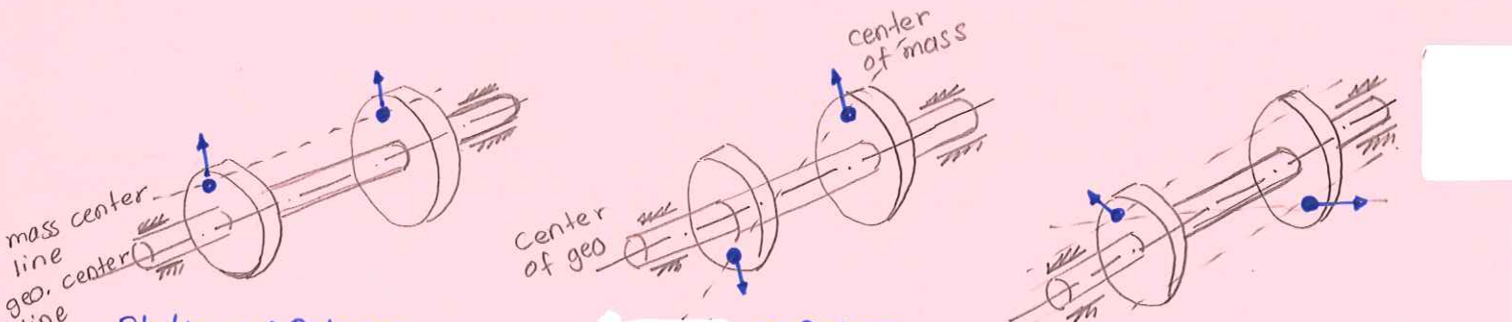
when center of mass start to be away from center of geometry it start to Cause driving Force that wears the machine Fast. that Force appears on machine spectrom as (1X), Runnig speed. and that amount or Amplitude of the imbalance equal to (mass x eecentricity) and for Large diam. that Force should in crease.

Causes of imbalance:

Eccentricity, shaft bow, casing blow holes, Corrision wear, bulidup material thermal distortion, etc .....

Types of imbalance:

1. static unBalance: center of geom away from center of mass with dist. (e) and the shifted center of mass line is parller to center of geom.
2. Couple unBalance: line of center of mass inclinde on the line of the line of center of geo.
3. dynamic unBalance: on that case it is combiend of static unBalance and couple, line of center of mass is shifted and inclinde too.



Static unBalance   un Balance   dynamic unBalance

Rotors types:

1. Rigid Rotor: operating below 1st critical speed and eccentricity will not change with Speed.
2. flexible Rotor: can bend, eccentricity depend on speed and position of the rotor, normaly Run after 1st critical Speed.

Balancing planes:

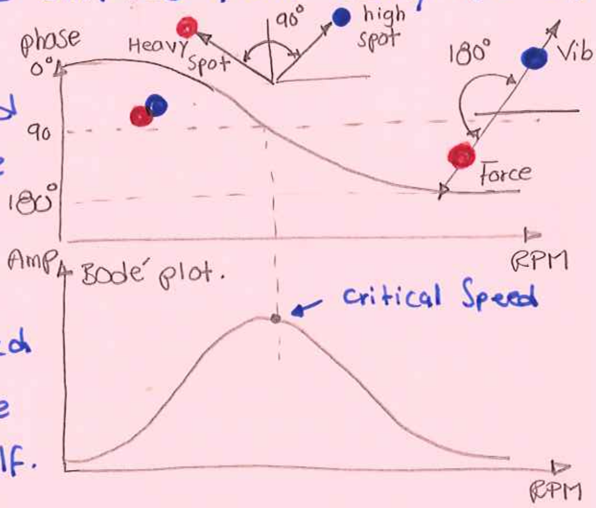
1. Single plane balancing. (static unBalance)
2. Two plane balancing (Couple unBalance), (dynamic unBalance)
3. multi plane balancing (flexible Rotors).

NOTE : Falce couple or (Quasi - static) unBalance is caused as aresult centrif-
doesn't act through the center of gravity may exsit on over hung Fance. also not easy to balance on single plan balancing.

Heavy spot, High spot, Lag on the sys:

Heavy spot: is alocation of unBalance Force and all calculation we do to try to find the H.S.

High spot : is the location of unBalance force we can measure But don't For get the Sys. lag. as that high spot is shifted from heavy spot & that depend on 3 things



A. you run above or below critical speed as if you below 1st critical speed the high and heavy spot will be shifted by an angle from (0-90°) normaly near to each other but if you above critical Speed they will be shifted by (180°), and will be 90° if you run on the critical Speed itself.

B. Mechincal lag: which is due to transmitted Force to our sensors through the shaft and bearings will be delay on the Signal.

C. Electrical Lag: sensors, cables and electronics inside the device.

Trial weight and Balancing steps:

1. measure Amplitude and phase use tacho which preferd to be in line with the sensor, that tacho will give aref. pulse to calculate and compare Balance with. (orignal run), meas. on H & V
2. trial run: add atrial weight and measure the change in vib. levels due to trial weight adding.
3. Calculate the correction weight and the location of the correction weight.

Before we start the Balancing we should know about polar plot and Balancing by vector calculations also some equations about Balance senstivity and infulance cofficient.

$\vec{V_o} : \vec{\alpha}\,\vec{u}$ ① where V_o : Orignal Vibration , α : infulance cofficient
u : unBalance force.

$\vec{V_{o+T}} : \vec{\alpha}\,(\vec{u} + \vec{TW})$ ② where TW is trial weight.
$: \vec{\alpha}\,\vec{u} + \vec{\alpha}\,\vec{TW}$ ②

by sobstract eq ② - ①

$\vec{V_{o+TW}} - \vec{V_o} : \vec{\alpha}\,\vec{TW}$ $\quad \therefore \vec{V_{TW}} : \vec{\alpha}\,\vec{TW}$ $\quad \therefore \alpha : \frac{\vec{V_{TW}}}{\vec{TW}}$ ③

$\therefore \alpha$: in fulance cofficient : $\vec{V_{TW}}$ or $\vec{T}$ which is calbration Factor or vibration due to trial weight effect only divided by ÷ trial weight.

$\because \vec{V_o} : \vec{\alpha}\,\vec{u}$ and $\vec{CW} : -\frac{\vec{V_o}}{\vec{\alpha}}$, $\vec{u} : \frac{\vec{V_o}}{\vec{\alpha}}$, $(\vec{V_o})$ or $(\vec{O})$

$\therefore$ from eq ③ $CW : -\frac{O}{\frac{T}{TW}} : -\frac{O \times TW}{T}$, where O and V_o are the Same Orignal vibration , Tw : trial weight. , $\vec{V_{TW}}$ or $\vec{T}$ are calbration Factor.

$\because CW : -\frac{\vec{V_o}}{\alpha}$ $\quad \therefore |\vec{-V_o}| : \vec{CW}\,\vec{\alpha} \rightarrow mm/s \angle^{\circ} + 180 : \vec{CW} \times mm/s/g \angle^{\circ}$

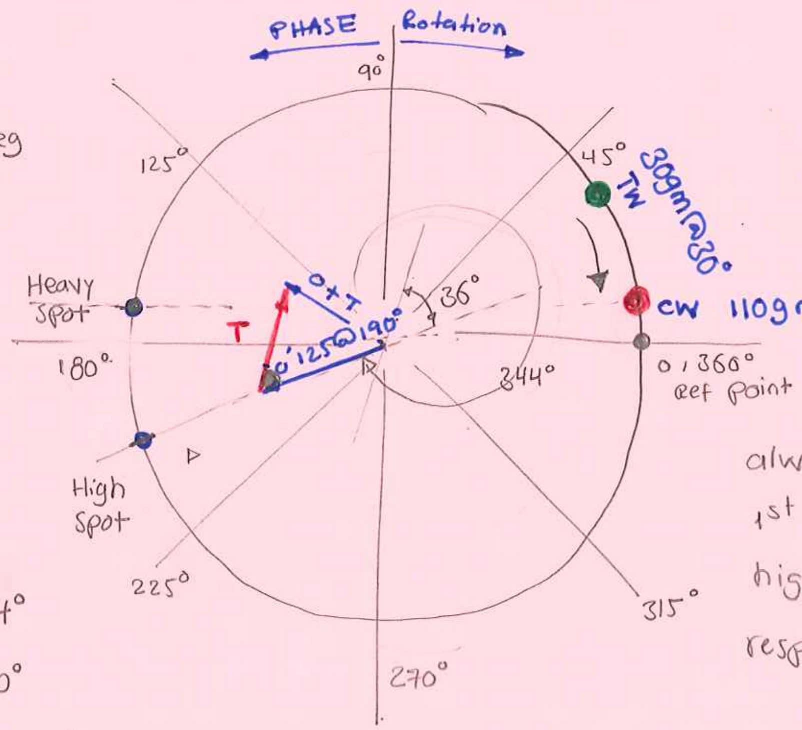
$\alpha : \frac{\vec{T}}{\vec{TW}}$ infulance cofficient and $\beta : \frac{\vec{TW}}{\vec{T}}$ (β) is Balancing Senstivity.

and you can use the information of (α) or (β) for one shot Balancing if you can't make more than One Run.

Vectors:

O : 125 µm @ 190°
TW : 75 gm @ 30 deg
O+T = 75 µm @ 150°

$CW = \frac{O\ TW}{T}$
$= \frac{125 \times 75}{85}$
$= 110gm.$



always think what happen 1st Heavy spot before high spot. (force then responce).

Heavy spot @ 174°
High spot @ 190°
sys lag = (174° - 190°) = - 16° + 360° = 344° angle bet. (heavy spot & high spot)

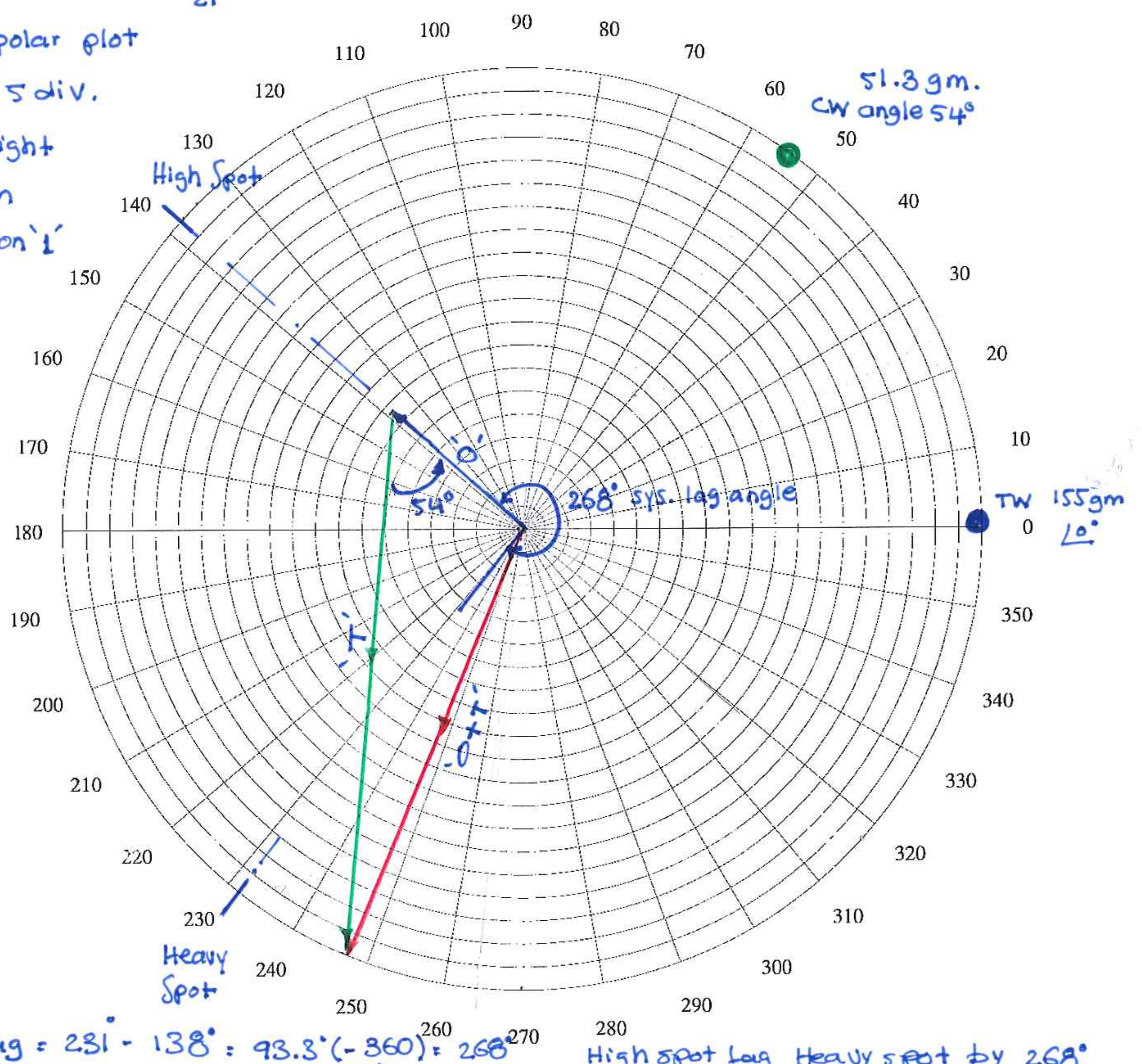
PA Fan Unit 4 (B)
Rotor weight : 710 kg
Shaft weight : 578 kg
Coupling weight : 79 kg
Speed : 1485 RPM
Rotor diam : 1850 mm.
NO. of Blades : 21
Angle bet. blades : $\frac{360}{21} = 17.1°$

Orignal Vib (O) : 1.591 $\angle 138°$ on FDE
Trail Run Vib (O+T) : 4.178 $\angle 246°$
Units mm/s RMS.

Trail weight calbration Factor ($\vec{T}$) = 4.8 mm/s $\angle 264°$
CW : (TWO) ÷ (T) : (155 x 1.5) ÷ 4.8 = 51.3 gm

Phase ← | → Rotation.

Scale on polar plot
1 mm/s : 5 div.
Trial weight
= 155 gm
@ position '1'



SYS. lag = 231° - 138° = 93.3° (-360) = 268°   High spot Lag Heavy spot by 268°

α : infulance coefficient = $\frac{\vec{T}}{TW}$ = $\frac{4.8 \angle 264°}{155 \angle 0°}$ = 0.031   0.031 mm/s/g $\angle 260°$

β : Balancing sensitivity = TW ÷ $\vec{T}$ = $\frac{155 \angle 0°}{4.8 \angle 264°}$ = 31 gm / mm/s

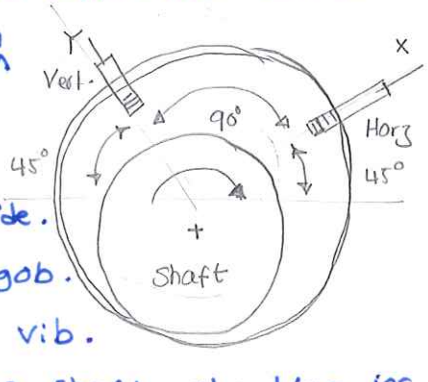
CW = $-\frac{O}{\alpha}$ ∴ $-O$ = CW α

_______ mm/s $\angle$ _______ +180° = _______ $\times$ 0.031 $\angle 260°$

∴ CW = _______ gm @ $\angle$ _______ °

Orbit Aanalysis:

Orbit Analysis is the most powerful way to diagnoze Journal or Fluid Film Bearing Faults using non contact eddy current or (proximity) probes But 1st we should understand how we get that orbit shape and why it appears with acertain shape as per the force it is affected with.



you can see two proximity probe with 90° apart & each of them on 45° position the (X) or horzontal prob. is meant to be Horz as (C.C.W) the 1st sensor from Right is (X) or (Horz) and that from driver Side. the distance bet. the prob and shaft is voltage gob. and when the voltage value increase means shaft vib. decrease and when voltage value decrease means shaft vibration inc.

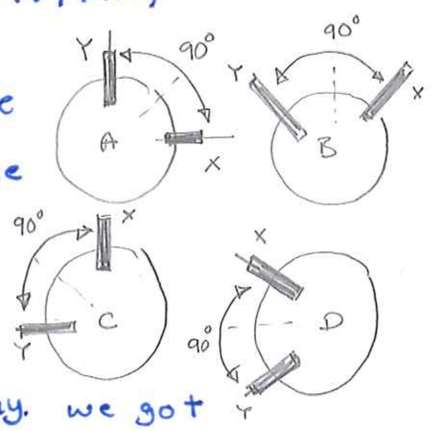
NotE: that high Freq. oscillator is used to induce eddy current on the probs.

Out put signal:

you have two out put Signal From proximity probe. (DC) voltage or Static voltage which represent shaft Relative location or position to the probe & (AC) voltage which Represent shaft vibration (disp. P-P) and also called dynamic Signal.

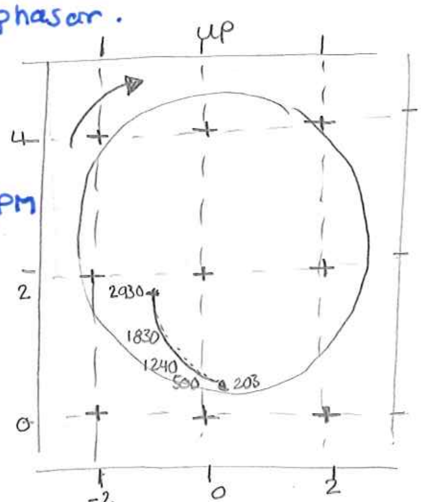
the transducer will have output sens. (mv/mil) and (v/mil)

probe conventions:



as we menthion before you have two proximity probe helping to draw the orbit shape and the position of the 2 probes could be by many positions as you see in the drawings. and the they seen as (X & Y) From the driver side. also you will get once per rev. signal from the proximity prob on the shaft key way. we got the timing marks on the orbit plot from the key phasor.

Shaft center line:



using a DC gab we can analyze the shaft (center line) location start from zero where machine Speed below 100 RPM Shaft should move to left (CW), shaft eccentricity Ratio (μ), {Normal distance, (0) at the center (1) shaft against bearing.

Direct and filterd signal:

we can see raw voltage orbit or we can see filterd orbit only at (1X) or (2X) and we can use key phasor on that. NotE some Journal have (2) prox-imity probes and we can use one of the as aspeed ref. and some Journal have (2) proximity prob. and 3rd one Just For Speed. detection.

slow Roll or (glitch) Removal Compensation:

the shaft not prefectly Round and could be shaft bow or Runout or bad Surface cleaning. (machining) and all of this Factors will affect on the dynamic signal and static voltage we want to know, so, to avoid that awave form recorded on alow Speed (100-400 RPM) and Substricted from the future measurement.

NotE: filter the signal from orbit could be done by 3 method. ① key phasor ② low resolution spect. ③ (TSA) Time sync. avg.

Orbit Analysis:

key on orbit Analysis 1st look to the no. of timing marks or key phasor dots:

A. **One time mark:**

1. **internal loops:** forward whirling or pressison and you will see sync. components on the spect. and on that case the orbit Freq. Ratio will be (no. of internal loops + 1), fig (1)

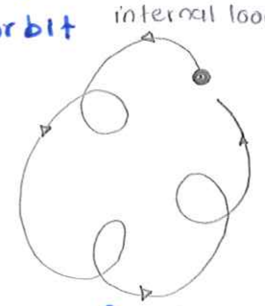


fig (1)

2. **External loops:** Backward whirling or pression and also you will see sync. component on the spect. and on that case the orbit Freq Ratio will (no. of external loops - 1), fig (2)

B. **More than one time mark:**

on that case you should see sub harmonic or non sync. component on the spectrum and the Freq. Ratio (1 ÷ no. of timing marks), fig (3).

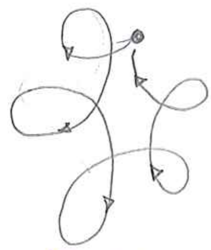


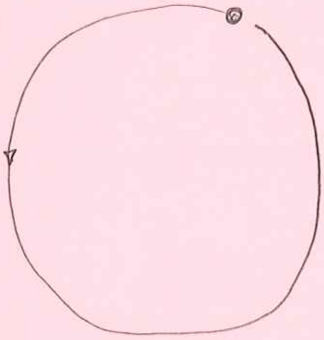
fig (2)

External loops

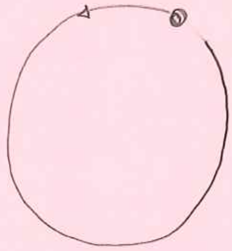
fig (4)

fig (3)

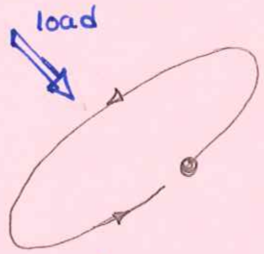
2nd in Orbit analysis you should look to vibration levels and pre load
Reason it could be due to Misalignment or coupling problem also unBalanc



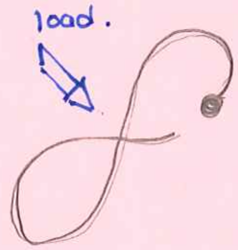
high Amp. Complete
Circle orbit (Resonance)
Critical Speed Could be
Coil whipl.



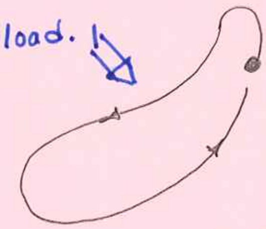
complete circle
orbit (imbalance)



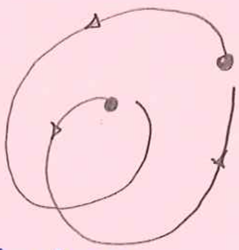
elliptical shape
excessive pre
load 1st Stage



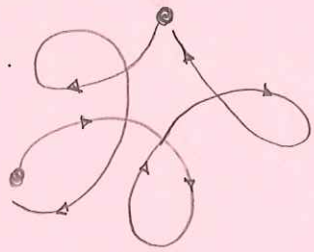
eight shape
excessive pre
load Misalignment
Last stage.



Kidny or banana
shape excessive
pre load 2nd stage
(Misalign ment)



Two timing marks
internal loop (non
-snc. Comp.) less than
1 (0.5x) and forward
whirling.



Two timing marks
External loops (non-sync.)
Back ward pressision.
(Rubing).

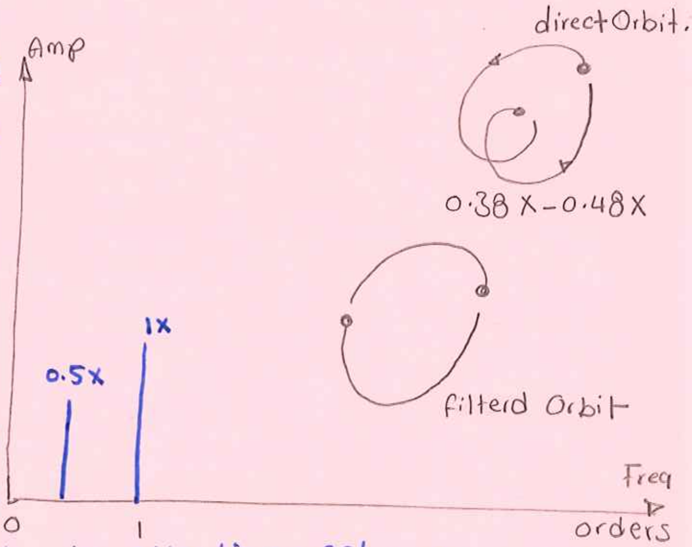
3rd you should look for the shaft center line location and eccentricity
normal the shaft center line should be away from the center (0.5)
(CW) Rotation on left direction. and if >0.7 so, you have increase
in pre load could be due to Misalignment. , if more than >0.95
So, you have heavly pre load and you usualy see eight orbit Shape.

Note: normaly Horz direction has less stiff. than vertical direction and the
orbit shape should be elliptical normaly But you should look to the
vibration level and how mush load you got.

orbit Rot. normaly from blan 

to bright. and timeing mark
or bright Represent key phasor.

Oil whirl: Fluid oil whirl is aself excited Fluidic malfunction that typically found on Journal or fluid film bearing at (0.38 - 0.48 X), causes Misalignment, Excessive clearnce, light load and low damping., also vibration pressison in same direction with shaft Rotation



NOTE : that shaft has low load on bearing & (M) eccenricity ratio ≃ jero and that due to Misalignment. means Shaft almost on Bearing center.

Oil whip: avery destructive condition happen when. the whirl freq. conicade with the resonant Freq. of the shaft (1st balance rotor resonance).

Rolling element Bearings:

Rolling element Bearings is the most importan part in your machine. and if the Bearing Fails it cas Be costly: Down time, secondry damage and more. less than 10% of the Bearing reach their design life time.

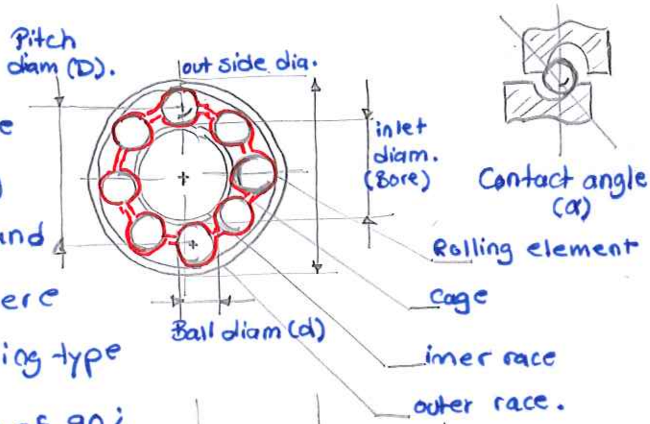
Bearing Failure : 16% handling and istallation, 14% Contamination, 34% Fatigue 36% Lubrcation.

How we can diagnose Bearing Fault:

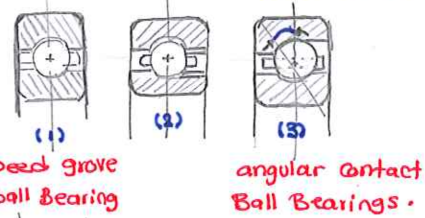
1. vibration Analysis 2. oil Analysis 3. acoustic emission 4. thermal ima 5. wear particle Analysis and more. the best and most common way and also what we will use her is vibration analysis.

Bearing Fault could be due to istllation errors like we mention befor, ex: Cocked bearing, unBalance, Bearing loose on shaft. Bearing loose in housing Excessive clearnce. Fluting from current Flow and high voltage. , also wears and cracks on low speed machines

Bearing design:

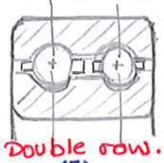


The four important parts on the Bearings are Outer race, inner race, cage and Rolling element. Bearing selection Based on loads and speeds., Rated life 10^6 of Rev. $L = (\frac{C}{P})^b$ where C: is load rating, P: radial load. b: is Bearing type Factor (3 For ball and 3.3 For roller), L_{10} is no. of 90% of Bearing would exceed. $L_{10} = \frac{10^6}{n60} (\frac{C}{P})^b$, n: speed.



Bearings types:

1. Deep grove 2. Filling notch 3. Angular Contact 4. shielded 5. Double Row 6. self Align spherical 7. taperd roller 8. needle and many other types.


Double row.
(5)

Bearing Fault by:

1. poor Lubrication.

on poor Lubrcation metal to metal contact increase wear, and too much grease can enter the motor and cause electrical problems. short. also over heat grease and reduce lubricant viscosity. and that will increase wear%.

$$BPFI = \frac{1}{2} n \left(1 + \frac{d}{D} \cos\alpha\right), \quad FTF = \frac{1}{2}\left(1 - \frac{d}{D} \cos\alpha\right)$$

$$BPFO = \frac{1}{2} n \left(1 - \frac{d}{D} \cos\alpha\right), \quad BSF = \frac{1}{2} \frac{D}{d}\left[1 - \left(\frac{d}{D}\right)^2 \cos^2\alpha\right]$$

How to calculate Bearing freqs.

2. installation errors:

Cocked Bearing is the most common istallation error and it could be in outer Race or inner race and you can see 1X, 2X and 3X on the Axial direction from the spectrum. you can use phase to know whatever it cocked from outer or inner race; mention on phase analysis's chapter.

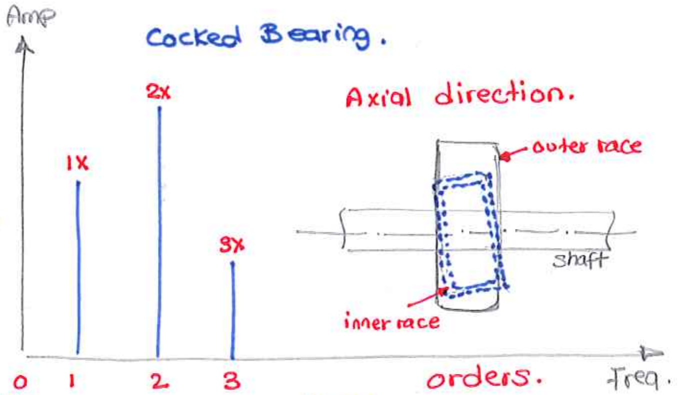


fig (1)

also Rotating looseness due to clearance prob. which cause skidding to the Bearing. and you can see Rotating looseness: as 1X + Harmonics with raised noise Floor and Random phase.

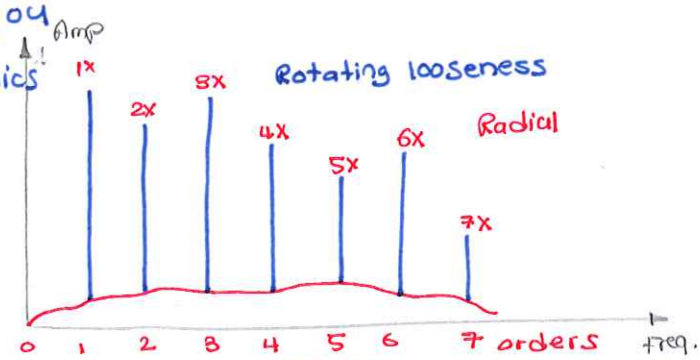
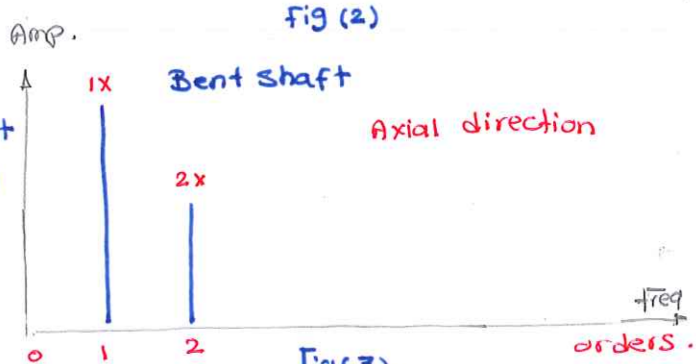


fig (2)

Bent shaft: also you can see Bent shaft on fig (3) as one of the main reason for Bearing fault. you can see hig 1X if the Bend is close to center of the shaft and 2X if it is more closer to the coupling. and it should be out of phase 180° accross the shaft and that is one of importat ways to know the diff. bet. imbalance and Bent shaft.



fig(3).

also excessive voltage or current:
excessive voltage or current, current will flow from the inner race through the rolling element to the outer race pitting can occur where there is alarge voltage diff. bet. the races. the outer race surface will look milky or have arippled. will appear on the spectrum as outer race fault.

as we mention before we have four freq. of interset, BPFI, BPFO, FTF, BSF (outer race freq, inner race freq., cage freq., Ball freq.). and those freqs. could be calculated from the geometry of the Bearing. and if we got any of them in our spectrum could be indicite of Bearing fault. also all those freq. must be non. harmonic freqs.

Tips to detect the Bearing Fault

1. you should double the ball spin Freq. as the ball hits the upper race and lower race per rotation.
2. BPFI + BPFO = # balls / rollers.
3. BPFO ≃ 0.4 X # Balls 4. BPF I ≃ 0.6X # Balls.

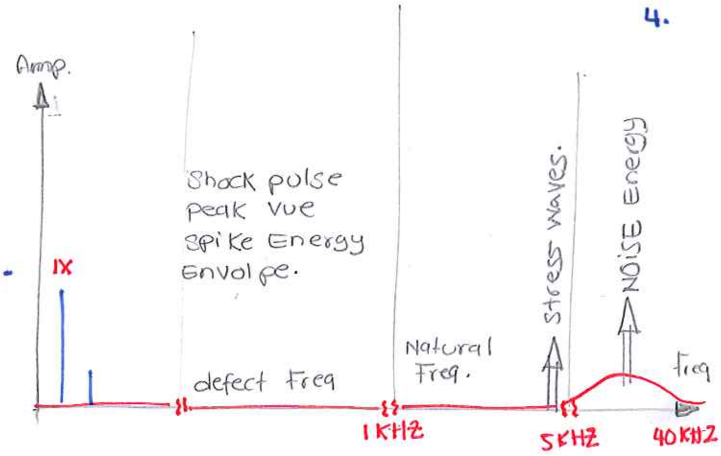
this rule should be applied for bearing with 8 to 12 balls.

Stage of Bearing Failure as per V.I:

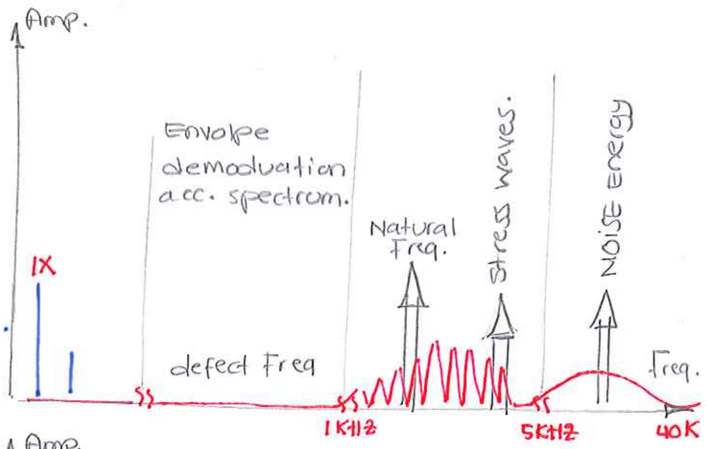
1. initial phase:
   A. noise level normal
   B. temp. level normal
   C. increase in (US) ultrasonic sound, acoustic emision, spike energy. and outer race deflection.
   D. overall vibration low, no. high vib. appears on velc. spectrum.
2. Second phase:
   A. slight increace in noise level.
   B. temp. normal
   C. large increase in ultra sound, acoustic emission an (S.E)
   D. slight increase in acc. overall vibration.
3. Third phase:
   A. noise level much higher
   B. slight increase in temp. levels
   C. v. high ultra sonic sound acoustic emission, spike energy.
   D. large increase on over all acc. and Start on velocity.
   E. Bearing freq. with harmonics and side Bands appears. on linear scale.
4. Final phase:
   A. high noise level.
   B. high temp. level.
   C. high increase in ultra Sonic sound, acoustic emission, SE,
   D. v. high noise floor & Spick Energy at low Freq. on SE spectrum.
   E. Failure could be any time.

Rolling element Brg. failure stages:

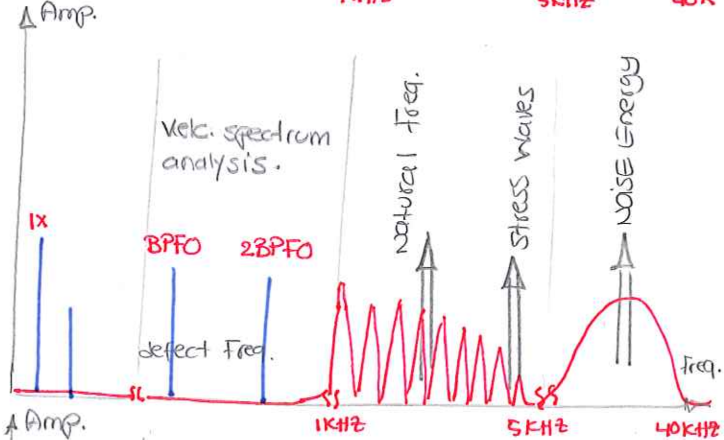
1. Stage one : subsurface damage only. Friction and minor impacts. , v. high Freq. vib-ration greater than 20KHZ , Slight noise & No high temp. (normal) very short duration impacts



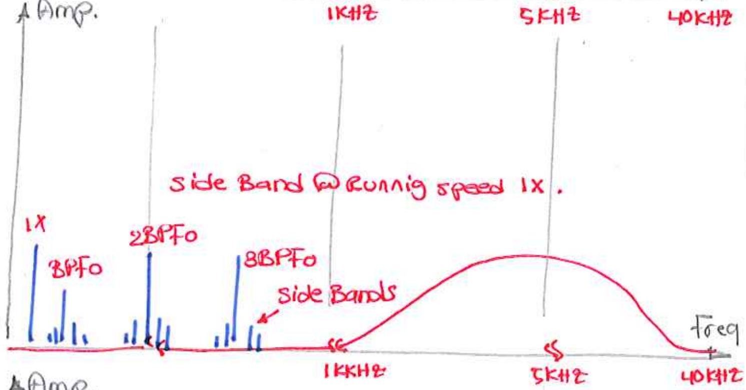
2. Stage two: subsurface damage only Friction and minor impacts , v. high Freq. vibration Start to increase , vibration signifcant enough to excite, structure, Bearing & sensor Envolpe, demodulation, spectrum shows defect signs on the spectrum, velocity spect. still not showing the defect Freq.



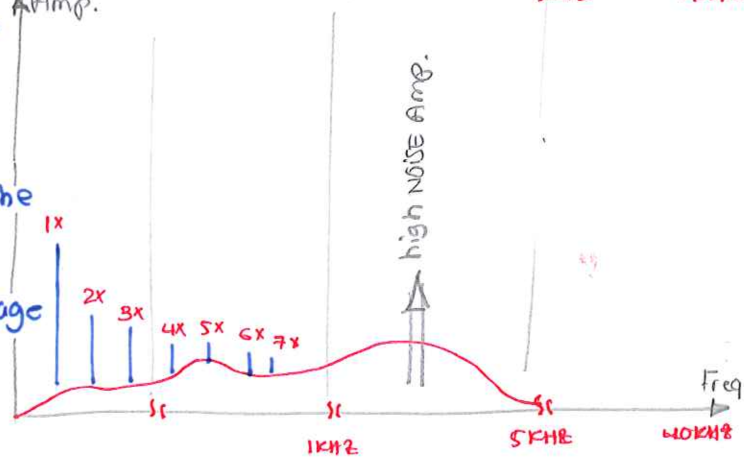
3. Stage three: more signifcant damage Bearing could fall in many ways far many Reasons. , very high Freq. increase in Amplitude. , Envolpe and demoduation are very effective and filters must set correctly in the setup. , harmonics and side Bands could appear in the spectrum.



4. Stage Four : more signifcant damge Bearing could Fail any time Bearing defect. Freq + harmonics and side Bands strongle appear on low Range spectrum. only high Amp humps on the high Freq. Range appear.



5. Stage Five: high 1X with harmonics amp. in the low Freq. Range spectrum with high Amp. Broad Band spikes (humps) also only high Amp (humps) appears on the high Freq. Range spect. , Bearing totaly damage Replace it ASAP , 2nd damage could happen any time.

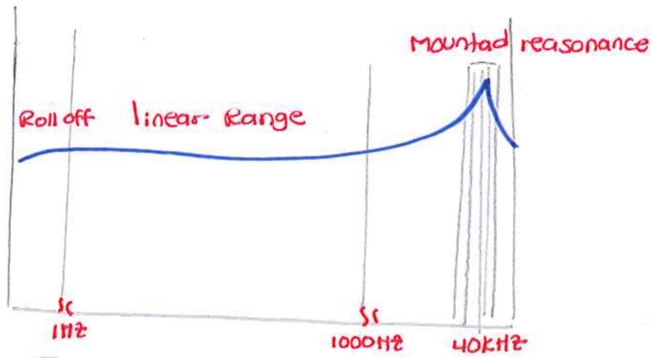


High Freq. techniques:

1. Stress Waves: result from metal to metal contact. roller and race way cause very Fa t, Low Amp., high Freq. impacts which can't be easily captured or collected. and on the other hand those events is a very good way to make early detection for the Bearing Fault., the stress waves is rush at the speed of sound 1500-8000 m/sec. also very high Freq. (5-50 KHZ) so, we should do certain techiques to be able to store this Fast, high Freq low Amp. signal (repeated impacts) which is req.

1. we need to Filter all high Amp. Low Freq signal as we can't see high Freq. low Amp. signal in the same even if we have high dynamic Range 90dB.
2. we need to sample very Fast as those event happen in a very high Freq. otherwise we will not be able to store those events, not enough sampling rate means that the high Freq. which will fall bet. digital sample points or (bins) will not be recorded. (measured).
3. Sensor should be accelerometer as acceleration is the Best way to measure high Freq. vibration. also transducer mountig is very important.
4. all sensors have linear meas. curve. all of them have mountad reas-onance so, the vibration range on the last left part From sensor Freq. Range curve could be resonating.
5. Meas. you should mount the sensors as much near as you can to the load zone.

Ⓐ use accelerometer to amplify the high Freq. Range vibration.



Freq. Range curve For sensors.

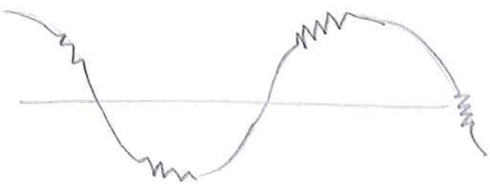
Ⓑ use high speed data acqusition to cap-ture the stress waves.

Ⓒ use demoduation tech. to capature high Freq. vibration.

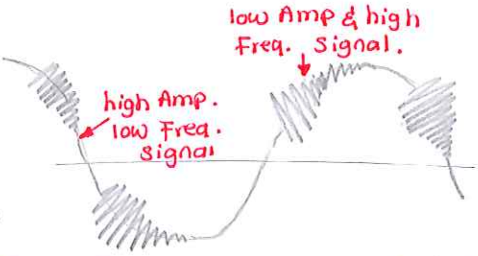
Ⓓ Monitor the machine with acoustic emission.

Enveloping and demodulation:

all what we care about is the repetation rate of the impacts on the high Range.



our starting point high Amp + low Freq. vibration such as, unBalance, misalignment etc. TWF have some transint events and we want to detect this transient events and know its Freq.



the ringing is the Natural Freq. you have carrier signal and carried signal and both at diff. freqns.

Remove the high Amp. low Freq. signal and keep only low Amp. high freq. Signal This can be done using anolg or digital circuit.

Now we will Rectify the signal and make it all positive.

then we will put alow pass filter which will remove all high Freq. resonance info and keep only Repeated perodic information we need. to see.

Shock pulse Method:

in shock pulse method we have atransducer designed to resonate at 32 KHz , the reasonance amplifies the shock pulse and resonance freq. and the sensor is mounted in the load zone.

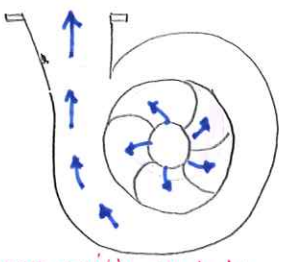
peak vue:

the peak vue is designed in avery high sampling rate which enable the data collecter to capature and store the stress waves which will be bet. the normal Freq. points in the (TWF), 102400 samples per second. the signal is still high pass filterd and rectified the the sys make peak value calculations, note the sample rate is 40 times Faster the normal sampling. also you can apply auto correlation to see the repeated Freq. signal.

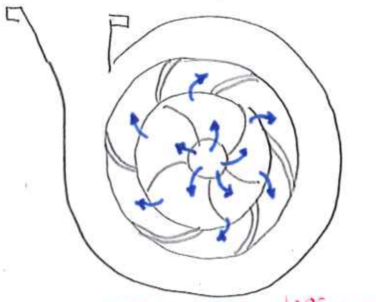
Pumps, Fans and Compressors.

pump, Fans and compressors are used to transport Fluid or gases. and convert Mechincal work into energy depend on pressure and velocity on that.

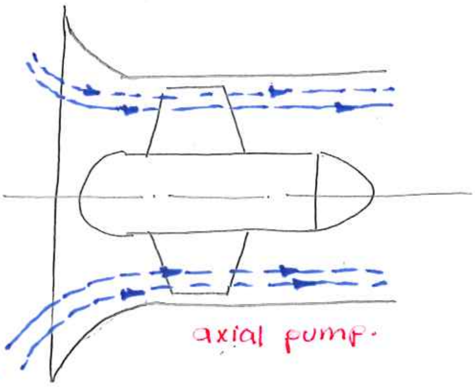
pumps are two types centrifugal pumps which can also be two types one of them one of them convert the velocity of flow using the pump casing or volute only & other types have adiffuser to build up that prossure on the pump. The 2nd type which is called turbine pump. which hase axial Flow direction and the space before and after the imppeller are the same. means suction & discharge are parallel to the imppeller on the axial direction. you can boild up more prossure using multi stage pump.



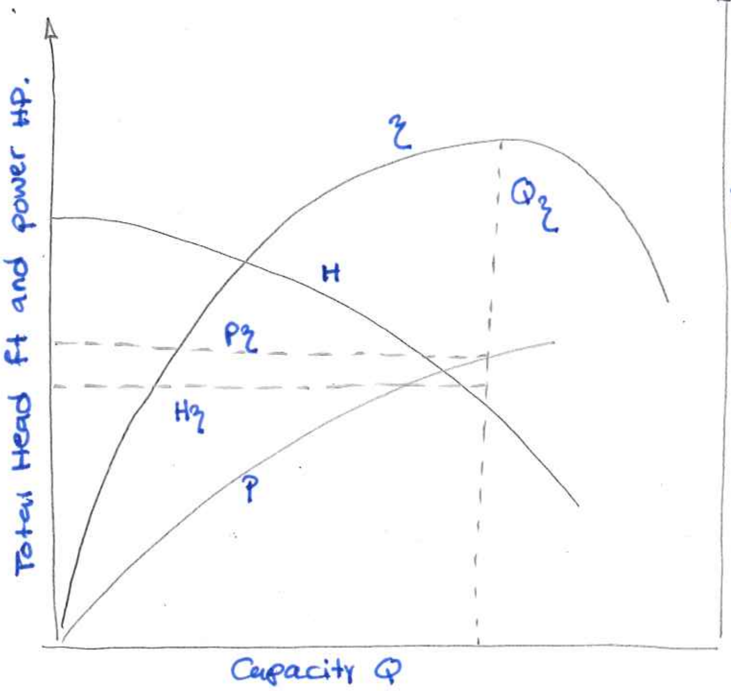
pump with volute only



pump with diffuser



axial pump.



Q : capacity gallons per min (gpm)
H : Head, (ft) P: Power (HP)
η : Efficincy S: Speed (RPM)
D: imppeller diam. γ : specific weight.

η%

(1.) $V = \frac{Q}{A}$ avg. Fluid velocity.

(2.) $H = \left(\frac{P}{\gamma} + \frac{V^2}{2g} + Z \right)_d - \left(\frac{P}{\gamma} + \frac{V^2}{2g} + Z \right)_s$

$(V^2/2g)$ Velocity Head

Total pump Head — acc. due to gravity — Elevation — press. Head. (P/γ) — $32\ ft/sec^2$

Total pump head represent the net work done on aunit weight of Fluid passing from inlet or suction Flang(s) to outlet or discharge flange (d). Bernoli's Eqn.

unlike Fans the Fluid pass is (non-compress) and on certain condition the Suction pressure could drop and that will make the Fluid to vaporize and make shock waves could destroy the imppeller and that case is called cavitation.

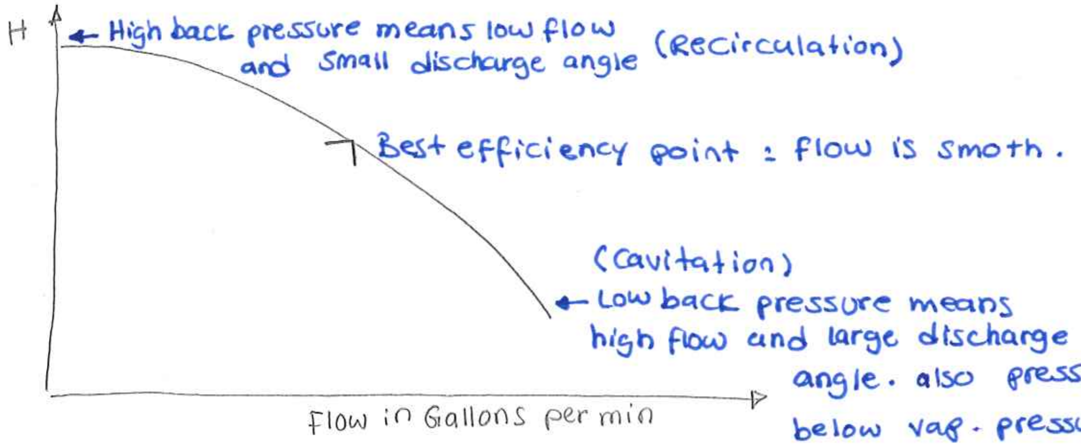
the pump (HP) = $\frac{QH(sp.\ gr.)}{3960}$ and η = HP ÷ power input to the pump shaft from drive machine, ex: motor power.

$N_s = \frac{N\sqrt{Q}}{H^{3/4}}$: specific speed which is used to judge efficincy
Q (gpm), H (ft), N (RPM).

cavitation phenomena happen when (NPSH) net positive suction Head is below the liquid vapour pressure.

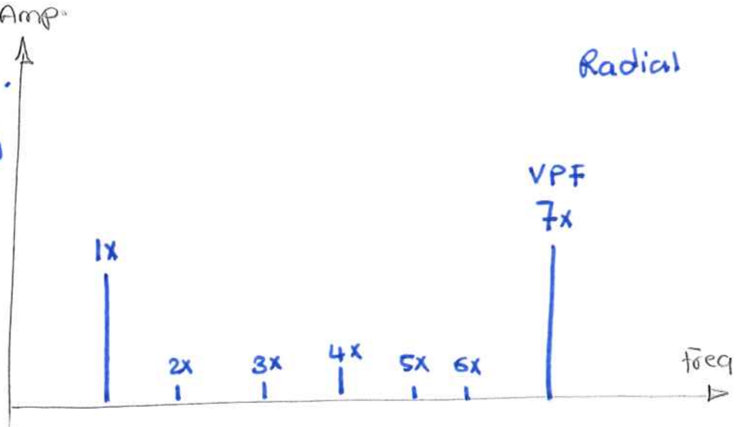
$NPSH = \frac{P_a - P_s - P_{vp}}{\gamma} + Z_{ps} + \frac{V^2}{2g}$ where P_a: atmospheric pressure

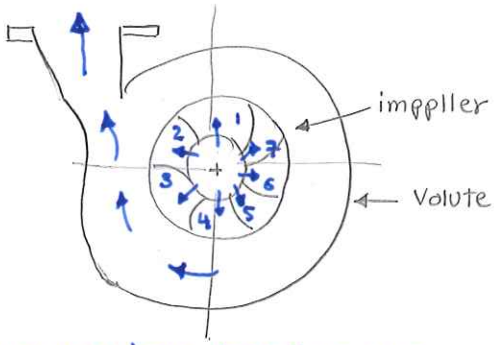
and P_s: gage suction pressure, P_{vp}: vapor pressur.

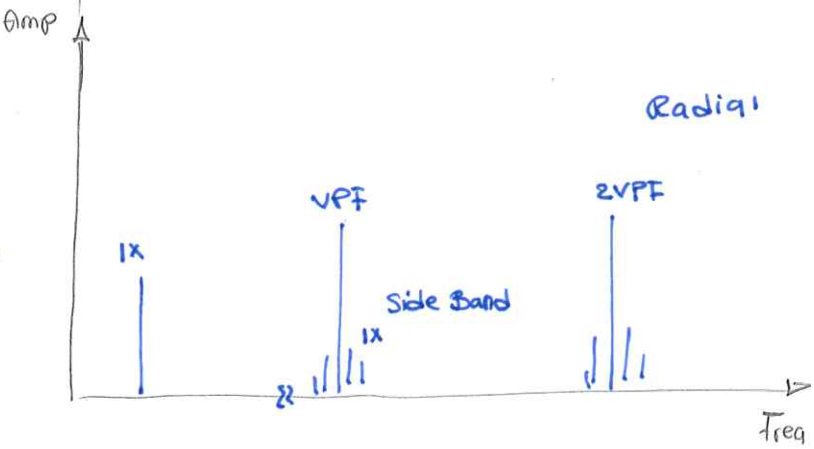


1.) suction pressure.
2.) discharge press.
3.) Fluid temp.
4.) Fluid speed.
increase on cavt.

one important about pumps is the vane passing freq. (VPF)
VPF = # of pump vanes x RPM. and the Reason of vane passing Freq. could be. Rotor or housig eccntricity; tip clearnce prob. ; vanes wear ; dirity damge or missing Filters. ; Non uniform blade angle.

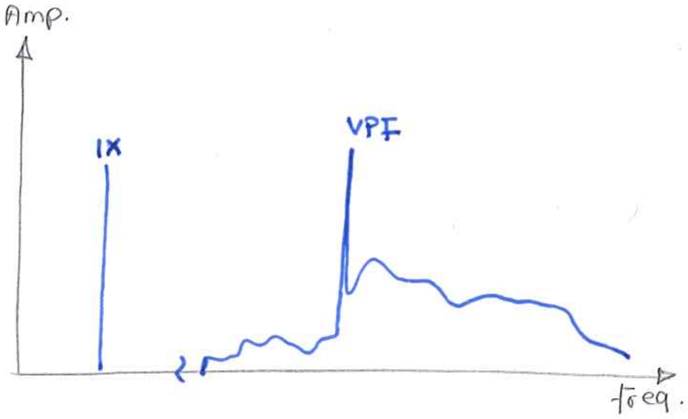




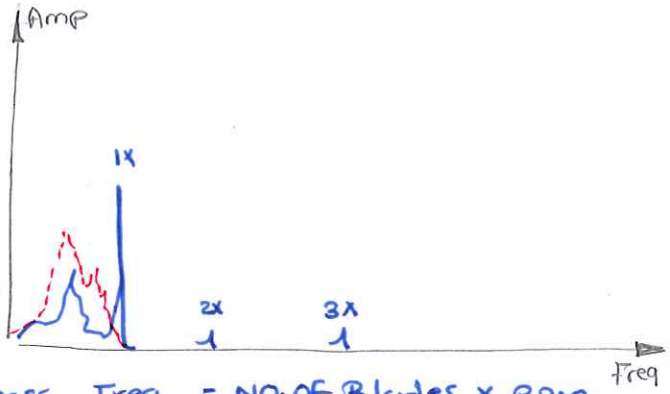


when you have impellor loose or pump starvation you might see VPF with harmonics also you could see side Bands at the Rumig Freq. 1x.

Cavitation: usualy happen when suction pressure or inteake is restricted and the NPSH is below liquid vap. pressure. the liquid vaproize when it coming over the impeller and high Noise genrated. you will see high Amp. humps around the VPF. on the Right side from spectrum. Random impacts on TWF.



Turbolence: happen when you got high Back pressure, Low flow, Low discharge angle, obstruction on discharge line. causing high hmps on the low Range Left side around 1X.



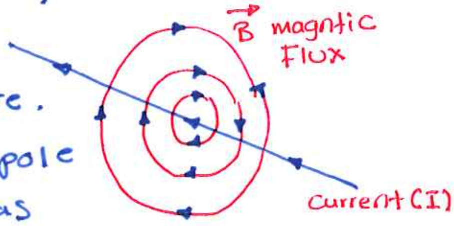
NOTE : on Fans you got (BPF) Blade pass Freq. = NO. of Blades x RPM and you can get the normal vibration fault such as imbalance or Misalignment ... etc.

Electric Motors Analysis

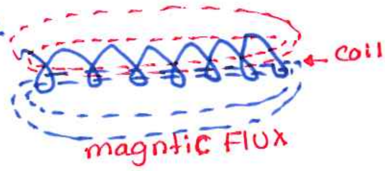
1st we need to understand Basics about how electrical motor works also what is motor types and its components.

Electromagntism:

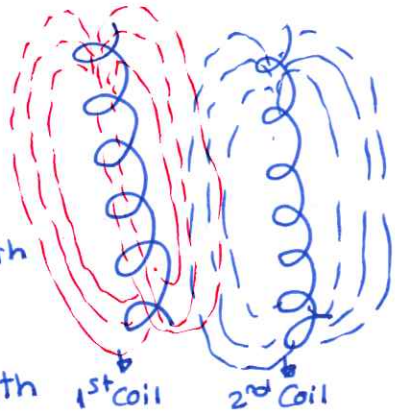
you can make amgnit by wire or coil and electric current as the current pass through the wire or coil it creats electro magntic field. and the direction of current and magntic flux can be determined by simple rule called (right hand rule)



you can increase the consentration of that magntic field by using a coil instead of using electrical wire. the coil has anorth pole at one end and south pole at he other end. also the process can be reversed. as if we pass acurrent through coil we genrate amagntic flux same if we move magnit field (coil) trough a magntic field we create acurrent.

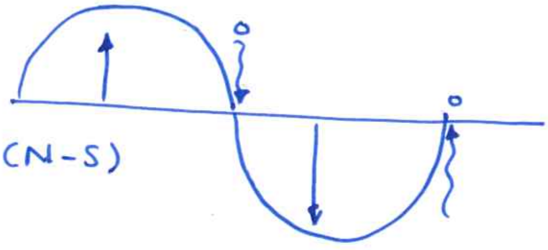


when current is induced in a coil which generate a magntic field if asecond coil is placed in the same mgntic field from 1st coil current will flow on that coil and it called induced current so it will constract its magnetic field with north and south poles.



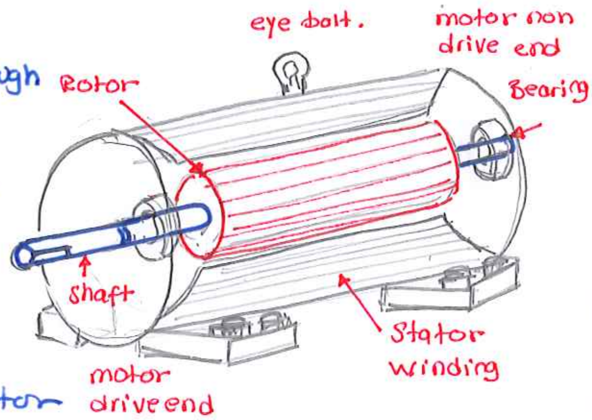
also when crront moving through acoil as the strength of coil increase the magntic field increase and when it reverse direction the two poles North and south reverse direction so. it called (AC) current as the strength change and direction change. that (AC) current make sine wave. the current increase and then go to zero then go increase to opsite direction until is goes to zero again. and comple that cycle (50/60) times per second and that called line freq. and that cycle

you can see that magntic force twice per cycle increace an d decrease one (N-S) and one (S-N)



Electric motors:

The stator is designed as when current pass through windings or coils magntic field is created, also by small arrangment on that mgnetic field we can make it rotating magnetic field. and you can have a2 pole 3 phase motor (N-S).



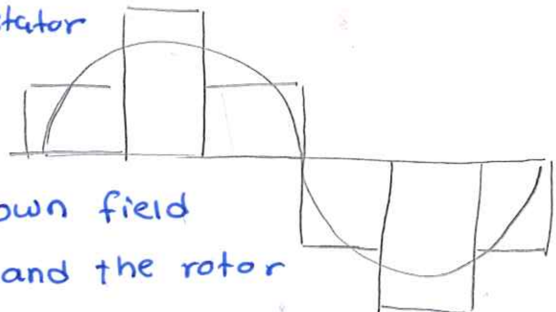
if we could put a rotor (mgneit) inside the stator you will see the the (N) will Run over (S) side from the roter and (S) from stator will Run after (N) from roter. thus the rotor spins. and if it rotates at line freq. (50 or 60) Hz it called sync. motors. sync. speed of the motor = (2 X LF) ÷ no. of poles. ∫ you can see 2 pole, 4 pole, 6 pole motors. so, sync. speed depend on the no. of poles.

Types of Motors:

1. AC sync. motor runs at the line freq.
2. AC induction motor.
3. DC Motor.

AC motor could be powerd up by single phase current or 3 phase current and 3 phase current most use.

On AC motor magntic Field is induced in the stator and it spins at syn. speed = 2LF / no of poles. that moving magntic field induced current on rotor bars., the rotor bars produce their own field which trying to lock out the stator field. and the rotor can't catch the stator so it slips. slip = sync. speed - Rotor speed.

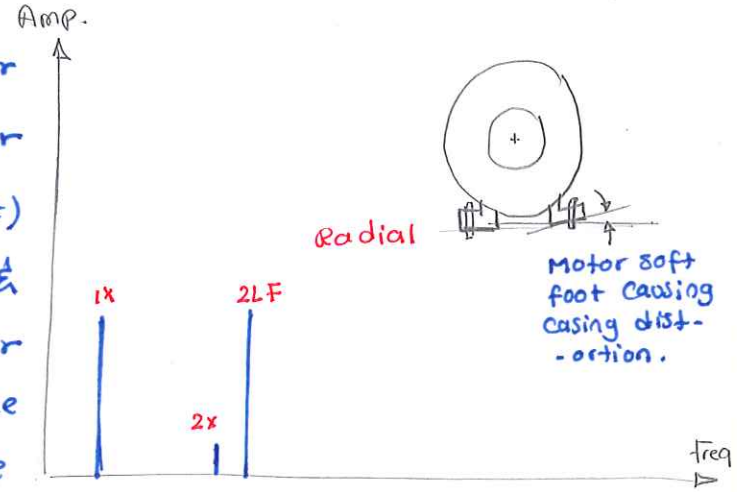


Motor Faults:

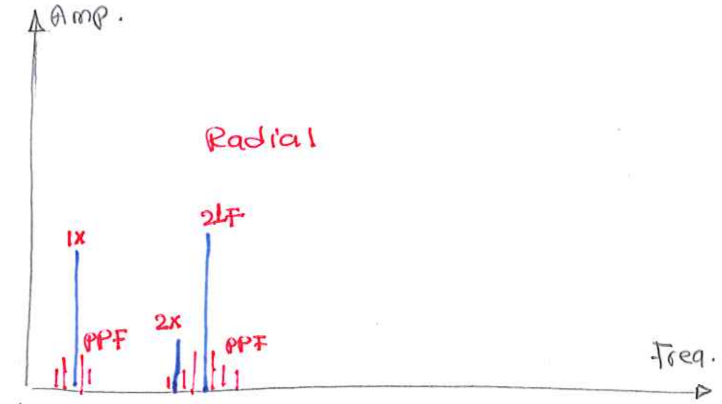
Note that motor insulation is very important factor (phase-phase), (coil-coil), (coil-ground), lamniations. also heating up should be avoided by any mean. (cooling fan), (cooling sys for large motors). also motor instllation and alignment are very important.

Electrical Motor Faults:

1. **Stator Eccentricity:** S.E or loose iron or shorted laminations ca be seen on the motor radial direction as 2LF. (100 HZ) or (120 HZ) as it produces uneven air gab bet. Rotor & Stator. Note that current peaks twice per cycle one(-ve) & one (+ve) cause two Force pulsation per cycle. also sof fot do the Same. (Fixed Air gab).

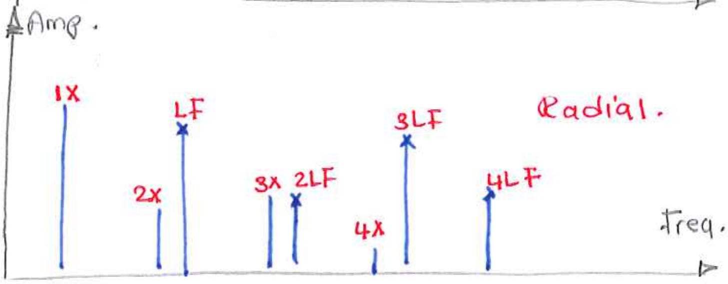


2. **Eccentric Rotor:** on Rotor eccentricity you can see (1X) also twice li e Freq + side Bands at (PPF) pole pass Freq which = Slip Freq X No. of poles, slip Freq = sync. Freq - rotating Freq. (Rotating variable air gab) and mos y appear in the Radial direction



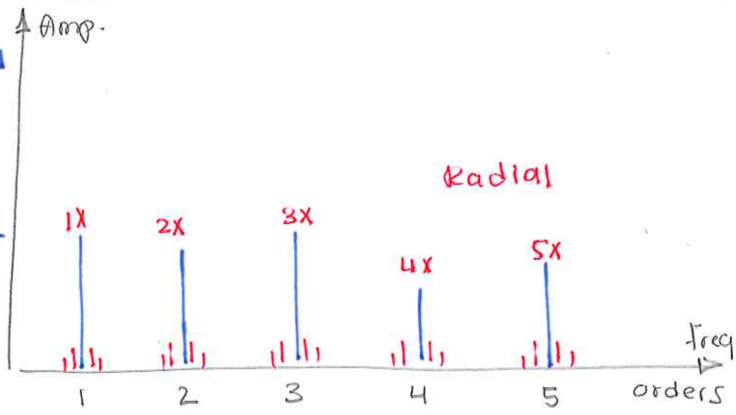
3. **Rotor bow:** unBalanced Rotor current will creat uneven thermal growth on the Rotor which cause Rotor bow. and that create rotor un Balance.

4. **Loose windings:** it will creat twice line freq 2LF with its harmonics on the radial direction. and it should be magntic induced vibration at 2LF + Harmonies.

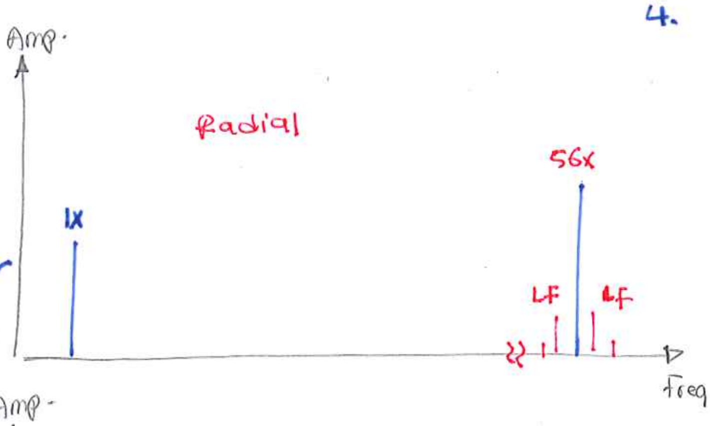


5. **Cracked or brocken Rotor bar:**

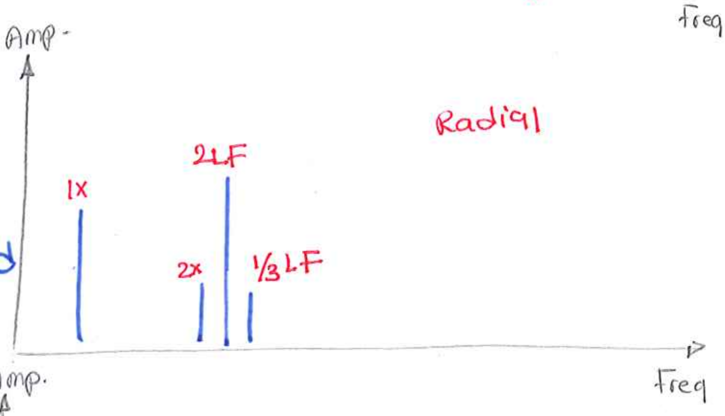
it w ll show 1X + harmonics on the Radial direction + Side Bands at the pole pass freq. around 1X and harmonics. and as mention before PPE = Slip Freq x # of poles., (MCSA) Motor current signature Analysis is v. important on that case to confirm the rotor bar defect.



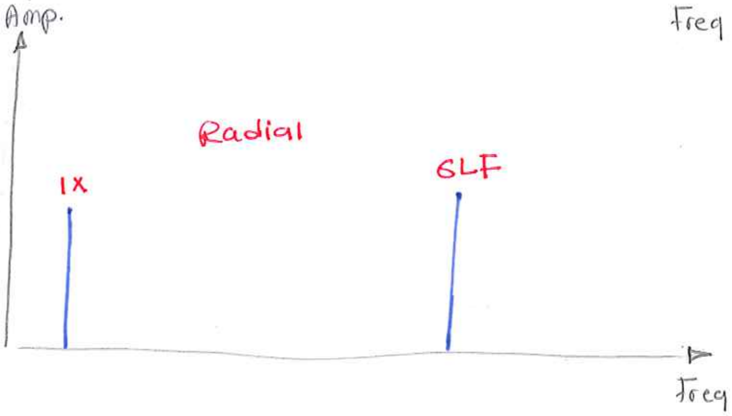
6. Loose Rotor bar: it will creat Roter bar passing Freq at the high Freq. Range should appear with side Bands at 2LF or sometime Runig speed and it appear on the Radial direction (MCSA) is v. good on hat case.



7. Loose connection: phasing problem due to Loose Connection on the Junction Box could cause high 2XLF with side Bands at 1/3 LF. as you normal have 3phase and on that case you have phase unBalance.



8. Silicon Controlled Rectifiers (SCR):- and that case only on (DC) Motors. and on that case you can see 6LF or 300HZ if you have 50HZ Freq. the SCR used ton convert From AC to DC.



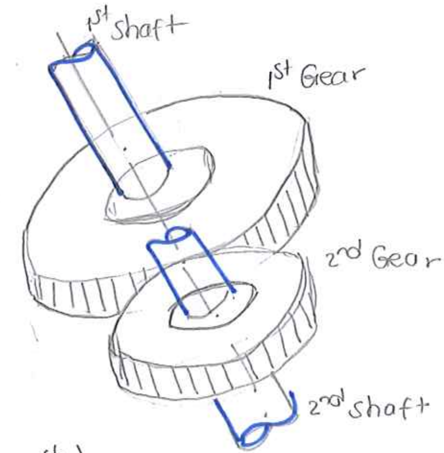
9. Rotor operating off magnetic center: you will see natural Freq. on the axial direction.

Gear Boxs faults and Analysis

Gear types and design:

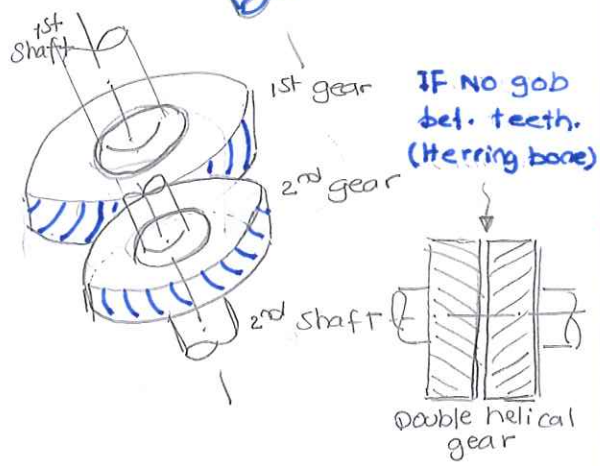
1.) Spur gears:

spur gears connect parllerl to the shaft and teeth cut are parllerl to the shaft too. there is no Axial (thrust) Forces, also they noiser than the other gears design.



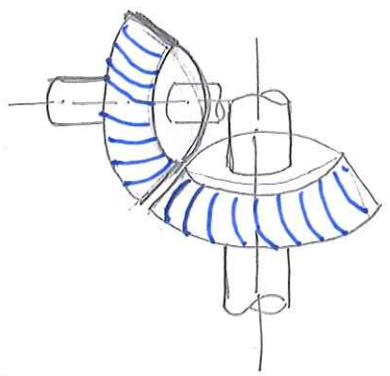
2) Helical gears:

gears are connected parrllel to the shaft Same as spur geacs but the teeth are cut at an angle to the shaft you can have Radial and axial Forces., used in high speed machines. angle up to 80°, double helical gear (Herring bone), more smoother and help in reduction of Axial load.



3) Bevel gears:

Convert or transmit power bet. intersecting Shafts usually 90° apart, two types of Bevel gear straight and Spiral and spiral is more smooth. and better Teeth meshing and used for higher Loads.

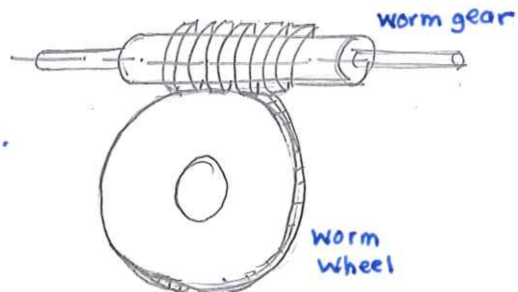


4.) Worm gear:

Power transmition, Reduction of Axial load.

could be diffuclt to analyze

Ratio: # weel teeth / # of threads on worm.



Forcing Freqs:

1. input speed.
2. output seed.
3. Gear mesh Freq.
4. Gear Assemply phase Factor
5. Hunting tooth.
6. Ghost Freq.

1. Gear Mesh Freq = # of teeth x shaft Speed.

2. Out put Speed = input Speed x (input # of teeth | out put # of teeth).

A.) Gear Assembly phase problem:

gear Assembly phase pattern cause agear wear poblems. which result on having sub harmonic of Gear Mesh.

B.) Gear wear and common factor:

All gears should be designed with prime no. of teeth (1, 3, 5, 7, 11, 13, 17, 19, ...) which will enable a certain teeth of the 1st gear to mesh with all teeth of the 2nd gear before contact the 1st teeth on the 2nd gear for the 2nd time. and that happen with all teeth and by that way we can be sure that we have equal meshing load at all teeth. and even wear.

C.) detect the common factor:

For Example if you heave 33 teeth gear and 21 gear what will be your Common factor 33 (1 X 3 X 11) , 21 (1 X 3 X 7) atooth on one gear will mesh with every third tooth on the other gear.

EX: 80 teeth gear with, 18 teeth gear (1 X 2, 3 X 5) , (1 x 2 X 3 X 3)
Common Factors (1, 2, 3) product of common Factor : 1 X 2 X 3 : 6
on that case. the tooth of 1st gear will mesh with every six tooth on the 2nd gear.

D) detect Gear Assemply phase Factor:

GAPF = GM / product of common factor.

E.) Hunting tooth Freq:

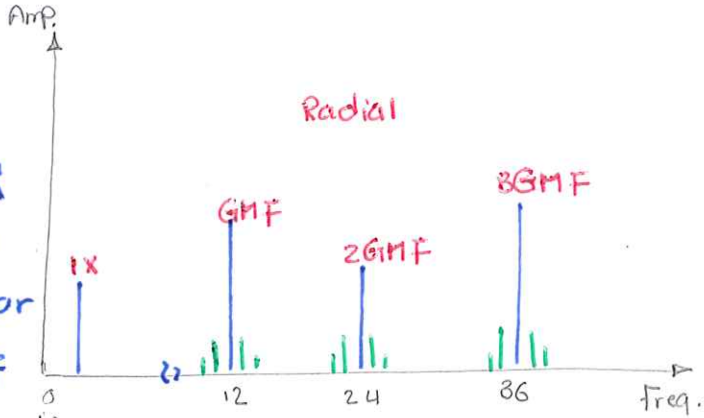
the Freq. which one tooth of the 1st gear meet or contact the same tooth on the other gear.

$$HTF = \frac{GM \times N_a}{Z_1 \times Z_2}$$

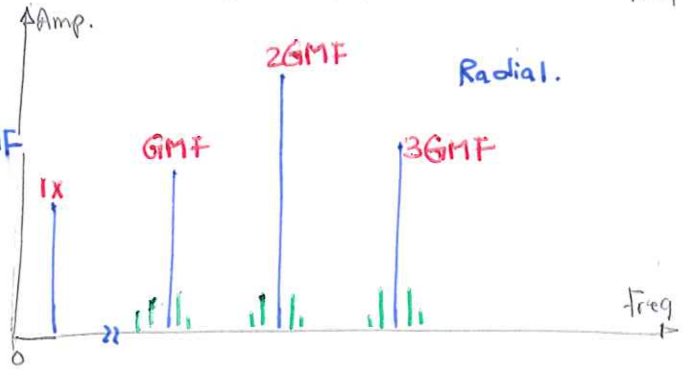
F.) Ghost Freq:

it is a Freq. normaly appear when you got new gear Box as aresult of Machining or surface finsh problem and it disappear by short time from runig the gear Box.

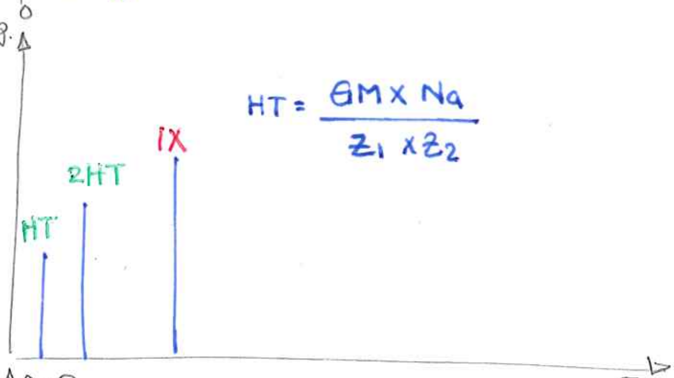
Gear Box Faults Analysis:



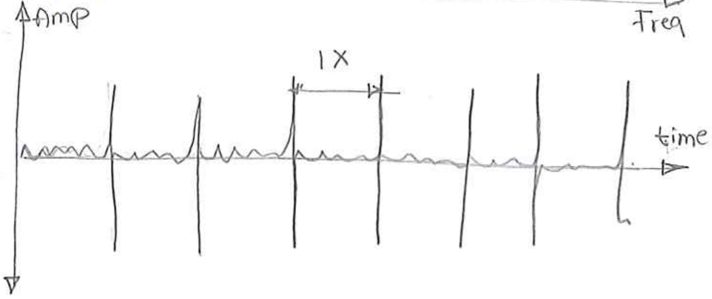
(1.) **Gear tooth wear:** shaft speed side Bands around the gear Meshing Freq & its harmonics. 1st Stage for the gear wear is the side Bands around the gear Mesh and harmonics 2nd Natural Freq of the gear is exited.



(2.) **Misaligned gear (distorted Box):** Normal on that case you will see 1GMF and 2GMF and 3GMF, But 2nd & 3rd GMF normaly are high Amp. also side Bands could appear on that case.



(3.) **Hunting tooth:** you can see 1st HT & 2nd HT Freq. on the gear Box spect. and normaly it is sub-harmonic. Component, and its appearnce it tells that the gear wear could inc--rease more faster other GBXs.



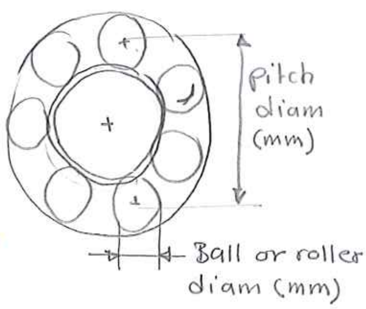
(4) **Cracked or Brocken teeth:** normaly that defect will appear at the GB TWF as a sharp high amp. impacts at the Runnig shaft Freq. with high crest Factor value.

the other Gears Faults such as eccentric gears, back lash, worn gears will appear on the spectrum as GM Freq. as 1st stage the Harmonics 2nd stage, and side Bands at the gear shaft Runnig Freq as 3rd stage.

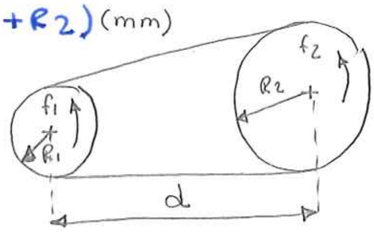
Vibration Analysis Equations (Math):

1. $A = 2\pi F v$
2. $v = 2\pi F D$
3. $dB = 20 \log Vm / Vr$
4. $T = \dfrac{N}{F_{max}}$ sampling time, N: No. of lines.
5. $R = 2\,(F_{max} \div N) \times W.F$ Resolution.
6. $M_{trail} = \dfrac{90\,M}{N^2 e}$ where (M) Rotor mass, (N) speed RPM, (e) trail weight (r) m.
7. $NF = \dfrac{1}{2\pi}\sqrt{\dfrac{K}{m}}$ where (k) stiffness, (m) mass. (NF) natural freq.
8. $f = \dfrac{16.66\,v}{\pi D}$, Roll freq. (speed), v: web velc. (m/min), (D) Roll diam (mm), f (HZ)
9. $FTF = \dfrac{\Omega}{2}\left[1 - \left(\dfrac{B}{P}\right)\cos CA\right]$
10. $BPFI = \left(\dfrac{N}{2}\right)\Omega\left[1 + \left(\dfrac{B}{P}\right)\cos CA\right]$
11. $BPFO = \left(\dfrac{N}{2}\right)\Omega\left[1 - \left(\dfrac{B}{P}\right)\cos CA\right]$
12. $BSF = \left(\dfrac{P}{2B}\right)\Omega\left[1 - \left(\dfrac{B}{P}\right)\cos^2 CA\right]$

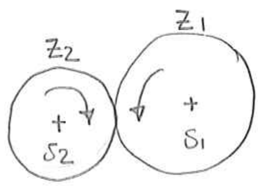
CA : contact angle deg°
Ω : machine speed. HZ
N: no. of Rolling element
P: pitch diam.
B: ball or roller diam



13. Peak = 1.414 Rms
14. 2peak = 1peak on single harmonic wave.
15. Motor sync. speed = $\dfrac{2\,LF}{n}$: where (n) no. of poles.
16. Belt Freq = $\dfrac{2\pi R_1 \times RPM_1}{60\,L}$, $L = 2\sqrt{d^2 + (R_2 - R_1)^2} + \pi(R_1 + R_2)$ (mm) (mm, mm)
17. $F = \dfrac{V}{L}$, $V = R_1 \omega_1$, $\omega = \dfrac{2\pi\,RPM}{60}$ Rad/sec.
18. $f_1 R_1 = f_2 R_2$, where f is pully speed.
19. $Z_1 S_1 = Z_2 S_2$: Z is no. of teeth on GB.



20. $CW = \dfrac{TW\,O}{T}$ where CW : correction weight
O: orignal weight, T: calibration Factor.



21. GM = # teeth x RPM GM Gear mesh freq.
22. VPF = # vanes x RPM G vane pass freq.
23. PPF = slip Freq x no. of pole (pole pass Freq.)
24. Slip Freq = sync. speed − actual speed.

From unit	to Unit	action
① inch	① mm	① x 25.4
② pound	② oz	② (1 pound = 14oz)
③ foot	③ m	③ (1foot = 0.304 m)
④ inch	④ mils	④ (1 inch = 1000 mils)
⑤ mm/s^2	⑤ g	⑤ ($9806\ mm/s^2 = 1g$)
⑥ kg	⑥ Ounce	⑥ (1 kg = 35.274 ounce)
⑦ kg	⑦ pound	⑦ (1 kg = 2.204 pound)

25. Gear Box Equations:

A. Gear Mesh = # of gear teeth x Shaft RPM

B. Out speed x out put # of teeth = input speed x input No. of teeth

C. GAPF = GM ÷ product of Common Factor (Na)

D. HTF = $\dfrac{GM \times Na}{Z_1 \times Z_2}$

E. diametral pitch = # of teeth ÷ pitch diam.

F. circural ptich = pitch diam (π) ÷ # of teeth of the gear