Queen's University
Mechanical Engineering

Machine Condition Monitoring

and

Fault Diagnostics

Chris K Mechefske

Current Topic

- Machinery Vibration Testing and Trouble Shooting
- Fault Diagnostics Based on Forcing Functions
- Fault Diagnostics Based on Specific Machine Components
- Fault Diagnostics Based on Specific Machine Types
- Automatic Diagnostics Techniques
- Non-Vibration Based Machine Condition Monitoring and Fault Diagnosis Methods

Outline of Machine Testing

- Introduction
- Test plans
- Selection of test equipment
- Site inspection
- Acceptance tests
- Baseline tests
- Resonance and critical speed testing

Outline of Machine Testing

- Fault, condition and balance tests
- Specifications
- Environment and mounting
- Presentation of data
- Reports
- Summary of machine testing

Introduction

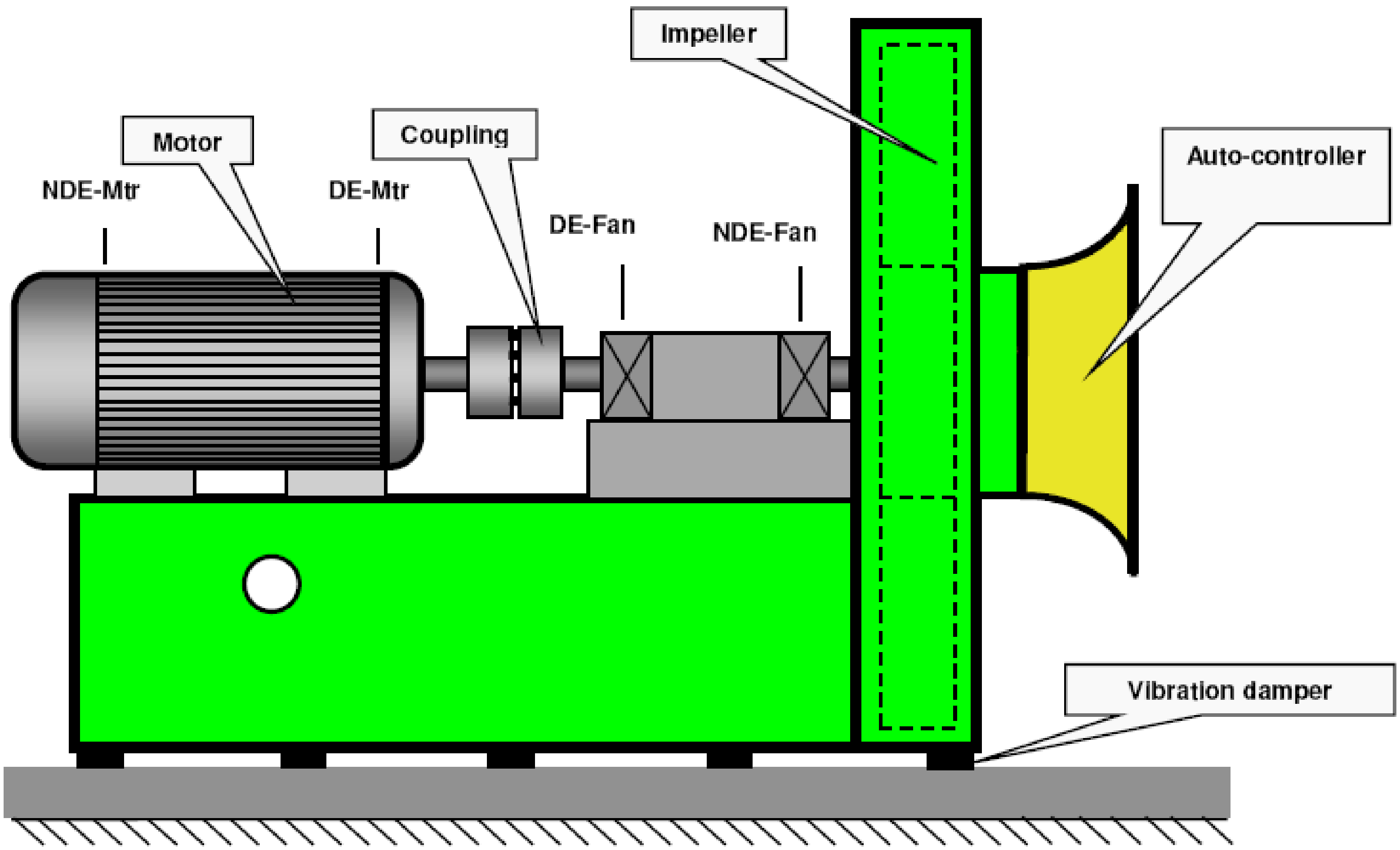
- Machine tests other than periodic monitoring are conducted to gain information about the design or condition of a machine.
- Reasons for machine tests include…
  - Acceptance
  - Baseline data for periodic monitoring
  - Design verification (damping, natural frequencies)
  - Fault diagnosis and condition evaluation
  - Balancing

Test Plans

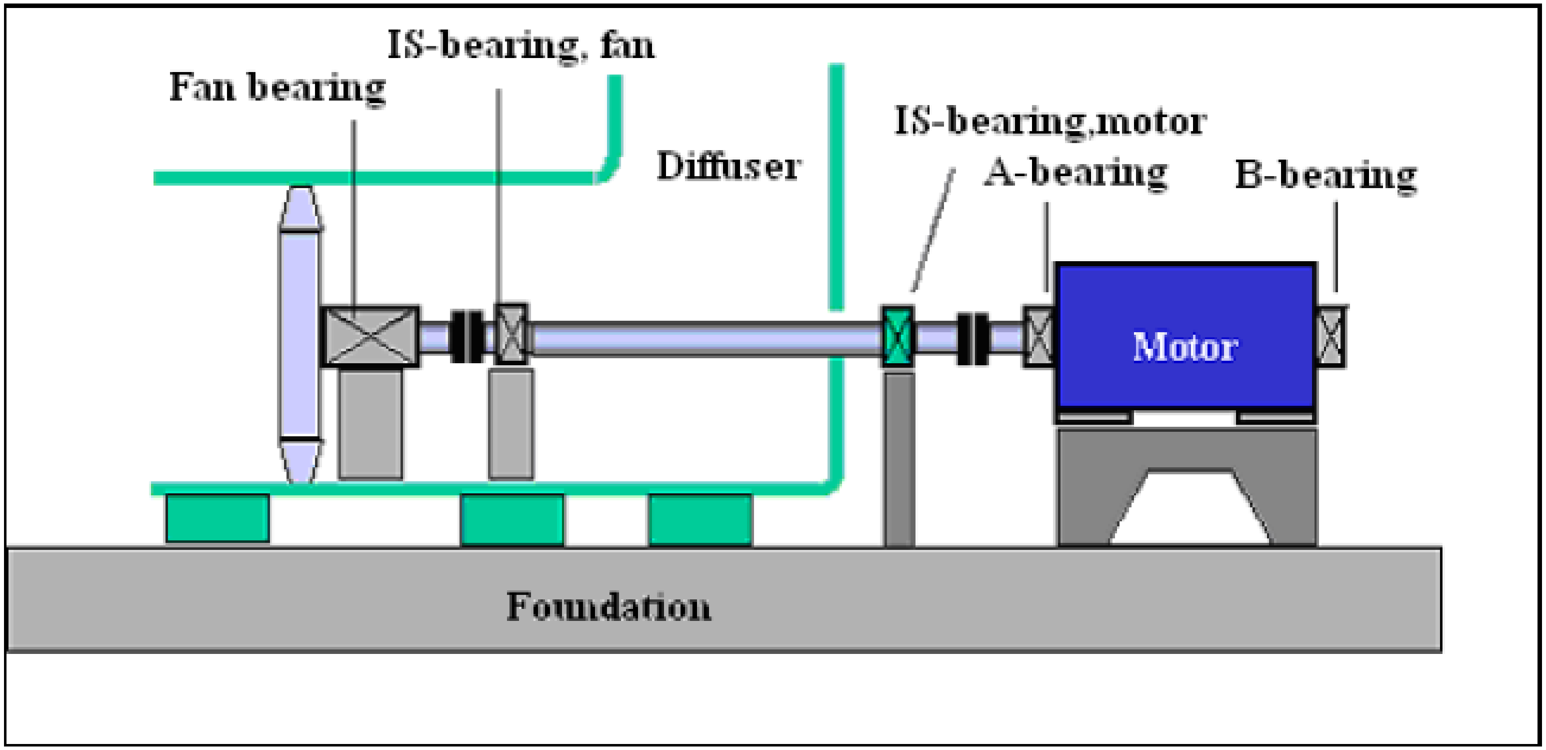
- Elements of a test plan
  - Description of the machine
  - Test types
  - Data to be acquired
  - Loads
  - Speeds
  - Machine configuration
  - Process conditions

Test Plans

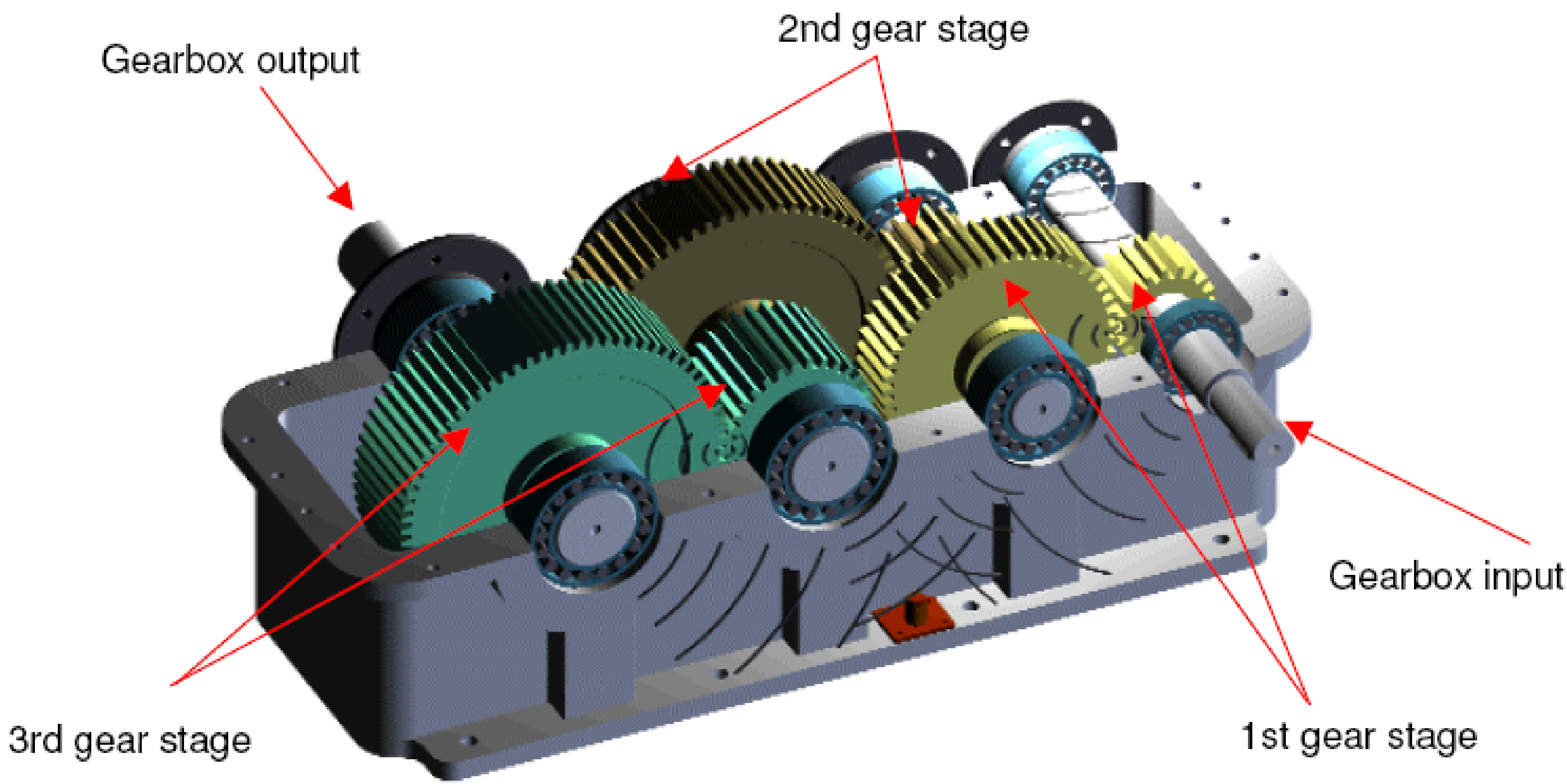
Sensor locations



Test Plans


IS-bearing, fan
Fan bearing
Diffuser
IS-bearing,motor
A-bearing
B-bearing
Motor
Foundation

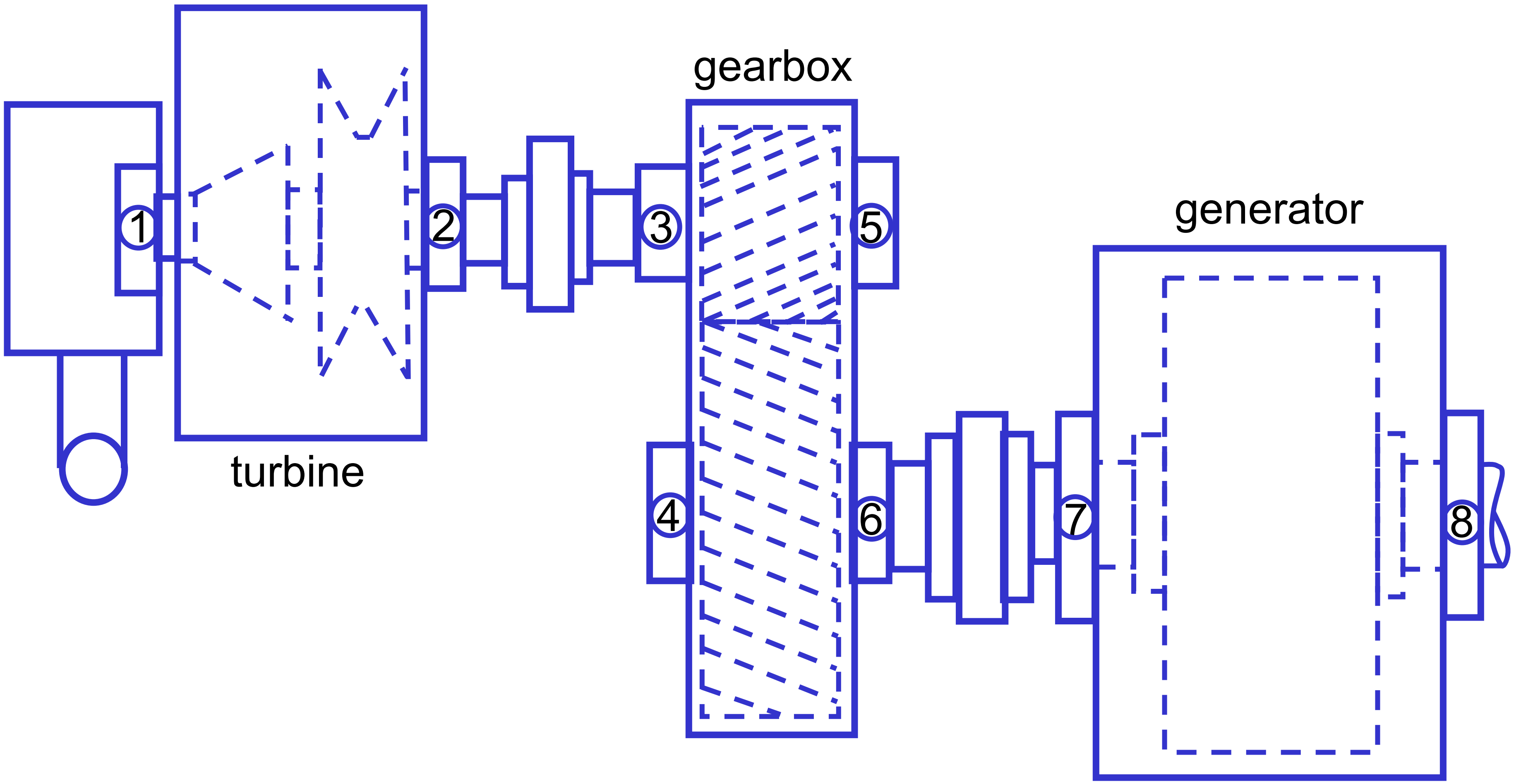
Test Plans



Gearbox output
2nd gear stage
Gearbox input
3rd gear stage
1st gear stage

Test Plans

Location of measurement points



Test Plans

Data acquisition plan for a turbine generator

Record no.	Measure (units)	Recorder Channel								Purpose
		1	2	3	4	5	6	7	8	
1	Velocity	1X	1Y	1Z	2X	2Y	2Z	1T	7T	Basic Turbine Analysis
2	Velocity or Acceleration	3R	3A	5R	5A	6R	6A	1T	7T	Basic Gearbox Analysis
3	Velocity	7X	7Y	7Z	8X	8Y	8Z	1T	7T	Basic Generator Analysis
4	Displacement (Pk to Pk)	1V	1H	2V	2H	thrust A	thrust B	1T	7T	Turbine Shaft Vibrations
5	Displacement (Pk to Pk)	7V	7H	8V	8H	3V	3H	1T	7T	Generator/ Gearbox Shaft Analysis
6	Displacement (Pk to Pk)	6V	6H	4A	4R	3A	5A	1T	7T	Gearbox Shaft/ Casing Analysis
7	Velocity	1Y	2Y	3R	6R	7Y	8Y	1T	7T	Cross Sensitivity
8	Velocity	1X	2X	3A	6A	7X	8X	1T	7T	Cross Sensitivity
9	Velocity	3Z	4Z	5Z	6Z	2Z	7Z	1T	7T	1X Phase Analysis

Test Plans

- The purposes of measurements are to perform time waveform, spectrum, phase, orbital, synchronous time and cross-channel analyses.
- The functions of individual measurement points
  - Triggers – recorded on turbine and generator shafts for filtering and averaging and axial phase analysis at 1X.
  - No.1 – records horizontal, vertical and axial data on the turbine governor and drive ends
  - No. 2 – provides data for gearbox analysis (1X velocity vibration and gear-mesh)

Test Plans

- No. 3 – measures basic casing data for analysis of the generator
- No 4 and 5 – record shaft vibrations on the turbine, generator and gear drive shaft for orbital analysis
- No 6 – measures casing and shaft vibrations for gearbox analysis
- No 7 and 8 – for dual-channel cross-sensitivity analyses
- No 9 – provides data for phase analysis at operating speed for the three machines

Test Plans

- Considerations on data acquisition
  - Data recording using tape recorders permits many different types of analyses
  - Data collectors are preferred if vibration levels are sensitive to speed or load
  - The setup parameters of data collectors must be selected prior to data acquisition
  - A two-channel data collector is required for orbit, synchronous averaging, and cross-channel analyses

Test Plans

- Purposes of different tests
  - Diagnostic test is concerned with the goal of the plan being followed (may vary)
  - Operating speed tests are conducted to obtain data for fault analysis and condition evaluation
  - Impact and start-up/coast-down tests are utilized to obtain natural frequencies and critical speeds

Test Plans

- Purposes of different tests
  - Acceptance tests are conducted to determine whether or not the new or repaired equipment meets the purchase specifications
  - Baseline tests are to acquire vibration data that are normal to the machine
  - Calibration tests are conducted for information on balance-weight sensitivity and phase lags in the machine

Selection of Test Equipment

- The selection of equipment depends on the goals of the plan and the equipment available.
- Examples of selection
  - Special transducers may be needed if low frequencies or high temperatures are involved
  - Tracking analyser will be required for start-up and coast-down tests
- Data collectors perform 95% of the work including data storage.

Site Inspection

- Site inspection and evaluation are important regardless of the type of data acquisition plan.
- Site factors that may account for excessive vibration include bolts, foundation, grouting, piping, and thermal conditions.
- Non-operating speed components of vibration should be eliminated by assessing the environment when the equipment is not operating and by obtaining time-averaged data.

Acceptance Tests

- Acceptance tests are conducted based on the purchase specification that includes procedures, measurement locations, process conditions, measures and acceptable levels of vibration.
- The purchase specification should include testing procedures as well as acceptable levels of vibration similar to ISO standards.
- Baseline tests should be conducted and compared with general vibration standards in the absence of purchase specification.

Baseline Tests

- Baseline tests are used to determine the nature and level of normal vibration of a machine.
- It should be conducted prior to and during periodic monitoring program activity.
- Condition can be observed and maintenance action initiated when baseline vibration levels change.
- Baseline tests are also able to reveal design and installation problems such as resonance, critical speeds, alignment, soft foot and distortion.

Resonance and Critical Speed Testing

- These tests are carried out to obtain information about the dynamic characteristics of a machine and its structural support and piping.
- The information can be used in machine diagnostics and redesign in order to overcome chronic problems.
- Resonance occurs when a vibratory force is equal to a natural frequency of the system.
- Resonances are often artificially excited with hammers and shakers to obtain natural frequencies.

Resonance and Critical Speed Testing

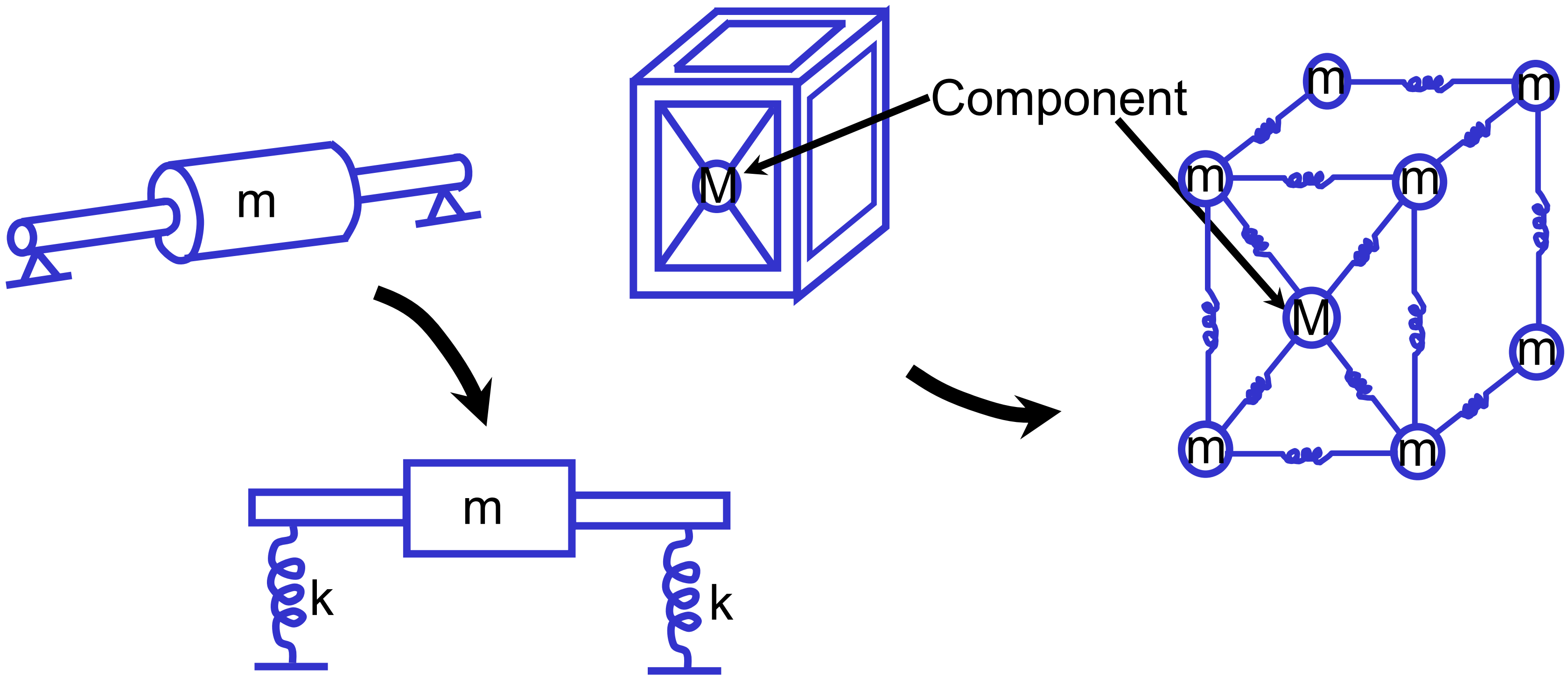
- Natural frequencies and mode shapes
  - The natural frequency is governed by design
  - Each machine/system has a number of natural frequencies that can be excited by impact, random forces or harmonic vibrating forces of the same frequency
  - In general, natural frequencies are not multiples of the first natural frequency
  - Vibration levels are amplified during resonance

Resonance and Critical Speed Testing

- Natural frequencies and mode shapes
  - A mode shape is defined as the deflection shape assumed by a system vibrating at a natural frequency
  - Mode shapes of a system are associated with natural frequencies
  - A mode shape consists of deflections at selected points in the system that are determined relative to a fixed point (e.g. end of a shaft)

Resonance and Critical Speed Testing

- Natural frequencies and mode shapes - mass-spring models of rotor and structures



Resonance and Critical Speed Testing

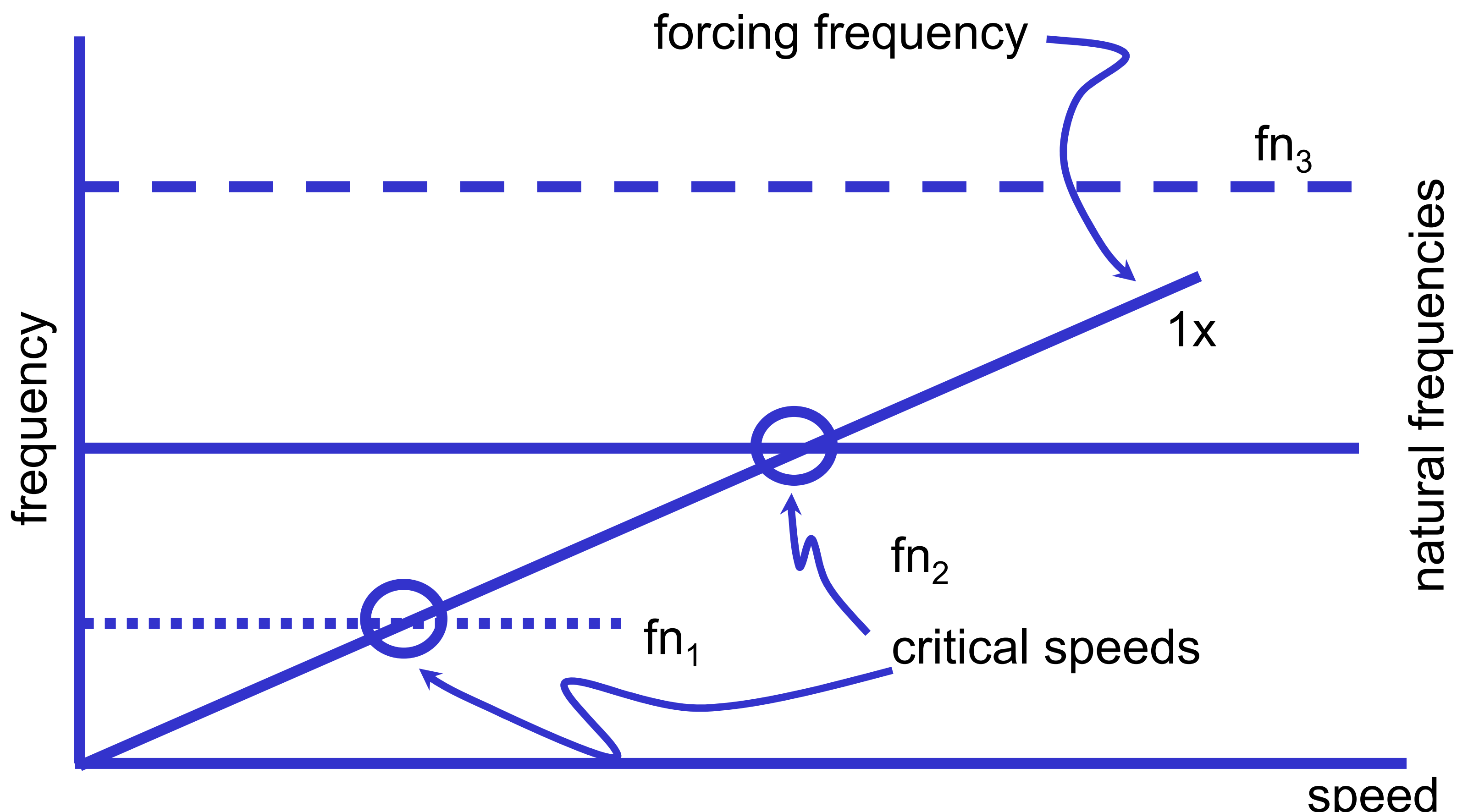
- Excitation
  - A machine or structure can be excited by one or more vibratory forces
  - The force may have a single (e.g. mass unbalance) or multiple (engines and compressors) frequencies
  - Vibratory forces can be caused by various factors including design, installation errors, manufacturing defects and wear

Resonance and Critical Speed Testing

- Interference diagram
  - An interference diagram is used to locate resonances and critical speeds with respect to operating speed
  - The point of intersection of one or more forcing and natural frequencies is a critical speed
  - An interference diagram can be generated from computer models or test data
  - Computer generated interference diagrams should be validated using test data

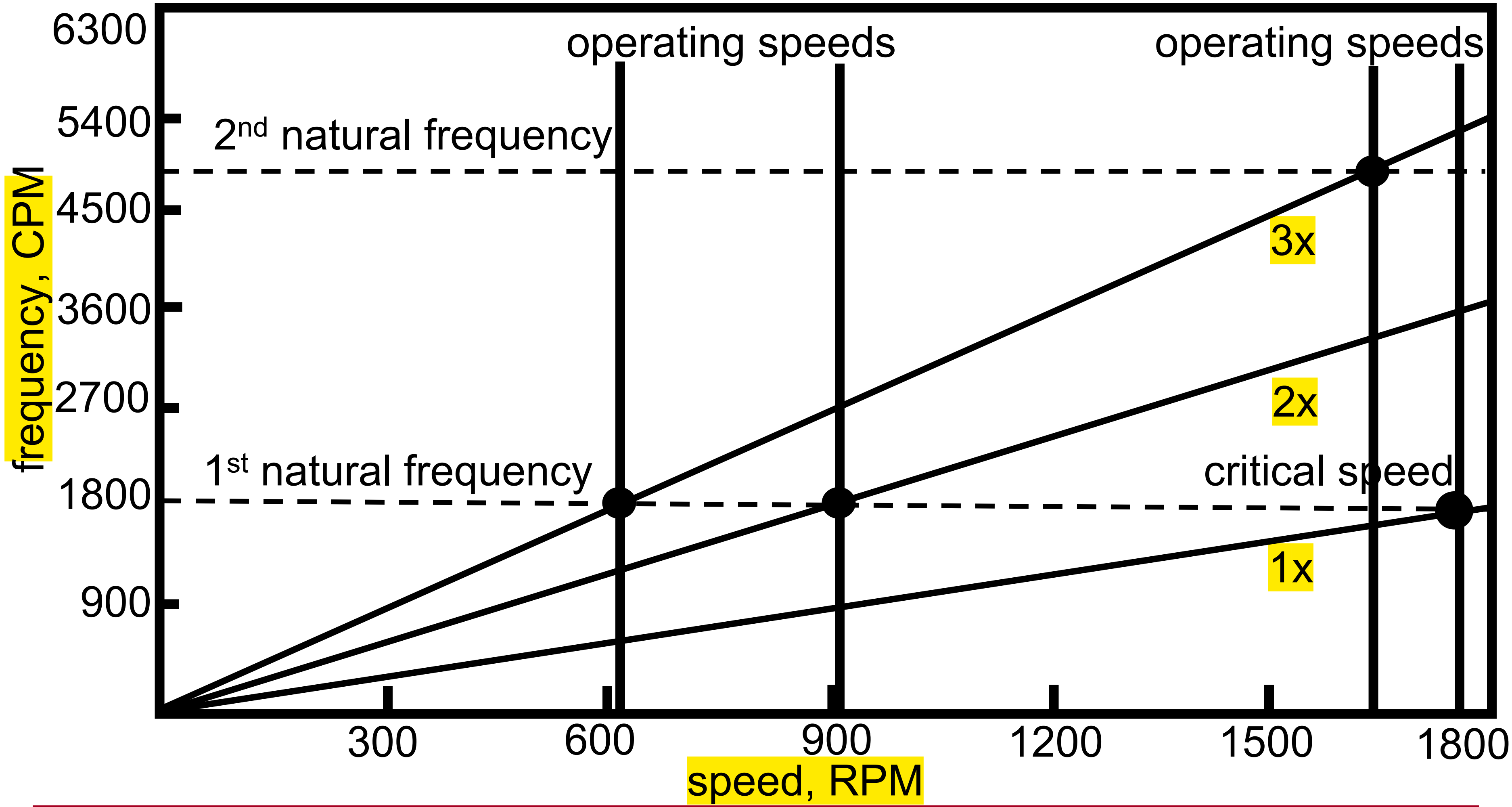
Resonance and Critical Speed Testing

An interference diagram for a rotor subject to mass unbalance

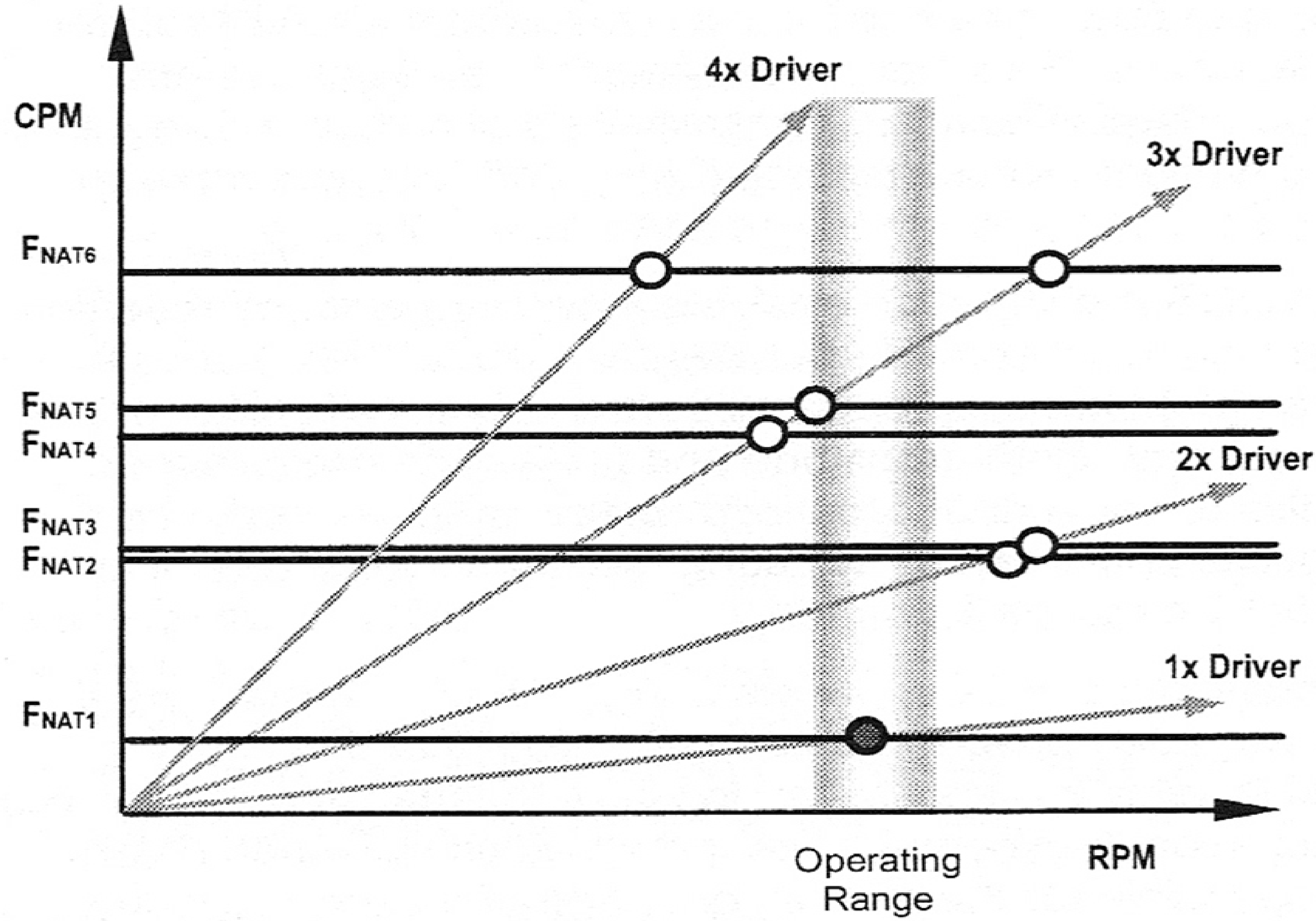


Resonance and Critical Speed Testing

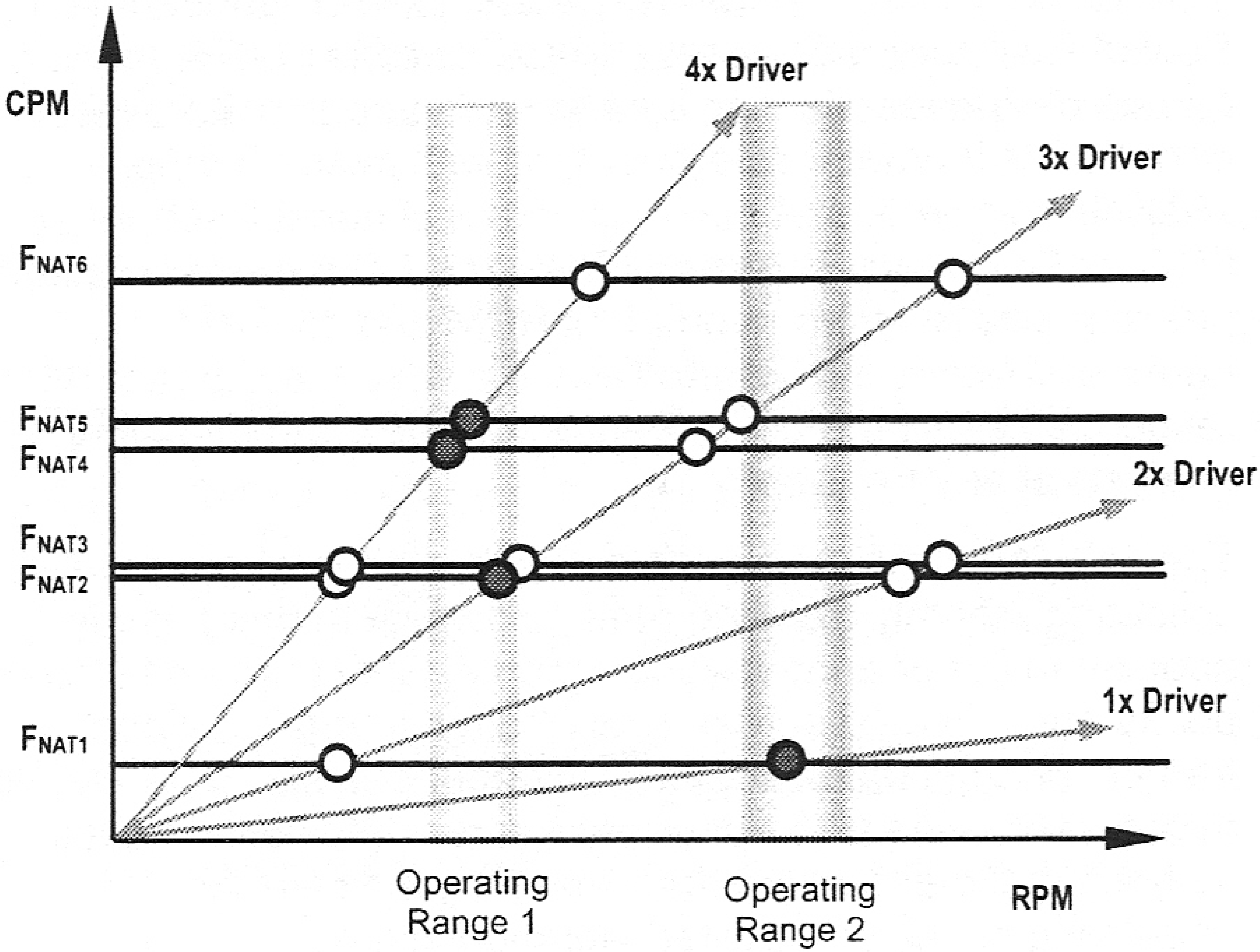
- Interference diagram for a motor-driven overhung fan



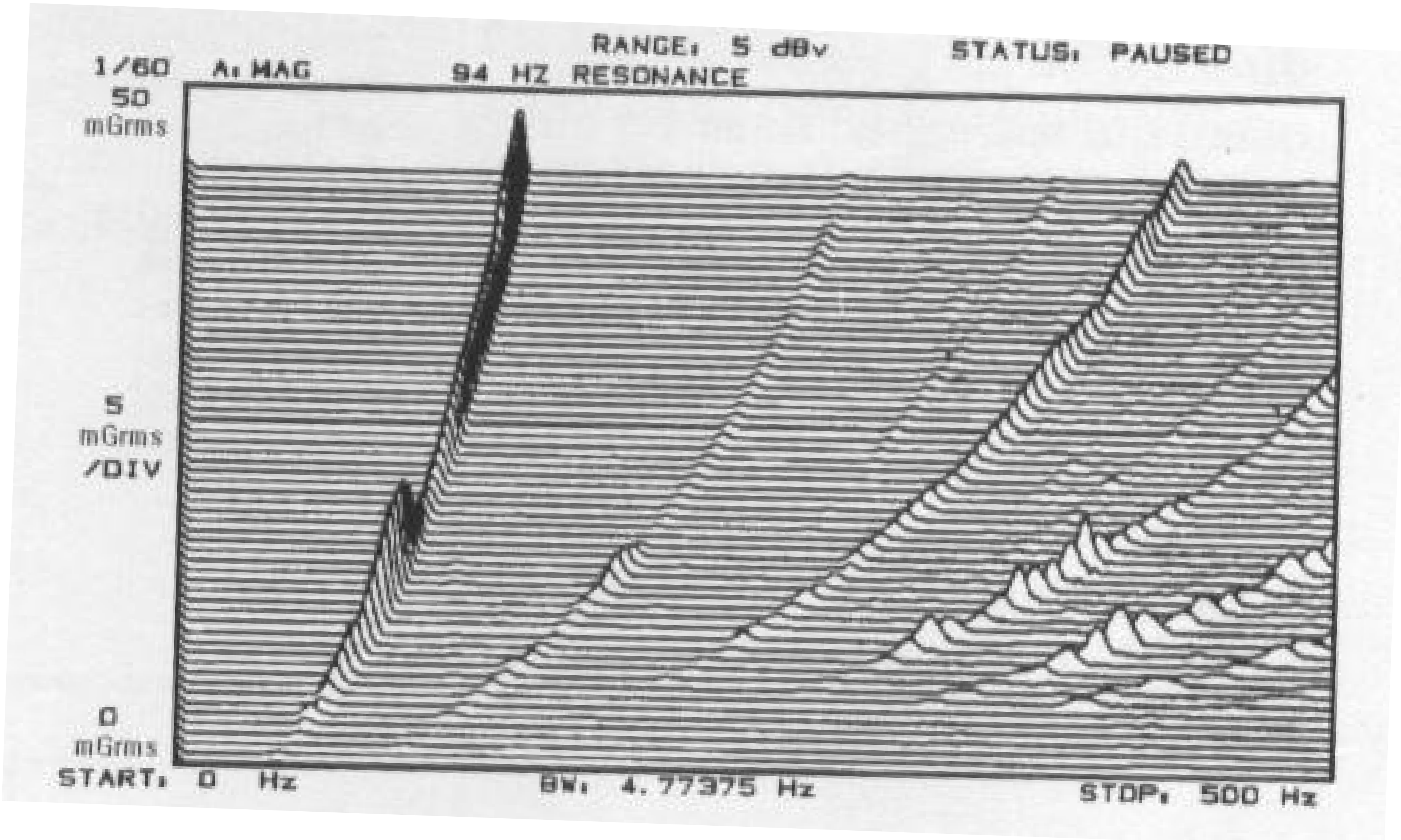
Resonance and Critical Speed Testing



Resonance and Critical Speed Testing



Resonance and Critical Speed Testing



Resonance and Critical Speed Testing

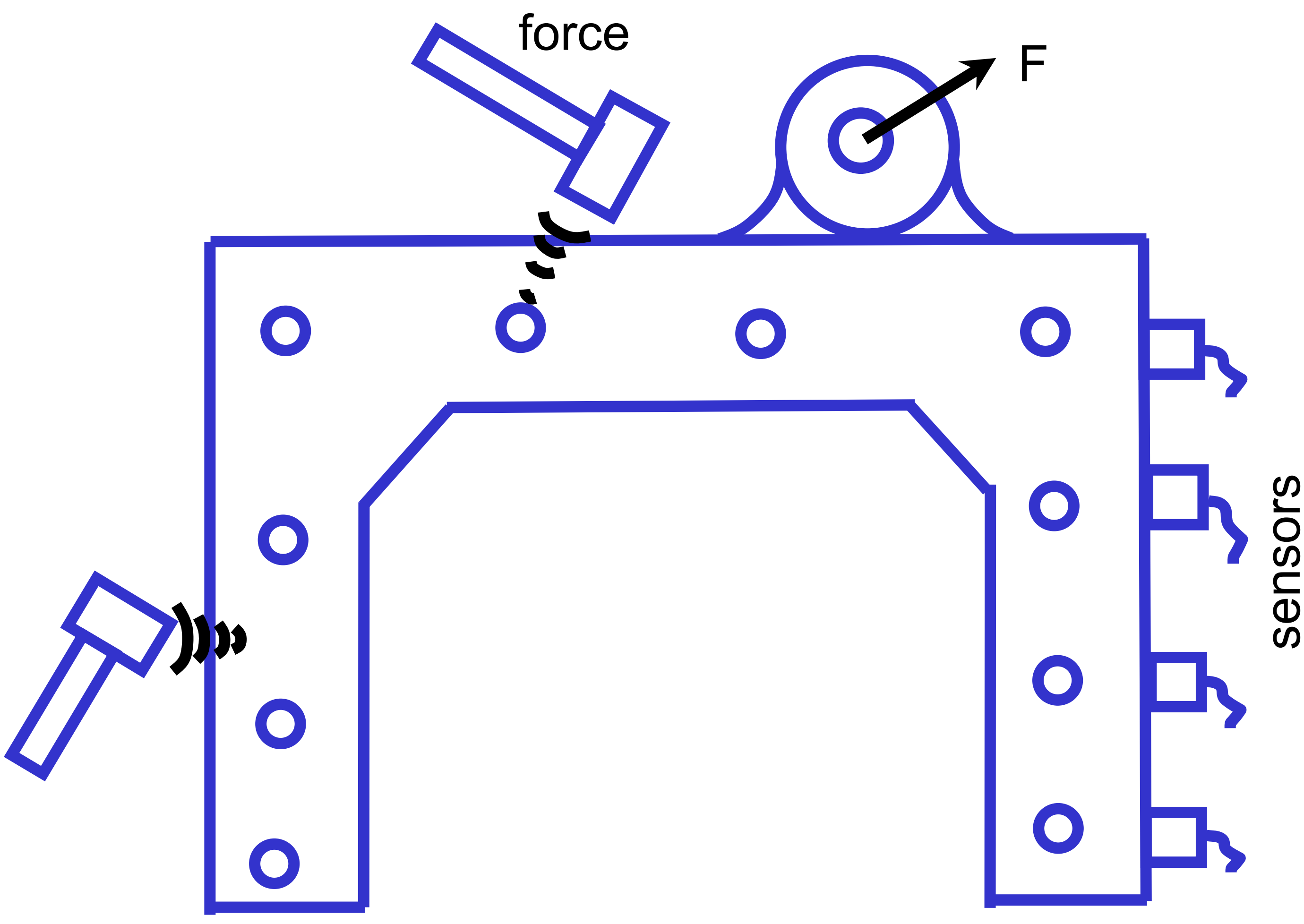
- Conducting a resonance test
  - Determine the vibrations of the structure at a number of known points during operation
  - Set up the data collector or analyzer for data acquisition and processing
  - The frequency span should be selected wide enough and with sufficient resolution
  - Only one impact should be made within the data acquisition time

Resonance and Critical Speed Testing

- Conducting a resonance test
  - Strike the structure with a 4x4 timber, mallet or hammer with a soft head in the direction of the desired mode (smaller hammers for smaller structures)
  - If the desired mode is not known, strike the structure in several directions (i.e. vertical and horizontal)
  - Measure and record the vibration levels at a number of reference points on the structure

Resonance and Critical Speed Testing

Repeatable impact and measurement points



Resonance and Critical Speed Testing

- Conducting a resonance test - Impact spectrum
  - The peaks on the spectrum of vibration levels at various measurement points indicate the natural frequencies of the structure
  - Some natural frequencies can not be excited at nodal points
  - A rule of thumb is that the spacing between forcing frequencies and natural frequencies should be 15%

Resonance and Critical Speed Testing

- Conducting a resonance test - considerations
  - The structure, piping or machine should be as close as possible to its operating state
  - Parts of a machine can not arbitrarily be removed and tested
  - Example

    The natural frequencies of a gear not mounted on its shaft differ from those when the gear is mounted

Resonance and Critical Speed Testing

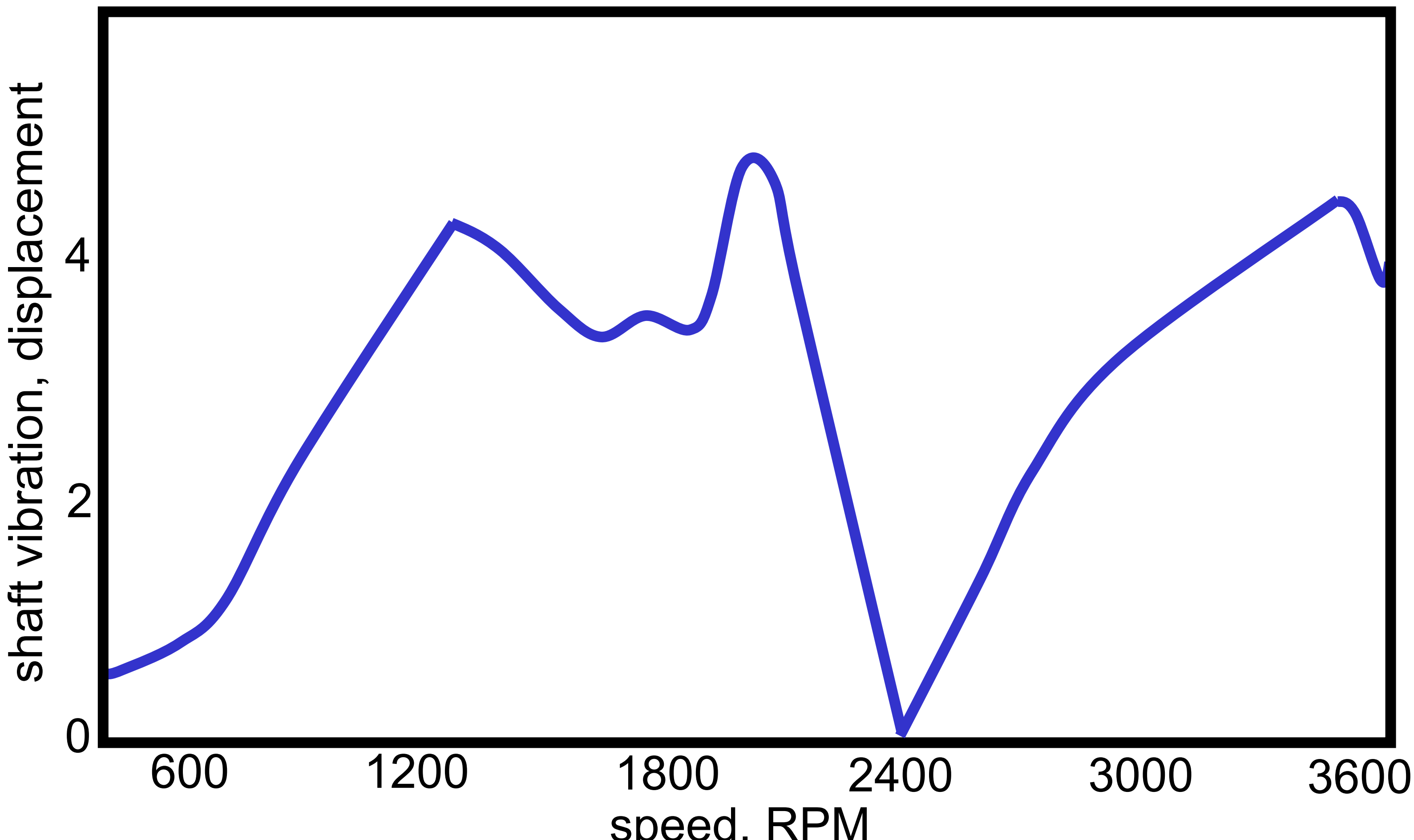
- Procedures for conducting a critical speed test
  - Select one or more appropriate transducers to measure the vibration
  - Proximity probes are preferred if they are permanently installed
  - Velocity and acceleration transducers should be close to the bearing
  - Wire the vibration transducers and trigger to a tracking analyser, tape recorder or data collector

Resonance and Critical Speed Testing

- Procedures for conducting a critical speed test
  - To perform coast down test, run the machine at 10 ~ 15 % over speed and then cut the power and allow the machine to coast down from normal operation
  - Process the data and identify the critical speeds from FFT spectrum, Bodé or polar plot
  - The natural frequency at an operating speed is not necessarily the measured natural frequency during start-up or coast-down test

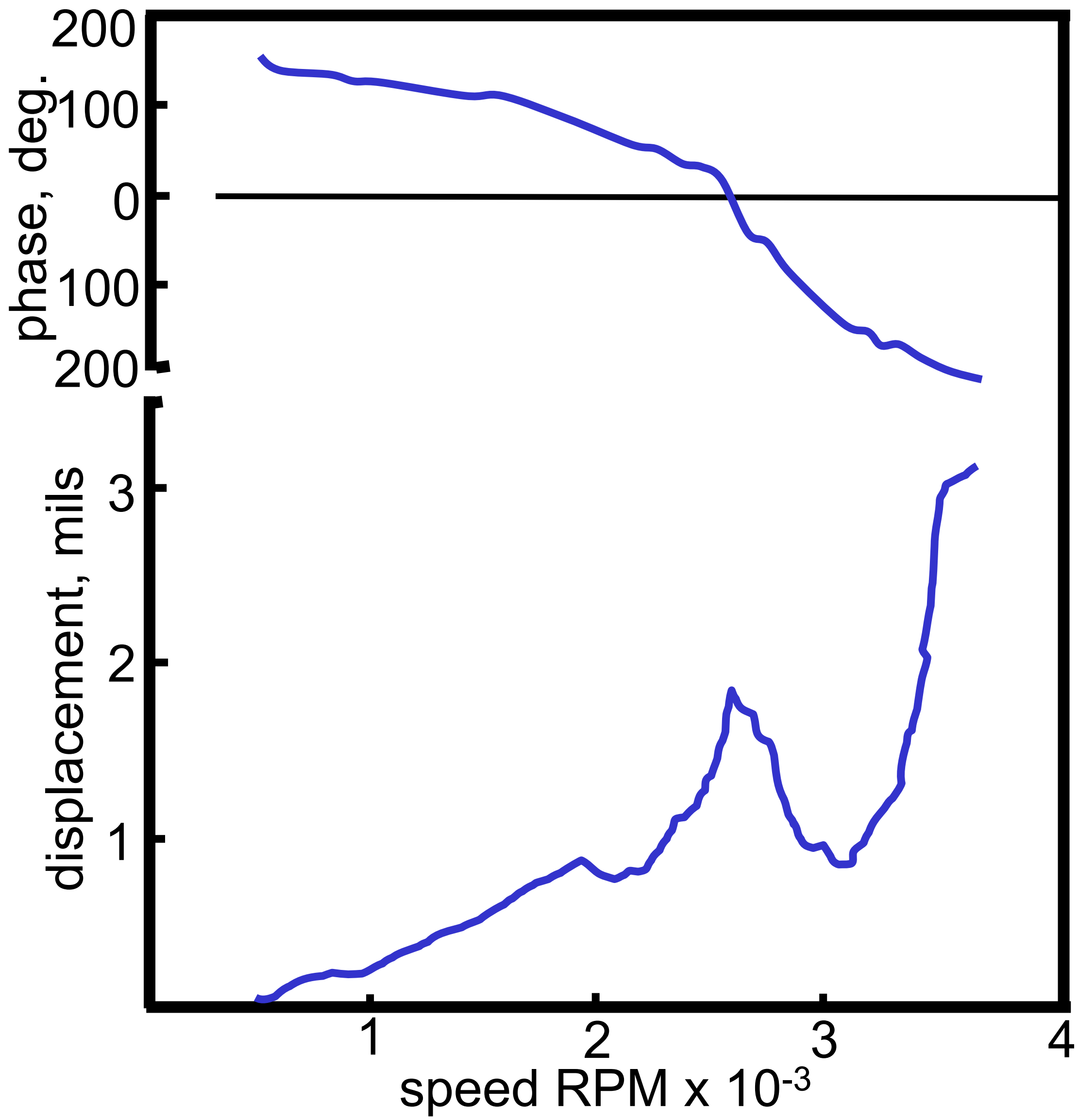
Resonance and Critical Speed Testing

Coast-down test of a steam turbine



Resonance and Critical Speed Testing

- Bodé plot of a coast-down test



Resonance and Critical Speed Testing

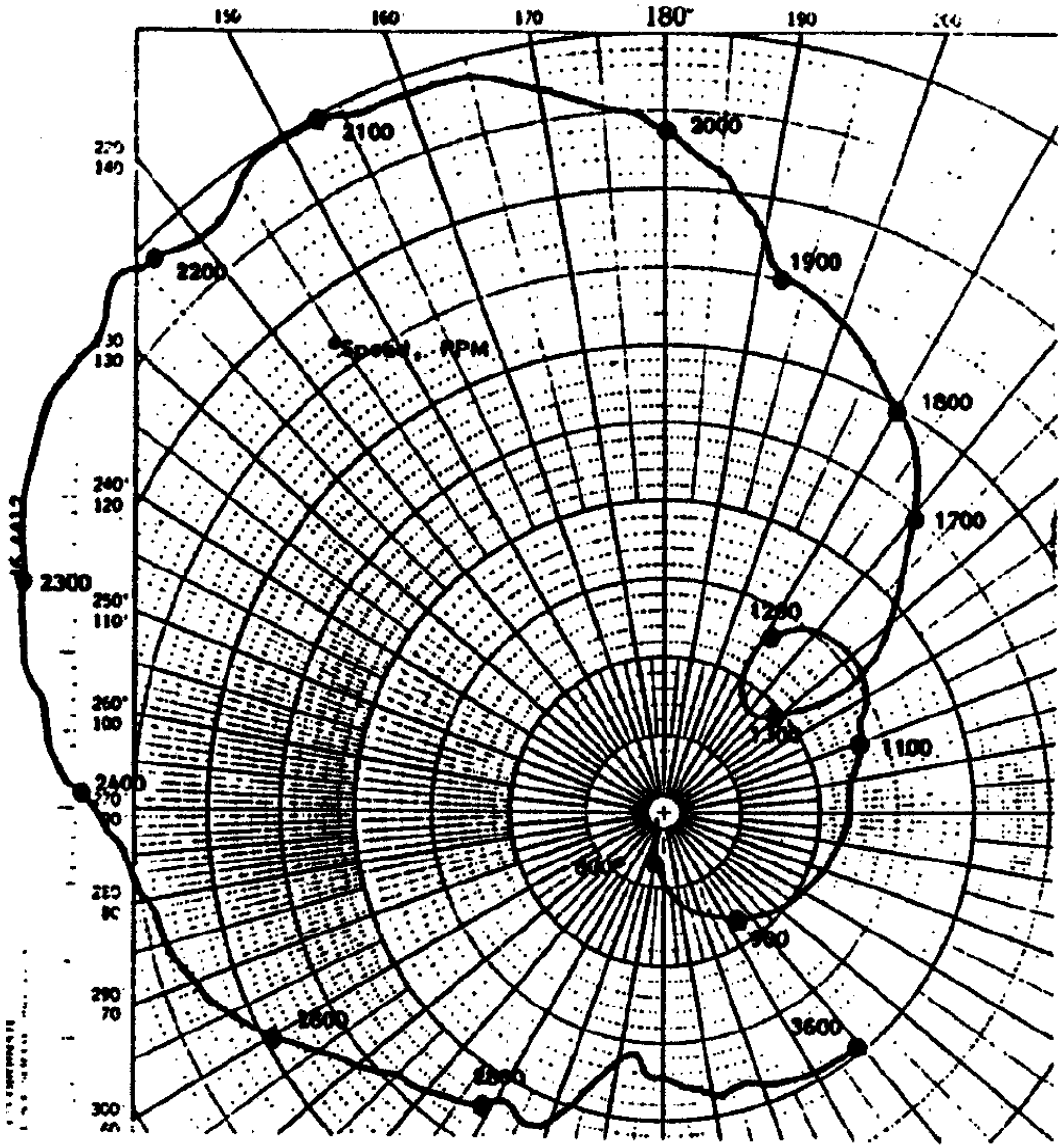
- Using the FFT analyzer/data collector
  - The peak hold feature holds and displays the peak values of all data after each spectrum is computed
  - The peak hold feature can be used to provide data on critical speeds
  - The relationship between acquisition time (T_s), number of lines (N) and frequency span (F_{max}) is: $T_s = N/F_{max}$

Resonance and Critical Speed Testing

- Using polar plots
  - Polar plots show the amplitude and phase of vibration at various speeds
  - The tracking analyser plots the real and the imaginary amplitudes at the various speeds
  - The small loop identifies the first critical speed of the generator (1,200 RPM)
  - The maximum vibration amplitude occurs at 2100 RPM
  - Operating speed is 3600 RPM

Resonance and Critical Speed Testing

- Polar plot of a start-up test of a generator bearing



Resonance and Critical Speed Testing

- A summary
  - A tracking analyser is best for rapid run-up and coast-down tests
  - Vibration is indicated in the filtered frequency band
  - Reference signal is generated by a proximity probe with notch or optical pickup with reflective tape
  - Peak vibration levels and phase changes indicate critical speeds

Resonance and Critical Speed Testing

- Signal-channel analyzer/collector may be used for impact tests in either time or frequency domains
- Triggering can be free or from a hammer source
- Vibration peaks indicate resonances
- During impact tests, a uniform (none) window should be used on the analyzer

Specifications

- The purposes of preparing a specification
  - To procure quality equipment and services
  - To avoid misunderstandings
  - To resolve differences of opinion
  - To establish a methodology for testing the equipment without controversy
- It is best to use existing ISO (or other) standards as guidelines for preparing a specification

Environment and Mounting

- Mounting is often a cause of excessive vibration especially on vertical pumps
- Natural frequencies should be set away from operating speeds by pump manufactures to avoid resonance
- The customer is responsible for ensuring the mounting is not interfering with natural frequencies
- Sufficient bracing and support should be used in piping to assure a natural frequency higher than pump specifications

Presentation of Data

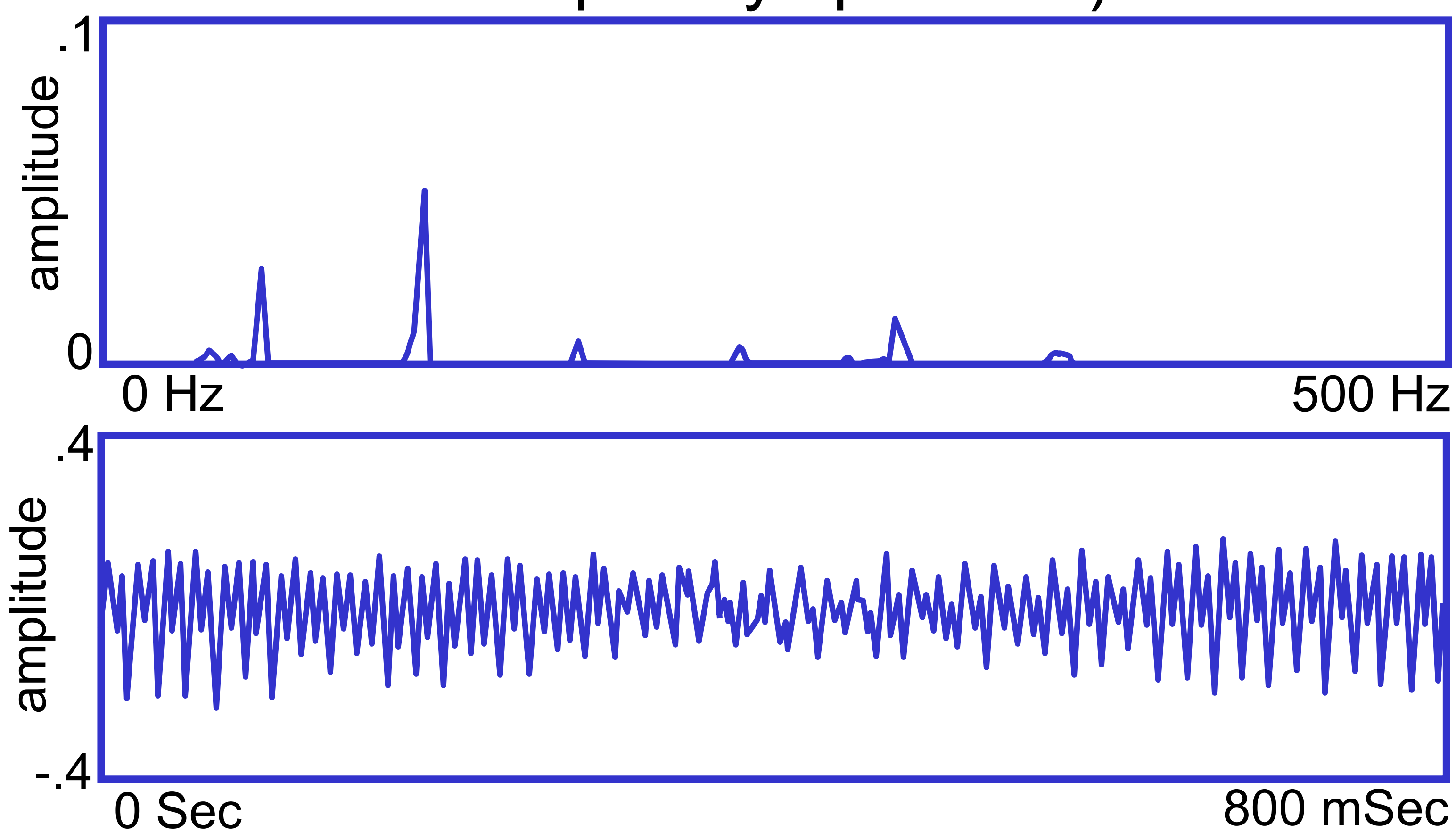
- The presentation of data is valuable for fault analysis, condition evaluation, baseline testing
  - Acceptance testing data is in a simple form involving overall levels
  - Spectral data provide resolution and dynamic range sufficient to discern important frequencies and amplitudes
  - The time waveform should be presented so that the data can be related to the physical characteristics of the machine

Presentation of Data

- Detailed waveform variations should be observable
- Amplitude trends may be used for long term monitoring
- The span of the time waveform should be equal to the data acquisition time from the analyzer
- Orbits should not be filtered at operating speed
- High frequency filtering may be used to remove noise
- The phase of operating speed vibration to a spot on the shaft is valuable for analysis

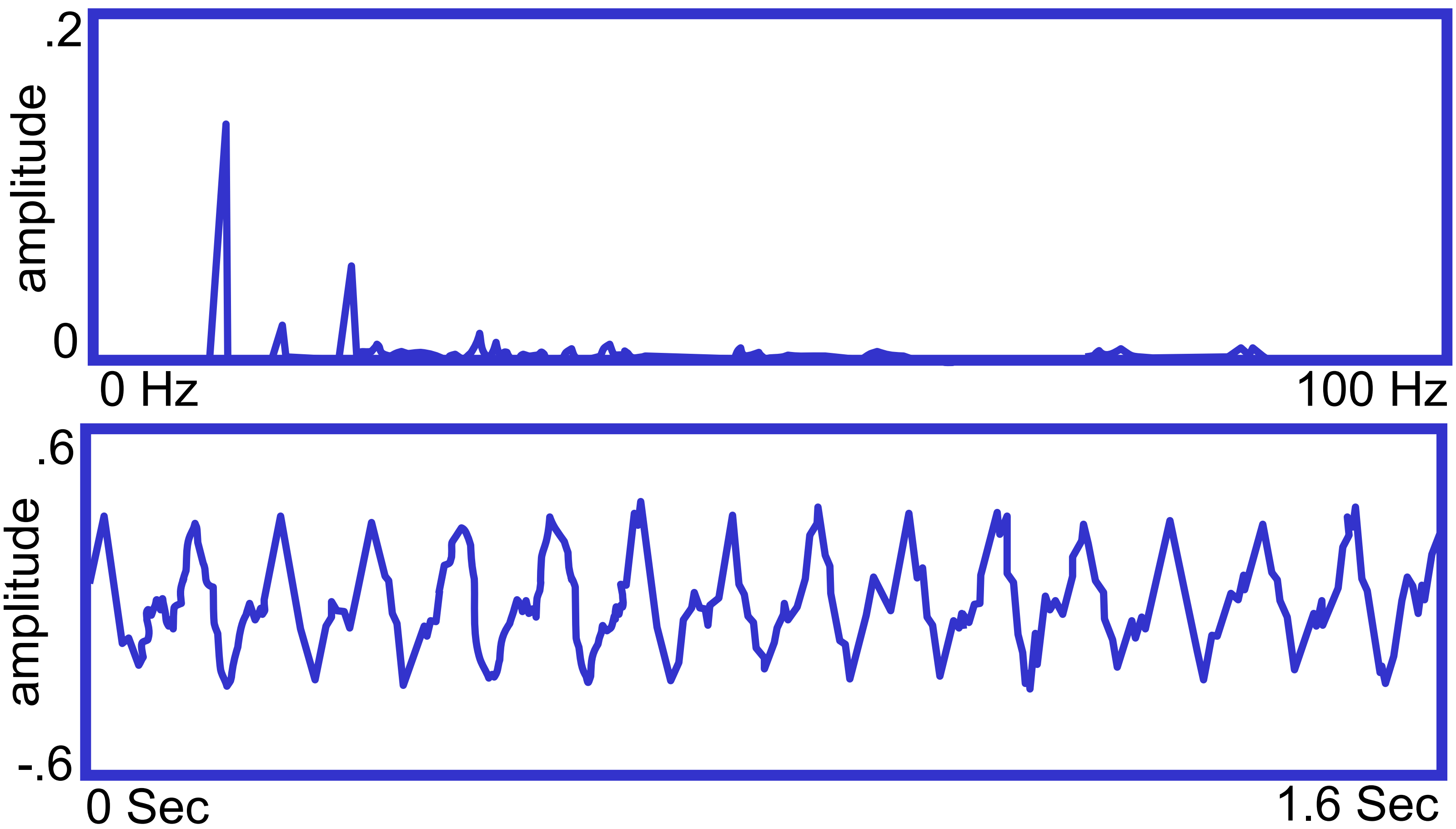
Presentation of Data

Spectrum and time waveform for an electric motor (variations in time waveform not obvious in frequency spectrum)



Presentation of Data

Data from a fan motor



Reports

- Reports should be written for each of the following activities:
  - Baseline testing
  - Acceptance testing
  - In-depth analysis including
    - Operational tests
    - Resonance and critical speed tests
    - Environment tests

Reports

- The organization of a report should include
  - Executive summary
  - Introduction
  - Technical discussion
  - Conclusions and recommendations
  - Appendix (technical data)

Reports

- The executive summary includes
  - A description of the equipment being tested
  - The symptoms of the problem
  - Major findings
  - Conclusions and recommendations

Reports

- The introduction section should describe
  - The equipment being tested
  - Purpose of the test
  - Approach to the test
  - Test equipment and techniques used

Reports

- Technical details supporting the conclusions and recommendations are presented in the technical discussion.
- Conclusions and recommendations are necessary for all major findings found in the survey or analysis.
- The appendix should include
  - A description of measurement points
  - Last measurement reports
  - Trend plots
  - Spectral data on exceptions and alarms

Reports

- Types and purposes of reports
  - Baseline reports
    - Provide a complete picture of the condition of the equipment or faults present
    - Contains the normal vibration levels to the best of the capability of the analysis
    - Suggest values for setting alarms
  - In-depth analysis
    - Includes selected time waveforms, spectra, orbits, tests from impact or coast-down tests

Reports

- Types and purposes of reports
  - Acceptance test report
    - Should be linked to the specification
    - May carry out a complete analysis of the machine during acceptance testing
    - After balancing, should show vibration levels and the trial weights applied
    - Final readings should be recorded
    - Conclusions and recommendations can be brief but inclusive

Summary of Machine Testing

- A test plan should be generated prior to data acquisition on a machine – acceptance tests, baseline tests, fault analysis, condition evaluation, design, and balancing
- The test plan should contain a description of the machine, the tests to be performed, the data to be acquired, loads, speeds, machine configurations, and process conditions

Summary of Machine Testing

- The data acquisition plan should provide details about sensors including location, measurement parameters, and process conditions
- If data are processed on site, the analyzer setups must be provided, including frequency spans, lines of resolution, range, windows, and time spans.
- Sometimes multiple data acquisitions are required to obtain adequate range and resolution

Summary of Machine Testing

- A site inspection should provide details about external vibrations and machine mounting
- Acceptance tests are to be listed in detail in the purchase specification of a new or required machine.
- Included in the acceptance tests are procedures, measurement locations, process condition, measures and the way they are processed, and acceptable vibration levels

Summary of Machine Testing

– Baseline tests are conducted to establish normal operating levels of vibration when the machine is in good operating condition

– Specifications should be used to assure the procurement of quality equipment

– Be realistic about acceptance levels and locating critical speeds

Summary of Machine Testing

- Good mounting environments and procedures will assure that equipment is operating properly
- Presentation and reporting of data provide quality analysis of quality data

General Vibration Analysis Techniques – Trouble Shooting

Excessive machinery vibrations can result in:

- component or structural failure
- Injury or environmental damage
- fatigue / cracking / plastic deformation
- product damage

To solve vibration problems:

- identify forcing functions
- eliminate or minimize effect

General Vibration Analysis Techniques – Trouble Shooting

General Steps

1. Identify the problem
2. Gather information
3. Determine possible forcing functions
4. Determine where to take data and what data collection equipment to use
5. Take vibration data
6. Analyse vibration data (and any other data available)
7. Make recommendations

General Vibration Analysis Techniques – Trouble Shooting

1. Identify the Problem

- inspect the site (overview)
- noise problems often solved using isolation and insulation
- true vibration problems need correction


NOTICE
120 VOLTS

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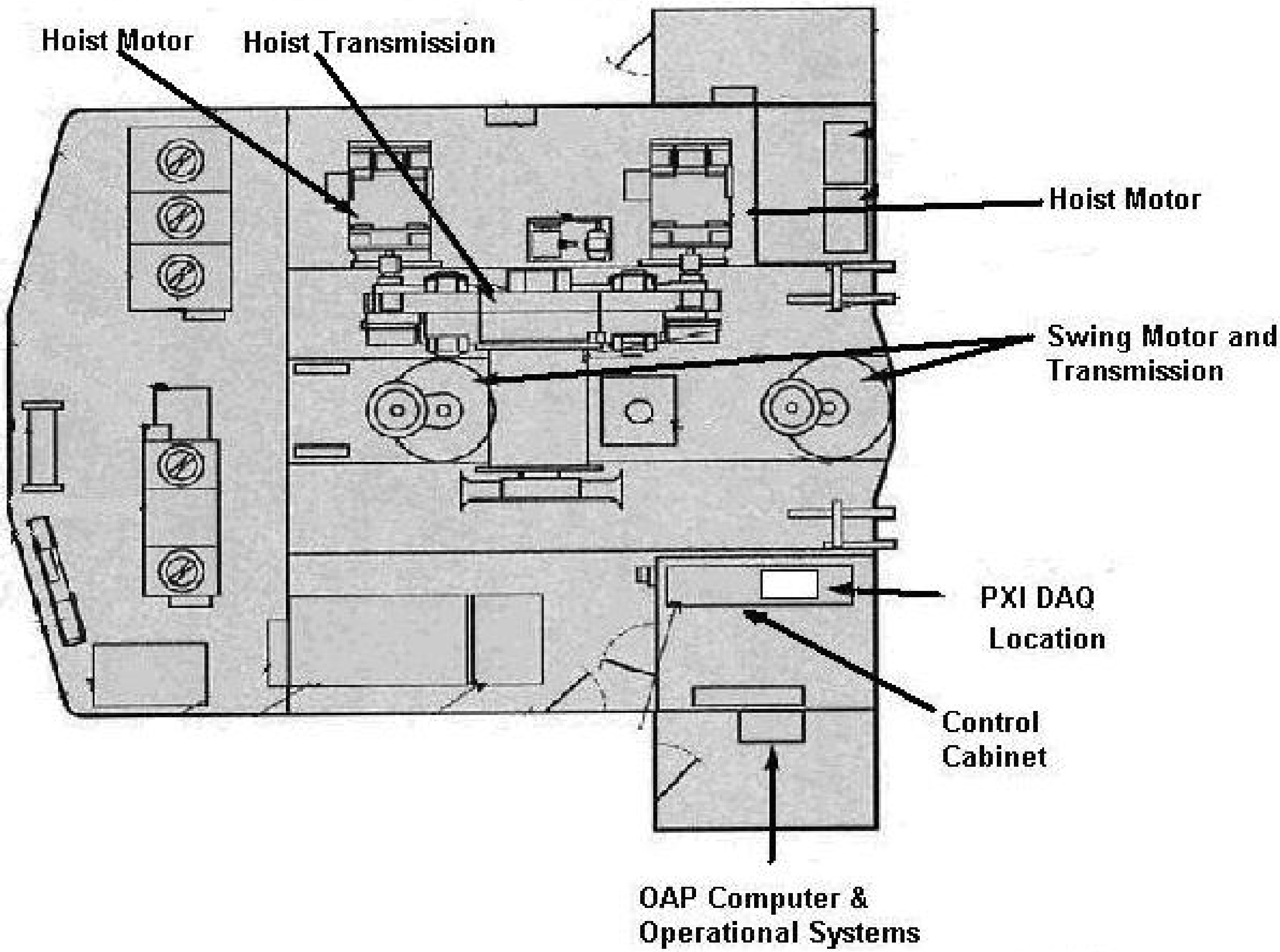


General Vibration Analysis Techniques – Trouble Shooting

2. Gather Information (as much as possible)

- sketch major machine components (note modifications)
- collect details on major components (specifications on motors, pumps, bearings, etc.)
- collect maintenance history
- talk to operators and maintenance staff

Trouble Shooting – Gathering Information

The sketch

- helps locate best positions for sampling vibration data

should include:

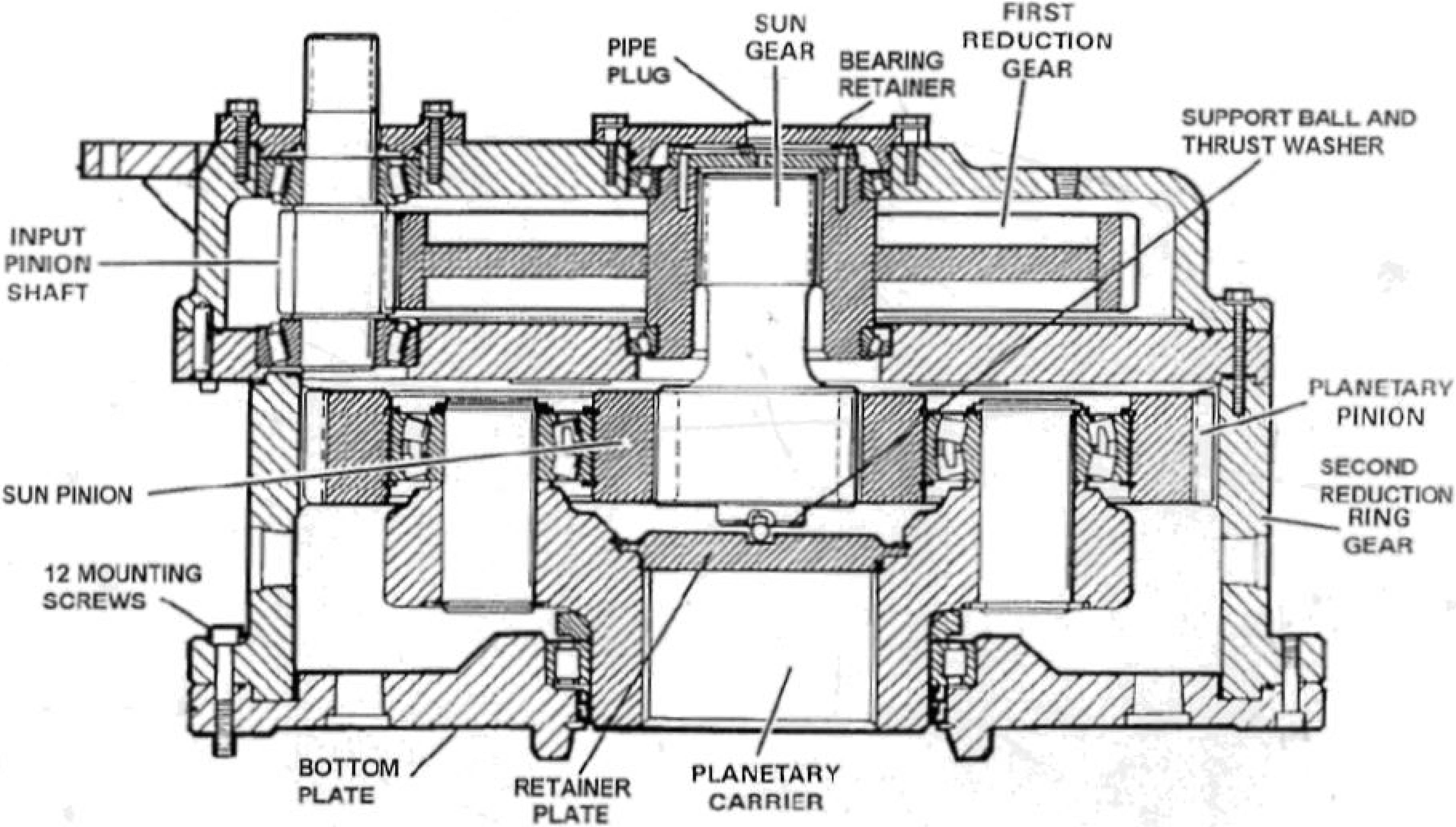
a) All major components

b) Shaft diameters, lengths

c) Rotor dimensions, weights

d) All bearing specifications

Trouble Shooting – Gathering Information

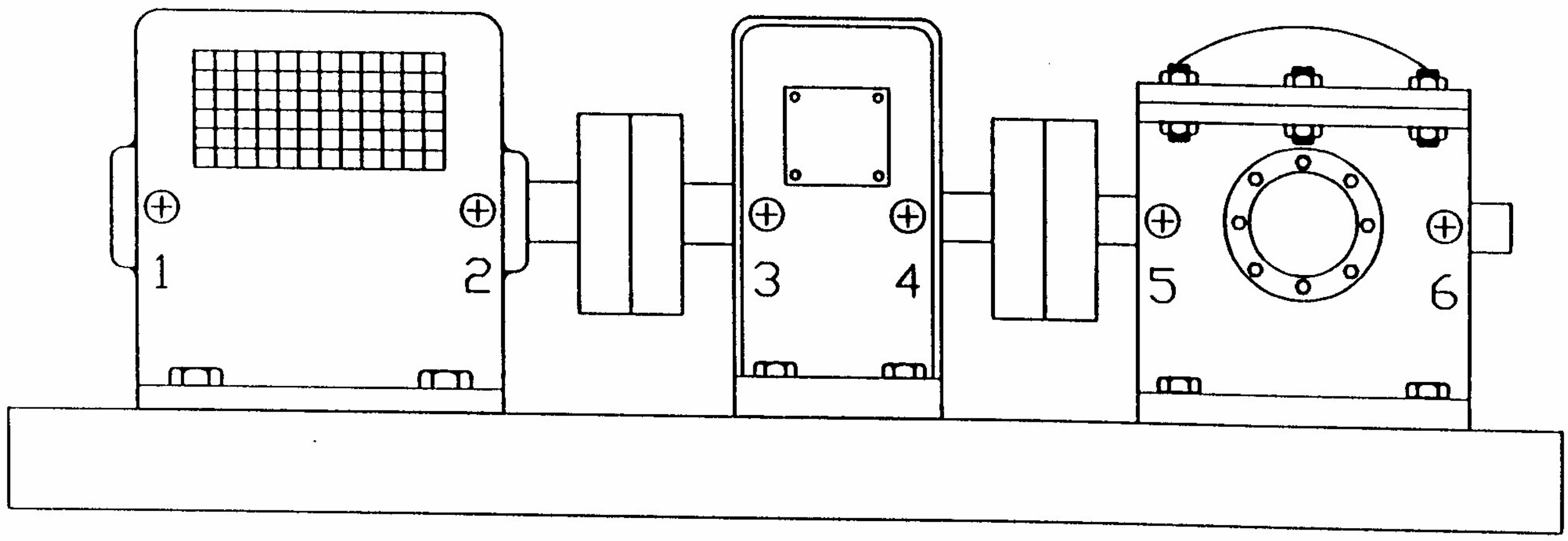


Trouble Shooting – Gathering Information

Characteristic	Symbol	Frequency
Input Pinion Gear Mesh Frequency	Finputpin-gm	269.2 Hz
Planet Gear Mesh Frequency	Fplanet-gm	19 Hz
Sun Gear Mesh Frequency	Fsun-gm	38.8 Hz
Planet Passing Frequency		1.5 Hz
Swing Pinion Gearmesh	Fswing-gm	6.3 Hz

Selected Gearbox frequencies at 950 rpm input

Trouble Shooting – The Sketch



Trouble Shooting – Gathering Information

Bearing specifications should include:

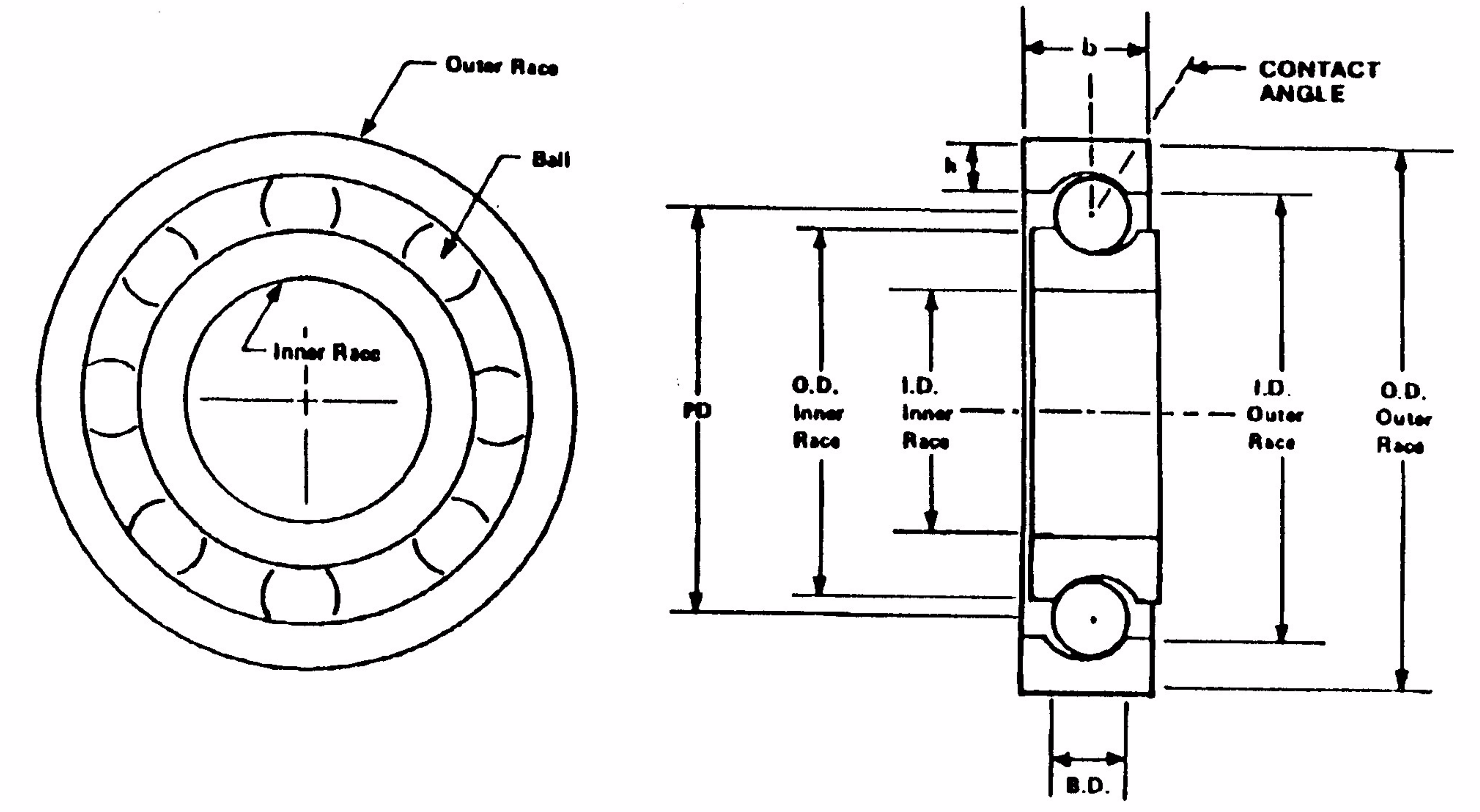
Bearing type, number

- ball & roller diameter
- # of balls, rollers
- pitch diameter
- contact angle
- shaft speed

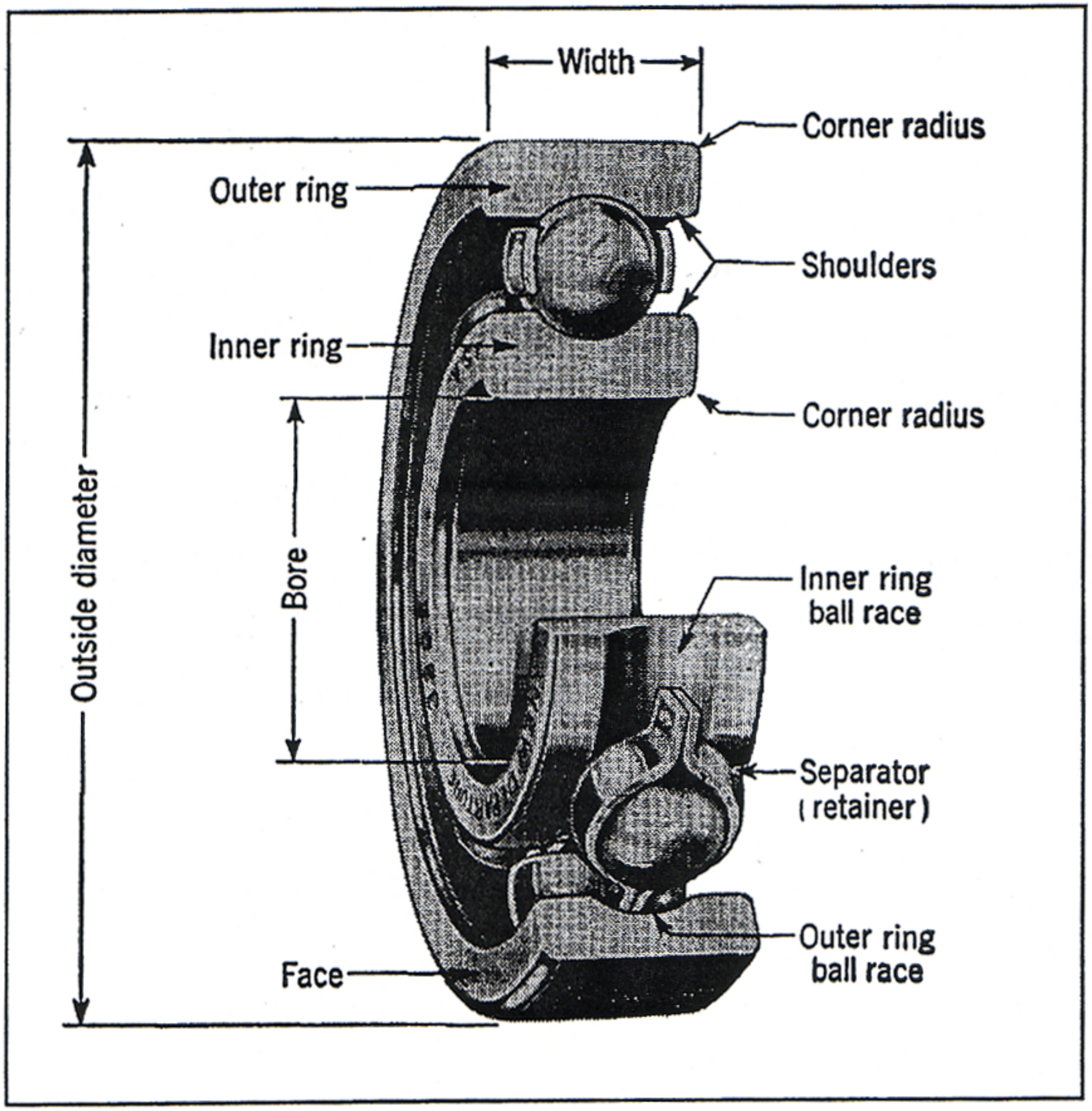
if sleeve bearings

- type
- clearance

Trouble Shooting – Roller Bearings



Trouble Shooting – Roller Bearings



Trouble Shooting – Roller Bearings

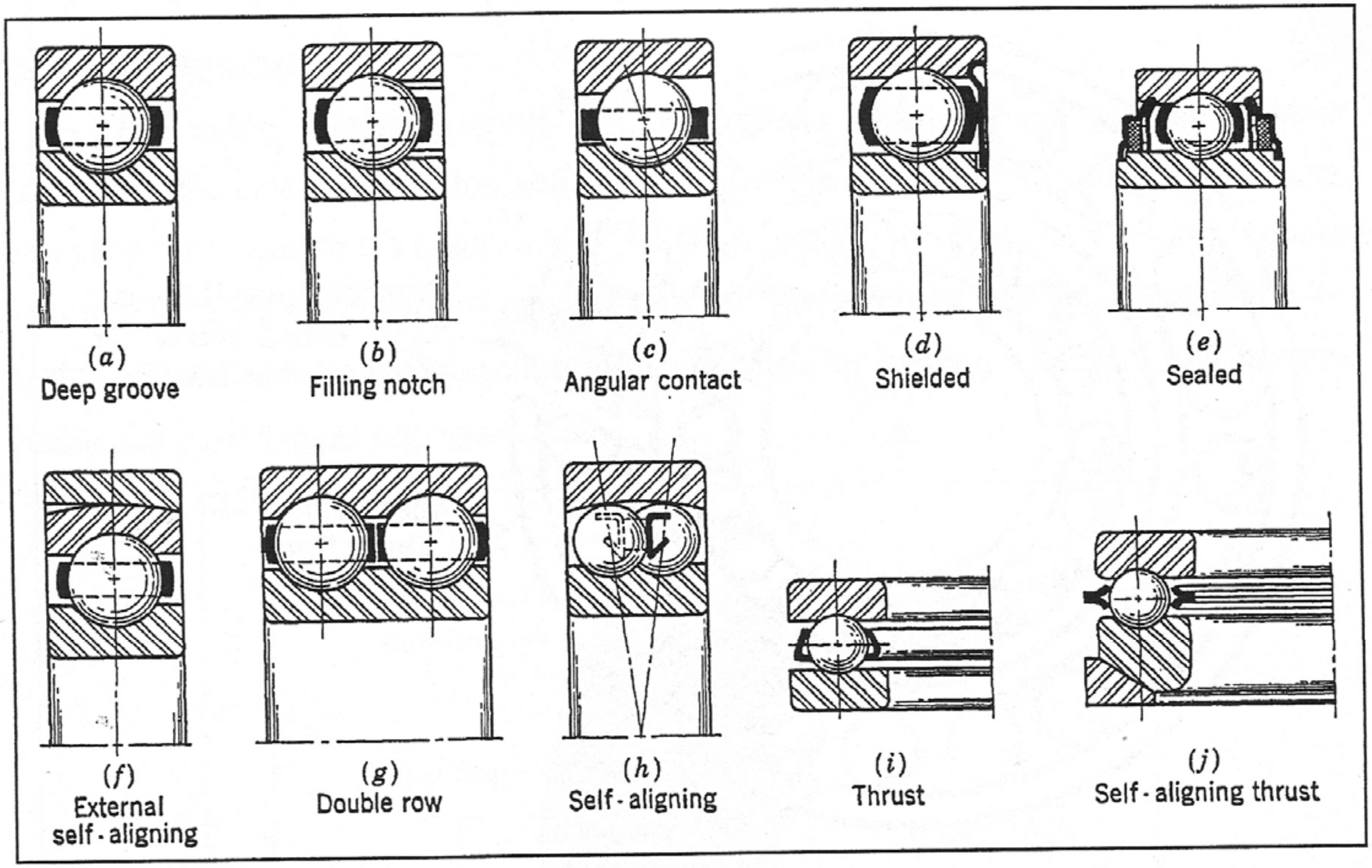


Figure 11.3. Types of Roller Bearings
(Courtesy of the Timken Roller Bearing Company)[11.10]

Trouble Shooting – Roller Bearings

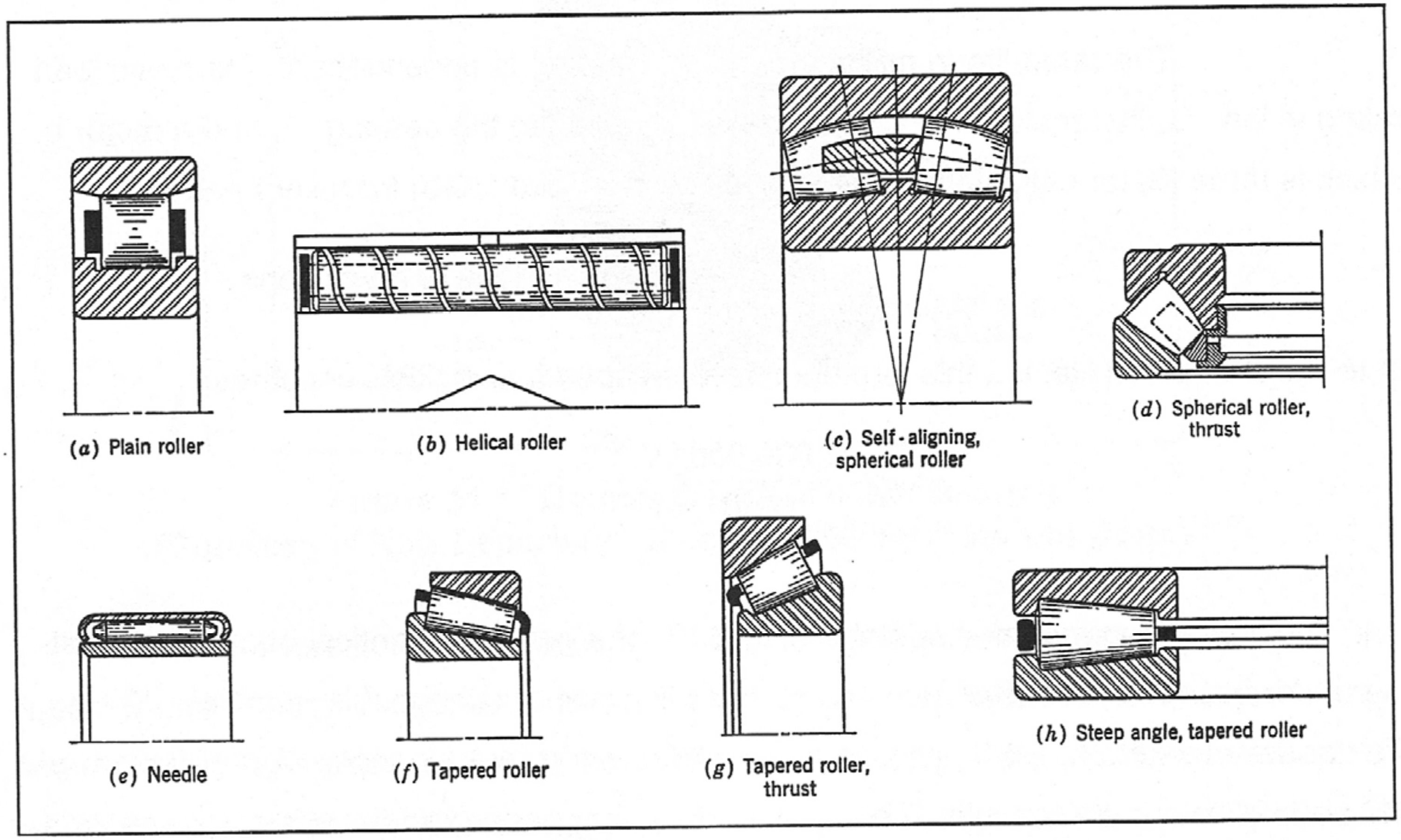


Figure 11.4. Types of Roller Bearings
(Courtesy of the Timken Roller Bearing Company)[11.10]

Trouble Shooting – Roller Bearings

FREQUENCIES (in Hertz)	RELATIONSHIP TO OPERATION
$f = \frac{N_s}{60}$	Shaft rotational speed
$f = \left(\frac{N_s}{120}\right)\left[1 - \left(\frac{d}{D}\right)\cos(\beta)\right]$	Rotational speed of ball cage when outer race is stationary
$f = \left(\frac{N_s}{120}\right)\left[1 + \left(\frac{d}{D}\right)\cos(\beta)\right]$	Rotational speed of ball cage when inner race is stationary
$f = \left(\frac{N_s}{120}\right)\left(\frac{D}{d}\right)\left[1 - \left(\frac{d^2}{D^2}\right)\cos^2(\beta)\right]$	Rotational frequency of a roller element
$f = \left(\frac{n_r N_s}{120}\right)\left[1 - \left(\frac{d}{D}\right)\cos(\beta)\right]$	Frequency of contact between a fixed point on a stationary outer race and a rolling element

f – frequency (Hz), N_s - shaft speed (RPM), D – pitch diameter

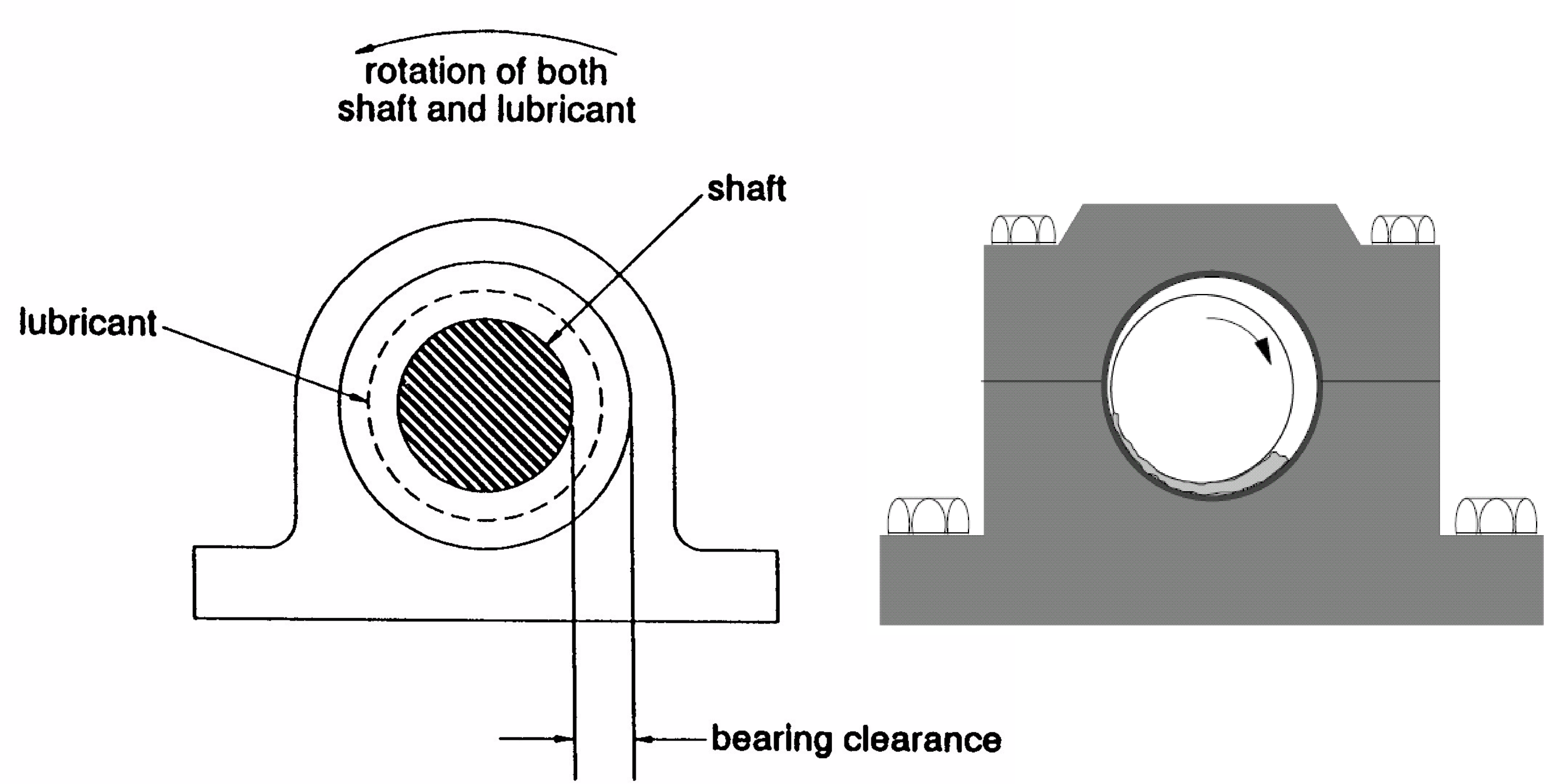
d – rolling element diameter, n_r - # of rolling elements

β – contact angle between race and ball

Trouble Shooting – Roller Bearings

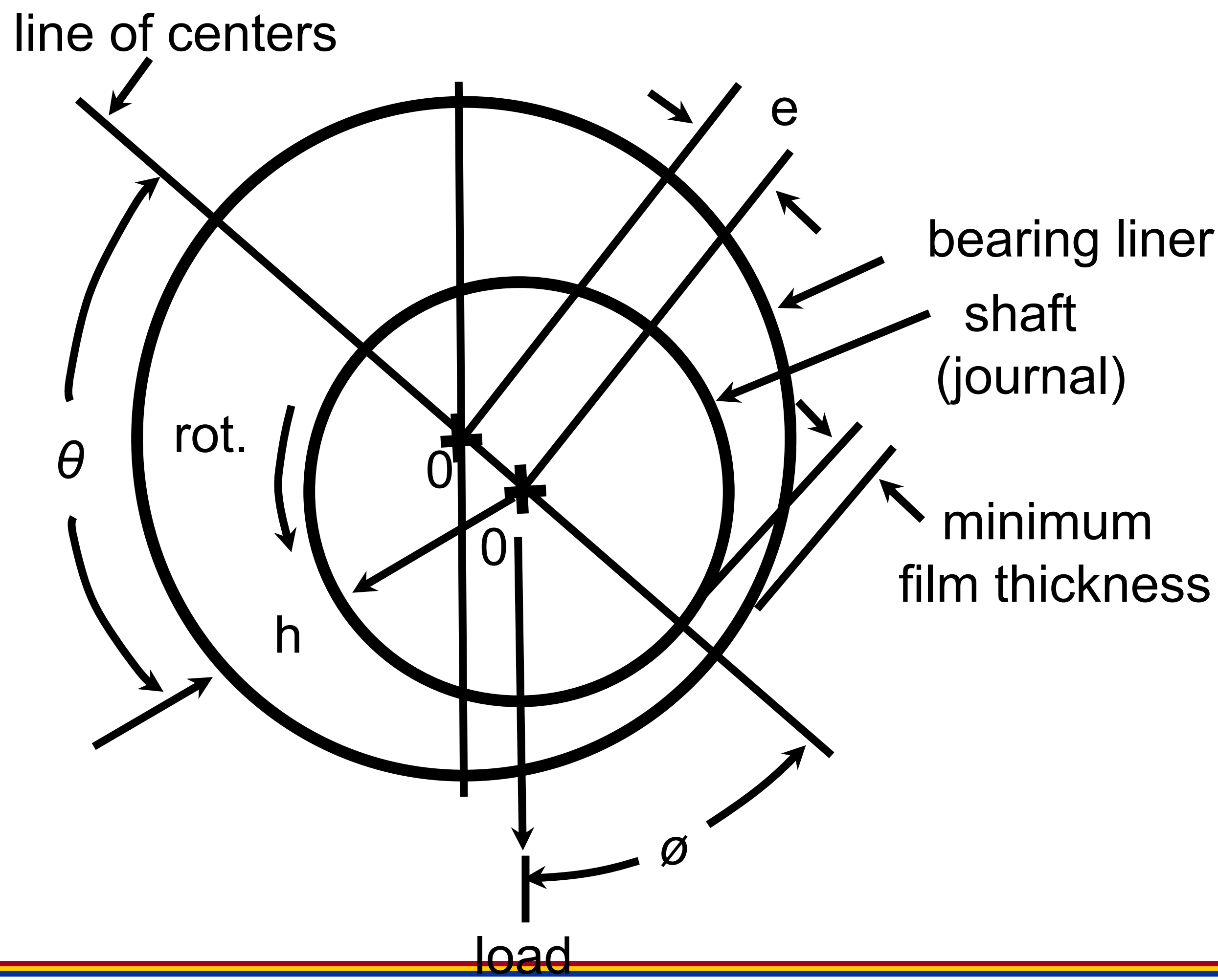
$f=\left(\frac{n_r N_s}{120}\right)\left[1+\left(\frac{d}{D}\right)\cos(\beta)\right]$	Frequency of contact between a fixed point on a stationary inner race with a rolling element
$f=\left(\frac{N_s}{60}\right)\left(\frac{D}{d}\right)\left[1-\left(\frac{d}{D}\right)^2\cos^2(\beta)\right]$	Contact frequency between a fixed point on a rolling element with the inner and outer races
$f=\left(\frac{N_s}{60}\right)\left[1-\frac{1}{2}\left(1-\left(\frac{d}{D}\right)\cos(\beta)\right)\right]$	Frequency of relative rotation between the cage and rotating inner race with stationary outer race
$f=\left(\frac{N_s}{60}\right)\left[1-\frac{1}{2}\left(1+\left(\frac{d}{D}\right)\cos(\beta)\right)\right]$	Frequency of relative rotation between the cage and rotating outer race with stationary inner race
$f=\left(\frac{n_r N_s}{60}\right)\left[1-\frac{1}{2}\left(1-\left(\frac{d}{D}\right)\cos(\beta)\right)\right]$	Frequency at which a rolling element contacts a fixed point on a rotating inner race with fixed outer race
$f=\left(\frac{n_r N_s}{60}\right)\left[1-\frac{1}{2}\left(1+\left(\frac{d}{D}\right)\cos(\beta)\right)\right]$	Frequency at which a rolling element contacts a fixed point on a rotating outer race with fixed inner race

Trouble Shooting – Journal Bearings

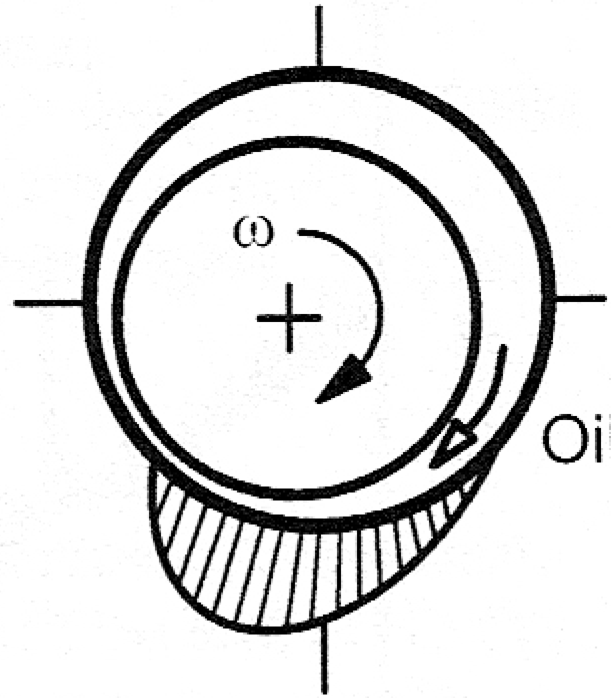


Trouble Shooting – Journal Bearings

- Fluid-film bearing geometry



Trouble Shooting – Journal Bearings



This design criteria is met through implementation of "sliding" surface contact most commonly by the production of a thin fluid film. The thin wedge-shaped film is developed between the journal and the bearing surface. Oil is entrained by the spinning journal into the film. Hydrodynamic pressure is created in the film, effectively "floating" the journal & carrying any applied loads.

Trouble Shooting – Journal Bearings

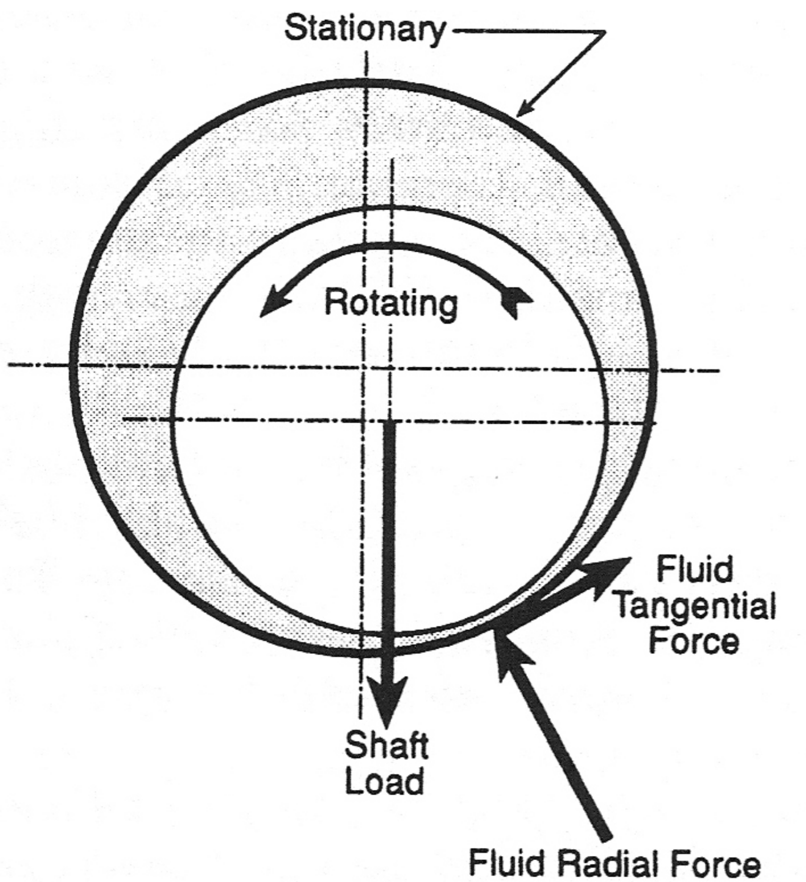


Fig. 9–20 Typical Radial Forces In A Fluid Film Bearing At The Support Point

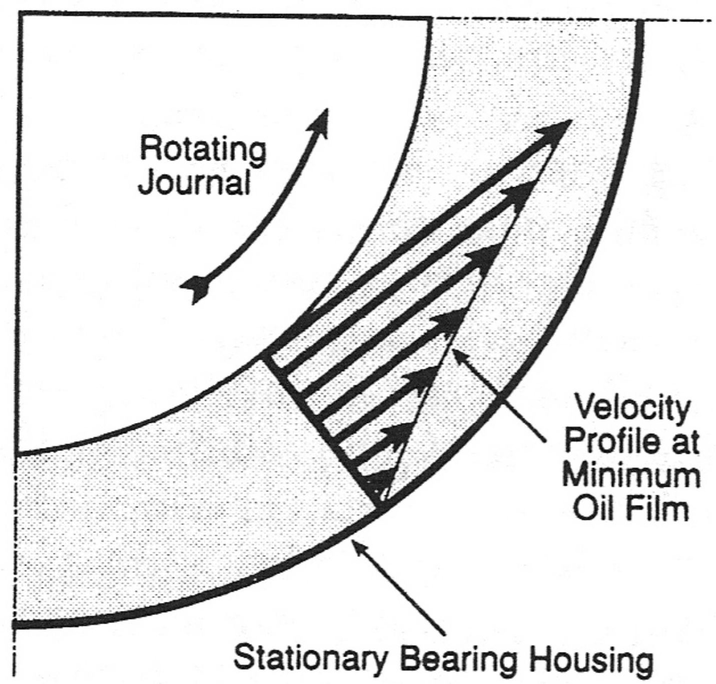
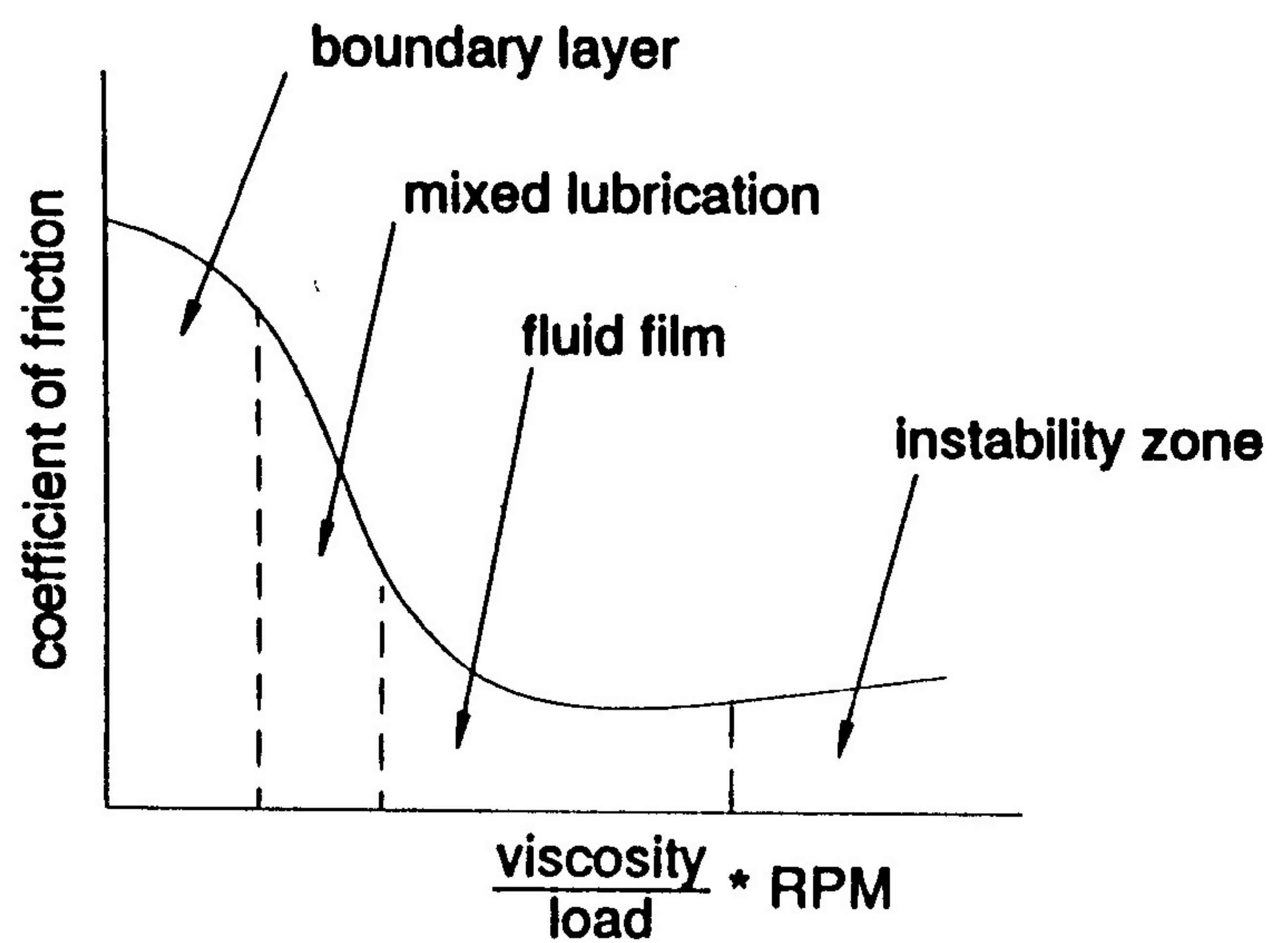


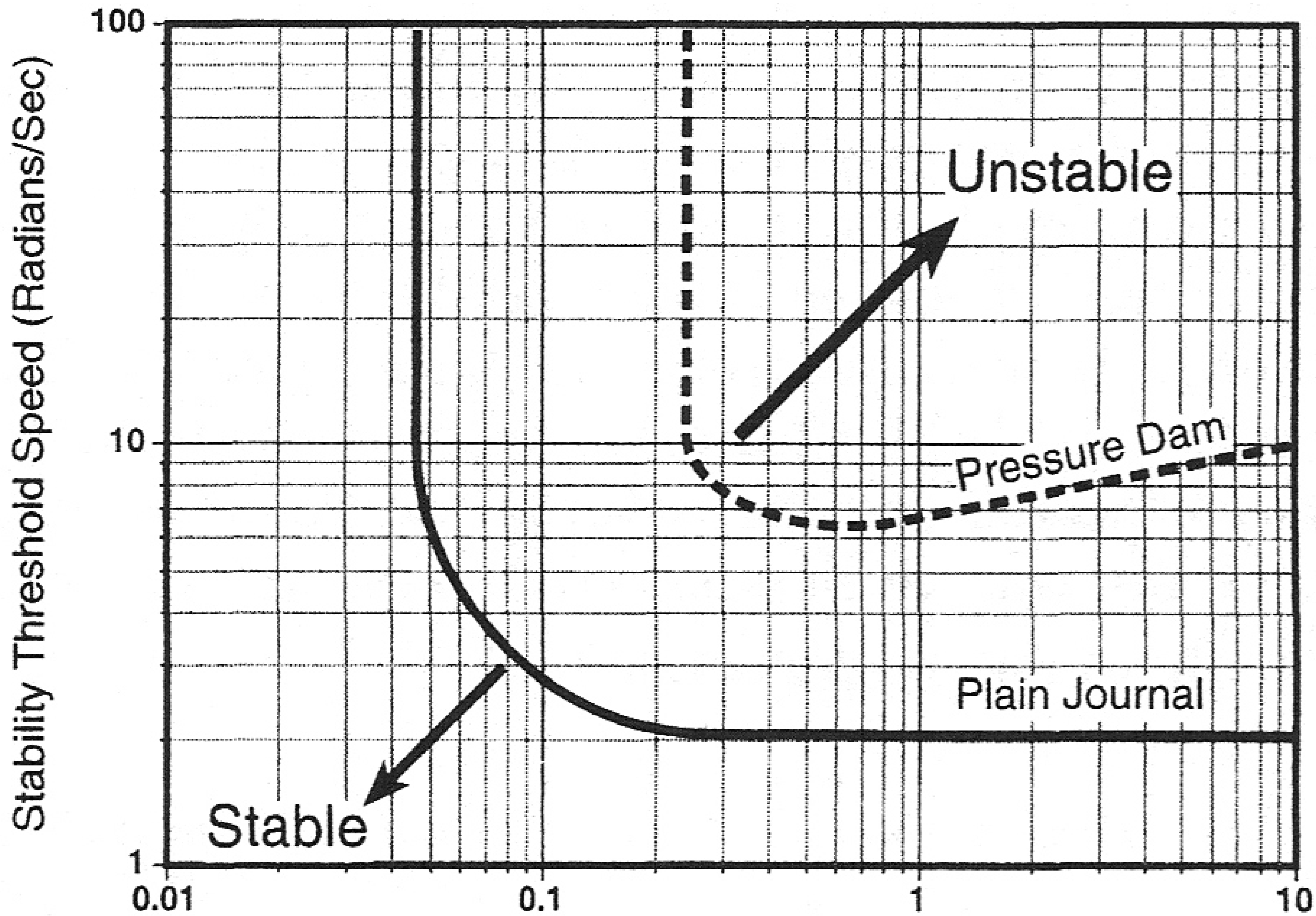
Fig. 9–21 Typical Bearing Oil Velocity Profile At The Point Of Minimum Oil Film

Trouble Shooting – Journal Bearings



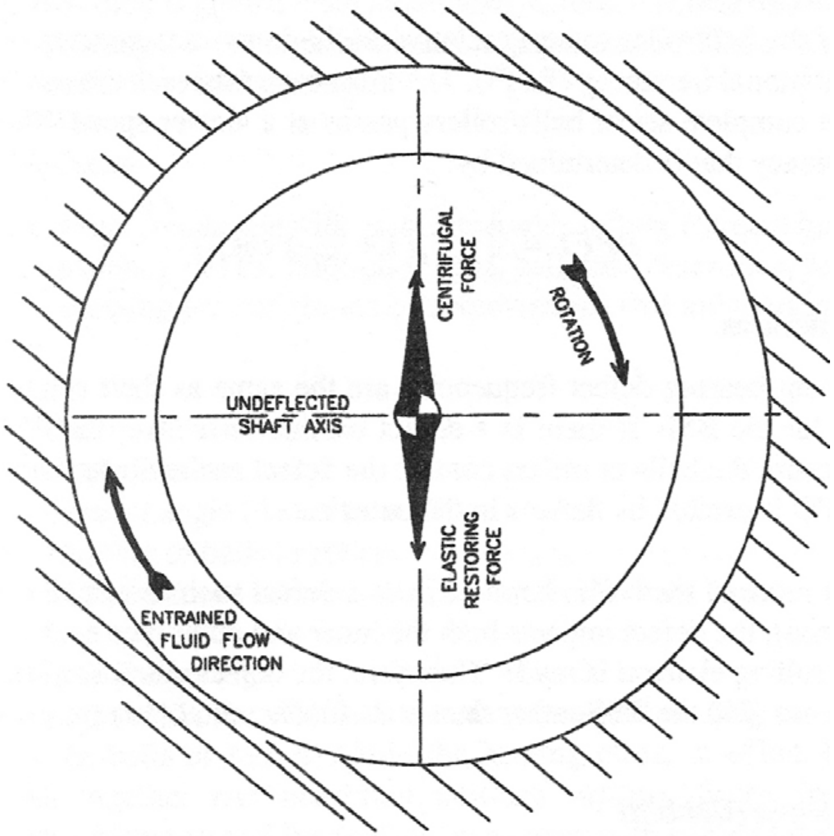
Friction versus RPM

Trouble Shooting – Journal Bearings

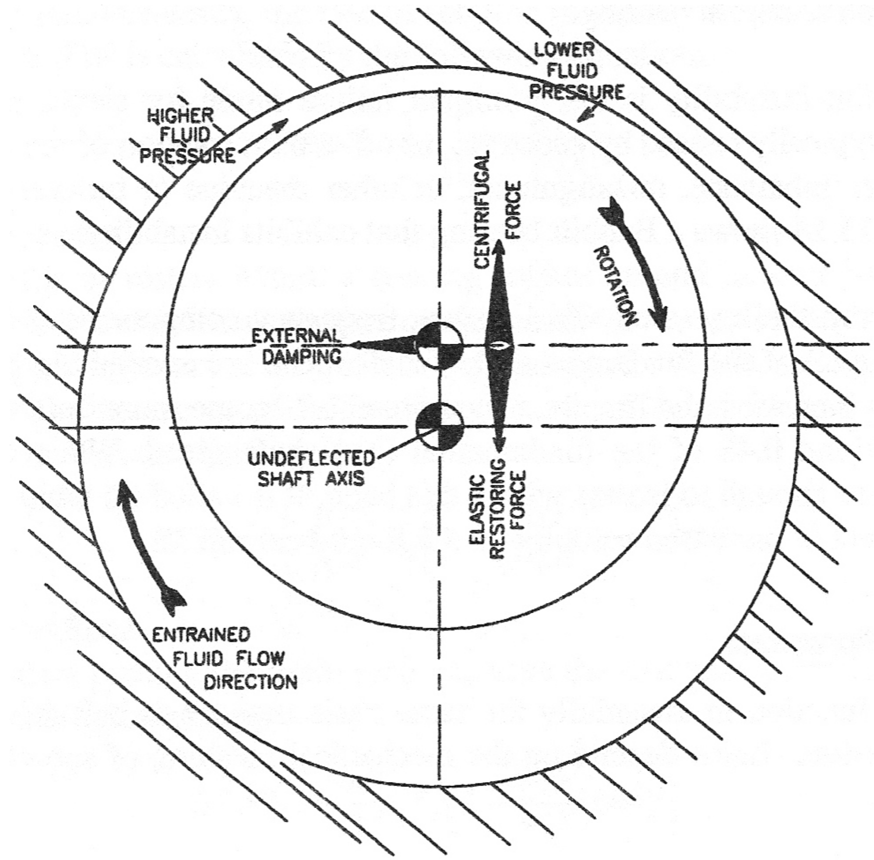


$$\text{Sommerfeld No.} = \frac{\text{Viscosity} \times \text{Speed} \times \text{Length} \times \text{Diameter}}{\text{Bearing Load}}\left[\frac{\text{Radius}}{\text{Clearance}}\right]^2$$

Trouble Shooting – Journal Bearings



Normal journal bearing – balanced forces



Journal bearing instability – unbalanced forces

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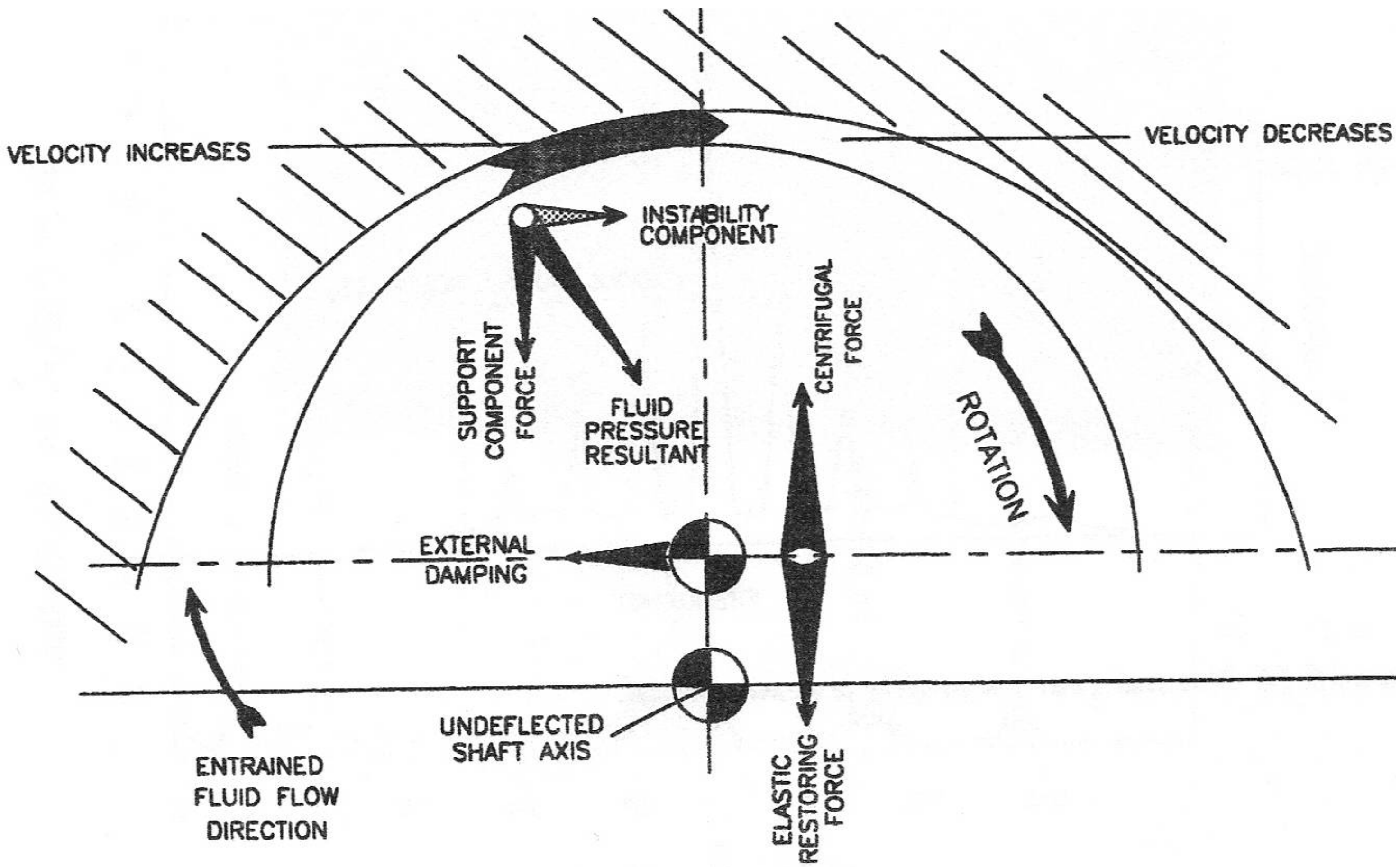
Trouble Shooting – Journal Bearings



Increased velocity may generate an unbalance force

Trouble Shooting – Journal Bearings

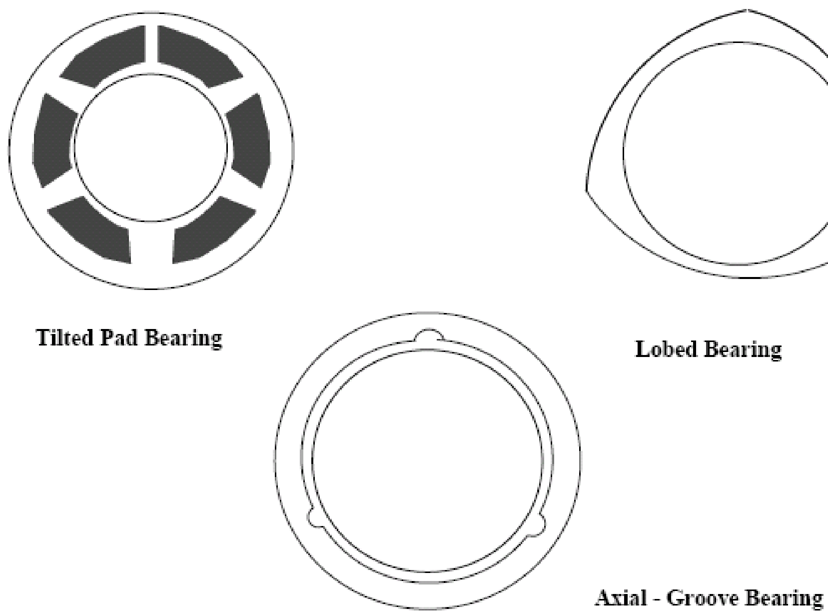
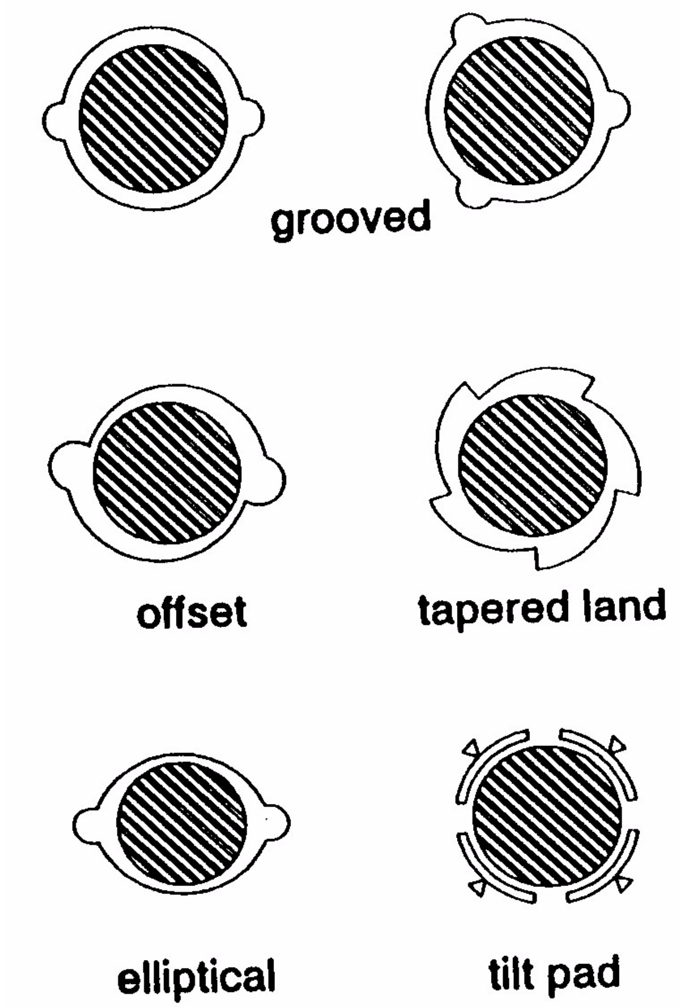
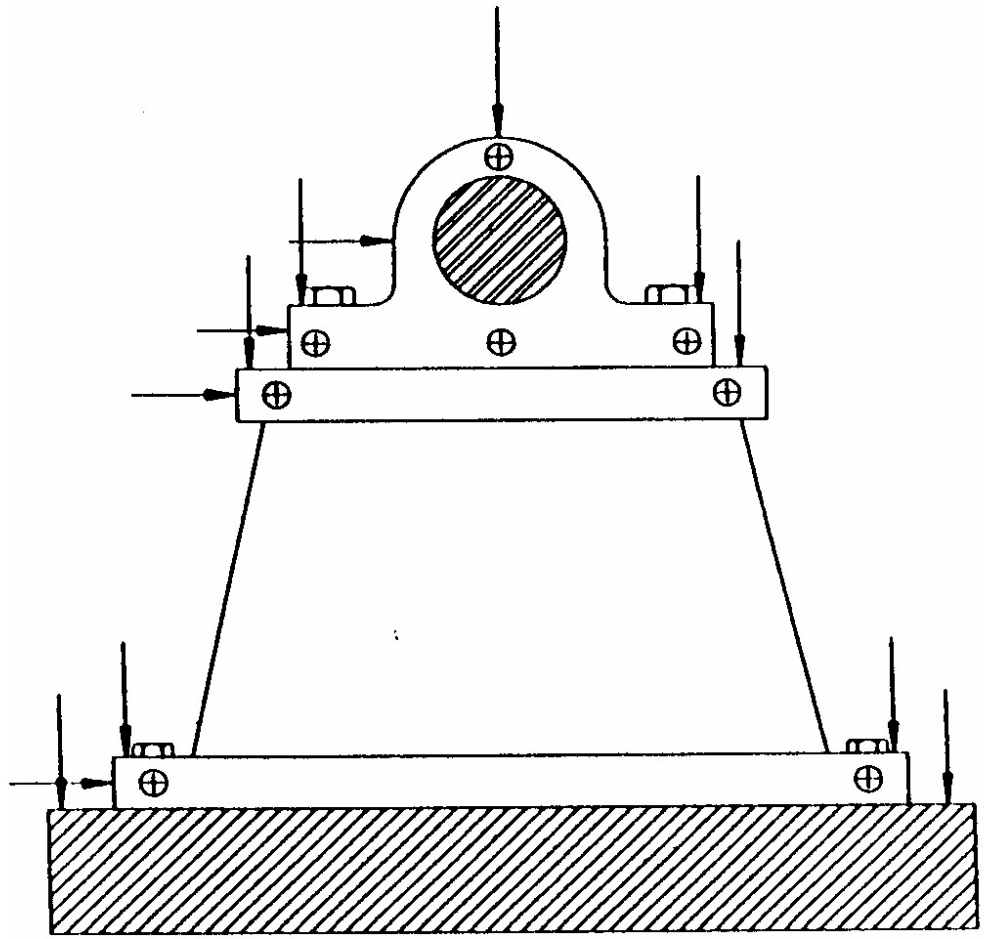


Figure 10 - Anti-whirl Bearings



Bearing designs that help prevent oil whirl

Trouble Shooting – Journal Bearings



Determining total bearing motion

Trouble Shooting – Gathering Information

Belts & chains

- centre to centre distance
- pulley pitch diameters
- # of belts
- belt length

Couplings

- type
- bending tolerance vs coupling length

Trouble Shooting – Gathering Information

Drives

- motors, engines, turbines

Gears

- type & layout
- # of teeth
- gear ratios
- drive gear speed

Fans

- # of blades

Pumps

- # of impellers

Trouble Shooting – Gathering Information

Anything else important

- nearby equipment : note the speed and nature of nearby machinery
- foundation structure, mounting orientation of machine etc.

Trouble Shooting – Gathering Information

Maintenance History

- what was the last thing done
- maintenance frequency
- look for root cause

example: several premature bearing failures

- poor installation techniques
- poor lubrication
- shaft bearing misalignment
- overloaded
- electrical discharge through bearings
- previous major failure, modifications

Trouble Shooting – Gathering Information

Operator's Input

- characteristics & severity of vibration
- onset of problem (sudden or gradual)
- continuous or intermittent (related to load, speed, temperature, time)
- previous similar problems (action taken)

General Vibration Analysis Techniques – Trouble Shooting

3. Possible Forcing Functions

Knowing these allows later focus of frequency analysis on characteristic defect frequencies.

Possibilities

Rotor Frequencies

- unbalance of rotor (stress relief, weight shift, material loss/gain)
- bow in rotor shaft (slow roll)
- bearing misalignment
- coupling misalignment

General Vibration Analysis Techniques – Trouble Shooting

Rolling element bearings

- low start up resistance, high running friction
- characteristic defect frequencies quite distinctive

General Vibration Analysis Techniques – Trouble Shooting

Sleeve (Journal) bearings

- shaft rides on layer of lubricating oil in bearing journal
- may be pressure fed
- optimum efficiency dependant on shaft speed, lubricant viscosity & load.
- oil whip, oil whirl

General Vibration Analysis Techniques – Trouble Shooting

Oil Whirl

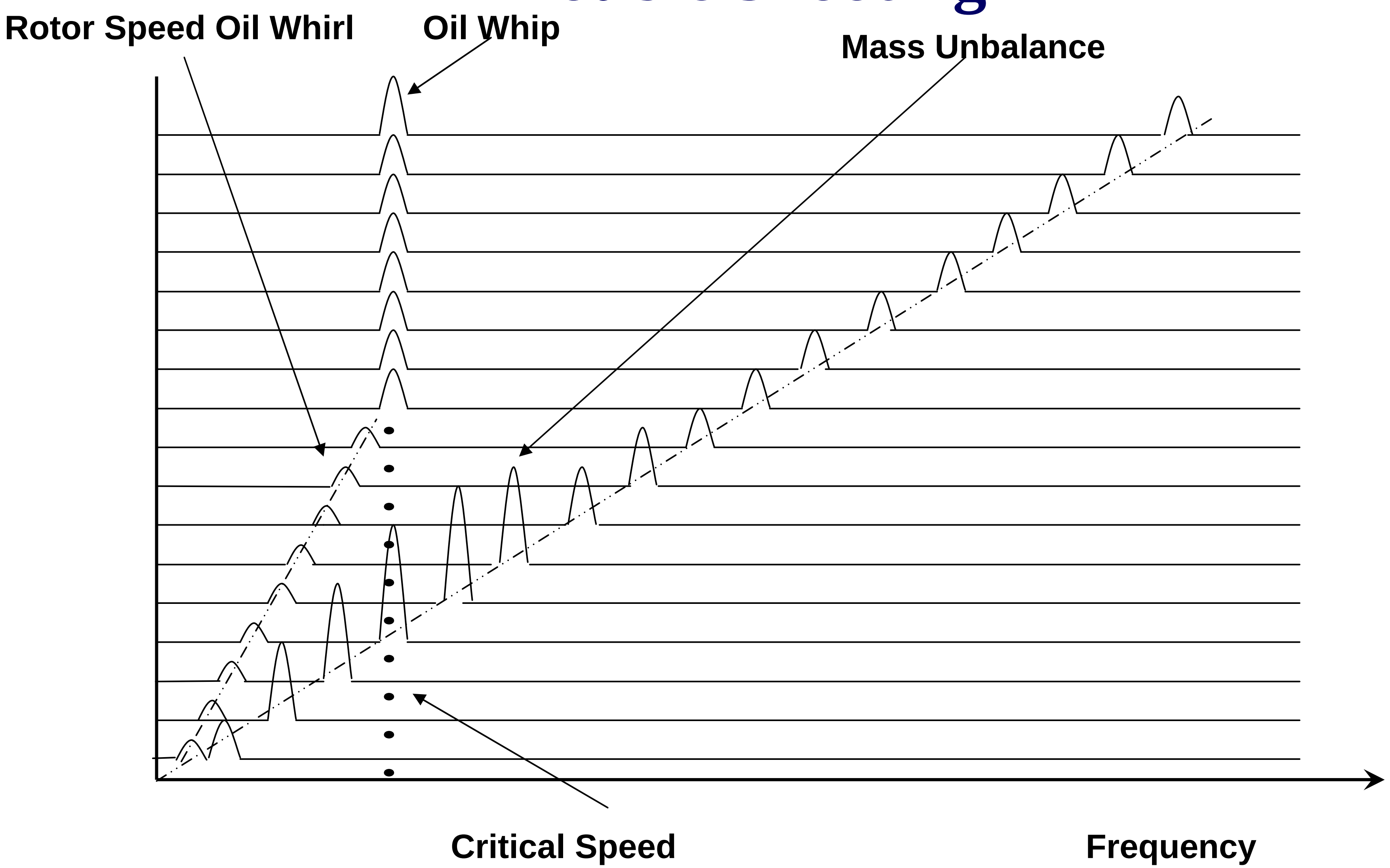
- bearing can not exert sufficient force on shaft to maintain a stable operating position
- corrected by using pressure dams or tilt pad designs
- shaft rides on an oil pressure gradient
- rotates within bearing clearance at just less than one half shaft rotational speed (~0.42X)

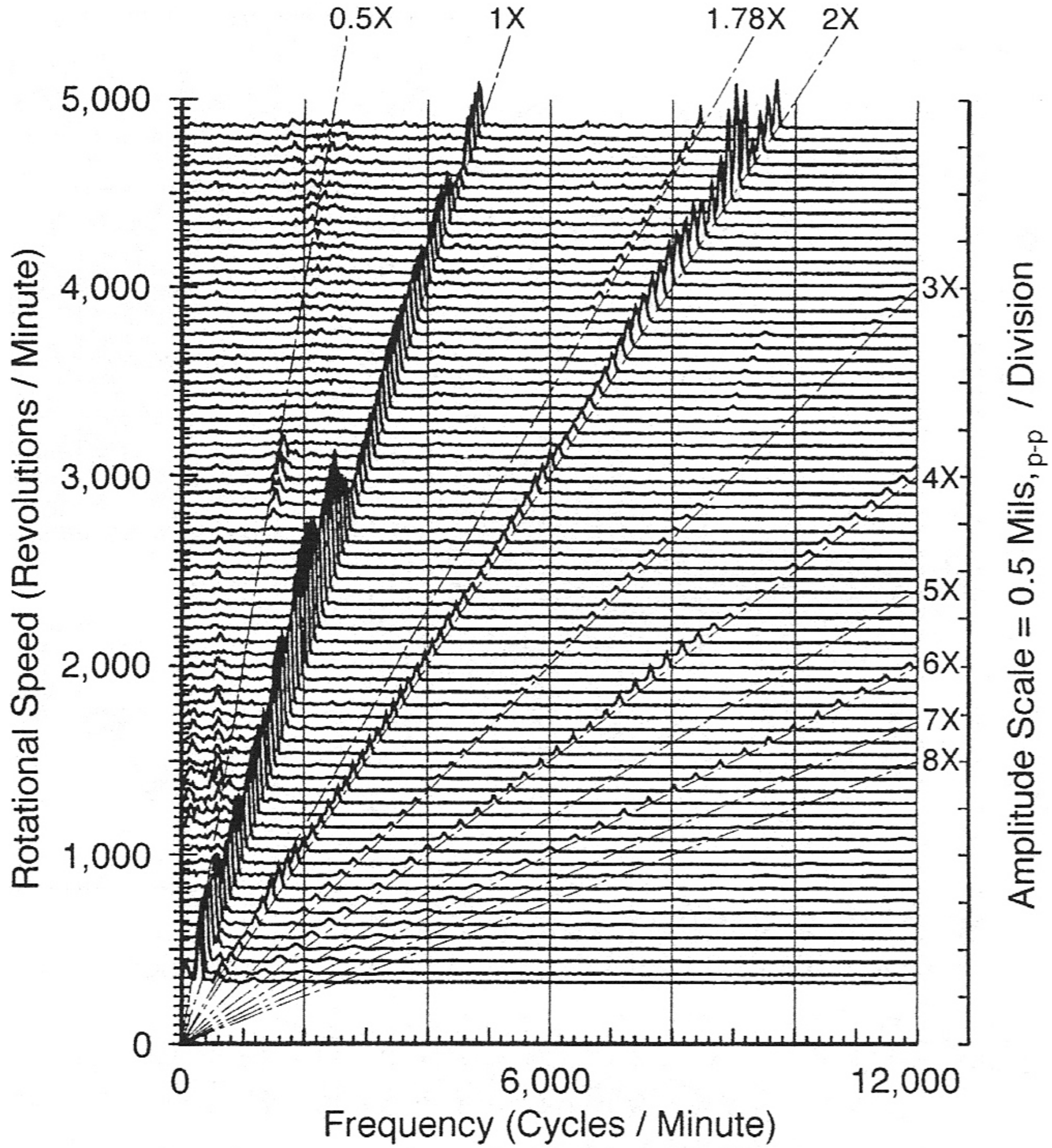
General Vibration Analysis Techniques – Trouble Shooting

Oil Whip

- occurs when sub synchronous instability (oil whirl) excites a critical speed (resonance)
- excitation remains at a constant frequency regardless of speed changes

General Vibration Analysis Techniques – Trouble Shooting





0.5X
1X
1.78X
2X
3X
4X
5X
6X
7X
8X
5,000
4,000
3,000
2,000
1,000
0
Rotational Speed (Revolutions / Minute)
0
6,000
12,000
Frequency (Cycles / Minute)
Amplitude Scale = 0.5 Mils, p-p / Division

General Vibration Analysis Techniques – Trouble Shooting

Rubs

- seal rubs
- loose bearing housings

Belt frequencies

- primary belt frequency - # of complete circuits per minute.
- belt length

General Vibration Analysis Techniques – Trouble Shooting

Gear Mesh Frequencies

- rotational speed × # of teeth
- offset parallel shafts
- planetary gears - speed changes on inline shafts

General Vibration Analysis Techniques – Trouble Shooting

Blade Pass Freq. (Fans, Pumps)

- # of blades $\times$ shaft rotational speed
- vibration created as blades pass outlet port
- high vibration levels if pump is operating far from optimum efficiency
- can induce duct (pipe) resonances

General Vibration Analysis Techniques – Trouble Shooting

Resonant Frequencies

- excited by forcing functions that are close in frequency to structural resonance (natural frequencies)

General Vibration Analysis Techniques – Trouble Shooting

4. Where to take Data and Equipment to Use

- transducers dependent on situation
- direction, (axial, vertical, radial)
- depends on problem & equipment being monitored
- overall survey followed by more detailed investigation

Identify Machine Running Speed

Running speed is critical for

- Baseline Comparison
- Identification of frequency dependant features

Identify Machine Running Speed

Determining Running Speed from Direct Measurement

- Observe speed from instrumentation on machine
- Take measurement using Tachometer or Strobe Light
- Remember that if possible speed should be steady during the data collection period (otherwise order tracking may be required)

Identify Machine Running Speed

Determining Running Speed from FFT spectrum

- In general, the first peak in an FFT will the first order followed by peaks at harmonic intervals
- If machine is driven by an induction motor at synchronous speed, look for vibration peaks at 1800 or 3600 rpm.

General Vibration Analysis Techniques – Trouble Shooting

5. Take Vibration Data

Time domain data

- check set up, overall amplitude transients, (spikes, discontinuities), stationary signal (changes with time, load), line frequency

General Vibration Analysis Techniques – Trouble Shooting

Frequency domain signal (signature)

- periodic components of time waveform
- relative amplitudes of frequency components
- harmonic relationships
- precise location of frequency components

General Vibration Analysis Techniques – Trouble Shooting

Within Frequency Signature:

- Synchronous Components
  - N $\times$ Speed of rotation, (N = integer)
  - N = 1 : fundamental frequency

General Vibration Analysis Techniques – Trouble Shooting

Where N = 1 to 8 (low multiples)

- imbalance
- belt pitch line vibration
- shaft/bearing misalignment
- bent shaft
- looseness
- blade pass frequency (pumps, fans)

General Vibration Analysis Techniques – Trouble Shooting

Where N > 8 (high multiples)

- gear mesh freq.
- blade pass (compressors, turbines)
- motor slot freq
- cavitation

General Vibration Analysis Techniques – Trouble Shooting

Sub synchronous (less than 1 $\times$ shaft speed)

- primary belt freq.
- oil whip, oil whirl
- rubs
- loose rolling element bearing in housing

Non Synchronous

- other components in machine
- other machines close by
- electrically caused vibrations

General Vibration Analysis Techniques – Trouble Shooting

6. Analyse Vibration Data

- estimate forcing functions present

7. Make Recommendations

- depends on many factors

Next Time…

- Machinery Vibration Testing and Trouble Shooting
- Fault Diagnostics Based on Forcing Functions
- Fault Diagnostics Based on Specific Machine Components
- Fault Diagnostics Based on Specific Machine Types
- Automatic Diagnostics Techniques
- Non-Vibration Based Machine Condition Monitoring and Fault Diagnosis Methods