Abstract

37th Turbomachinery Symposium

Case Study:

TORSIONAL OSCILLATION TROUBLE ON VFD MOTOR DRIVEN RECIP COMPRESOR

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High vibration problems including failed coupling parts on a VFD motor driven reciprocating compressor are analyzed and the root causes and solutions are discussed in this costly field issue.

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Initial Problem

- VFD Controlled Electric Motor Driving a 4 Throw Reciprocating Compressor (1230 Kw @ 600 RPM – 1000 RPM)
- Connected by an Elastomeric Block Type Coupling
- High Vibrations Noticed on the Motor

Initial Problem

Initial Problem

- In Depth Vibration Readings Taken to Determine Root Cause
- 5 mm\sec @ 83.2 Hz Horizontal on Motor NDE
- Approximately 5x Running Speed
- However, Frame Measurements Led to Discovery of Foundation Bolts not Tightened Properly

Initial Problem

- Bolts Tightened and New Measurements Taken
- Now Dominant Frequency is @ 66.5 Hz Axial, with Amplitudes Above 6 mm/s on Both Ends of Motor
- Approximately 4X Running Speed
- Everything is Questioned, Including Coupling
- Coupling has 10 Blocks in Cavities, but Only 5 are Driving; so Coupling Problem Could Explain 5X but not 4X

INITIAL CONCLUSION

- Tightening of Bolts Changed the Dominant Frequency
- Natural Frequencies on the Motor (non-tightened bolts) Measured at 42, 73, and 95 Hz
- High Vibration Coming from Amplification of Resonance of Motor Base/ Frame Suspected
- Dynamic Stiffness of Motor Feet / Base Connection Needs to be Increased

Measurement Results

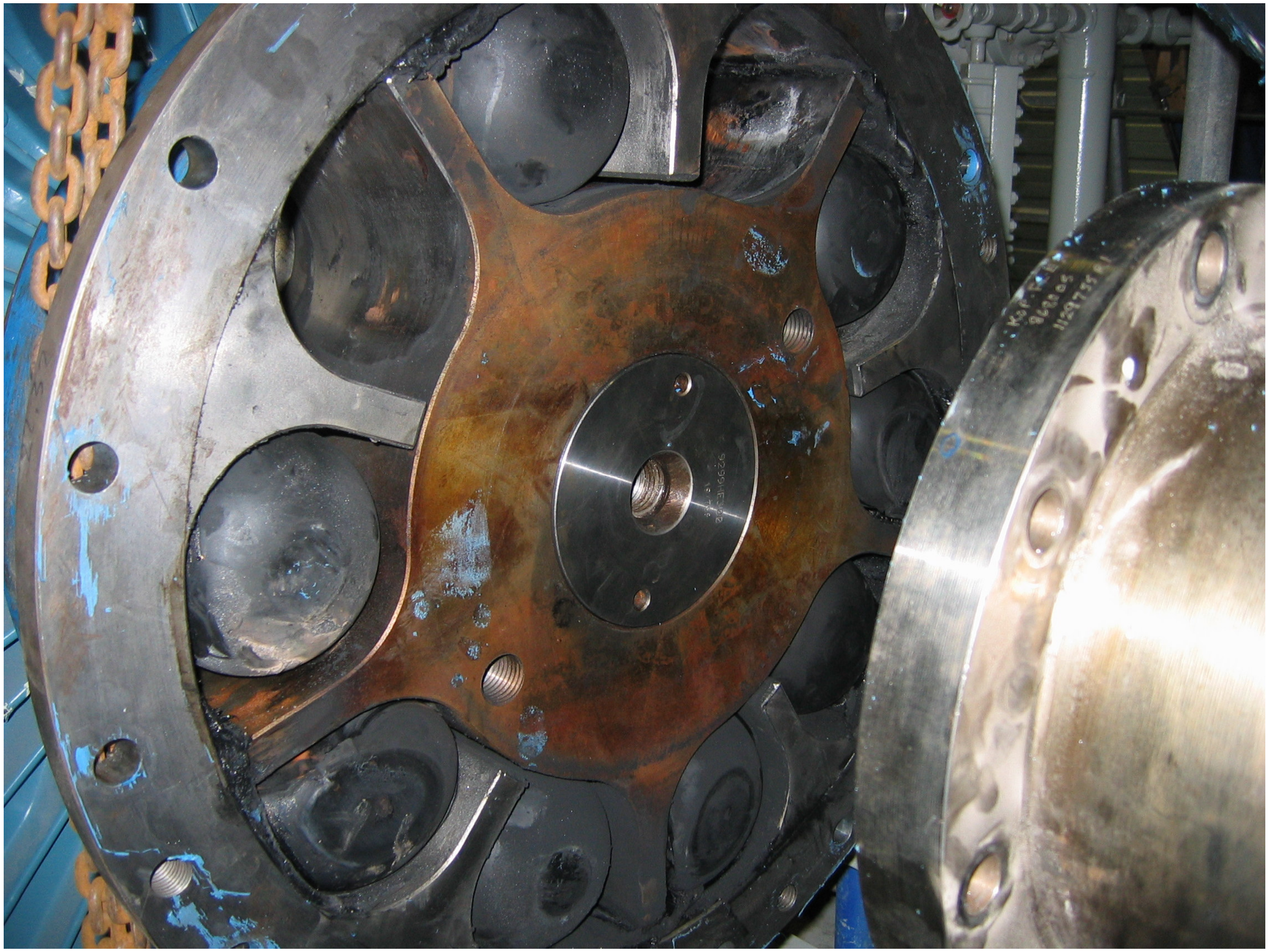
		06-nov-07			08-nov-07		
		X	Y	Z	X	Y	Z
Compressor	Overall [mm/s]	2.8	4.6	2.9	4.0	4.8	3.6
	Max [mm/s] @ Hz	1.3 @ 183	1.3 @ 100	1.2 @ 183	1.8 @ 66.5	2.4 @ 50	1.2 @ 150
	[mm/s] @ 66.5 Hz	0.6	0.4	0.4	1.8	0.3	1.2
	[mm/s] @ 83.2 Hz	0.3	0.9	0.2	0.8	0.2	0.3
E-motor NDE	Overall [mm/s]	2.4	**6.4**	1.6	**7.6**	3.1	4.1
	Max [mm/s] @ Hz	1.8 @ 66.5	5.0 @ 83.2	1.0 @ 66.5	6.5 @66.5	1.6 @ 83.2	3.4 @ 66.5
	[mm/s] @ 66.5 Hz	1.8	1.8	1.0	**6.5**	1.0	3.4
	[mm/s] @ 83.2 Hz	0.4	**5.0**	0.4	1.2	1.6	0.7
E-motor DE	Overall [mm/s]	2.3	3.9	2.0	**7.3**	4.4	5.5
	Max [mm/s] @ Hz	1.8 @ 66.5	2.5 @ 66.5	1.4 @ 66.5	6.3 @ 66.5	3.1 @ 66.5	4.5 @ 66.5
	[mm/s] @ 66.5 Hz	1.8	**2.5**	1.4	**6.3**	3.1	4.5
	[mm/s] @ 83.2 Hz	0.5	1.4	0.2	1.1	1.1	1.1

E-motor Overall ? 2.5 mm/s

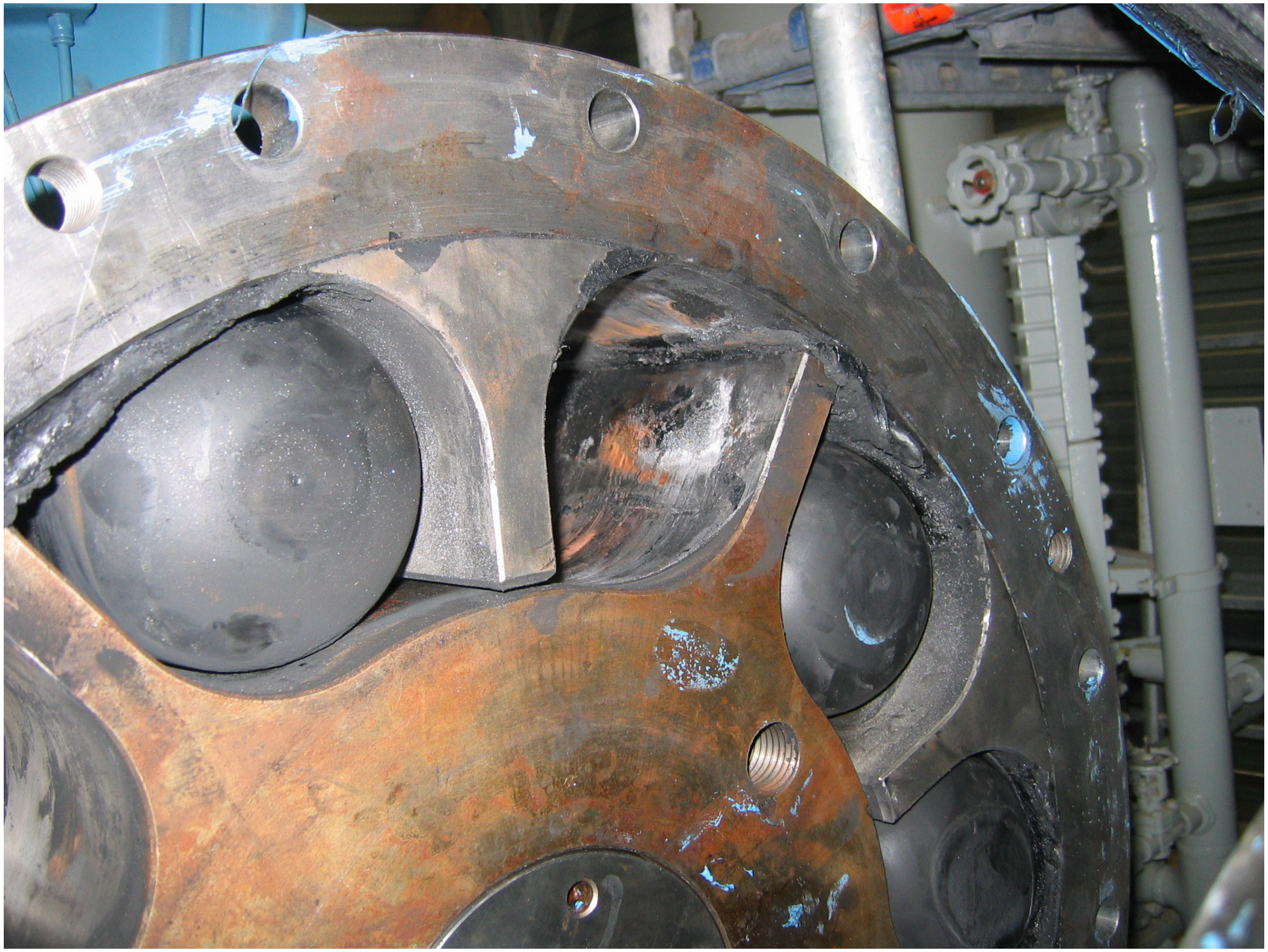
Coupling Problem Suspected

- Motor Foot Bolts Regrouted
- At or About the Same Time the “Smell of Burned Rubber” was Noticed Around the Machine
- At the First Opportunity, the Machines were Shut Down for Inspection
- Rubber Blocks were Damaged

Coupling Problem Suspected



Coupling Problem Suspected



Coupling Problem Suspected

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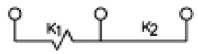
Coupling Problem Suspected

- Did the Coupling Cause the Machine Vibration Leading to its Failure? or
- Did the Machinery Vibrations Cause the Failed Coupling?

Coupling Problem Suspected

- Original Torsional Analysis Reviewed by Coupling Vendor
- Issues Found
  - Only One Coupling Stiffness Used in Model (Block Coupling Stiffness Varies with Torque and Alignment, Amongst Other Factors)
    - Tolerance
    - Durometer, Age
    - Temperature

Coupling Problem Suspected



MASS ELASTIC SYSTEM

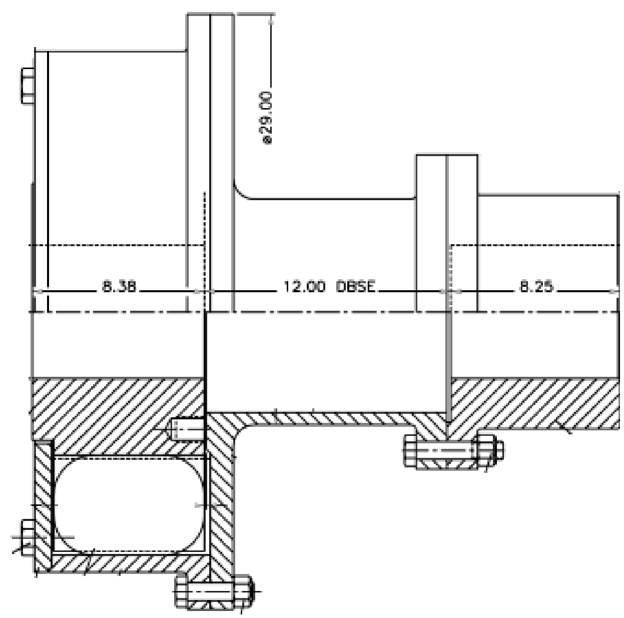
J1 = (1/2 BLOCKS + HUB) = 40.13 LB-IN-SEC^2

K1 = BLOCK STIFFNESS = 4.65 X 10^6 LB-IN/RAD

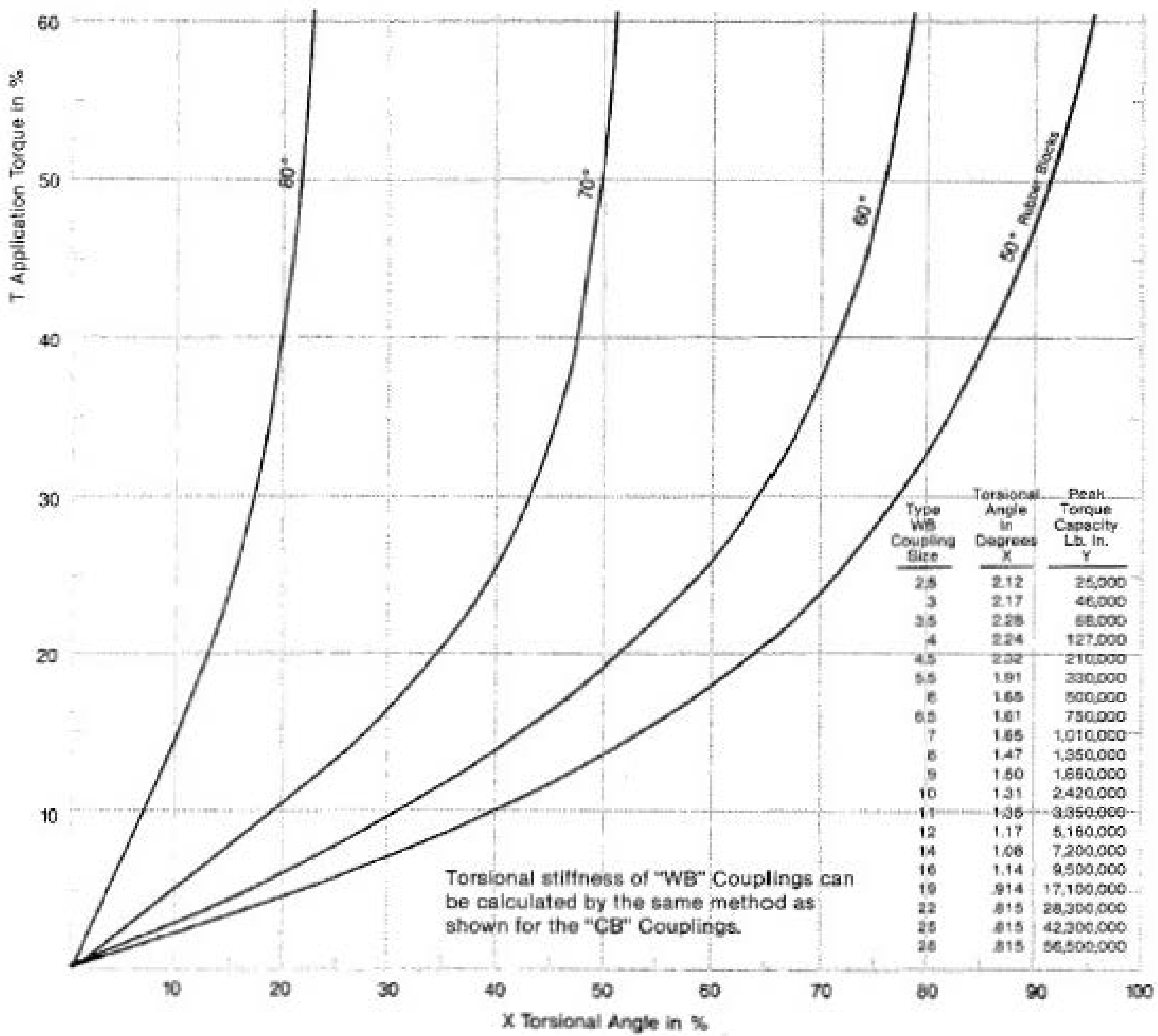
J2 = (1/2 SPACER + SLEEVE ASS'Y + 1/2 BLOCKS) = 51.34 LB-IN-SEC^2

K2 = SPACER STIFFNESS = 480 X 10^6 LB-IN/RAD

J3 = (1/2 SPACER + RIGID) = 45.70 LB-IN-SEC^2



Coupling Problem Suspected



Type WB Coupling Size	Torsional Angle In Degrees X	Peak Torque Capacity Lb. In. Y
2.5	2.12	25,000
3	2.17	46,000
3.5	2.28	68,000
4	2.24	127,000
4.5	2.32	210,000
5.5	1.91	330,000
6	1.65	500,000
6.5	1.61	750,000
7	1.65	1,010,000
8	1.47	1,350,000
9	1.60	1,860,000
10	1.31	2,420,000
11	1.36	3,350,000
12	1.17	5,160,000
14	1.08	7,200,000
16	1.14	9,500,000
19	.914	17,100,000
22	.815	28,300,000
25	.815	42,300,000
28	.815	56,500,000

Coupling Problem Suspected

- Damping of the Rubber Blocks not Modeled

$C = K / (M * w)$	[lb * in * sec / rad]
K – coupling stiffness (table)	[lb * in / rad]
M – magnification factor	[dimensionless]
W – torsional vibration freq.	[rad/sec]

for Duro 80 $M_{\text{Natural Rubber}} = 5.0$; $M_{SBR}=3.0$

- Most Importantly, the Vibratory Torque Capacity of the Blocks was Exceeded

Coupling Problem Suspected

- Coupling was Selected early Using a Service Factor
- Coupling Dynamic Torque Capacity was +/-63,000 lb-in up to Vibration Frequency of 500 cpm and less beyond
- The Torsional Report Predicted Values Varied with Different Cases, but Largest Value was +/- 75,000 lb-in in the Running Speed Range, but Not at a Resonant Frequency
- An Issue of Poor Communication Between the Coupling Supplier and Analysts

Coupling Problem Suspected

Case	Predicted Torque [Nm]		Allowable Torque [Nm]		Comments
	Max	Min	Max	Min	
Case 1	23250	7569	35900	-7160	Acceptable
Case 2	17303	452	35900	-7160	Acceptable
Case 3	14686	4429	35900	-7160	Acceptable
Case 4	21699	7360	35900	-7160	Acceptable
Case 5	19291	5162	35900	-7160	Acceptable
Case 6	19396	6522	35900	-7160	Acceptable

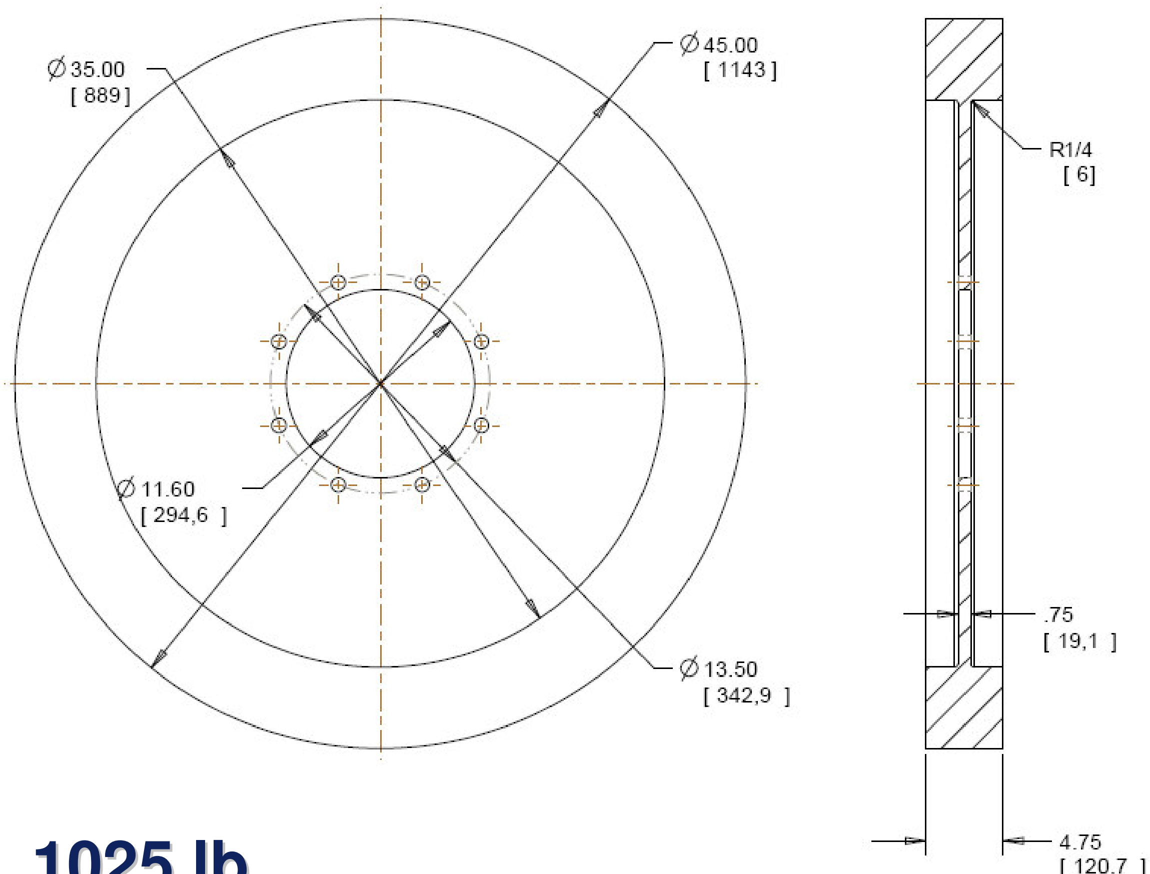
Possible Solutions

- Replace Coupling with One with Higher Vibratory Torque Capacity (would take too long to manufacture)
- Introduce Flywheel(s) into System to Reduce the Vibration Magnitude which would also Change the Resonant Frequencies
- Internal Flywheels were Available from the Compressor Manufacturer, but did not have Enough Inertia to Reduce Amplitude

Actual Solution

- A Large Flywheel Bolted to the Coupling Hub/Spacer Connection
- Plus Using High Damping Material Blocks of the Same Size as Before but with Lower Dynamic Magnification Factor (3 vs. 5)
- This Put Resonant Points into the Running Speed Range, but the Magnitudes were Sufficiently Reduced to be Within the Coupling Vibratory Torque Capacity

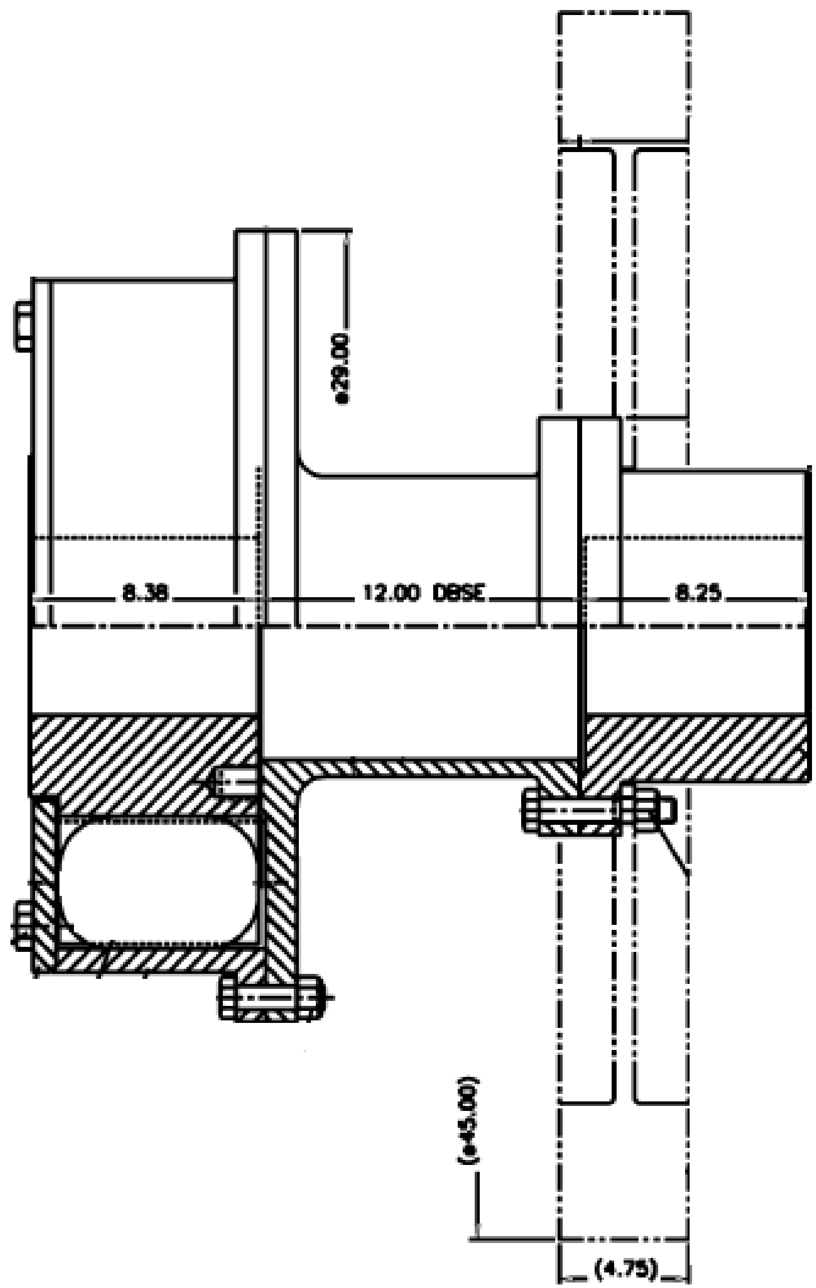
Actual Solution



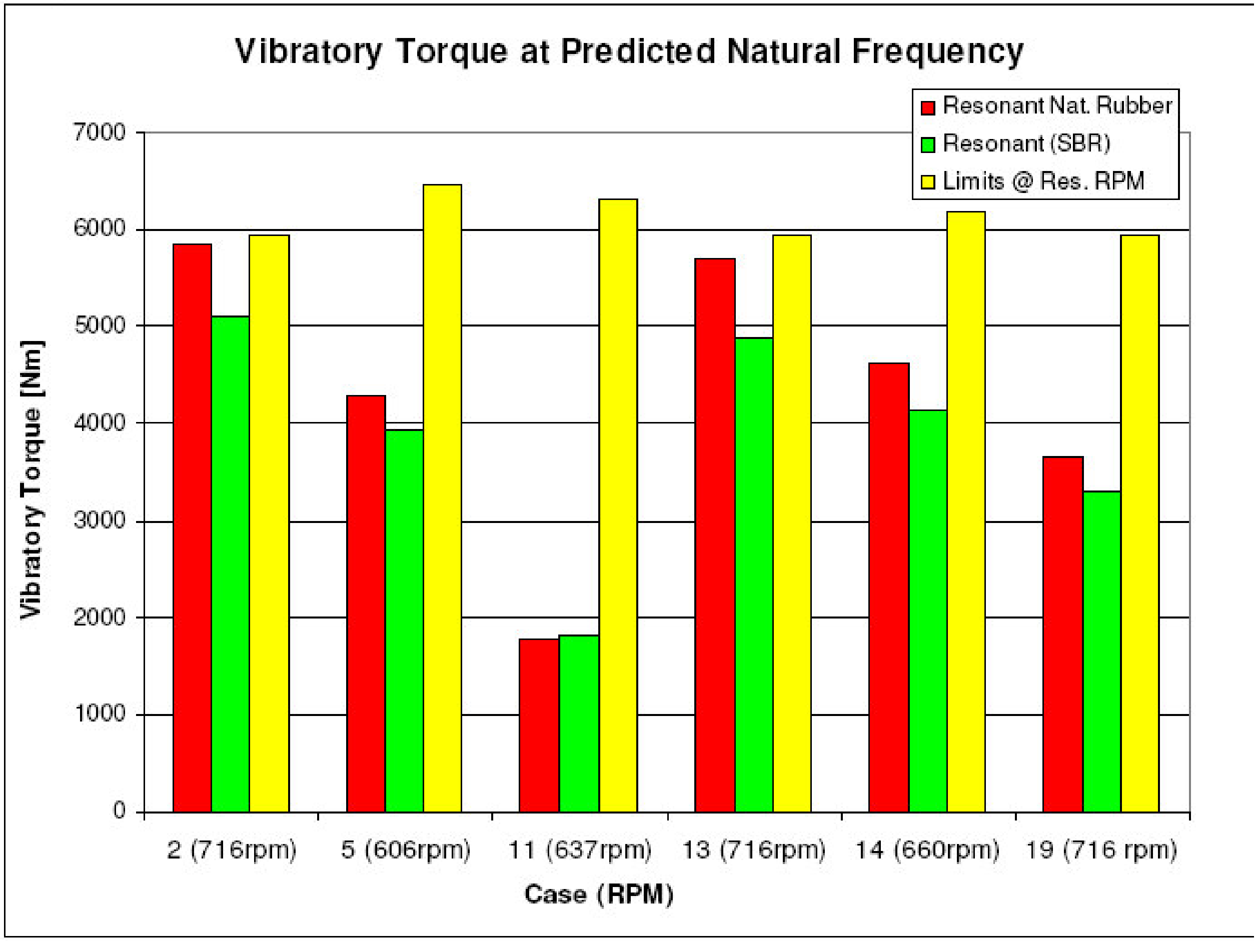
1025 lb

375000 lb-in^2

Actual Solution



Actual Solution



Actual Solution

case	res. Speed [rpm]	Size 8 "CB" Vib. limit [lb.in]	Size 8 "CB" Vib. limit [N.m]	Calculated vib torque Nat. Rubber [N.m]	Ratio Tnat.rub/Tlimit	Calculated Vib.Torque SBR N.m	Ratio Tsbr/Tlim
2	716	52646.4	5948.3	5843.5	0.98	5101.8	0.86
5	606	57225.5	6465.6	4287.1	0.66	3928.2	0.61
11	637	55815.6	6306.3	1790.7	0.28	1814.9	0.29
13	716	52646.4	5948.3	5688.7	0.96	4887.5	0.82
14	660	54834.5	6195.5	4625.6	0.75	4143.7	0.67
19	716	52646.4	5948.3	3655.5	0.61	3291.2	0.55

Lessons Learned

- Complete Torsional Analysis in a Timely Manner and Review with ALL Equipment Suppliers
- Equipment Suppliers Need to be Clear on the Limitations and Assumptions in Their Data Used for the Torsional Model
- On Trains Prone to Torsional Issues, Complete an Analysis – Do Not Use Service Factors
- Even if the Analysis is Complete, There are Many Possibilities for Errors, So an Actual Vibration Measurement is Recommended
  - Before Equipment is Needed to be in Operation
  - At the Most Possible Loading Conditions