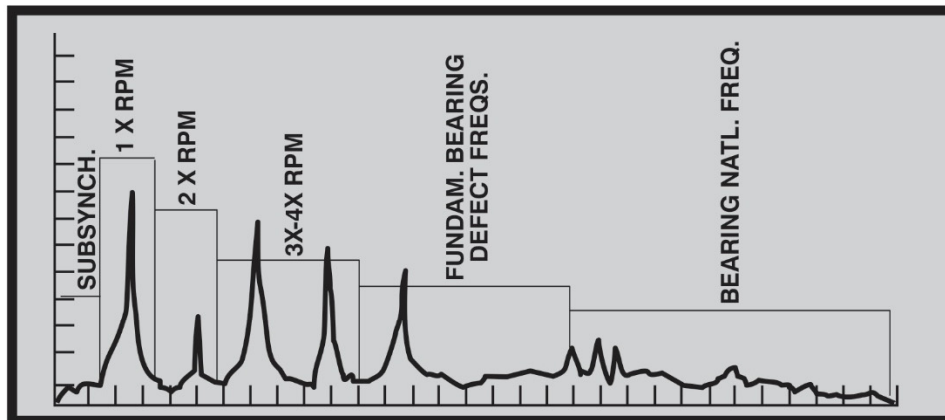




ISO CATEGORY II (ANALYSIS I)



Mr. James E. Berry, P.E.
of Technical Associates of Charlotte

Technical Associates Of Charlotte

1230 West Morehead Street, Suite 400 Charlotte, N.C. 28208, U.S.A. TELEPHONE: (704) 333-9011 FAX: (704) 333-1728
www.technicalassociates.net

SPECIALISTS IN PREDICTIVE MAINTENANCE, MACHINERY DIAGNOSTICS, AND VIBRATION REDUCTION

TABLE OF CONTENTS AND SEMINAR AGENDA

PREDICTIVE MAINTENANCE AND VIBRATION SIGNATURE ANALYSIS I

<u>SECTION</u>	<u>SUBJECT</u>	<u>PAGE</u>
CHAPTER 1	PRINCIPLES OF VIBRATION	1-1
1.1	Introduction to Vibration	1-1
1.2	Period and Frequency	1-3
1.3	Amplitude	1-4
1.3.1	Displacement	1-4
1.3.2	Velocity	1-5
1.3.3	Acceleration	1-5
1.3.4	Amplitude Unit Conversions	1-6
1.3.5	RMS, Peak, and Peak-to-Peak Vibration Amplitude	1-8
1.3.6	When to Use Displacement, Velocity, or Acceleration	1-9
1.3.7	How Much is Too Much Vibration?	1-15
1.4	Phase	1-17
1.5	Displaying Vibration Data	1-19
1.5.1	The Time Domain	1-19
1.5.2	The Frequency Domain	1-19
1.6	Understanding a Vibration Spectrum	1-21
1.6.1	Describing Spectral Peaks	1-21
1.6.2	Frequency Resolution and Accuracy	1-24
1.6.3	Overall Vibration (Analog vs. Digital)	1-28
CHAPTER 2	FUNDAMENTALS OF DIGITAL DATA ACQUISITION AS IT RELATES TO VIBRATION DATA COLLECTION	2-1
2.1	Introduction	2-1
2.2	Dynamic Range & Full Scale Value	2-3
2.3	Creating a Digital Time Waveform	2-5
2.3.1	Aliasing	2-6
2.3.2	Relating the Number of Samples in the Time Waveform to the Number of Lines in the Spectrum	2-9
2.4	Windowing	2-10
2.4.1	Hanning Window	2-12
2.4.2	Uniform Window (Rectangular Window)	2-14
2.4.3	Flat Top Window	2-15
2.4.4	Window Summary	2-16
2.5	Frequency Domain Averaging	2-18
2.5.1	Linear Averaging	2-18
2.5.2	RMS Averaging	2-19

<u>SECTION</u>	<u>SUBJECT</u>	<u>PAGE</u>
CHAPTER 3	VIBRATION INSTRUMENTS	3-1
3.1	Instrument Comparisons	3-1
3.2	General Capabilities of Each Vibration Instrument Type	3-5
3.2.1	Overall Level Vibration Meters	3-5
3.2.2	FFT Data Collectors	3-6
3.2.3	Spectrum Analyzers	3-7
CHAPTER 4	VIBRATION SENSORS OVERVIEW AND PROPER SELECTION	4-1
4.1	Accelerometers	4-2
4.1.1	Accelerometer Performance Characteristics	4-3
4.2	Velocity Sensors	4-10
4.2.1	Seismic Velocity Sensors	4-11
4.2.2	Piezoelectric Velocity Sensors (“Integrated Accelerometers”)	4-12
4.3	Non-Contact Eddy Current Displacement Probes	4-13
4.4	Selection Criteria for Sensors	4-18
4.5	Sensor Mounting	4-20
CHAPTER 5	INTRODUCTION TO HIGH FREQUENCY ENVELOPING	5-1
5.1	What is High Frequency Enveloping?	5-1
5.2	Collecting High Frequency Enveloping Measurements	5-2
5.3	The Need for Multiple Measurement Types	5-4
5.4	Importance of HFE Time Waveform	5-4
5.5	Real World High Frequency Enveloping Example	5-5
CHAPTER 6	DIAGNOSING MACHINE PROBLEMS USING VIBRATION SIGNATURE ANALYSIS	6-1
6.1	Mass Unbalance	6-12
6.1.1	Characteristics of Unbalance	6-12
6.1.2	Force (Static) Unbalance	6-14
6.1.3	Couple Unbalance	6-15
6.1.4	Dynamic Unbalance	6-16
6.1.5	Overhung Rotor Unbalance:	6-17
6.1.6	Summary of Unbalance Phase Behavior	6-19
6.2	Eccentric Rotors	6-21
6.3	Bent Shaft	6-25
6.4	Misalignment	6-27
6.4.1	General Response Characteristics	6-27
6.4.2	Angular Misalignment:	6-29
6.4.3	Parallel Misalignment (Also known as Offset Misalignment):	6-31

<u>SECTION</u>	<u>SUBJECT</u>	<u>PAGE</u>
6.4.4	Misaligned Bearing Cocked on the Shaft:	6-32
6.5	Natural Frequencies and Resonance	6-33
6.5.1	Natural Frequency	6-33
6.5.2	Resonance	6-36
6.6	Mechanical Looseness	6-38
6.6.1	Mechanical Looseness Type A – Structural Frame / Base Looseness	6-38
6.6.2	Mechanical Looseness Type B– Looseness Due to Rocking Motion or Cracked Structure / Bearing Pedestal	6-41
6.6.3	Mechanical Looseness Type C – Loose Bearing or Improper Fit Between Rotating Components	6-41
6.7	Introduction to Rolling Element Bearings	6-45
6.7.1	Conditions that Produce Bearing Fault Frequencies Without Actual Bearing Damage	6-47
6.8	Load Effects on Bearing Service Life	6-51
6.9	Rolling Element Bearing Spectral Fault Analysis	6-51
6.9.1	Characteristics of Bearing Fault Frequencies	6-57
6.9.2	Challenges in Detecting and Trending Rolling Element Bearing Faults	6-61
6.10	Bearing Fault Analysis	6-63
6.10.1	Electrically Induced Bearing Fluting	6-64
6.11	Typical Spectra For Tracking Failure of Rolling Element Bearings	6-66
6.11.1	Scenario A – The Classic Bearing Failure Scenario	6-67
6.12	Introduction to Gearbox Problem Detection	6-74
6.12.1	Normal Gearbox Spectrum	6-77
6.12.2	Gear Tooth Wear	6-78
6.13	Electrical Problems in AC Induction Motors	6-80
6.13.1	Stator Fault Spectral Patterns	6-81
6.13.2	Eccentric Rotors	6-84
6.13.3	Broken or Cracked Rotor Bars	6-89
6.13.4	Motor Problems Associated With Rotor Bar Passing Frequency	6-90
6.14	Belt Drive Problems	6-92
6.14.1	Worn, Loose, or Mismatched Belts	6-93
6.14.2	Pulley Eccentricity	6-95
6.14.3	Pulley Misalignment	6-96
6.15	Exercise Answer Sheets	6-98
CHAPTER 7	VIBRATION DATABASE DEVELOPMENT TOOL USING THE PROVEN METHOD (5TH EDITION)	7-1
7.0	Introduction to Specifying Measurement Parameters	7-1
7.1	Review of Problems Detectable By Vibration Analysis	7-2
7.2	Overview of Tables II, IIA and III	7-9

<u>SECTION</u>	<u>SUBJECT</u>	<u>PAGE</u>
7.21	Table II "Overall Vibration Alarms and Machine Condition Rating Chart"	7-9
7.22	Table IIA "Recommended Measurement Setup Parameters for Various Machine Types"	7-12
7.23	Table III "Recommended Spectral Alarm Bands for Various Machine Types"	7-16
7.3	Introduction to Specifying Spectral Alarm Bands & Frequency Ranges	7-24
7.31	Two Types of Spectral Alarm Bands	7-25
7.32	Which Vibration Parameter to Use in Spectral Alarm Bands - Displacement, Velocity or Acceleration?	7-26
7.4	Description of Each Case Specification in Table IIA and III	7-28
	Case A - General Rolling Element Bearing Machine Without Rotating Vanes: (Motors, Gearbox Lower Frequency Measurements, etc	7-28
	Case B - General Sleeve Bearing Machine Without Rotating Vanes: (Sleeve Bearing Motors, Gearbox Lower Frequency Measurements, etc.....	7-31
	Case C - Gearbox High Frequency Points with Known Number of Teeth:.....	7-31
	Case D - Gearbox High Frequency Points with Unknown Number of Teeth:.....	7-32
	Case E - AC Induction Motor Electrical Rotor Bar Pass Frequency Point: (Single Point Usually Taken on Outboard Motor Bearing Horizontal Direction)	7-33
	Case F - AC Induction Motor Electrical Measurement Point: (Single Point Usually Taken on Inboard Motor Bearing Horizontal Direction)	7-34
	Case G - Centrifugal Compressors, Blowers and Pumps	7-36
	Type 1 - Driven Centrifugal Component with Known Number of Vanes (or Blades) and Rolling Element Bearings:.....	7-37
	Type 2A - Centrifugal Machines with Unknown Number of Vanes and Rolling Element Bearings	7-37
	Type 2B - Centrifugal Blowers & Compressors With Unknown Number of Blades and Rolling Element Bearings	7-37
	Type 3 - Driven Centrifugal Component with Known Number of Vanes (or Blades) and Sleeve Bearings:.....	7-38
	Case H - DC Motors: Full-Wave and Half-Wave SCR Controlled Rectifier.....	7-38
	Type 1 - Full-Wave Rectified Motors (Measure on Commutator-End Bearing in the Horizontal Direction):.....	7-39
	Type 2 - Half-Wave Rectified Motors (Measure on Commutator-End Bearing in the Horizontal Direction):.....	7-39
	Case I - Electrical Induced Fluting on DC Motors and AC Induction Motors Controlled by a VFD (VFD = Variable Frequency Drive).....	7-40
	Type 1 - Full-Wave or Half-Wave Rectified DC Motors:	7-40
	Type 2 - AC Induction Motors Controlled by a VFD (Variable Frequency Drive):.....	7-40
	Case J - Machine Tool Spindles and Multi-Gear Heads (Ref. 40)	7-41
7.41	Vibration Alarms for Machine Tool Spindles:	7-44
7.5	Examples - Specification of Spectral Alarm Bands For Sample Machines:	7-45

<u>SECTION</u>	<u>SUBJECT</u>	<u>PAGE</u>
7.6	Periodic Reevaluation of Spectral Alarm Band Setups on Each Family of Machines	7-49
7.61	Procedure For Evaluating the Effectiveness of Specified Overall Alarm Levels and Spectral Band Alarms:.....	7-50
7.62	Example - "Statistical Analysis of Overall Vibration Velocity in 4 Client Power Plants Using the Procedure Recommended Above":.....	7-51
7.7	Definitions.....	7-54
7.8	References	7-56

CHAPTER 8 GUIDELINES FOR VIBRATION ACCEPTANCE TESTING OF NEW AND REBUILT MACHINES8-1

8.1	Collecting Vibration Data for Acceptance Testing.....	8-1
8.2	Analyzing Vibration Acceptance Testing Data	8-9
8.3	Vibration Acceptance Testing Documentation	8-17
	References.....	1

CHAPTER 9 OPERATING BASICS OF COMMON MACHINES AND RECOMMENDED MEASUREMENT LOCATIONS9-1

9.1	Introduction.....	9-1
9.2	Fans	9-1
9.2.1	Operating Basics - Axial Flow Fans	9-1
9.2.2	Operating Basics - Centrifugal Fans	9-2
9.3	Pumps	9-6
9.3.1	Operating Basics - Rotary Lobe Pump.....	9-6
9.3.2	Operating Basics - Centrifugal Pump.....	9-7
9.4	Compressors	9-9
9.4.1	Operating Basics - Rotary Screw Compressor.....	9-9
9.4.2	Operating Basics - Reciprocating Compressor	9-11
9.4.3	Operating Basics - Centrifugal Compressor.....	9-14
9.5	Measurement Locations	9-15
9.5.1	Measurement Locations - Inline Axial Flow Fans.....	9-17
9.5.2	Measurement Locations - Centrifugal Fans	9-17
9.5.3	Measurement Locations - Centrifugal Pumps	9-20
9.5.4	Measurement Locations - Rotary Lobe Pumps	9-20
9.5.5	Measurement Locations - Rotary Screw Compressors (Single Stage).....	9-21
9.5.6	Measurement Locations - Reciprocating Compressors	9-22
9.5.7	Measurement Locations - Centrifugal Compressors	9-22

CHAPTER 10 GLOSSARY OF COMMON VIBRATION TERMINOLOGY (COURTESY OF HEWLETT PACKARD, NOW CALLED AGILENT).....10-1