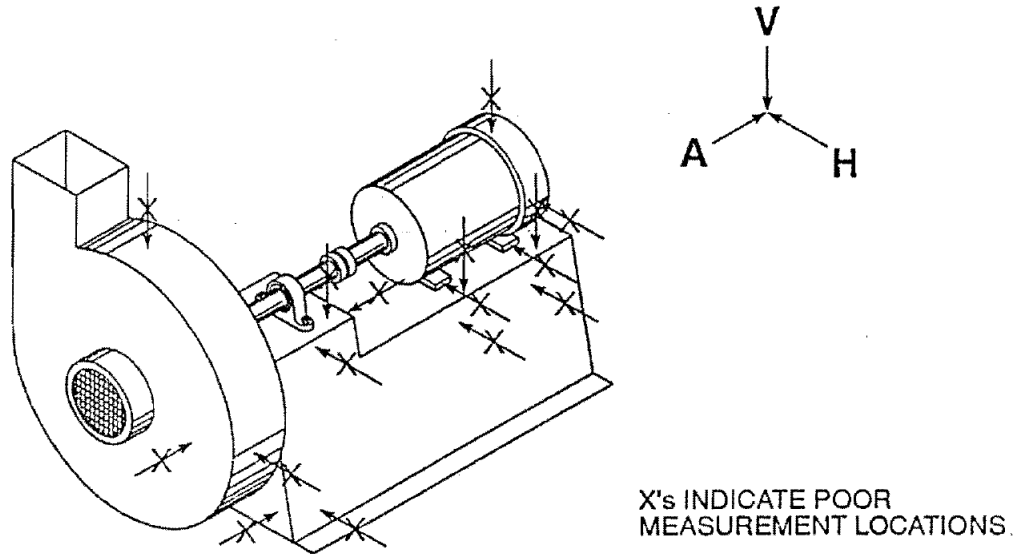
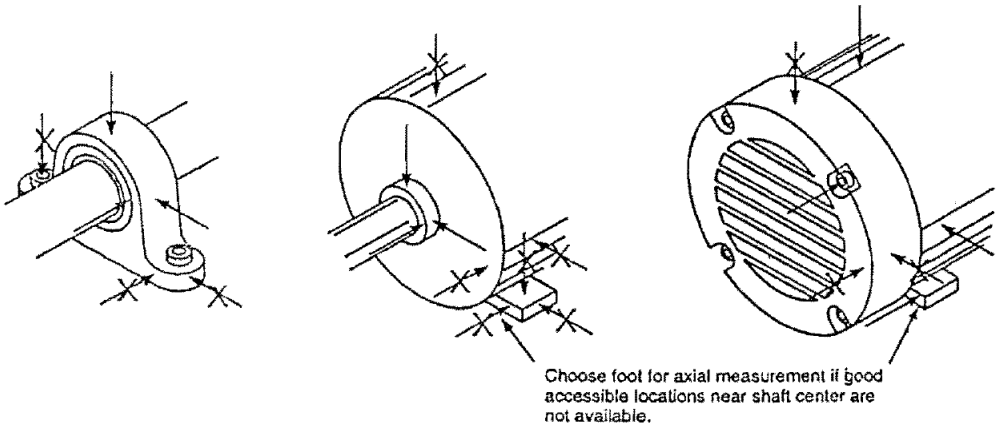
สาเหตุและอาการของการสั่นสะเทือน

2103541 Vibration Monitoring and Analysis

ตำแหน่งวัดการสั่นสะเทือน



TYPICAL MACHINE WITH FABRICATED BASE

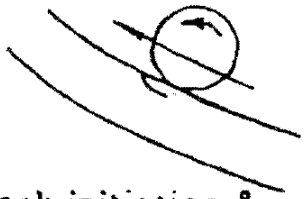
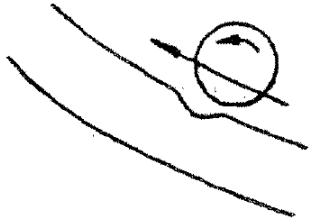
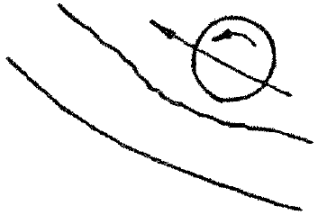


PILLOW BLOCK BEARING MOTOR DRIVE END MOTOR FAN GUARD

- เลือกวัดในตำแหน่งที่ใกล้หรือมีการส่งผ่านการสั่นสะเทือนโดยตรง เช่น แบริ่ง
- ไม่วัดในชิ้นส่วนที่มีความแข็งเกร็งต่ำ เนื่องจากผลที่ได้จะเป็นการสั่นหรือกระพือของโครงสร้างแทน

ตัวอย่างการวิเคราะห์สัญญาณในโดเมนเวลา (1)

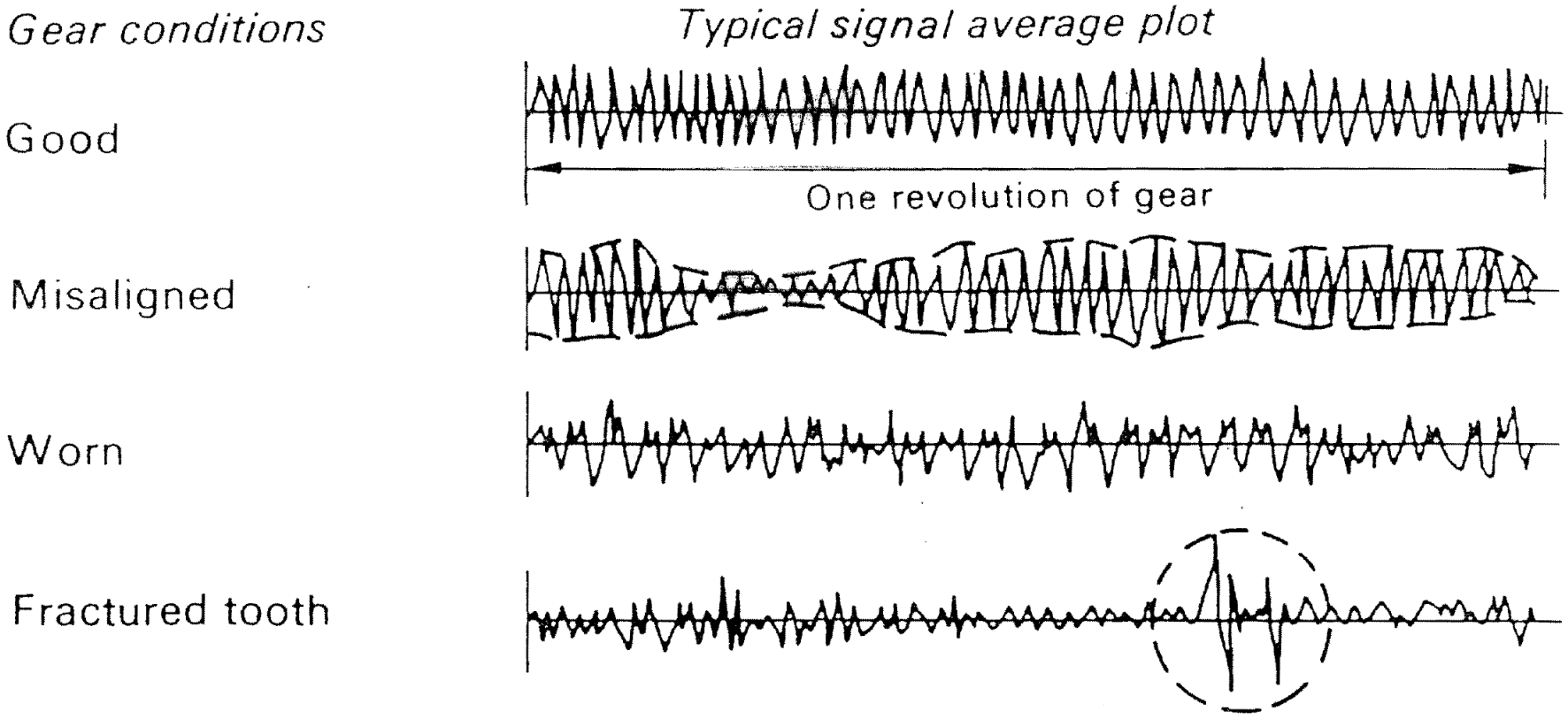
ลักษณะการสั่นสะเทือนในโดเมนเวลาเปลี่ยนไปตามระดับความเสียหาย

Degree of deterioration	Light (initial)	Middle (caution)	Heavey (damage)
Failure state	 Crack initiation & propagation	 Flaking	 Propagation of flaking
Vibration wave	 Acoustic emission wave level	 Observed vibration according to impact	 Vibration of bearing case is excited by heavy flaking
Frequency	about 300 ~ 600 kHz	5 ~ 50kHz	500 ~ 600Hz

Propagation of Vibration Status

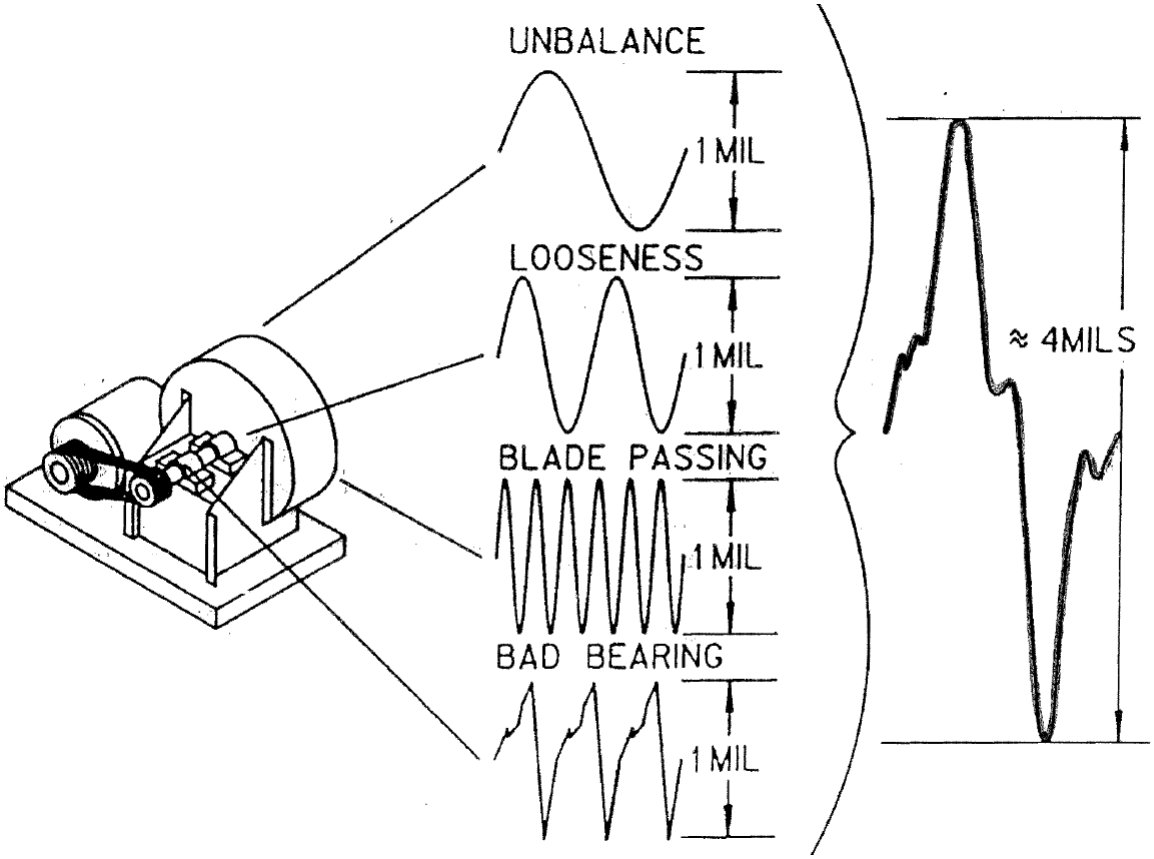
ตัวอย่างการวิเคราะห์สัญญาณในโดเมนเวลา (2)

ลักษณะการสั่นสะเทือนในโดเมนเวลาอาจใช้บ่งบอกถึงสาเหตุของความเสียหายได้

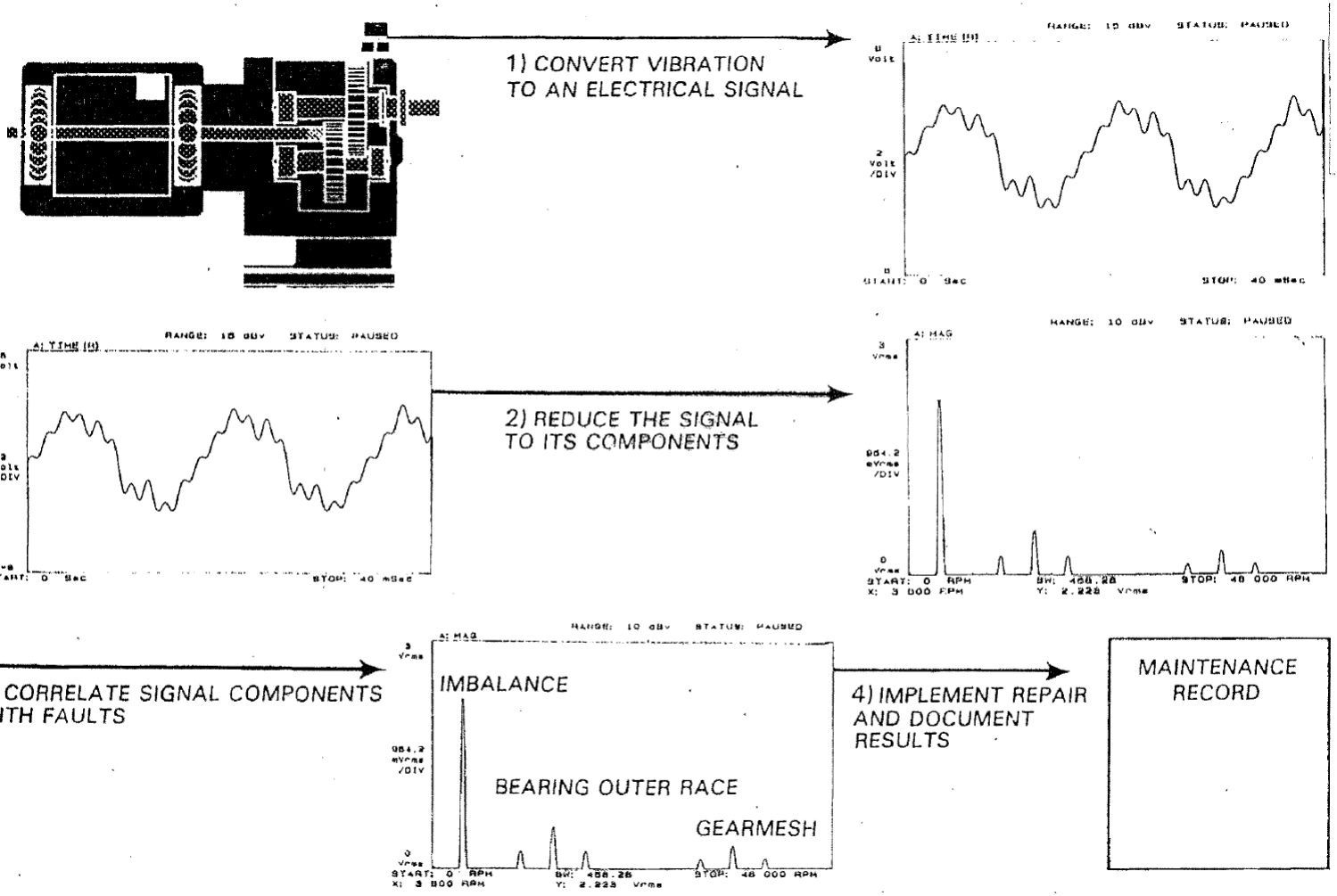


ตัวอย่างการวิเคราะห์สัญญาณในโดเมนความถี่ (1)

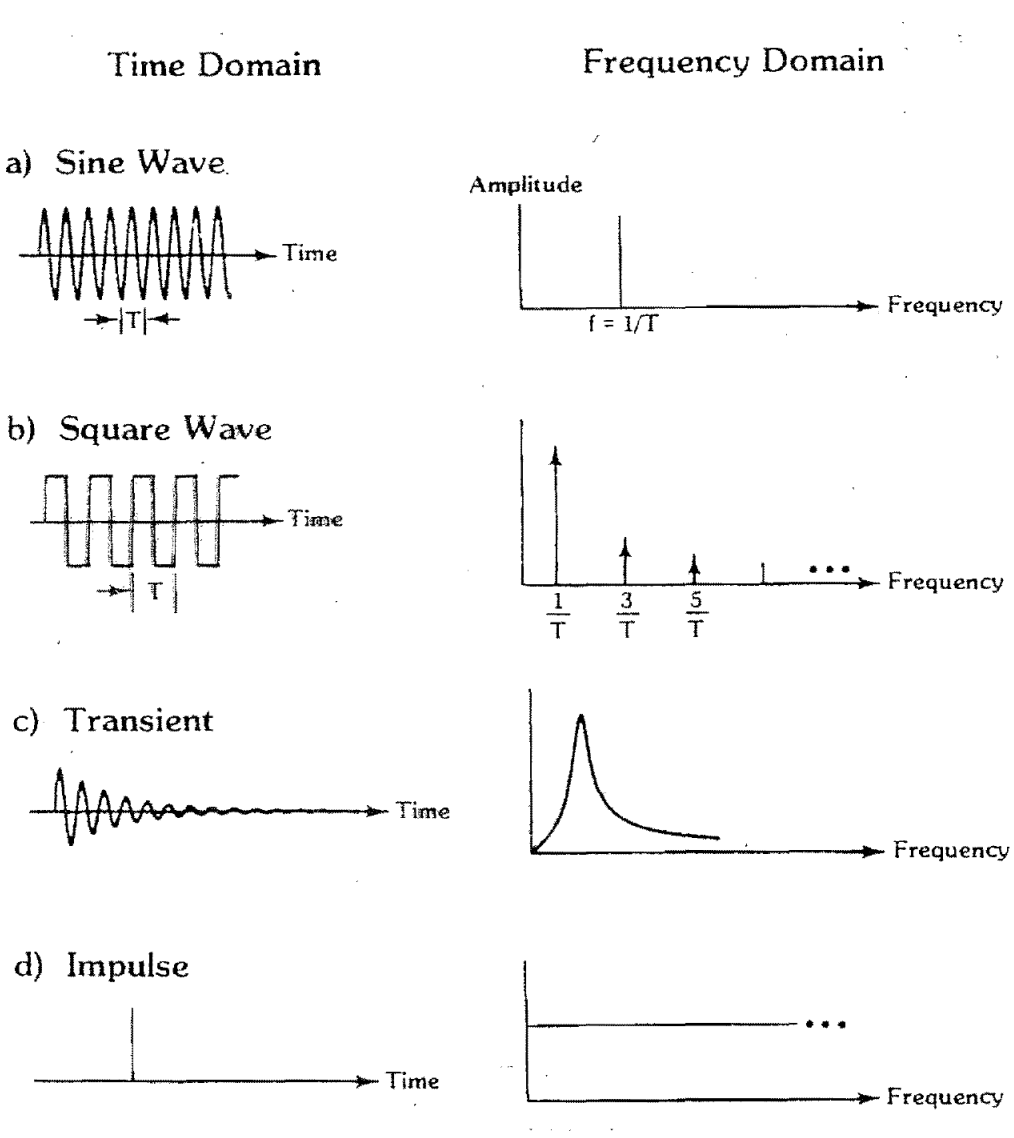
ลักษณะการสั่นสะเทือนในโดเมนเวลาอาจเกิดจากการสั่นสะเทือนหลายๆ สาเหตุ หลายๆ ความถี่ประกอบกัน การวิเคราะห์ความถี่จะเหมาะสมกว่า

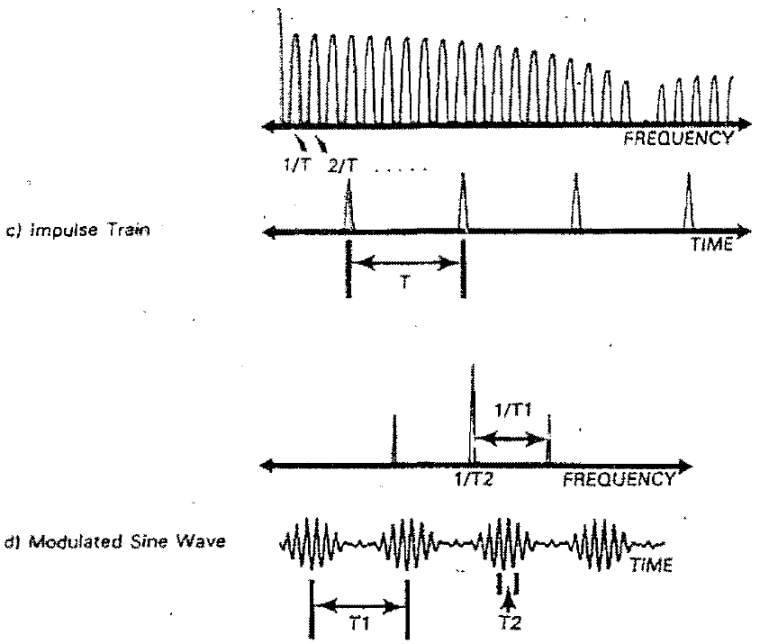


ตัวอย่างการวิเคราะห์สัญญาณในโดเมนความถี่ (2)

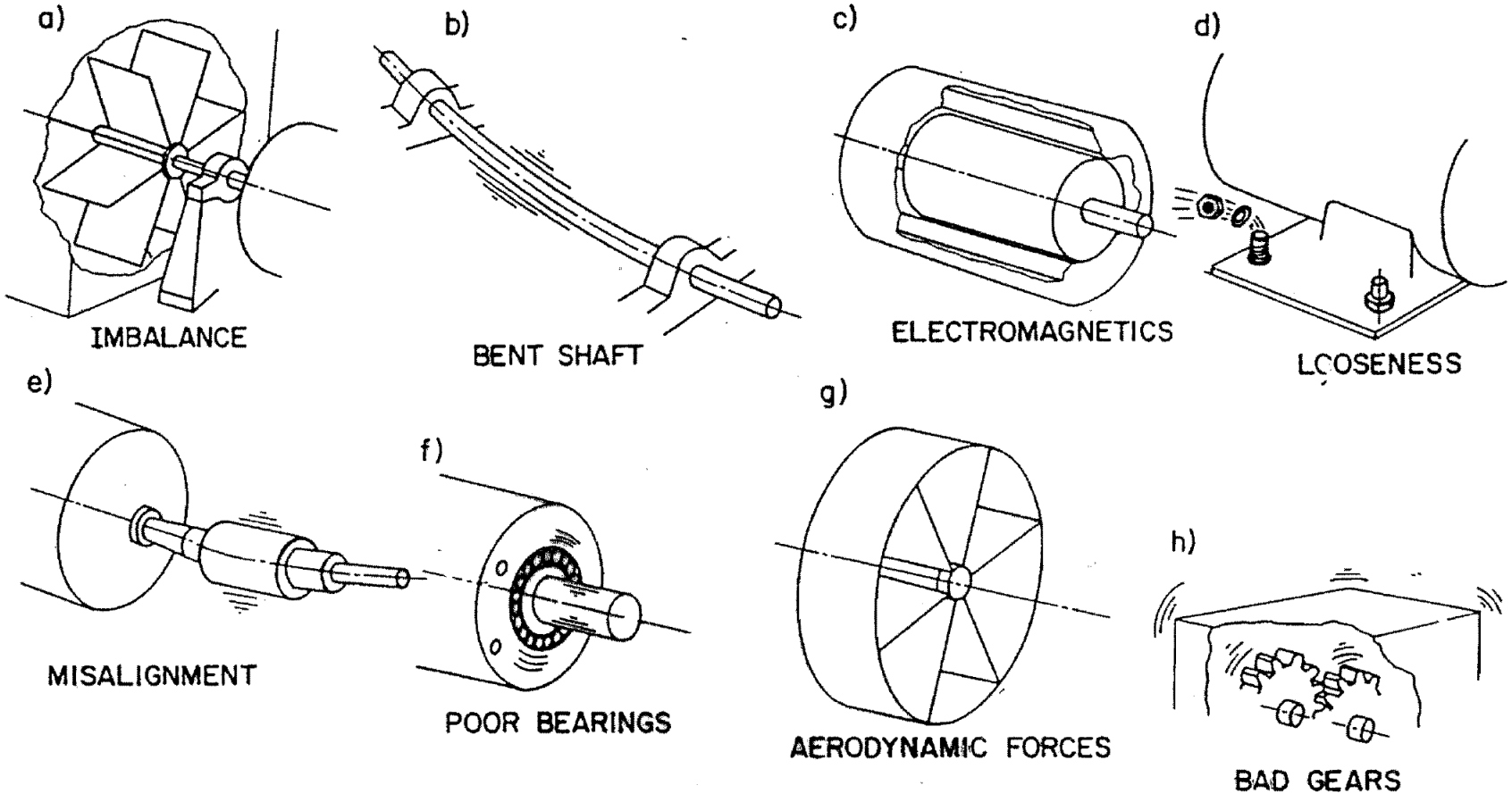


Time Domain VS Frequency Domain





Machinery Noise and Diagnostics



Imbalance (1)

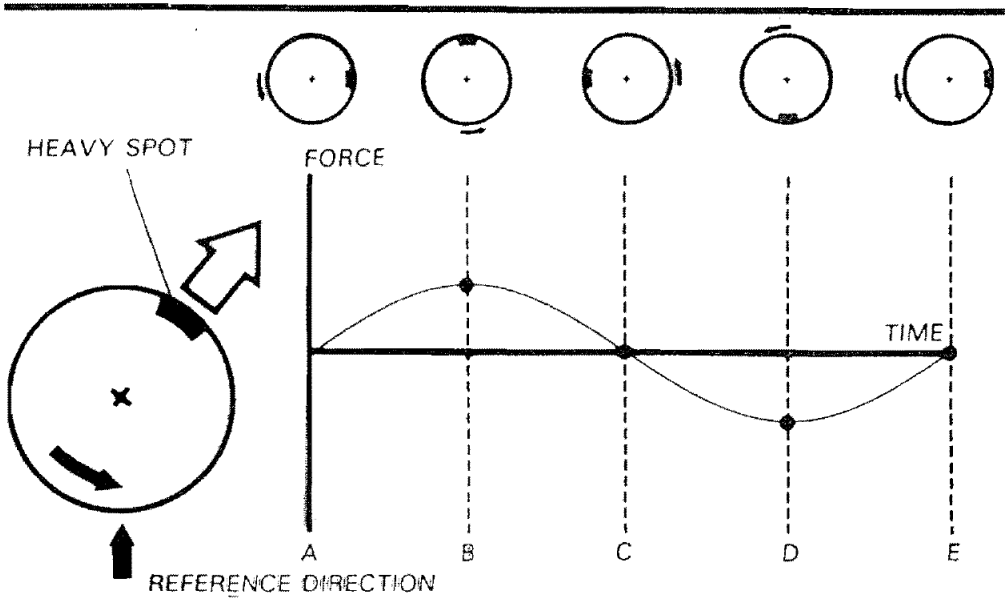


Figure 2.1-1
A heavy spot on a machine rotor results in a rotating force vector that appears sinusoidal from a fixed reference.

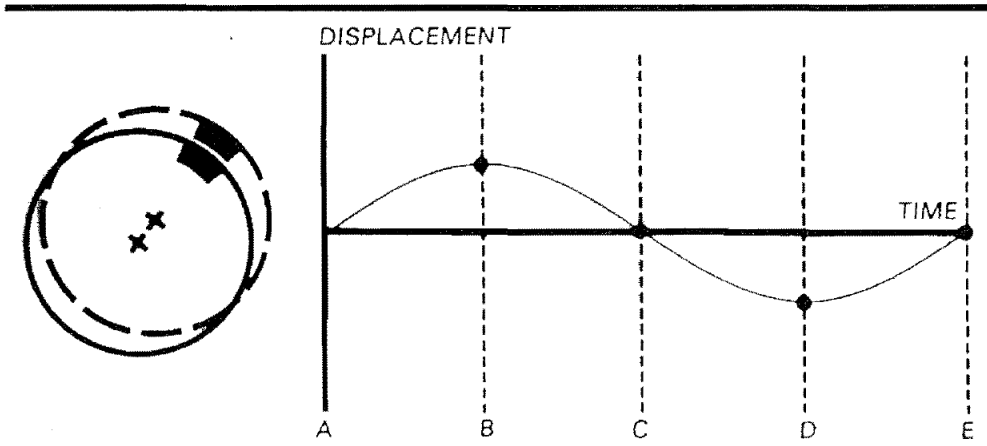
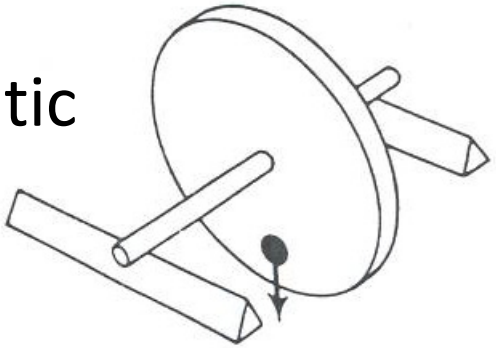
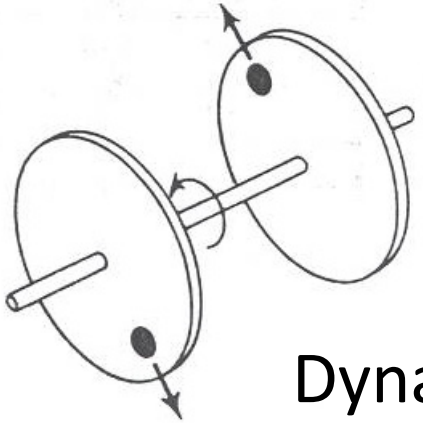


Figure 2.1-2
The imbalance force produces a vibration whose displacement has approximately the same waveform as the force itself.

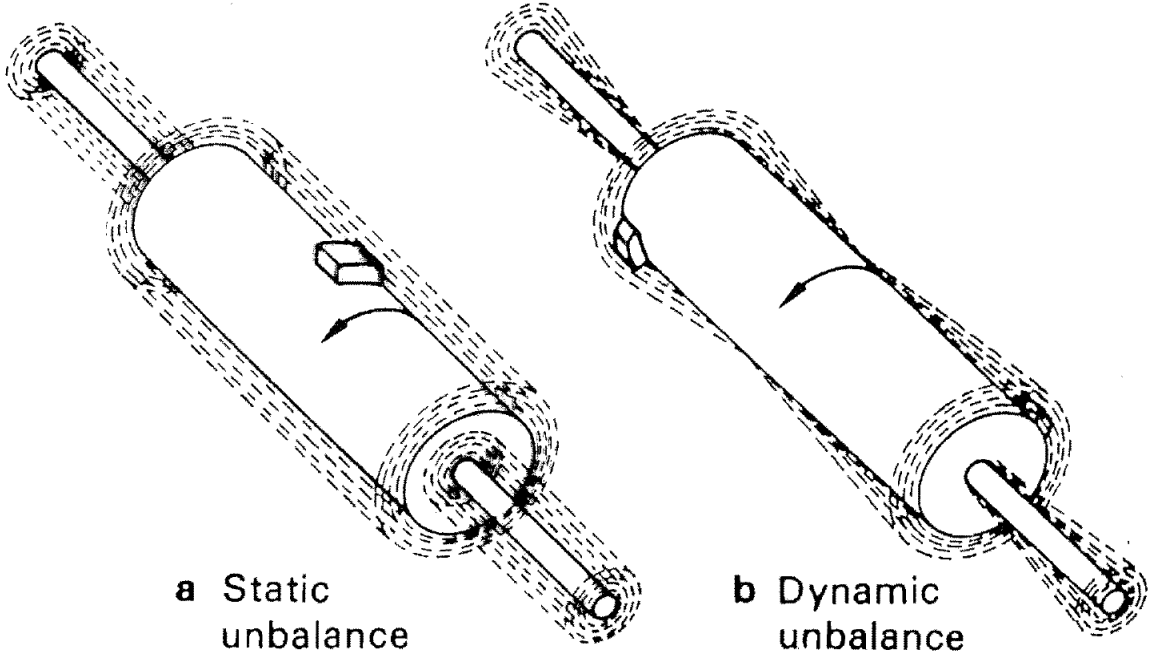
Imbalance (2)

Static

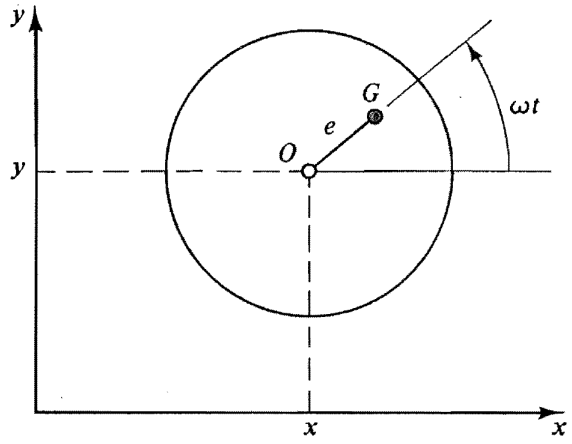




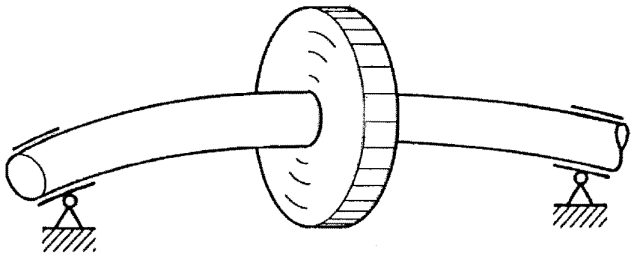
Dynamic



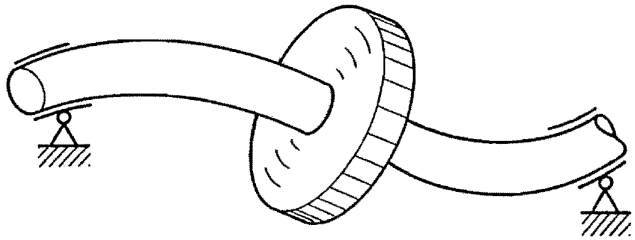
Imbalance (3)



(a)

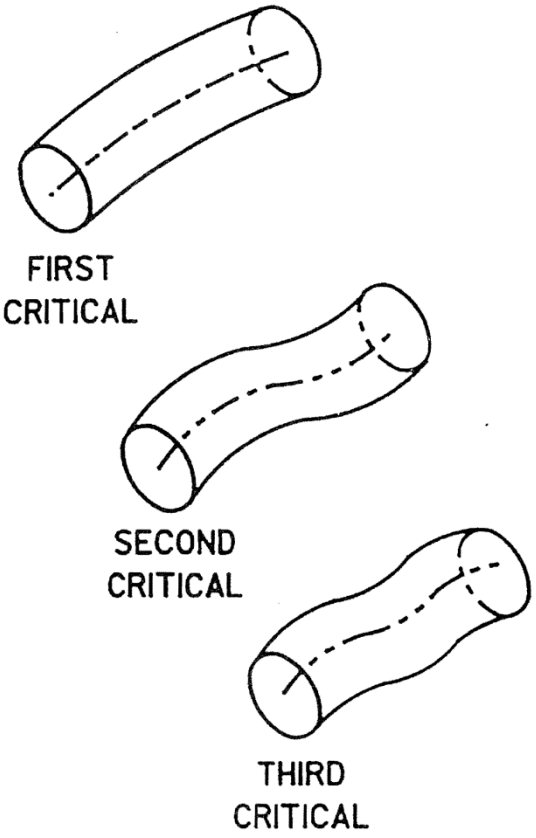


(b)



(c)

การไม่สมดุลของ rotor กระตุ้นให้เพลาสั่นสะเทือน และจะมีลักษณะการเสียรูปขึ้นอยู่กับความเร็วรอบหมุน และ Mode shape ของเพลา



Imbalance (4)

Waterfall spectral ของการสั่นสะเทือนเนื่องจากความไม่สมดุล การสั่นสะเทือนจะเกิดมากที่ 1 เท่าของความเร็วรอบหมุนเพลา (1x rpm)

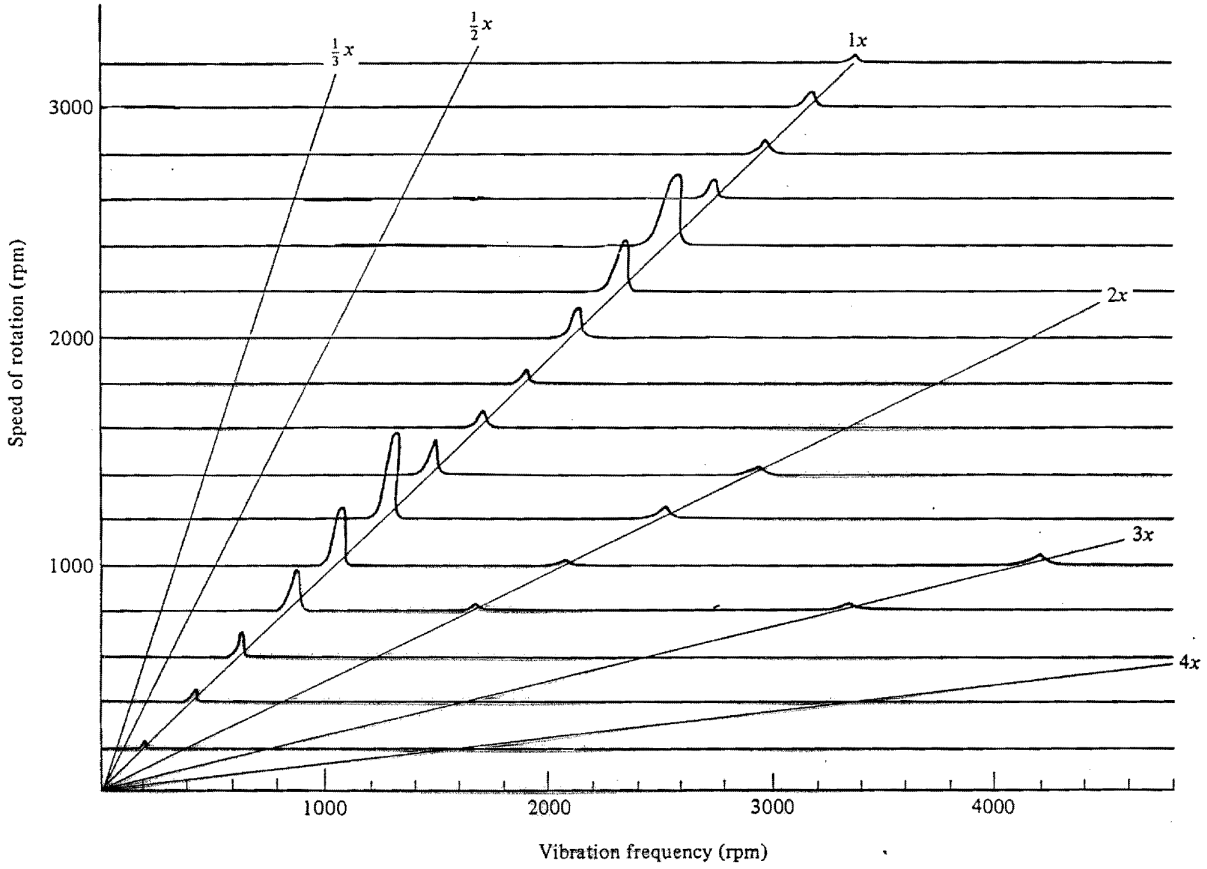
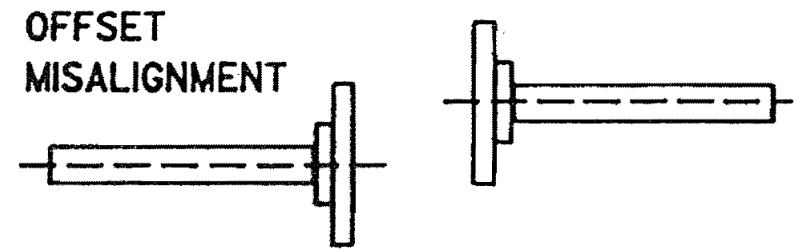
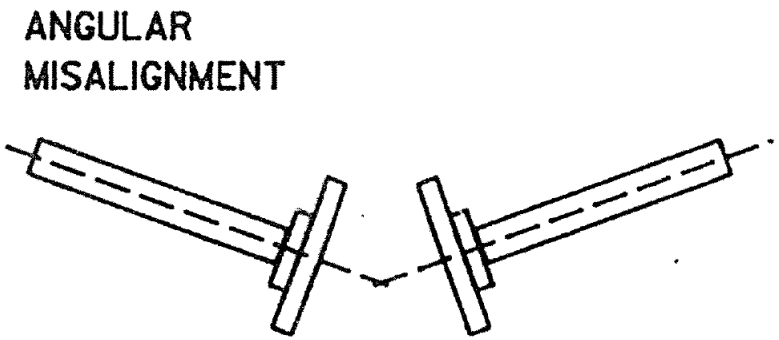
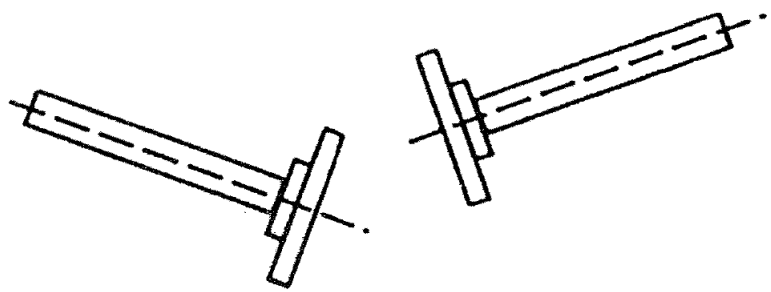


Figure 14.18 Spectral plot exhibiting large (1X) frequency due to unbalance.

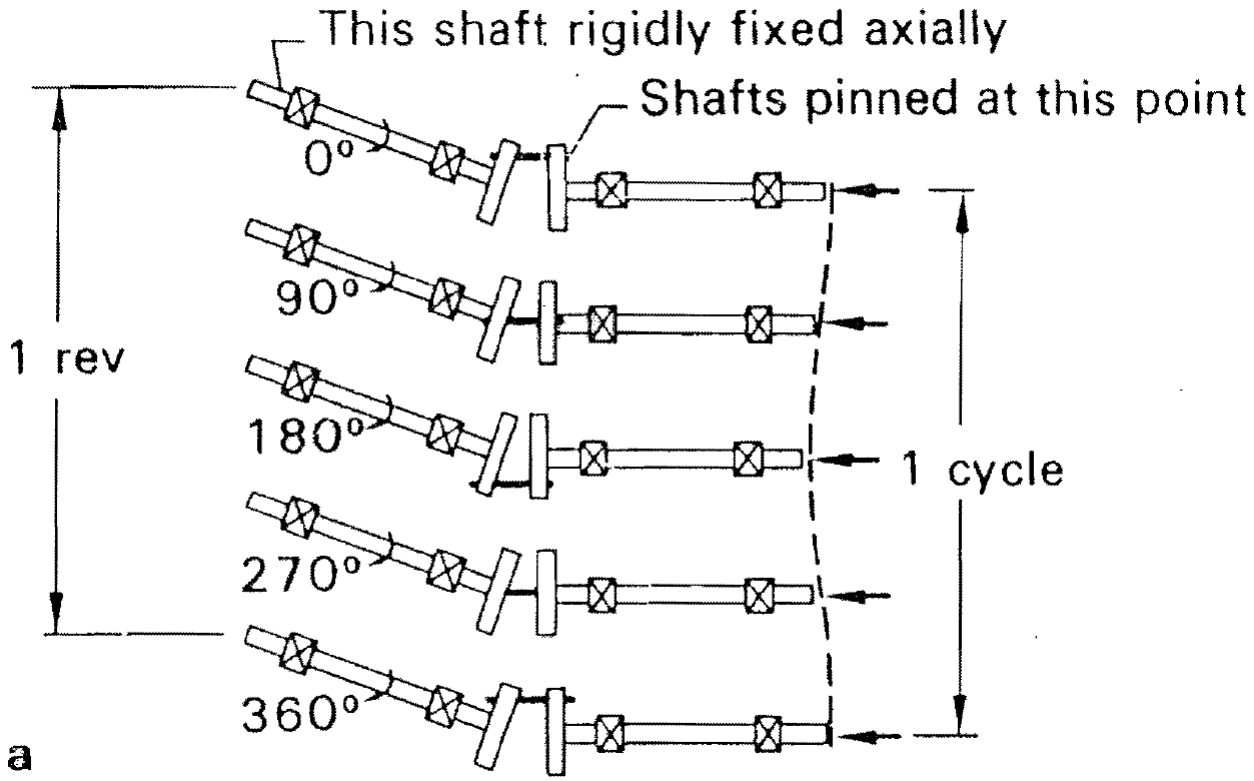
Basic types of misalignment







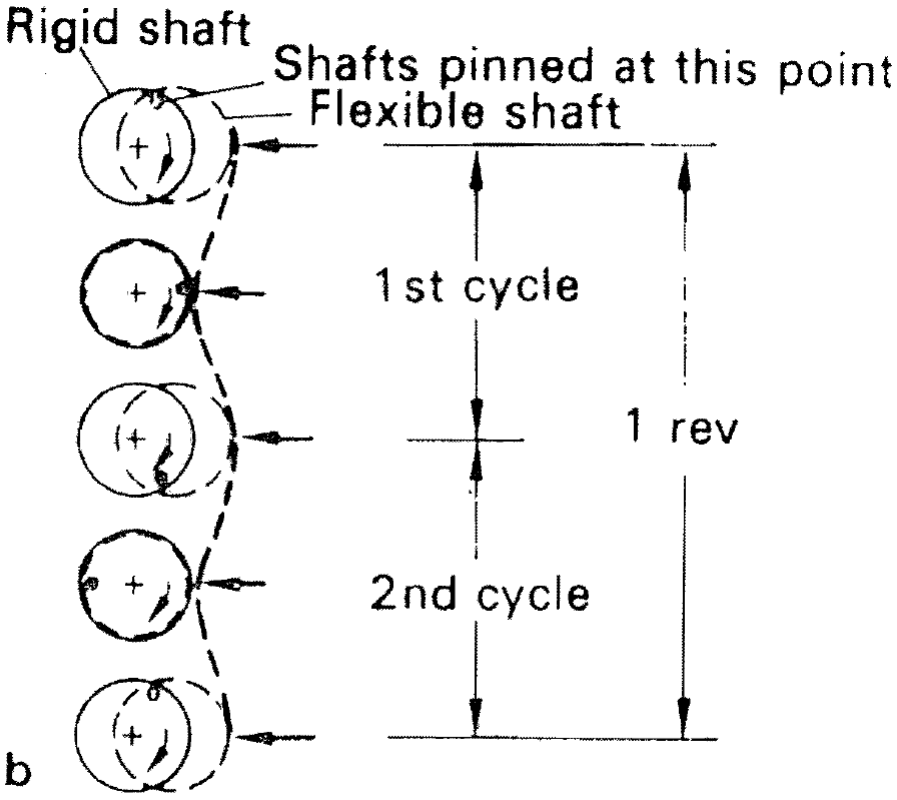
Misalignment – Angular misalignment



Angular misalignment (Axial vibration)

การสั่นสะเทือนจะเกิดที่ 1 เท่าของความเร็วรอบหมุนเพลา (1x rpm)

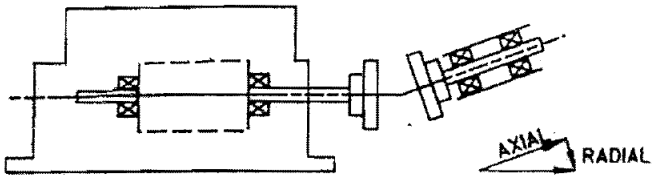
Misalignment – Offset misalignment



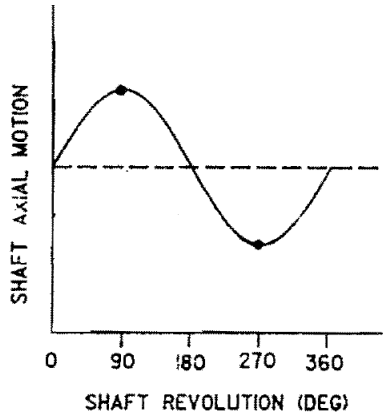
Offset (parallel) misalignment (Radial vibration)

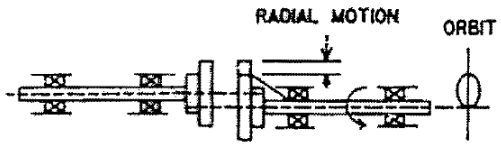
การสั่นสะเทือนจะเกิดที่ 2 เท่าของความเร็วรอบหมุนเพลา (2x rpm)

Misalignment

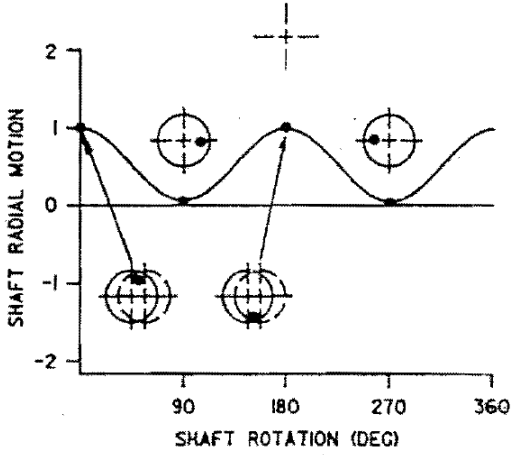


SHAFT ANGULAR MISALIGNMENT AND SYNCHRONOUS FREQUENCY AXIAL AND RADIAL VIBRATION GENERATED BY SINGLE-ENGAGEMENT PINNED COUPLING

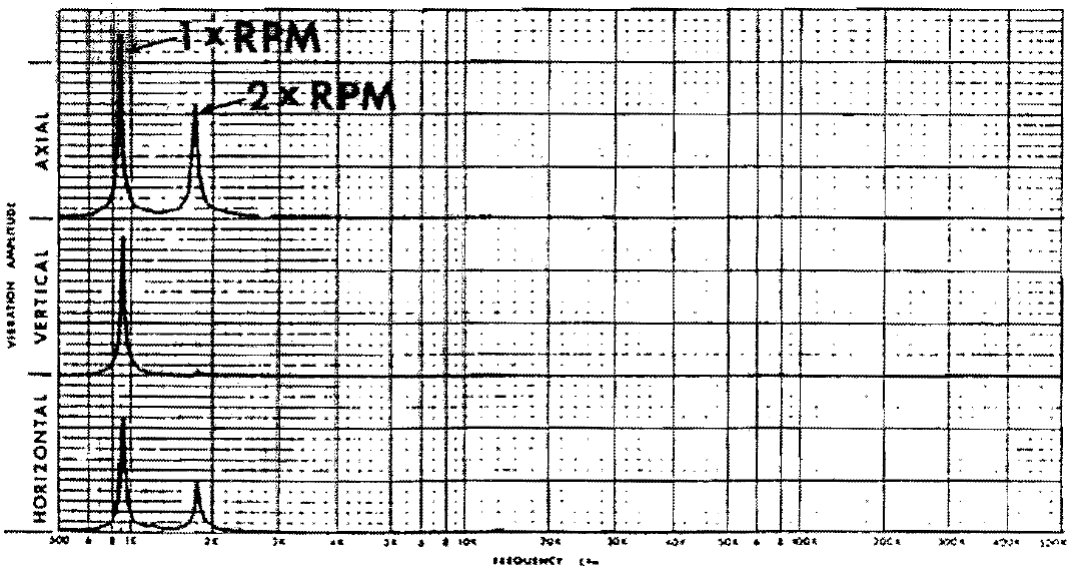




SHAFT OFFSET MISALIGNMENT AND TWICE SYNCHRONOUS FREQUENCY RADIAL VIBRATION GENERATED BY SINGLE PINNED COUPLING



Vibration from a misalignment problem



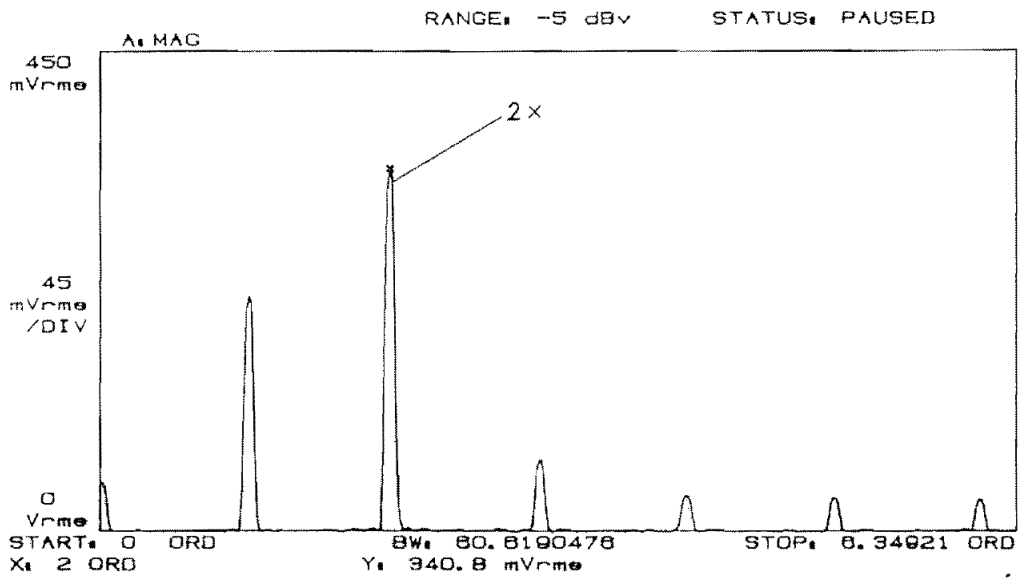


Figure 4.4-1
Alignment problems are usually characterized by a large 2× running speed component, and a high level of axial vibration.

Waterfall spectral from a misalignment problem

Waterfall spectral ของการสั่นสะเทือนเนื่องจาก misalignment การสั่นสะเทือนจะเกิดมากที่ 1 และ 2 เท่าของความเร็วรอบหมุนเพลา

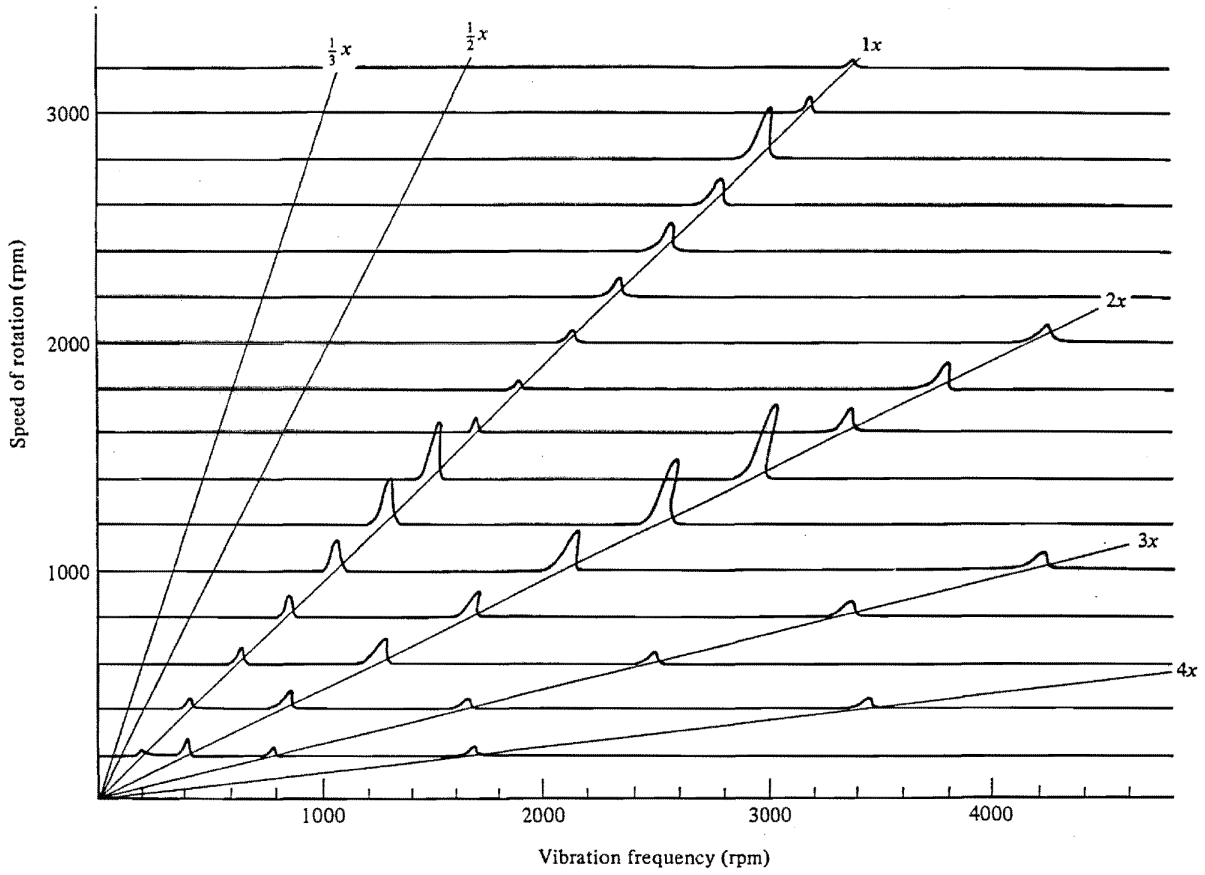
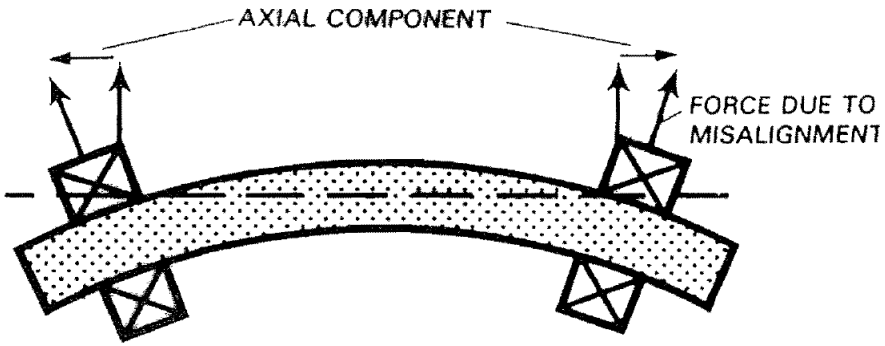


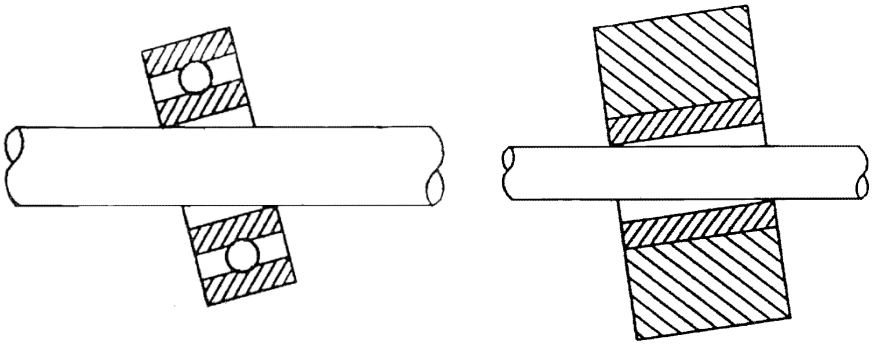
Figure 14.20 Spectral plot exhibiting misalignment.

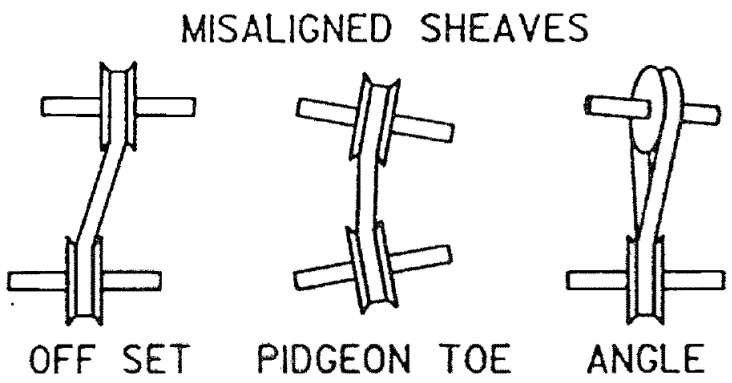
สาเหตุอื่น ๆ ของ misalignment problem

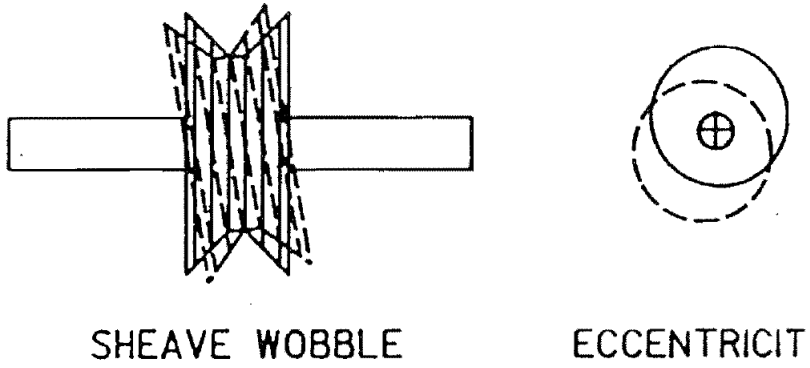
A bent or misaligned shaft results in a high level of axial vibration



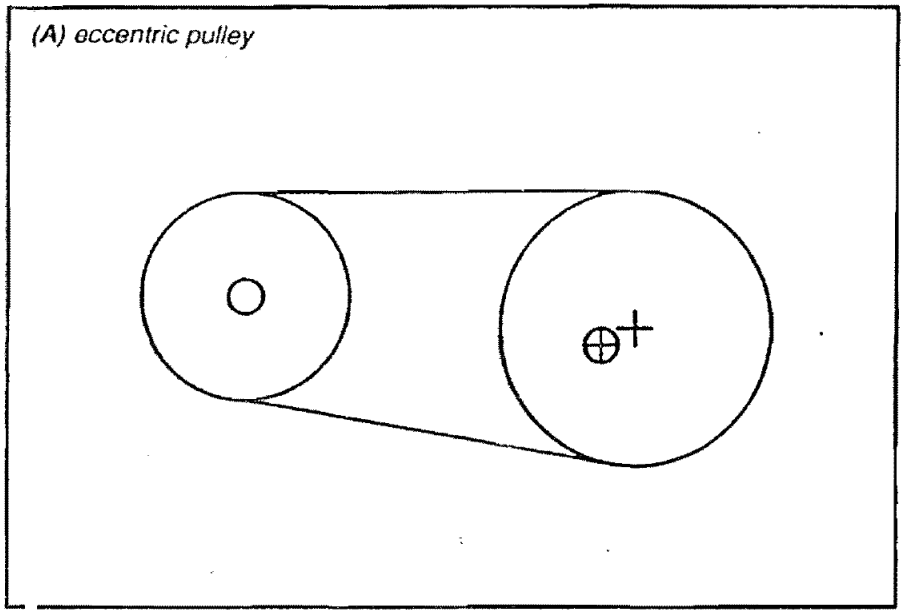
Misaligned rolling bearing/ sleeve bearing and shaft



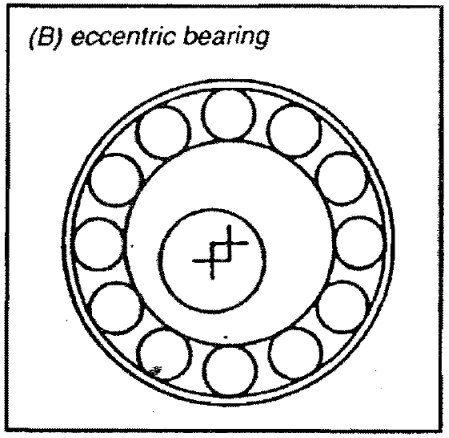


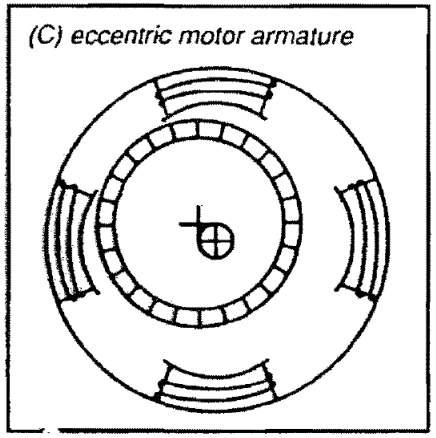


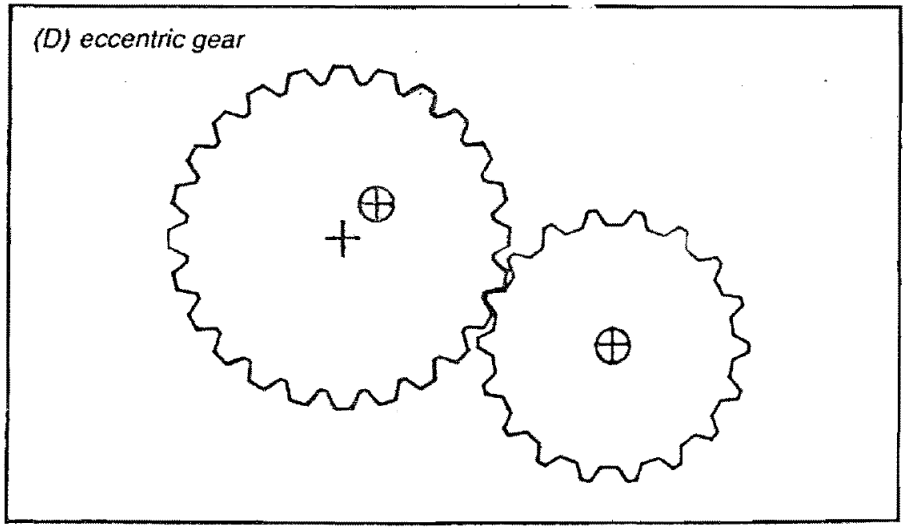
Eccentricity



การเยื้องศูนย์ จากการที่จุดศูนย์กลางของรูปร่างไม่ตรงกับจุดศูนย์กลางการหมุน







Looseness

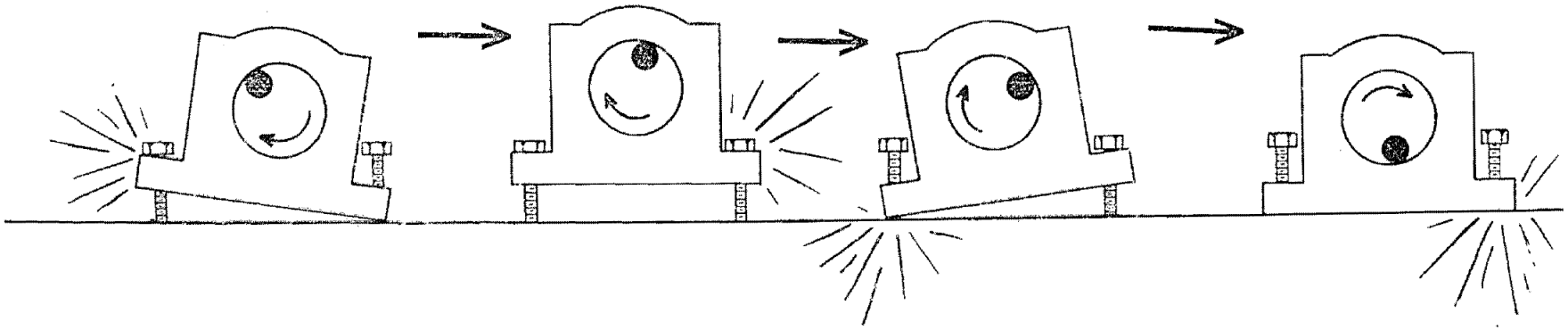


Figure 135. Looseness which allows the machine to rock and bounce as illustrated by this sequence can produce vibration at 2 x RPM, 3 x RPM, 4 x RPM or even higher harmonics.

Gear vibration

z_1 = จำนวนฟันของเฟืองขับ

z_2 = จำนวนฟันของเฟืองตาม

f_1 = ความถี่การหมุนของเพลาขับ

f_2 = ความถี่การหมุนของเพลาตาม

ความถี่การขบ

(Gear meshing frequency, GMF)

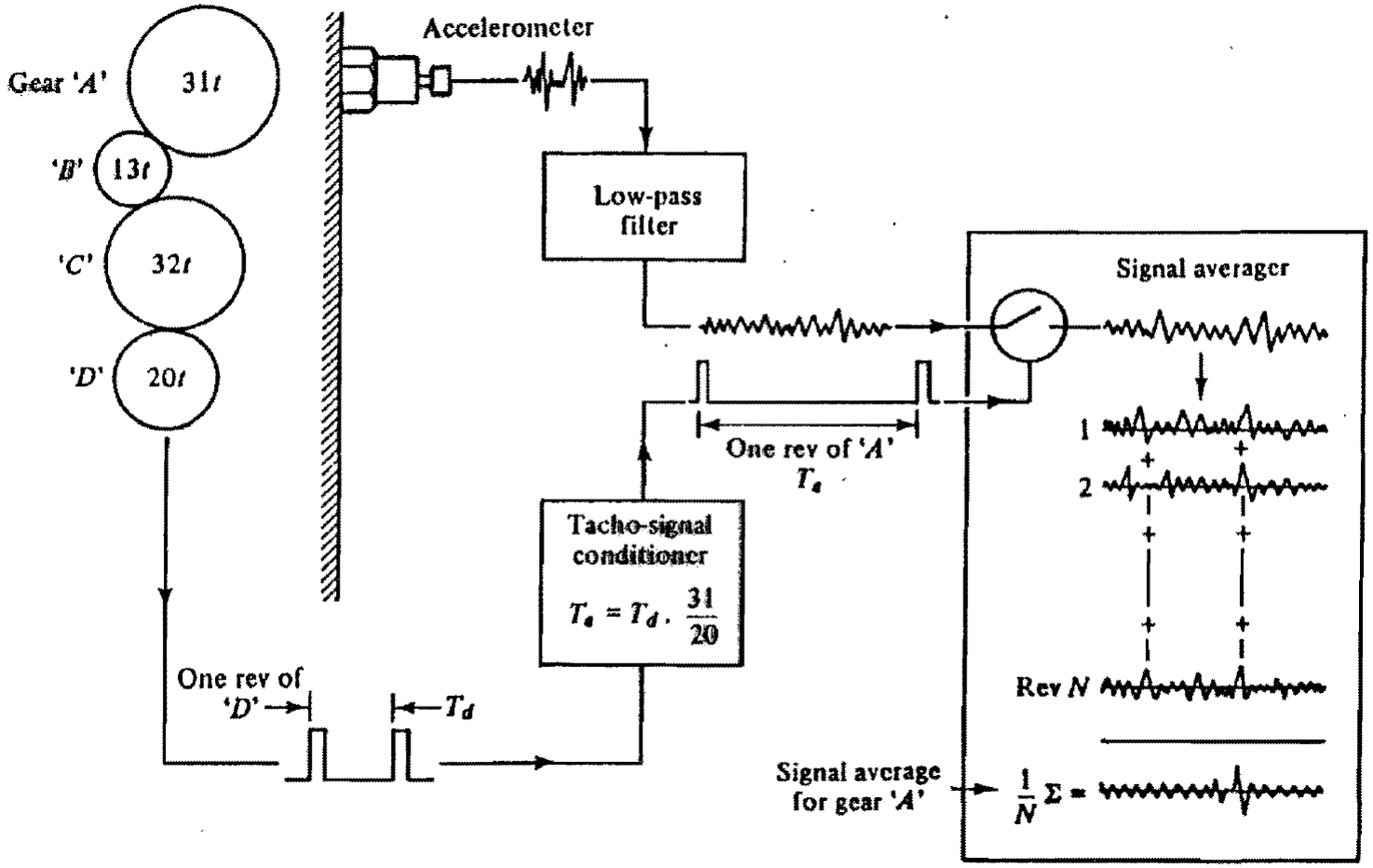
เฟืองขับหมุน 1 รอบ มีการขบกันของฟันเท่ากับ z_1 ครั้ง → $f_z = z_1 \times f_1$

เฟืองตามหมุน 1 รอบ มีการขบกันของฟันเท่ากับ z_2 ครั้ง → $f_z = z_2 \times f_2$

จากความสัมพันธ์ของความเร็วรอบหมุน และจำนวนฟันจะได้ →

$$f_z = z_1 \times f_1 = z_2 \times f_2$$

Signal averaging applied to gearboxes



Time domain of gear vibration signal

The type of gear defects which this method can detect, and their associated signal average plots, are:

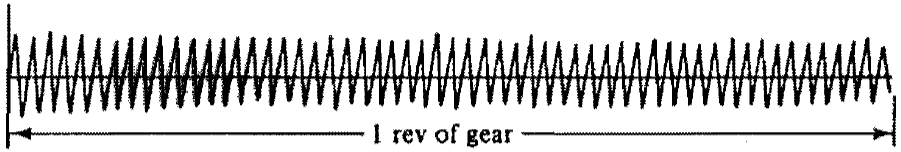
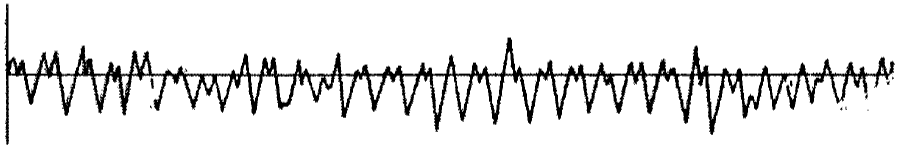
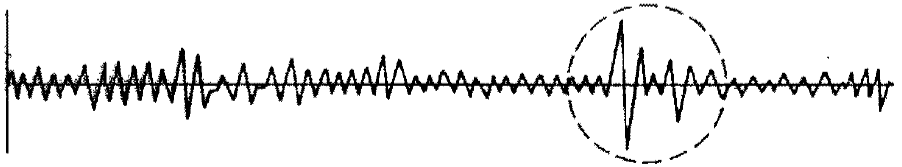
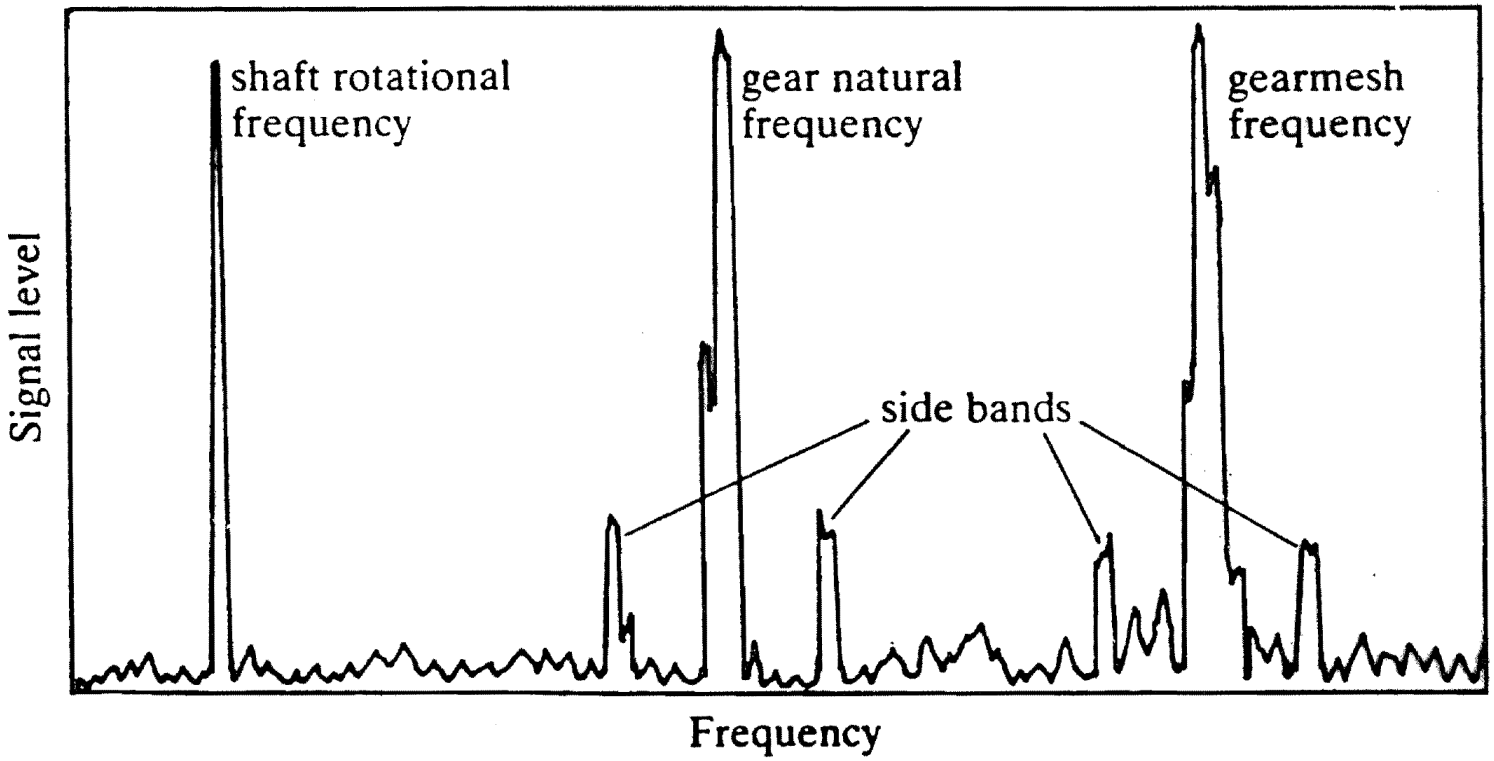
Gear condition	Typical signal average plot
Good	
Misaligned	
Worn	
Fractured tooth	

Figure 14.2 Time-series averaging of time-domain gearbox signals.

Gear vibration signal



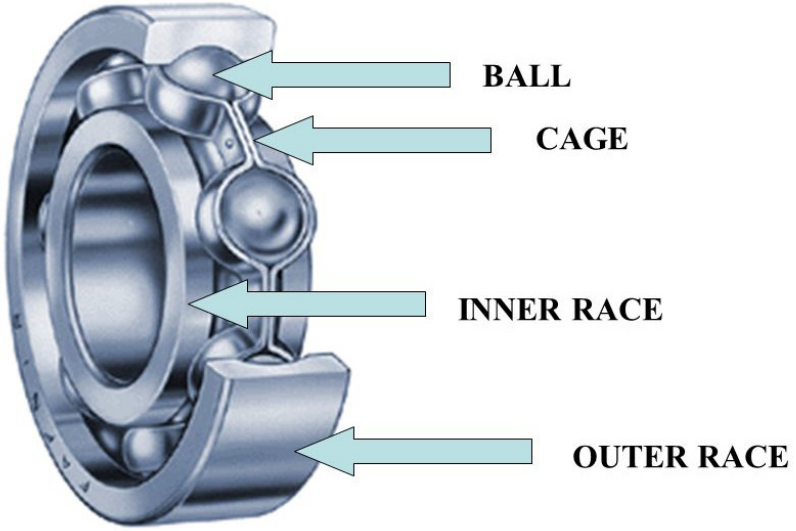
Bearing defects

Causes of bearing defects

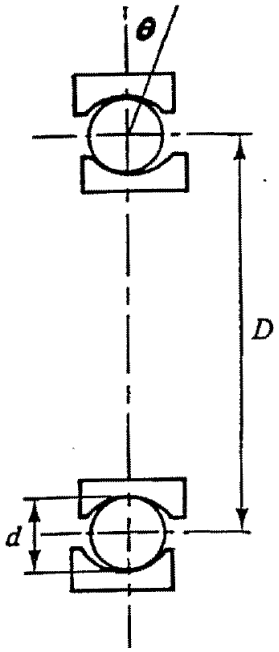
- Excessive load
- Misalignment
- Defective shaft & housing
- Fault mounting
- Improper fit
- Improper lubrication
- Poor sealing

Failure modes

- Inner race
- Outer race
- Rolling elements
- Cage
- Lubrication



Frequencies of bearing vibration

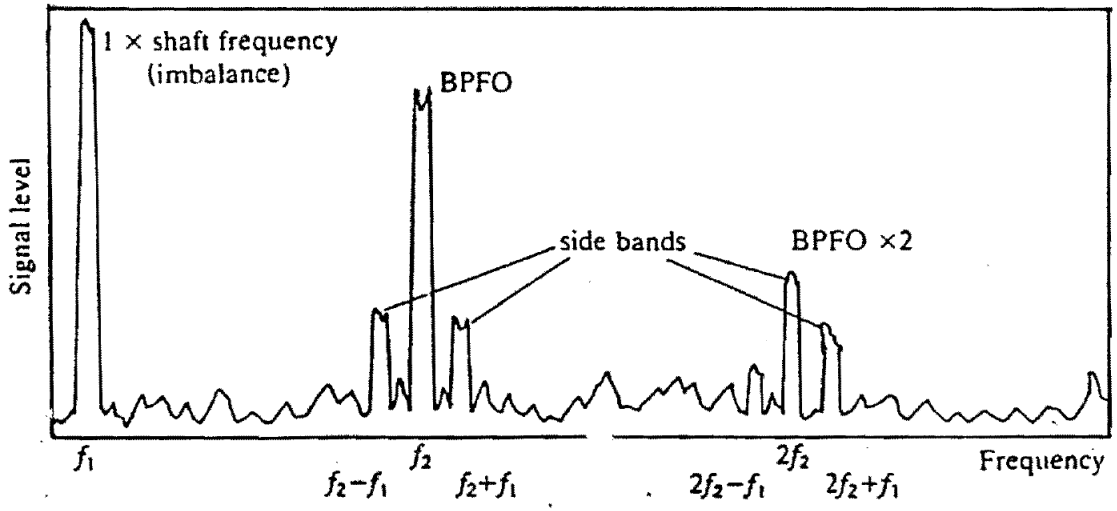


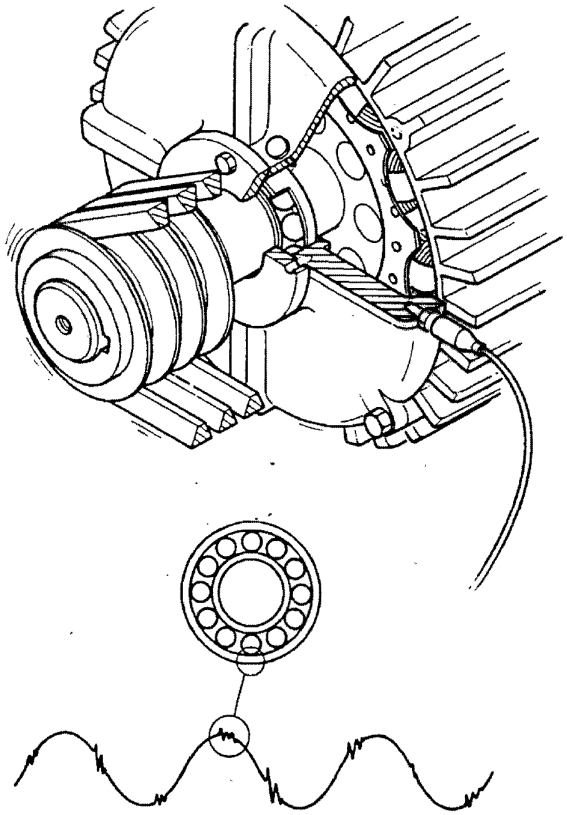
Outer race frequency $\frac{n}{2}\frac{N}{60}\left(1-\frac{d}{D}\cos\theta\right)$

Inner race frequency $\frac{n}{2}\frac{N}{60}\left(1+\frac{d}{D}\cos\theta\right)$

Rolling element frequency $\frac{D}{d}\frac{N}{60}\left[1-\left(\frac{d}{D}\right)^2\cos^2\theta\right]$

Cage frequency $\frac{N}{120}\left(1-\frac{d}{D}\cos\theta\right)$





การวัดการสั่นสะเทือนของแบริ่ง

Vibration from magnetic force

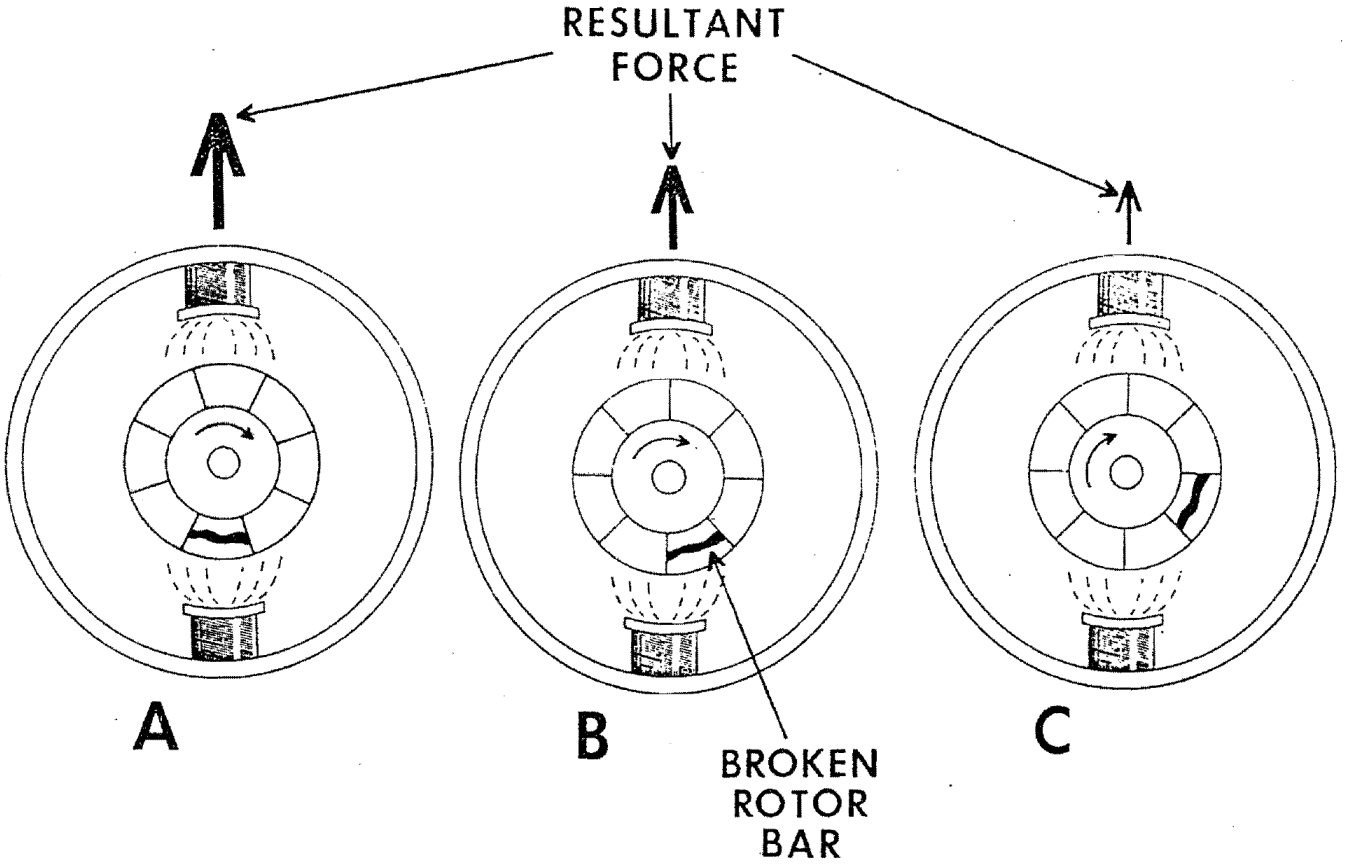
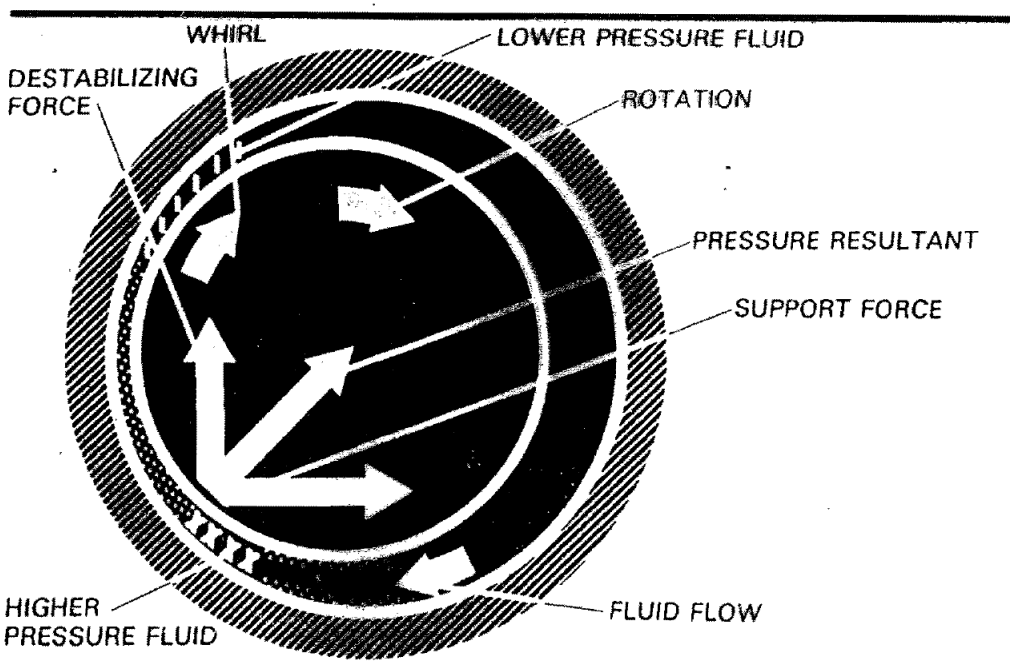


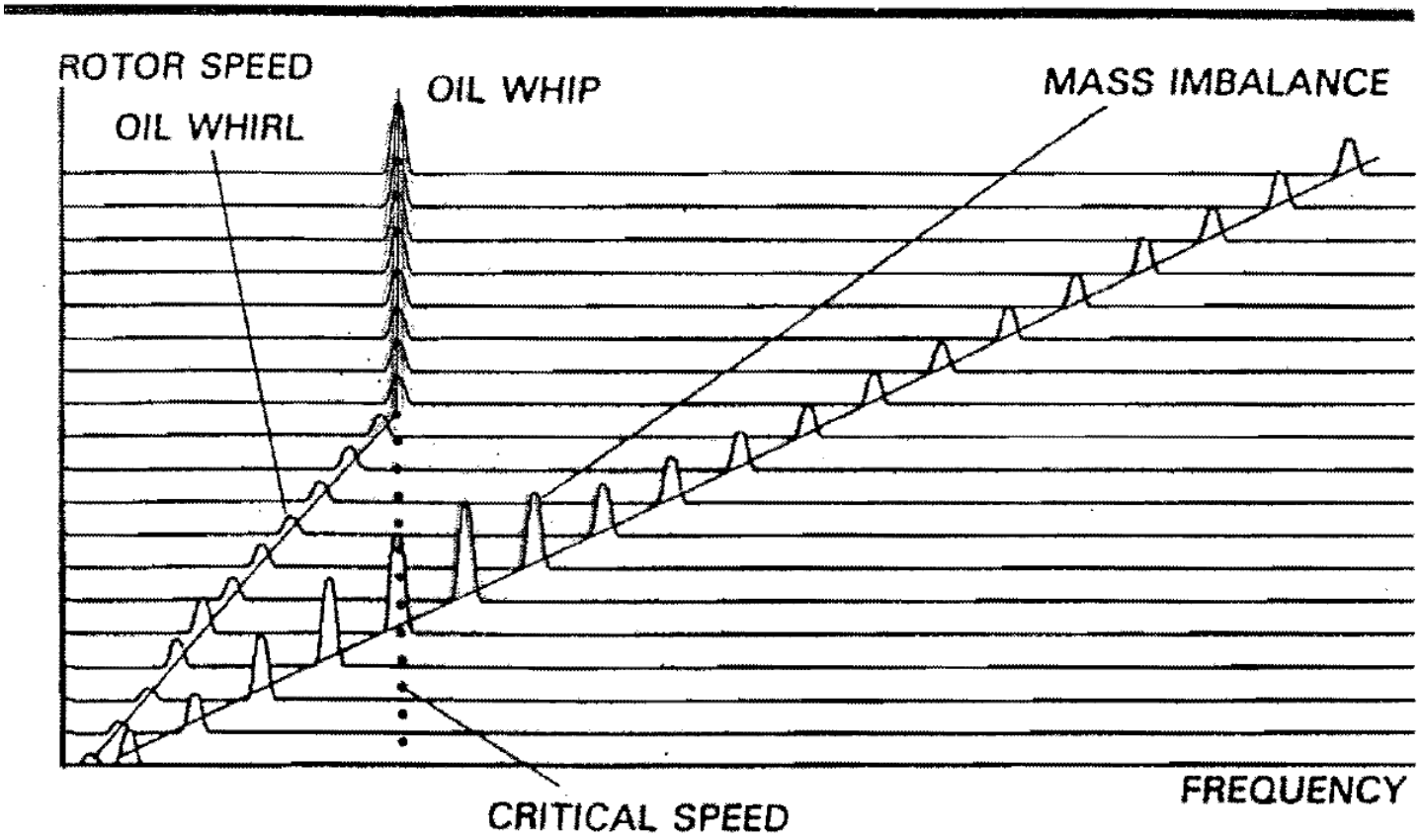
Figure 158. Magnetic forces between the armature and stator will vary periodically as the defective rotor bar "slips" relative to the rotating magnetic field of the stator.

Oil whirl/ Oil Whip (1)



- ความแตกต่างของความดันใน Fluid-film bearing ทำให้เกิดแรงในแนวเส้นสัมผัส ซึ่งส่งผลให้เกิด Whirl
- Whirl มักเกิดที่ประมาณ 0.4-0.48 เท่าของความเร็วรอบหมุนเพลา
- ถ้าความถี่ของ whirl ตรงกับความถี่ธรรมชาติของระบบ จะเกิดการ Whip ขึ้น ถึงแม้ว่าจะเพิ่มความเร็วรอบหมุนเพลา Whip ยังเกิดที่ความถี่เท่าเดิม

Oil whirl/ Oil Whip (2)



Frequency range and typical machinery vibrations

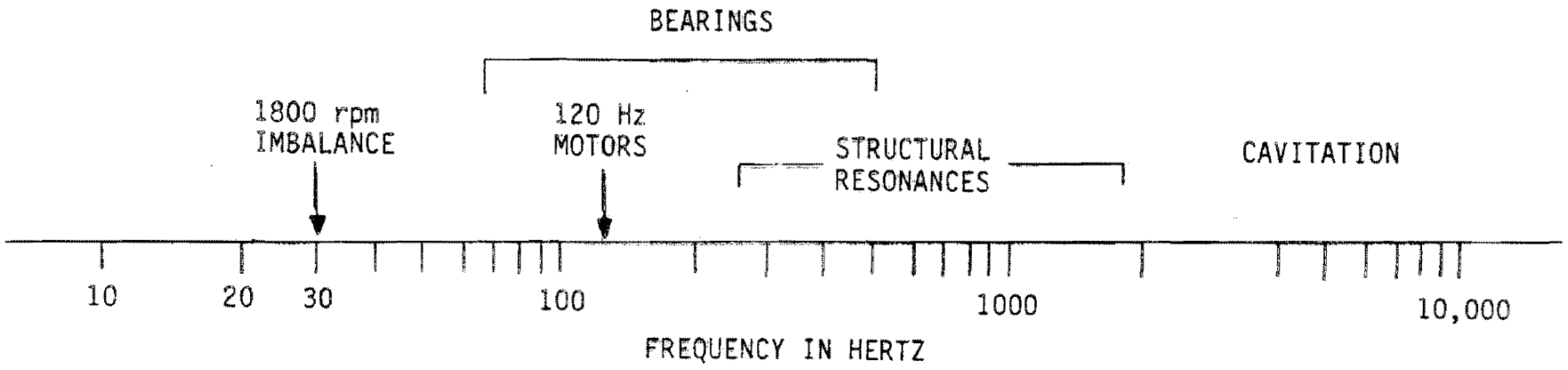


Figure 4.1 The frequency spectrum and typical machinery vibrations.

Causes VS Vibration

Vibration identification chart (amplitude, frequency, phase)

Cause	Amplitude	Frequency	Phase	Remarks
Unbalance	Proportional to unbalance Largest in radial direction	1 x RPM	Single Reference Mark-stable repeatable	Most common cause of Vibration
Misalignment Couplings or Bearings and Bent Shaft	Large in axial direction. 50% or more of radial vibration	1 x RPM usual 2 & 3 x RPM sometimes	Single Double or Triple	Best found by appearance of large axial vibration. Use dial indicators or other method for positive diagnosis. If sleeve bearing machine and no coupling misalignment. balance the rotor.
Bad Bearings Anti-Friction Type	Unsteady-use velocity, acceleration, and Spike Energy Measurements	Very high Several times RPM	Erratic - Multiple Marks	Bearing responsible most likely the one nearest point of largest high frequency vibration. Spike Energy measurement recommended when analyzing bearing failures.
Eccentric Journals	Usually not large	1 x RPM	Single Mark	If on gears largest vibration in line with gear centers. If on motor or generator vibration disappears when power is turned off. If on pump or blower attempt to balance.
Bad Gears or Gear noise	Low-Use Velocity, Acceleration, and Spike Energy Measurements	Very High Gear Teeth times RPM	Erratic - Multiple Marks	Velocity, Acceleration, and Spike Energy measurements recommended when analyzing gear problems. Analyze higher orders and sideband frequencies.
Mechanical Looseness	Sometimes Erratic	2 x RPM	Two Reference Marks, - Slightly Erratic	Usually accompanied by unbalance and/or Misalignment
Bad Drive Belts	Erratic or Pulsing	1,2,3,&4 x RPM of Belts	One or Two depending on Frequency, Usually Unsteady	Strobe Light best tool to freeze faulty Belt.
Electrical	Disappears when power is turned off	1 x RPM or 1 or 2 x synchronous frequency	Single or Rotating Double Mark	If vibration amplitude drops off instantly when power is turned off cause is electrical. Mechanical and electrical problems will produce "beats".
Aerodynamic or Hydraulic Forces	Can be large in the axial direction	1 x RPM or Number of blades on fan or impeller x RPM	Multiple Marks	Rare as a cause of trouble except in cases of resonance.
Reciprocating Forces	Higher in line with motion	1,2,& higher orders x RPM	Multiple Marks	Inherent in reciprocating machines, can only be reduced by design changes or isolation.

Vibration VS Causes

Frequency In Terms Of RPM	Most Likely Causes	Other Possible Causes & Remarks
1 x RPM	Unbalance	1) Eccentric journals, gears or pulleys 2) Misalignment or bent shaft — if high axial vibration 3) Bad belts if F ?M of belt 4) Resonance 5) Reciprocating forces 6) Electrical problems
2 x RPM	Mechanical Looseness	1) Misalignment if high axial vibration 2) Reciprocating forces 3) Resonance 4) Bad belts if 2 x RPM of belt
3 x RPM	Misalignment	Usually a combination of misalignment and excessive axial clearances (looseness).
Less than 1 x RPM	Oil Whirl (Less than ½ RPM)	1) Bad drive belts 2) Background vibration 3) Sub-harmonic resonance 4) "Beat" Vibration
Synchronous (A C Line Frequency)	Electrical Problems	Common electrical problems include broken rotor bars, eccentric rotor, unbalanced phases in poly-phase systems, unequal air gap.
2 x Synch. Frequency	Torque Pulses	Rare as a problem unless resonance is excited
Many Times RPM (Harmonically Related Freq.)	Bad Gears Aerodynamic Forces Hydraulic Forces Mechanical Looseness Reciprocating Forces	Gear teeth times RPM of bad gear Number of fan blades times RPM Number of impeller vanes times RPM May occur at 2, 3, 4 and sometimes higher harmonics if severe looseness
High Frequency (Not Harmonically Related)	Bad Anti-Friction Bearings	1) Bearing vibration may be unsteady — amplitude and frequency 2) Cavitation, recirculation and flow turbulence cause random, high frequency vibration 3) Improper lubrication of journal bearings (Friction excited vibration) 4) Rubbing