WORLD-CLASS OUTSTANDING INTERNATIONAL

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FIELD INVESTIGATION OF GEARBOX VIBRATION DUE TO CRACKED MOTOR ROTOR BARS

BY ROSS PINNER
AND TROY FEESE

42nd Turbomachinery
29th Pump SYMPOSIA

LUFKIN

EDI
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TEXAS A&M ENGINEERING
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Bio – Ross Pinner

Mr. Pinner the Chief Engineer for Low Speed and Marine Gearing at Lufkin Industries, Inc. located in Lufkin, Texas. He has 29 years of experience in design the design of gear reducers used in various industrial application in industries such as: plastics, rubber, steel, mining, oilfield, flood pumps, dredging and marine propulsions.

In his current position he is the principle engineer responsible for the design and engineering support of Lufkin's Low Speed and Marine Gear product lines. He received a BSME from Texas A&M University in 1984. He is a licensed Profession Engineer in the State of Texas.

Bio – Troy Feese

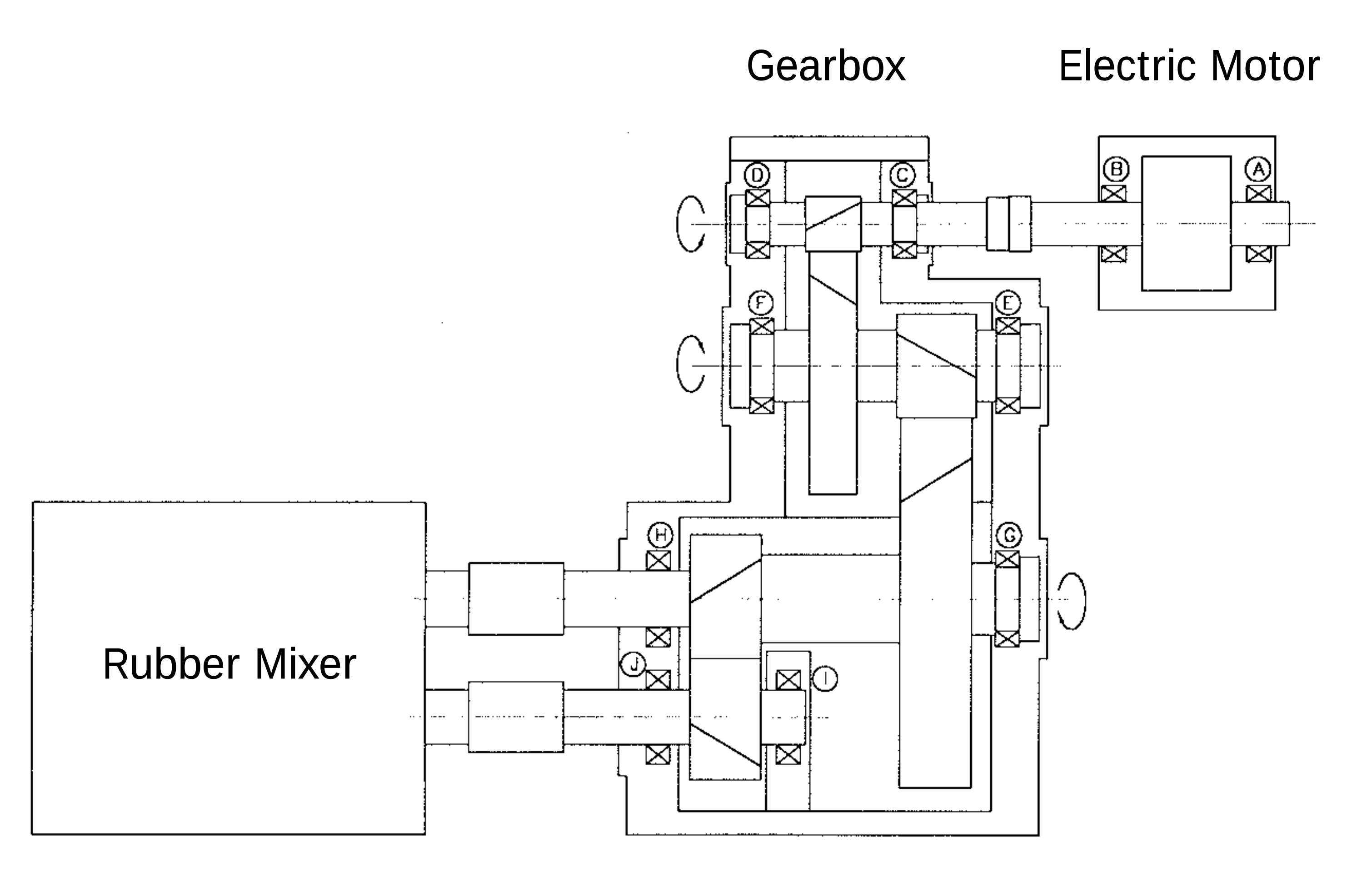
Mr. Feese is a Senior Staff Engineer at Engineering Dynamics Incorporated (EDI) in San Antonio, Texas. He has over 22 years of experience performing torsional vibration, lateral critical speed, and stability analyses as well as evaluating structures using finite element methods.

He conducts field studies of rotating and reciprocating equipment. He is a lecturer at the annual EDI seminar and has written technical papers on torsional vibration, lateral critical speeds, and balancing. He received a BSME from The University of Texas at Austin in 1990 and has a MSME from UTSA. He is a member of ASME, Vibration Institute, and is a licensed Professional Engineer in Texas.

Problem Statement

Approximately one year after installing a new gearbox, vibration levels were gradually increasing. The tire plant requested that the gearbox manufacturer investigate under warranty. A field study was performed by an independent engineering company to measure the vibration of the motor, gearbox, and rubber mixer unit at the plant.

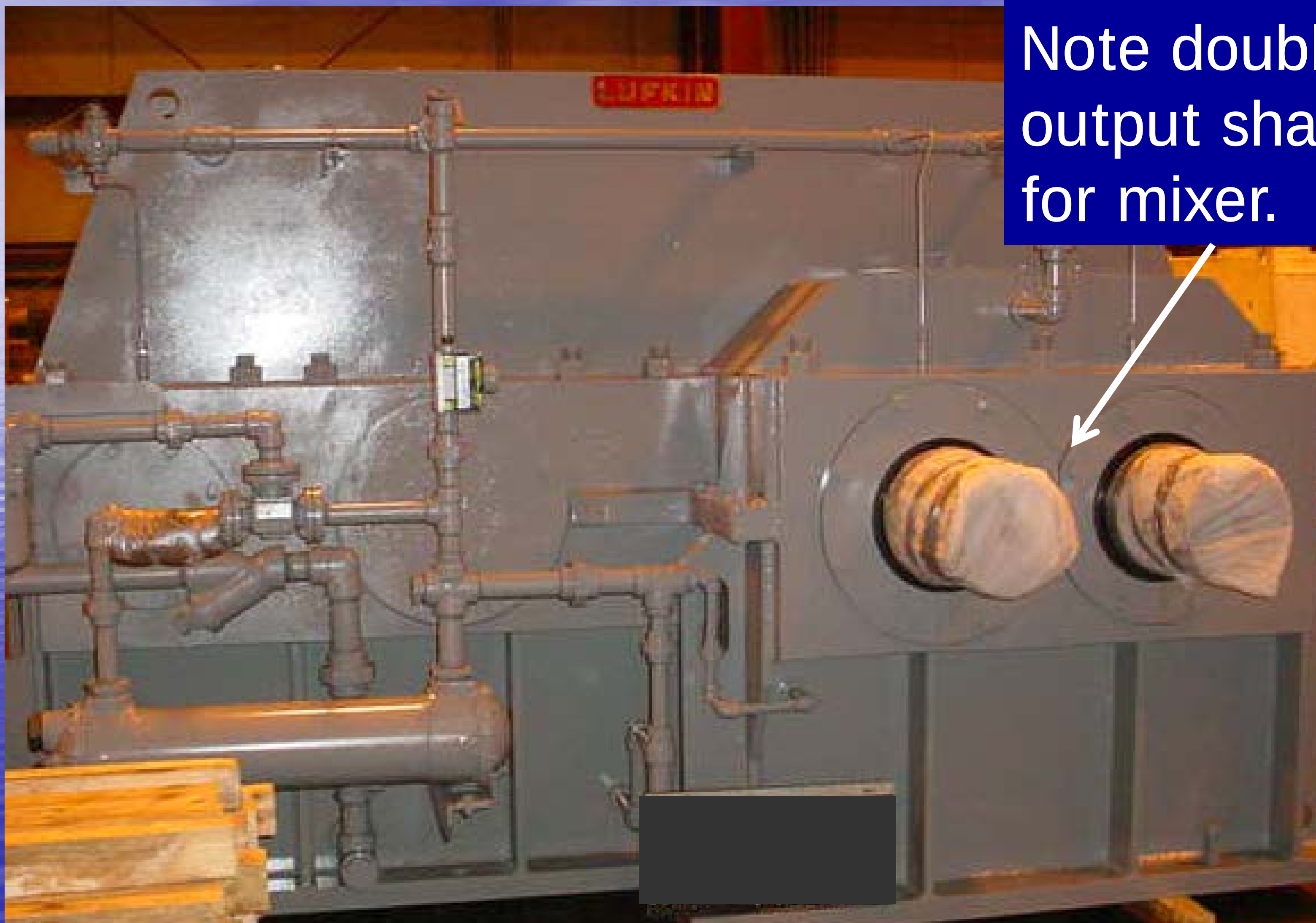
Motor – Gearbox – Mixer Unit For Tire Production



Equipment Description

- Original motor manufactured in 1969
- Two-speed induction motor rated for 1000 HP @ 595 RPM / 2000 HP @ 1190 RPM
- New Speed Reducer, Ratio = 19.94:1
- New Mixer, Two “Four-Wing” Rotors
- HS Coupling: Rubber Blocks in Compression
- LS Couplings: Gear Style

New Gearbox at Shop



Note double output shafts for mixer.

Background

- Various rubber grades for tire production.
- Mixing occurs in 2 min. batches, motor cycles loaded and unloaded conditions.
- 1969 Originally Commissioned
- 1972 Motor Bearings and Rotor Bar Broke
- 1976 – 1986 Broken Gear Teeth
- 1986 Mixer Rotors Replaced
- 1986 – 1994 Motor Bearing Failures and High Vibration at Int. Gear Mesh Frequency

Background Continued

- 1994 Motor coupling was gear style then replaced with new coupling using rubber blocks in compression
- 1996 New gearbox and new mixer
- 1996 Vibration levels were acceptable.
- 1997 Vibration levels gradually increased.
  - Soft insulation material under motor bearings replaced with ceramic insulation.
  - Motor could not be operated at 1200 RPM due to high vibration at motor bearings.

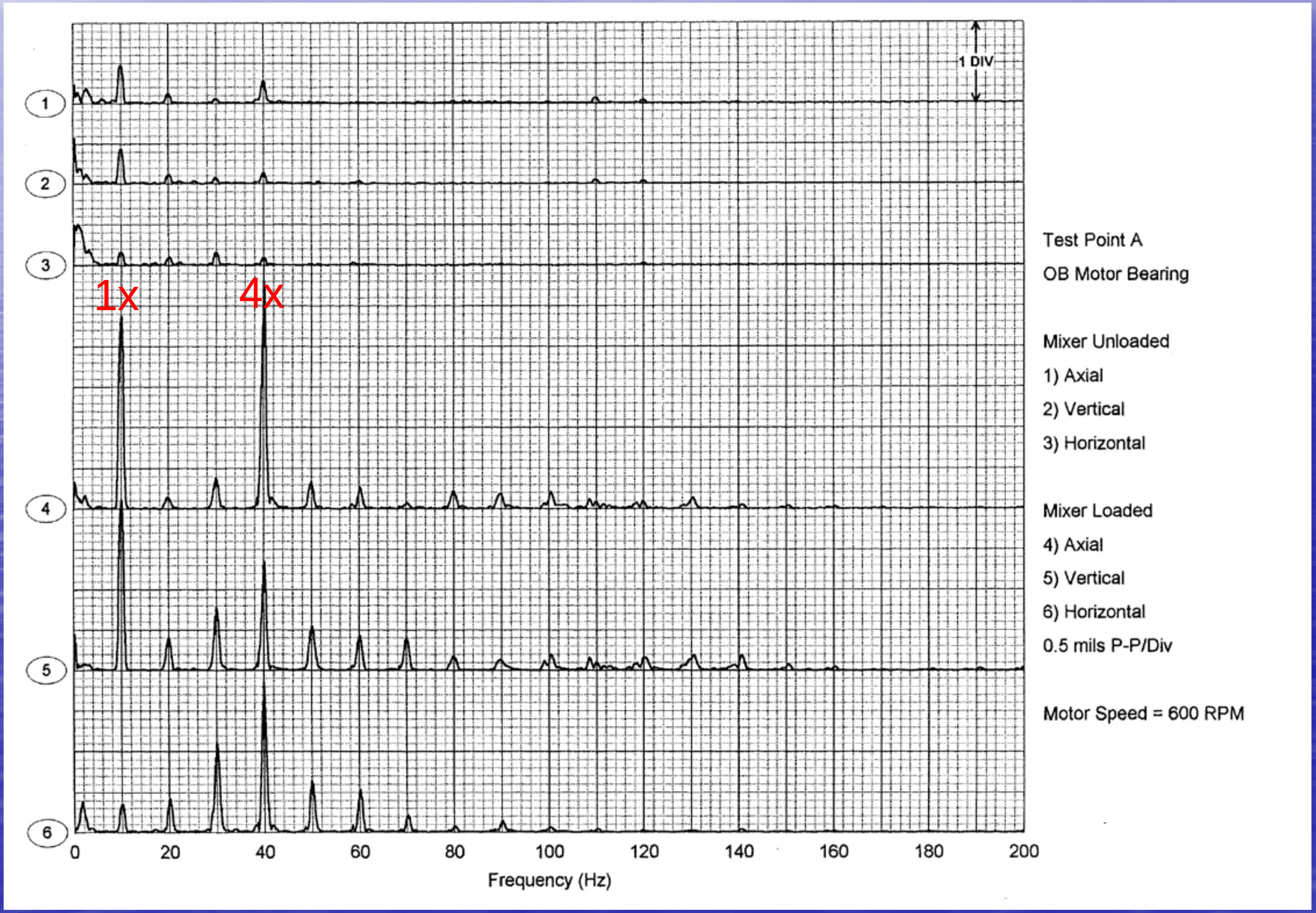
Test Results

- With mixer empty and motor unloaded, vibration was low at both speeds.
- With mixer and motor loaded, significant vibration at 600 RPM and excessive vibration at 1200 RPM operating speed.
- Vibration returned to low level between batch runs when running unloaded.
- Vibration at multiples of motor speed.

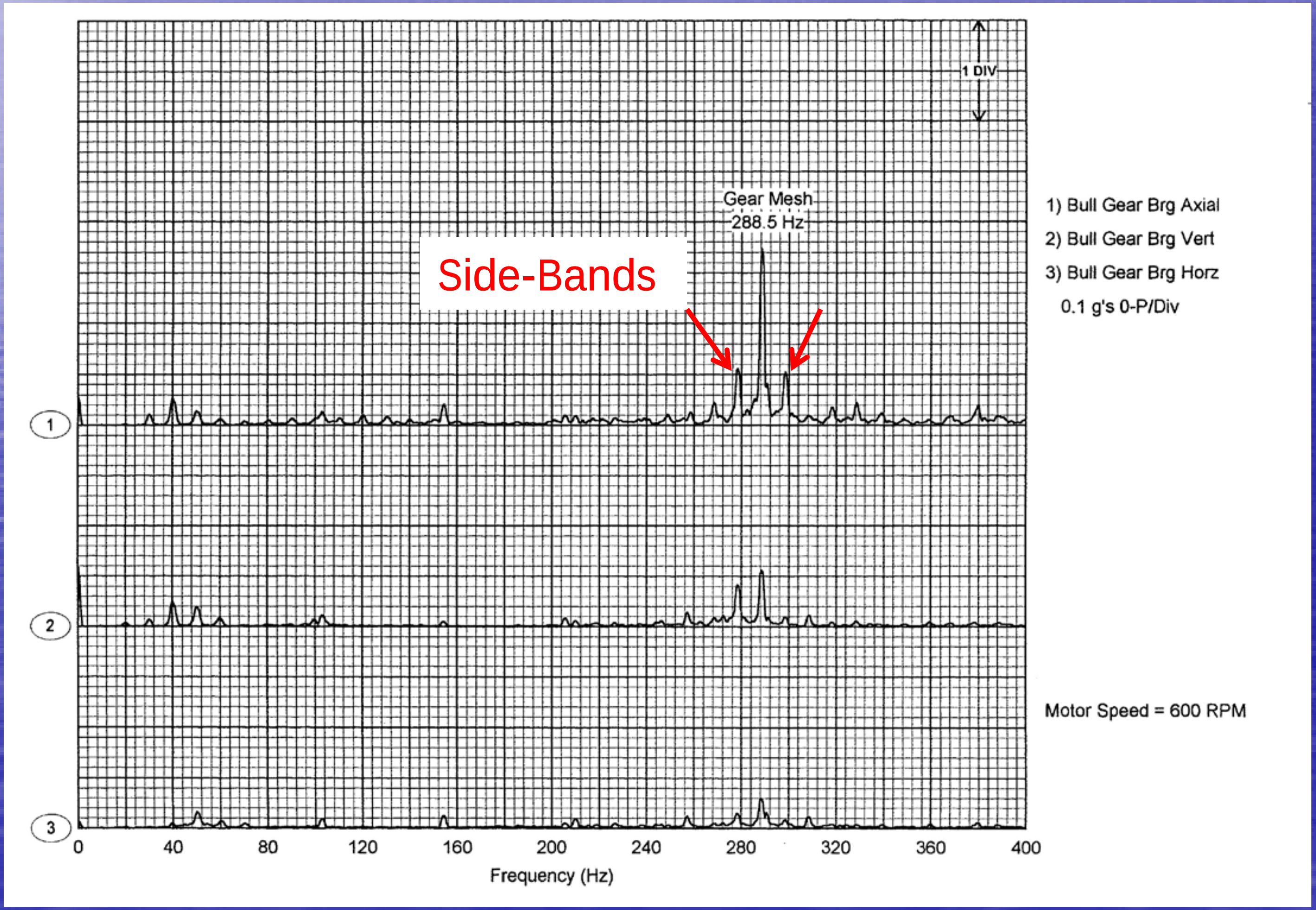
Frequencies at Low Motor Speed

Shaft	Rotating Speed (CPM)	Rotating Frequency (Hz)	Number Gear Teeth	Mesh Frequency (Hz)
Motor	597	9.95		
HS Pinion	597	9.95	29	288.5
IS Gear	119	1.98	146	288.5
IS Pinion	119	1.98	26	51.4
LS Gear	30	0.50	103	51.4
Roto Pinions	30	0.50	33	16.5
Mixer	30	0.50		

Note high vibration at 4x motor speed when mixer was loaded.



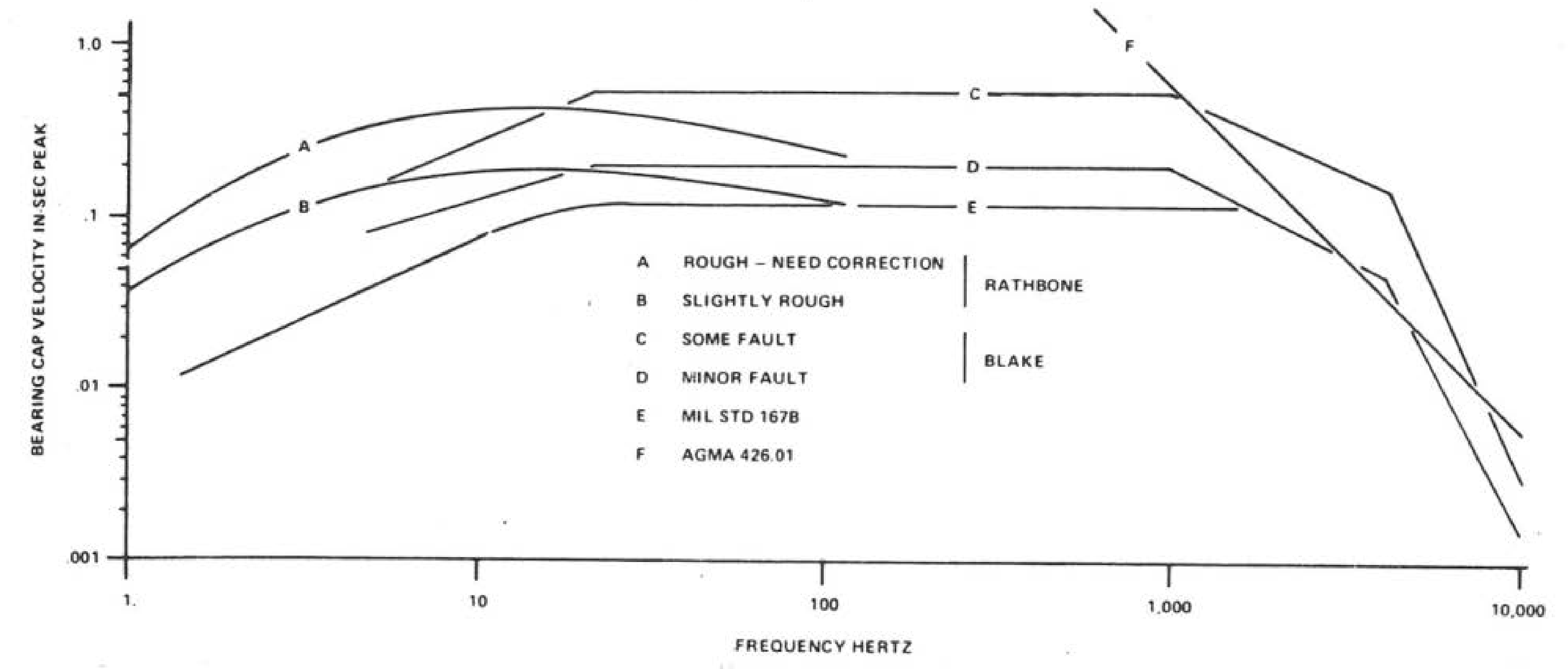
0.17 g's peak at gear mesh frequency
Note side-bands with 10 Hz spacing
This indicates fluctuating motor speed



Various Vibration Limits [Taylor]

Above 600 Hz, AGMA allows gearbox case vibration up to 10 g's

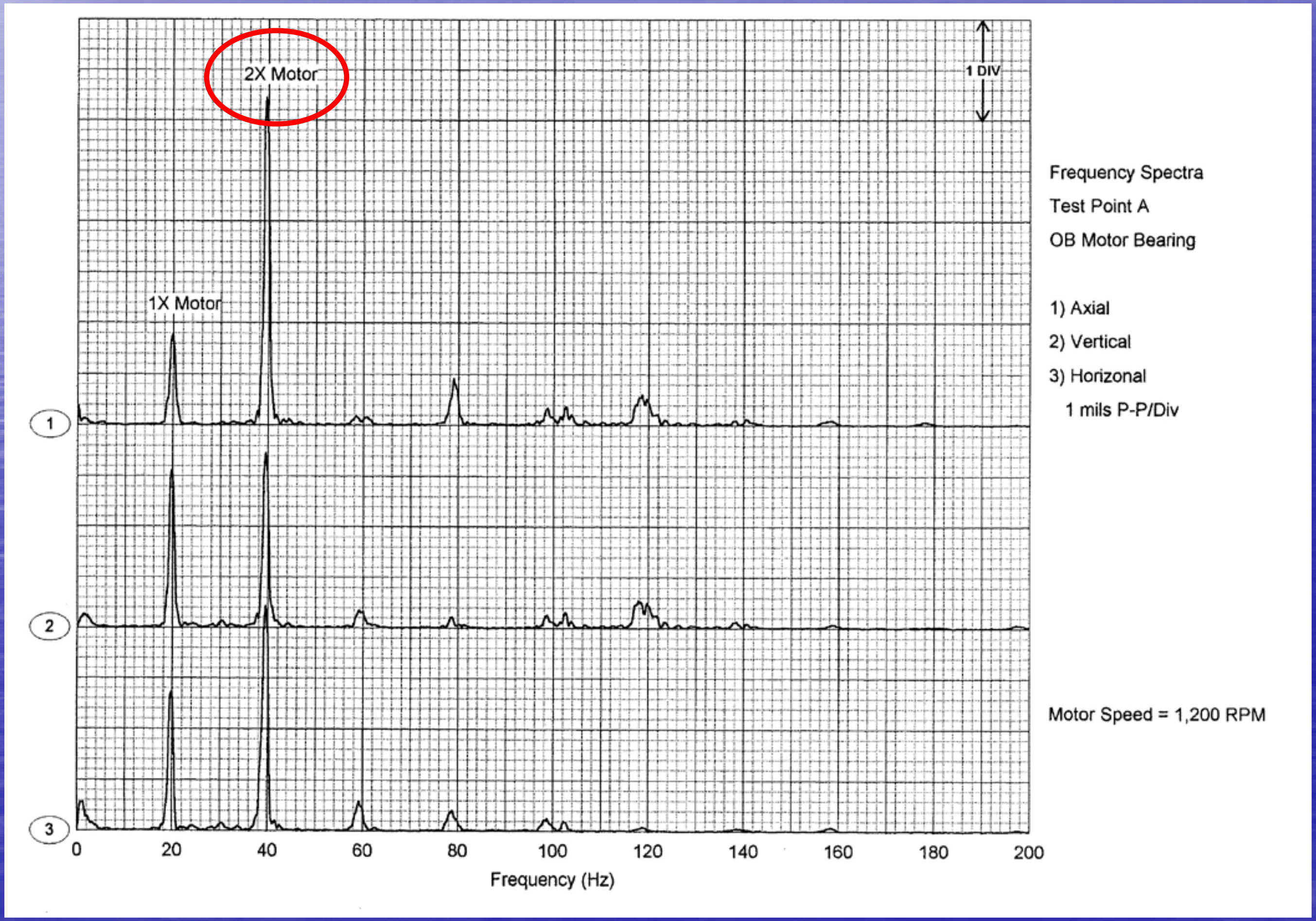
Figure 10–4 Comparison of Casing Vibration Limits



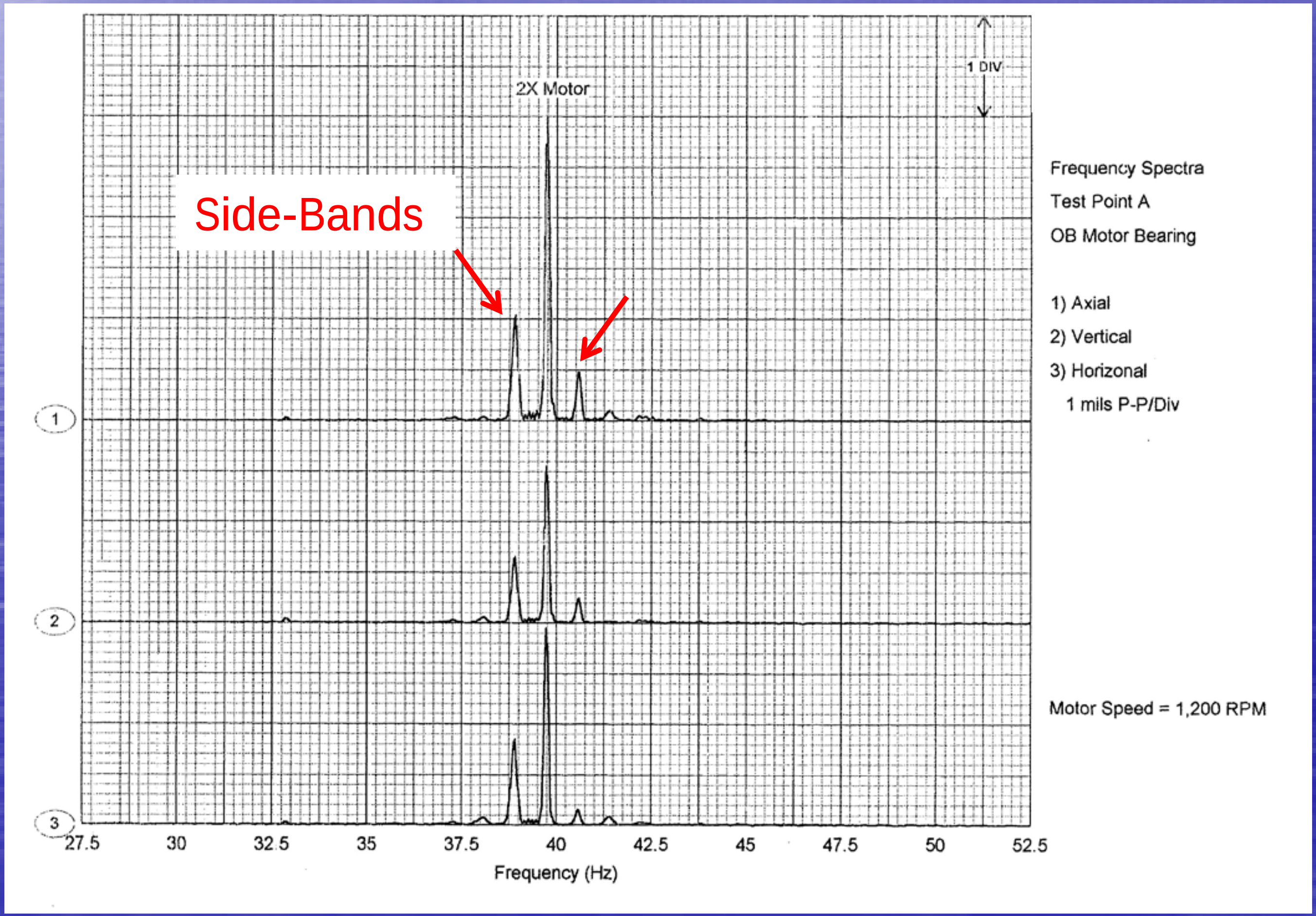
Frequencies at High Motor Speed

Shaft	Rotating Speed (CPM)	Rotating Frequency (Hz)	Number Gear Teeth	Mesh Frequency (Hz)
Motor	1192	19.9		
HS Pinion	1192	19.9	29	576.1
IS Gear	237	3.95	146	576.1
IS Pinion	237	3.95	26	102.6
LS Gear	60	1.00	103	102.6
Roto Pinions	60	1.00	33	32.9
Mixer	60	1.00		

Motor Vibration > 3 mils p-p at 2x Running Speed



Frequency Zoom Window of Motor Vibration



Compare to “Text Book” Example of Broken Rotor Bars [Taylor]

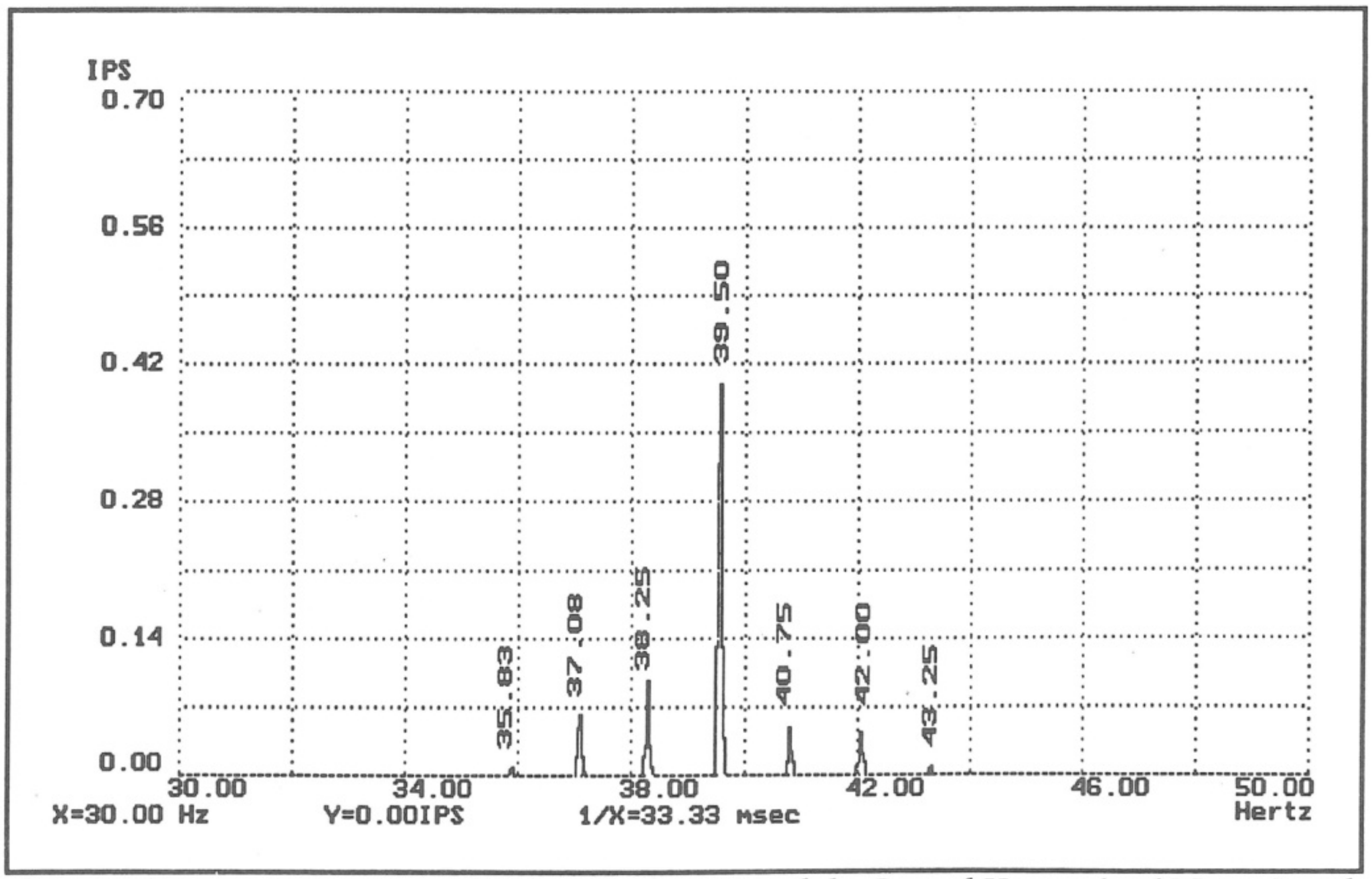
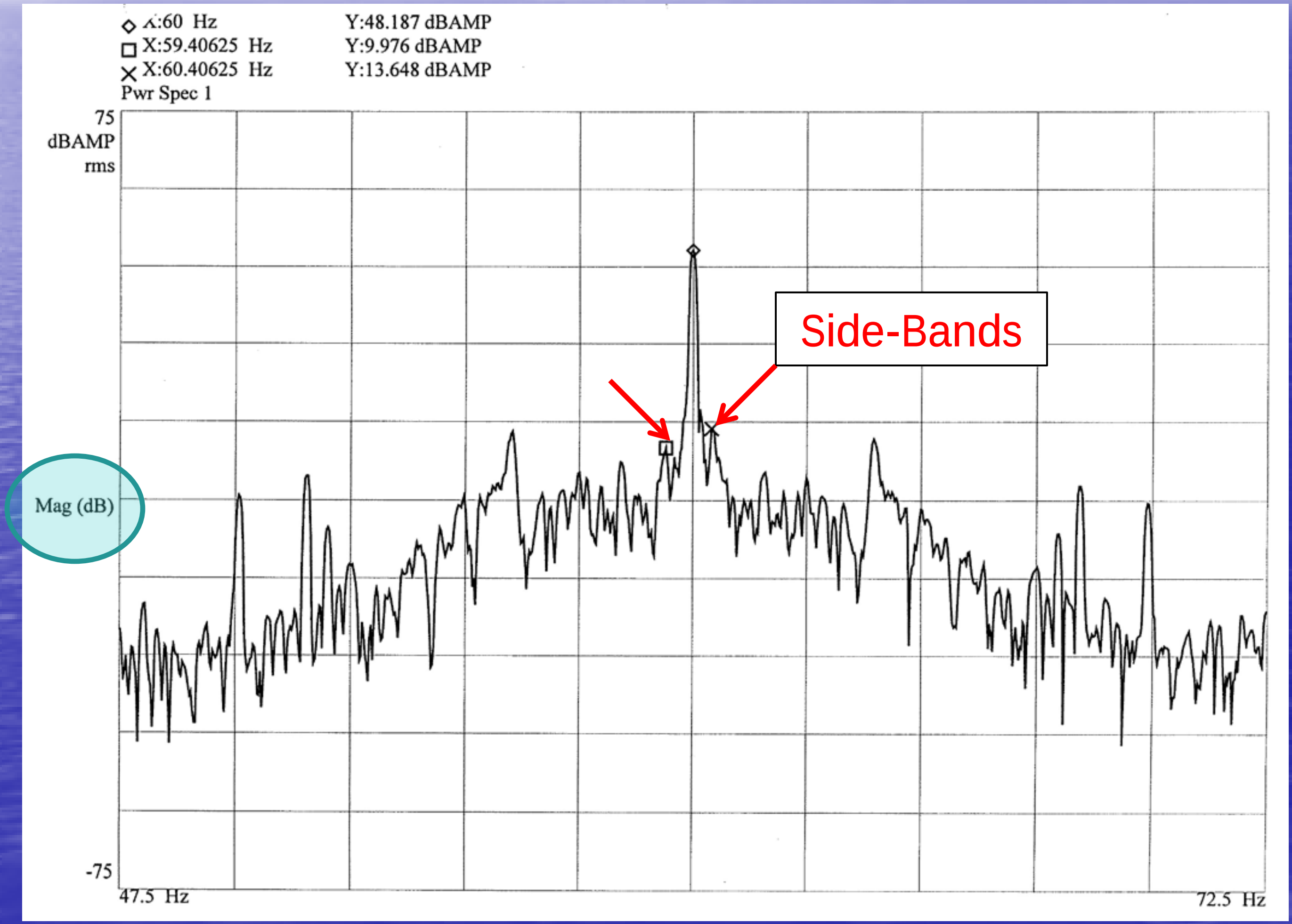


Fig. 4-28. Frequency Spectrum of 20 Hz Window around the Second Harmonic of Motor Speed.

Motor Current Analysis

- Mixer not loaded long enough at low speed.
- At high speed, side-bands less than 45 dB below line frequency indicates a problem.
- Motor Speed at Full Load = 1192 RPM, Slip Frequency = 8 RPM or 0.1333 Hz
- Spacing of Side-Bands = Slip Freq x No. Poles (0.133 x 6 = 0.8 Hz)
- Repeated loading / unloaded hard on motor and believed to cause fatigue cracks.

48 – 10 = 38 dB Perform Vibration Test
48 – 14 = 34 dB Overhaul ASAP



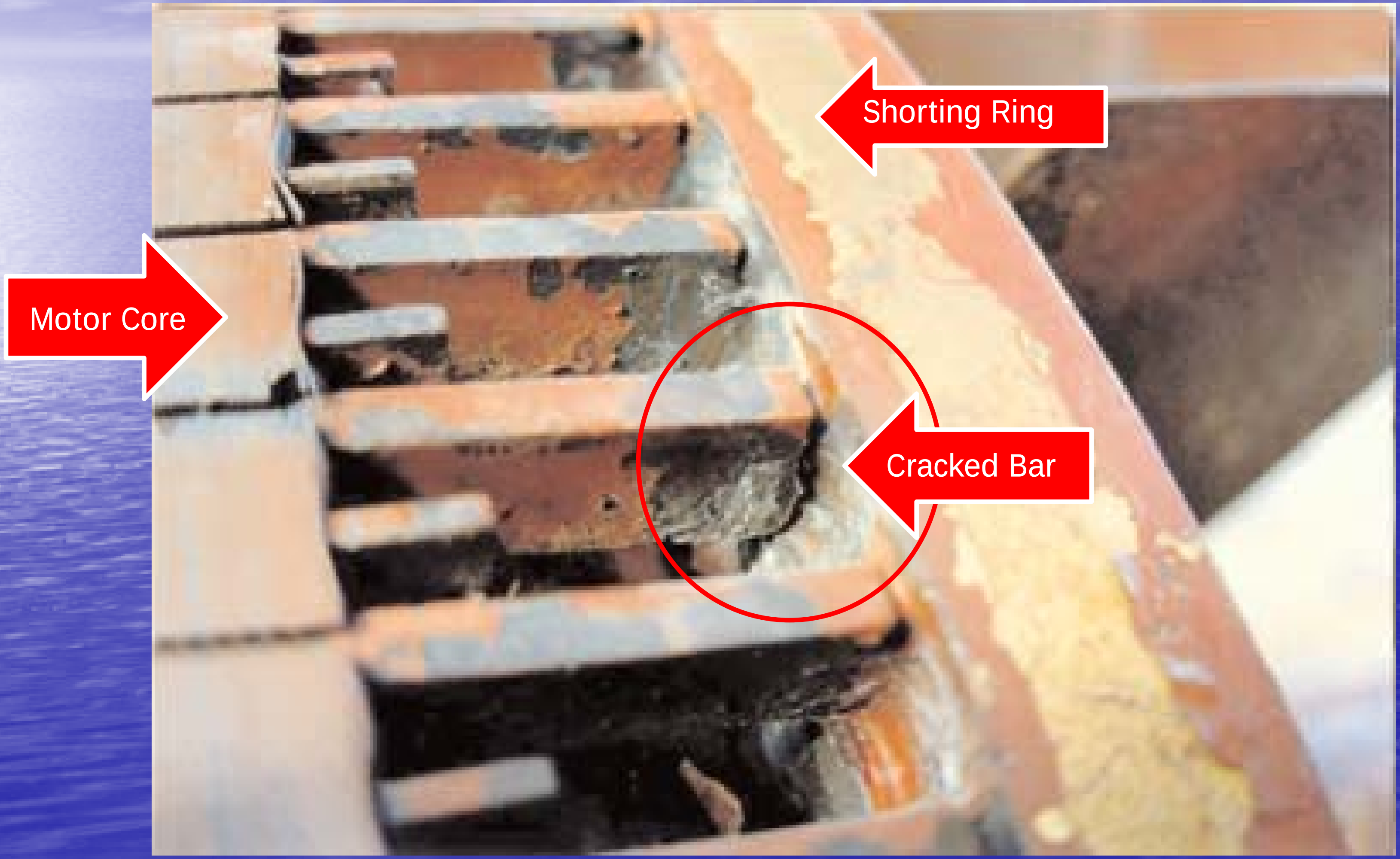
Severity Chart *

TABLE III
MOTOR CURRENT ANALYSIS SEVERITY AND RECOMMENDED CORRECTIVE ACTION CHART

CAT. NO.	$\frac{F_L}{F_P}$ dB	$\frac{F_L}{F_P}$ RATIO	$\frac{F_P}{F_L}$ RATIO %	ROTOR CONDITION ASSESSMENT (1)	RECOMMENDED CORRECTIVE ACTION (1)
1	>60 dB	>1000	<0.10%	Excellent	None
2	54-60	501-1000	.10-.20%	Good	None
3	48-54	251-501	.20-.40%	Moderate	Continue Surveys; Trend Only
4	42-48	126-251	.40-.79%	Rotor Bar Crack May Be Developing or Problems with High Resistance Joint(s)	Reduce Survey Intervals; Trend Closely
5	36-42	63-126	.79%-1.58%	Two Rotor Bars Likely Cracked or Broken & Problems with High Resistance Joints Likely	Perform Vibration Tests to Confirm Problem Source & Severity
6	30-36	32-63	1.58-3.16%	Multiple Cracked or Broken Rotor Bars & End Rings Indicated; Also Slip Ring & Joint Problems	Overhaul ASAP
7	<30 dB	<32	>3.16%	Multiple Broken Rotor Bars & End Rings Very Likely; Severe Problems Throughout	Overhaul or Replace ASAP

* Used with written permission from Technical Associates of Charlotte.

Unrelated Example of Broken Bar / Cracked Weld *



* Used with written permission from Iris Power Engineering.

Conclusions

- No problems found with new gearbox.
- Cracked motor rotor bars caused vibration of motor, gearbox, and plant floor.
- Vibration and current analysis used to diagnose motor rotor bar problem.
- Was not previously detected by motor shop because not tested under load.
- The Babbitt in the motor bearings was also damaged.

Trouble Shooting Steps:

- Measure vibration on equipment at various locations and directions.
- Determine if vibration changes with load.
- Does vibration exceed allowable level?
- Relate measured frequencies to low speed, high speed, gear mesh, etc.
- Note any unusual side-bands in FFT.
- Take additional readings such as motor current to help diagnose problem.

References

- Taylor, <u>The Vibration Analysis Handbook</u>, First Edition, 1994.
- Berry, "Comparison of Motor Current Analysis and Vibration Analysis in Detecting Rotor Bar Problems," Technical Associates of Charlotte, 1992.
- Culbert and Jivajee, "Current Signature Analysis," Iris Power Engineering, Diagnostic News, Spring 2005.
- Feese, EDI Technical Report 71886, Dec. 1997.
- Thomas and Gilmore, "Motor Current Signature Analysis to Detect Faults in Induction Motor Drives," Texas A&M Turbomachinery Symposium, 2003.