Torsional Vibration Analysis Report

Report 36204
January 25, 2018

Torsional Vibration Analysis
for
XTO Energy

Reported by:
Deb K Wernsman

IDC Engineering
130 Enterprise Court
Metamora, Illinois 61548
Phone: (309) 383-3200
Fax: (309) 383-3250

Requested By:	Vishal Varia
Application:	Gas Compression
Unit Number:	US-123064
Engine Dealer:	Mustang Cat
Engine Model:	G3616
S.O. Number:	SJTHN
P.O Number:	201711992
Ariel Reference:	AP032548
Compressor:	KBZ/6

CATERPILLAR®

System Description

A Caterpillar G3616 engine is coupled to a four-stage Ariel KBZ/6 reciprocating compressor through a TB Woods GCF 511-92 coupling. The compressor manufacturer has provided six load cases for the compressor. A vibration analysis has been performed for each load case to ensure torsional compatibility of the system.

Conclusion

The analysis was completed with an Ariel B-7445 (19,920 lb-in^2) Auxiliary End Internal Flywheel. The internal flywheel is being used to lower the 6.0 order resonance within the compressor manufacturer's Torsional/Lateral Awareness Curve. This auxiliary end flywheel must be added in order for the conclusions of this analysis to apply.

The following analysis indicates this system will be free of serious levels of torsional vibration for the conditions described. Damper thermal loading is within the damper manufacturer's recommended limit. Engine front crank vibration levels are acceptable. The crankshaft combined order stress values have been reviewed and have been found to meet Caterpillar's limits. Torque levels in the coupling are within the coupling manufacturer's recommended limits. The predicted compressor crankshaft alternating torque and vibratory velocities at the auxiliary end of the compressor crankshaft are within the compressor manufacturer's recommended limits.

Caterpillar does not recommend operating any system under engine misfire conditions.

For different compressor load conditions Caterpillar strongly recommends another vibration analysis be performed to verify torsional compatibility of the driveline.

Recommended Limits

Torsional vibration limits are as follows:

Displacement at front of engine crankshaft:	≤ 1.00 degrees for 0.5 and 1.0 orders
	≤ 0.25 degrees for 1.5 order
	≤ 0.15 degrees for orders above 1.5
Stress in engine crankshaft:	≤ 48.0 MPa for combined orders

System Data

Engine model G3616 rated at 5000 bHp, 1000 rpm operating speed

Engine Damper GP: Caterpillar Part No. 439-0652
Assembly: Caterpillar Part No. 7C-2123 (Quantity 2)

Engine Flywheel: Caterpillar Part No. 379-9041

Coupling: TB Woods GCF 511-92

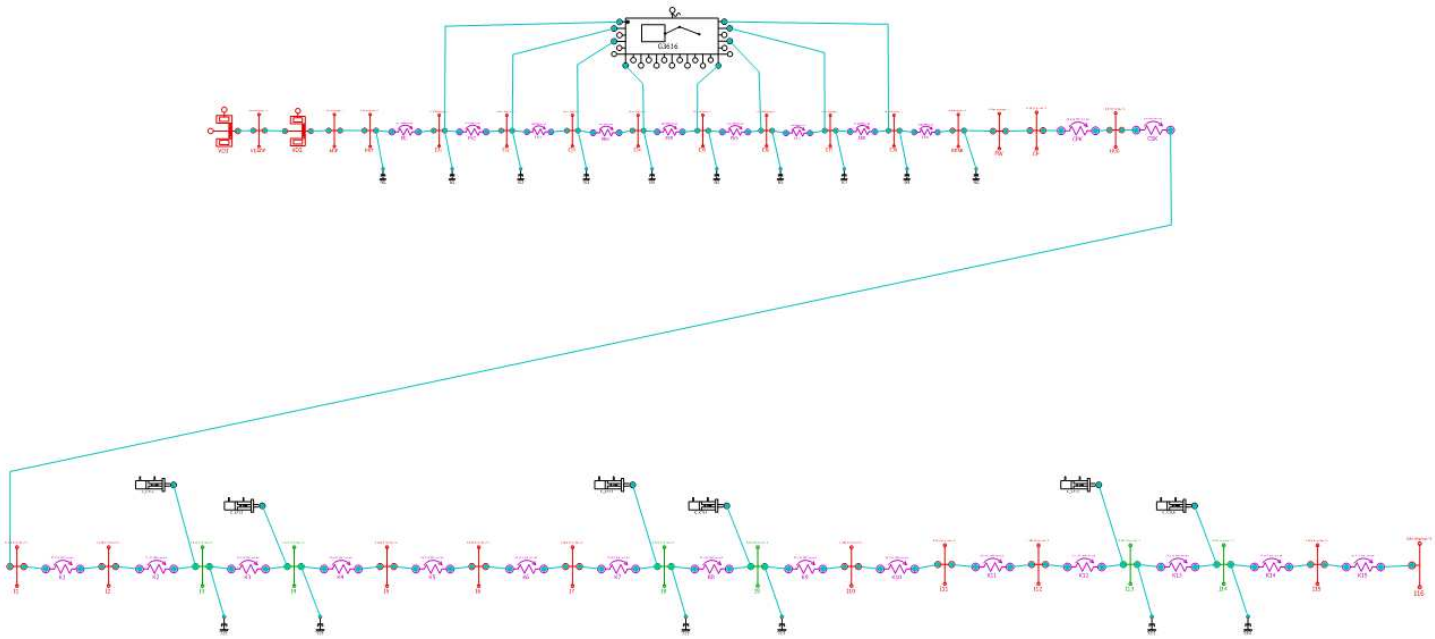
Compressor: Ariel KBZ/6

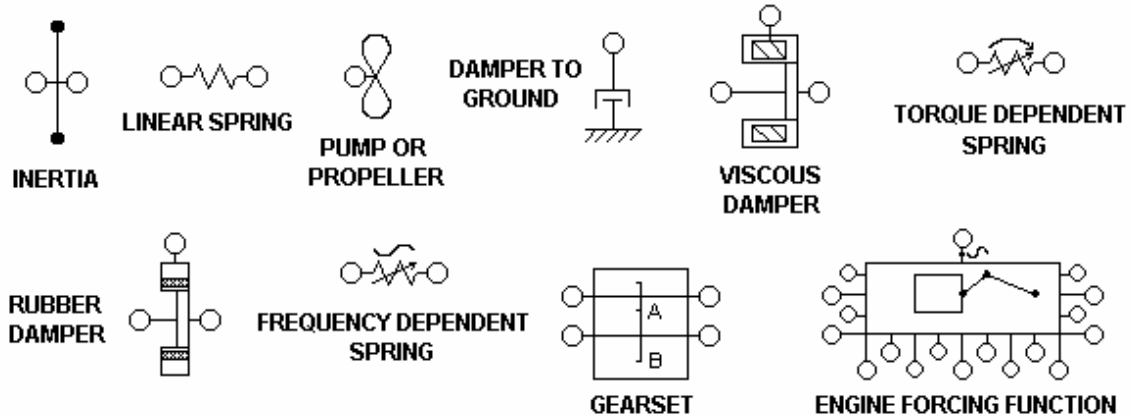
Comp. Flywheel: Ariel Part No. B-7445 (19,920 lb-in^2) Auxiliary End Flywheel

Engine Data

Cylinder Bore:	300 mm
Crank Radius:	150 mm
Connecting Rod Length:	600 mm
Reciprocating Weight:	755.5466 N

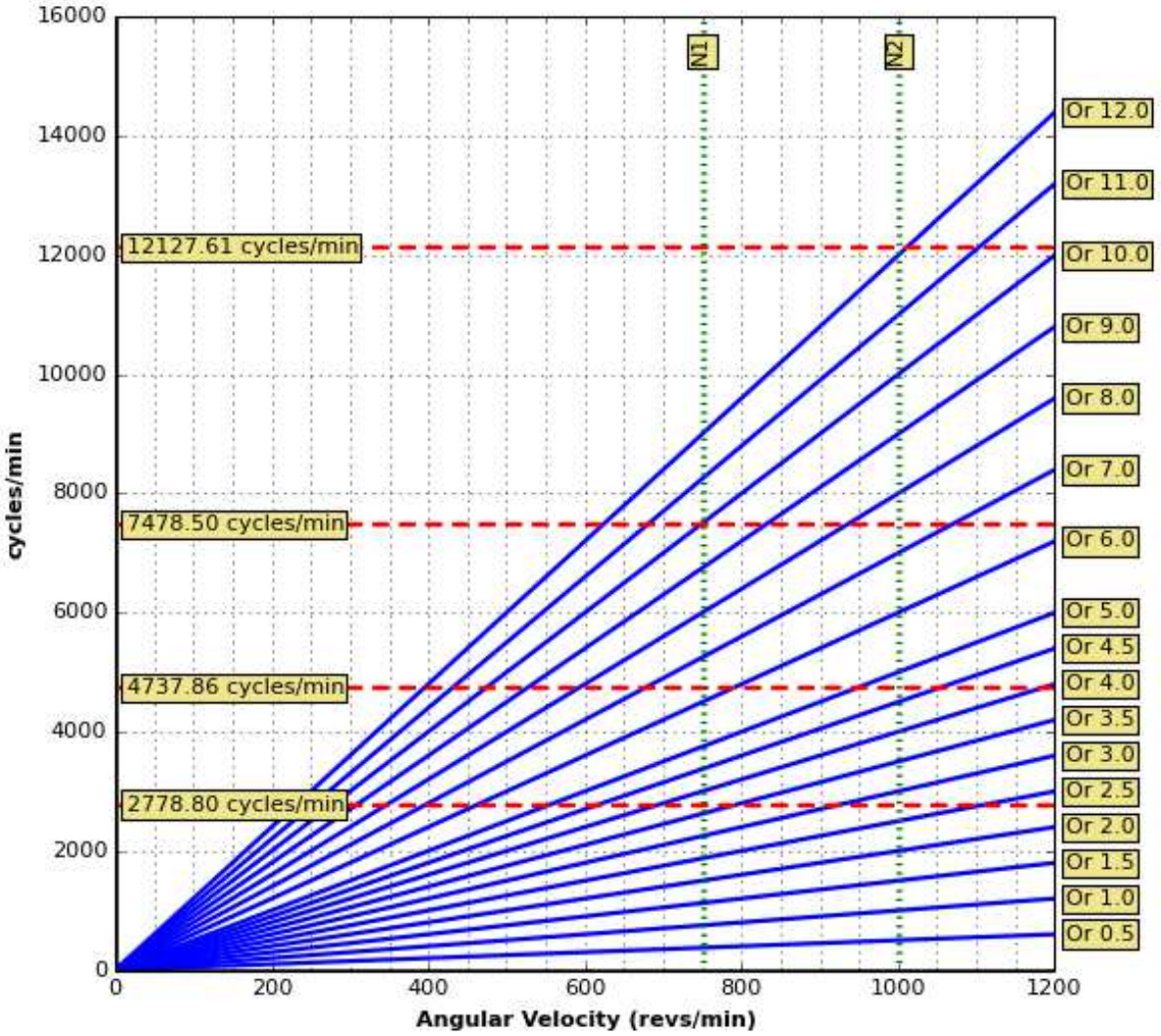
Report Contents



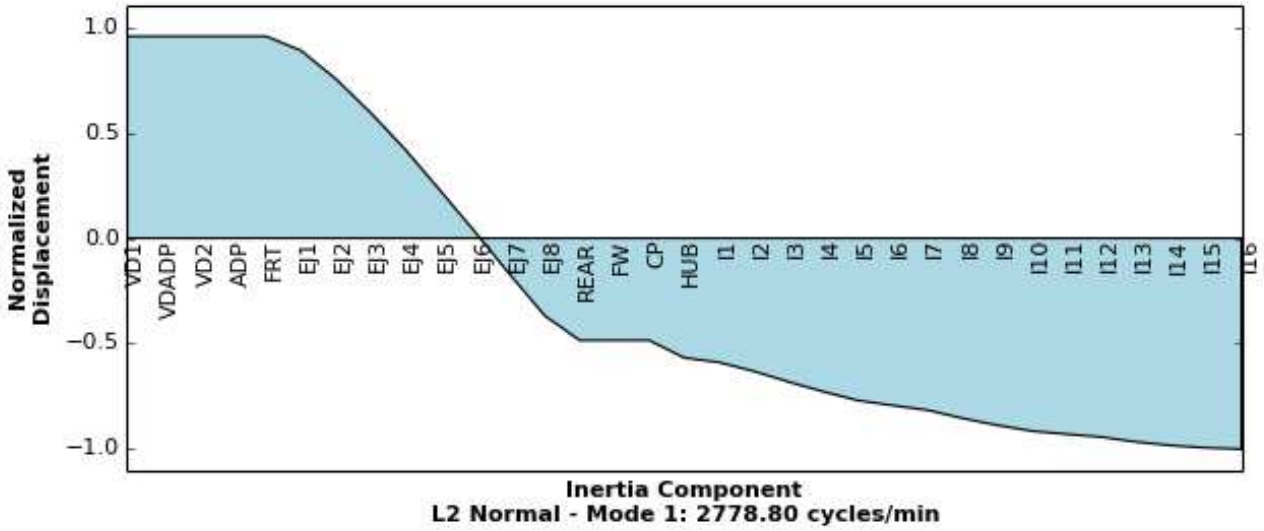

INERTIA
LINEAR SPRING
PUMP OR PROPELLER
DAMPER TO GROUND
VISCOUS DAMPER
TORQUE DEPENDENT SPRING
RUBBER DAMPER
FREQUENCY DEPENDENT SPRING
A
B
GEARSET
ENGINE FORCING FUNCTION

Inertia Name	Inertia	Damper Name	Damping	Spring Name	Stiffness	Damping	Relative Damping	Diameter
	Nms²		Nms/rad		MNm/rad	Nms/rad	Ψ	mm
VD1 Ring	28.900							
VD1 Hsng	7.863							
VDADP	0.661							
VD2 Ring	28.900							
VD2 Hsng	7.863							
ADP	2.139							
FRT	3.640	FGC	350.0	EK1	61.290		0.20	216.0
EJ1	15.176	EC1	20.0	EK2	39.190		0.20	216.0
EJ2	15.031	EC2	20.0	EK3	38.920		0.20	216.0
EJ3	15.031	EC3	20.0	EK4	39.910		0.20	216.0
EJ4	15.031	EC4	20.0	EK5	38.780		0.20	216.0
EJ5	15.031	EC5	20.0	EK6	39.910		0.20	216.0
EJ6	15.031	EC6	20.0	EK7	38.920		0.20	216.0
EJ7	15.031	EC7	20.0	EK8	39.190		0.20	216.0
EJ8	15.176	EC8	20.0	EK9	61.290		0.20	216.0
REAR	8.800	RGC	1400.0					
FW	73.841							
CP	11.560			CPK	39.912			
HUB	8.540			CSK	134.000			215.9
I1	0.438			K1	67.871			215.9
I2	1.268			K2	55.520			215.9
I3	3.926	CC1	100.0	K3	55.226			215.9
I4	3.927	CC2	100.0	K4	55.107			215.9
I5	1.282			K5	96.923			215.9
I6	0.641			K6	96.923			215.9
I7	1.282			K7	55.107			215.9
I8	4.051	CC3	100.0	K8	55.226			215.9
I9	4.043	CC4	100.0	K9	55.107			215.9
I10	1.282			K10	96.923			215.9
I11	0.641			K11	96.923			215.9
I12	1.282			K12	55.107			215.9
I13	4.051	CC5	100.0	K13	55.226			215.9
I14	4.043	CC6	100.0	K14	55.107			215.9
I15	1.086			K15	92.733			215.9
I16	5.960							

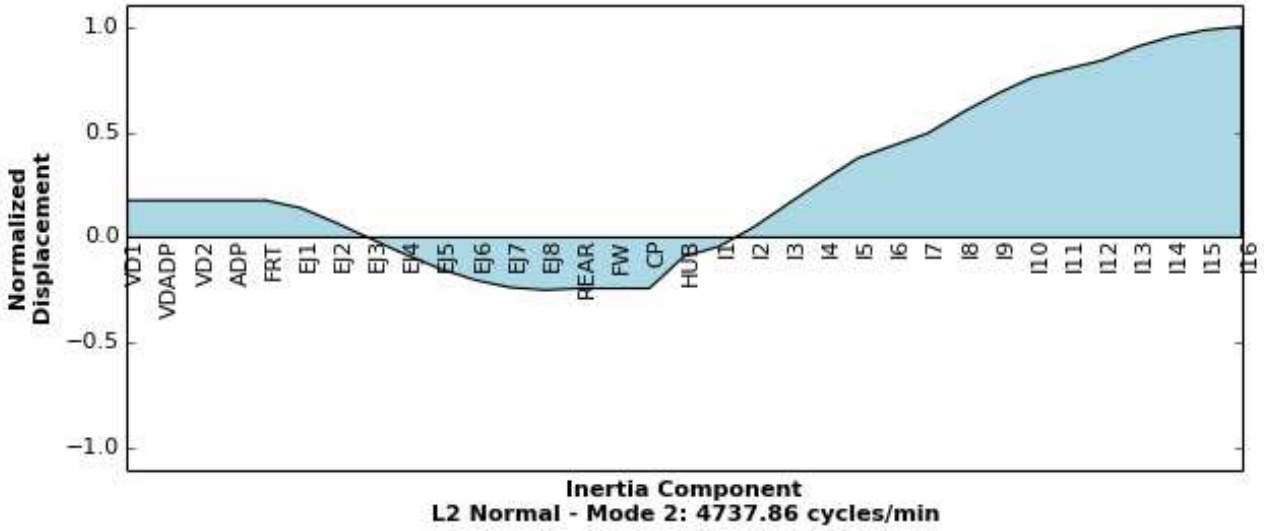
Resonant Speed Diagram



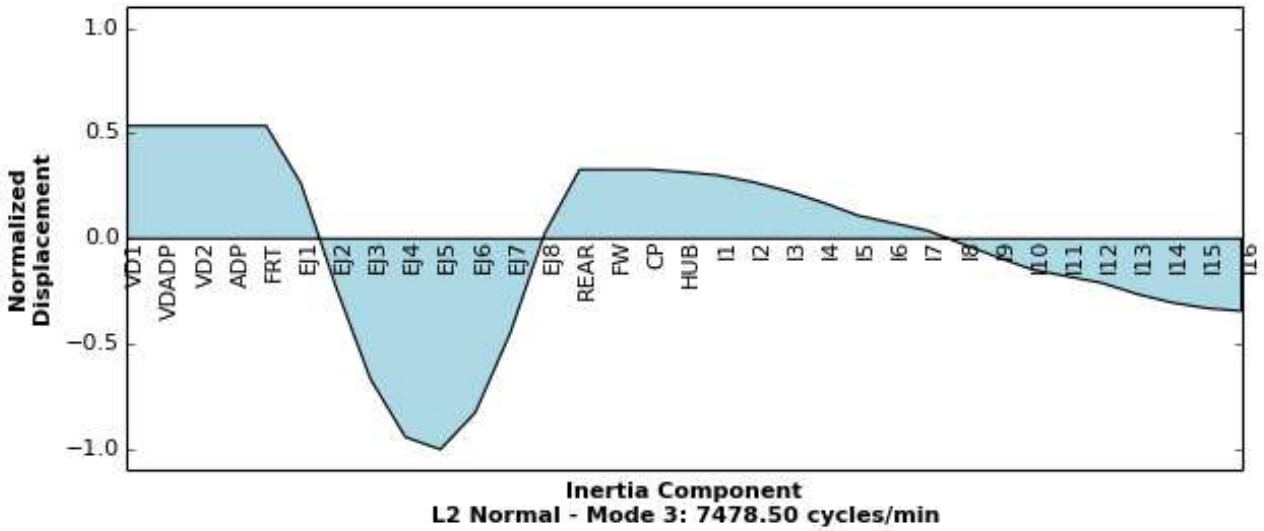
Mode Shapes



L2 Normal - Mode 1: 2778.80 cycles/min

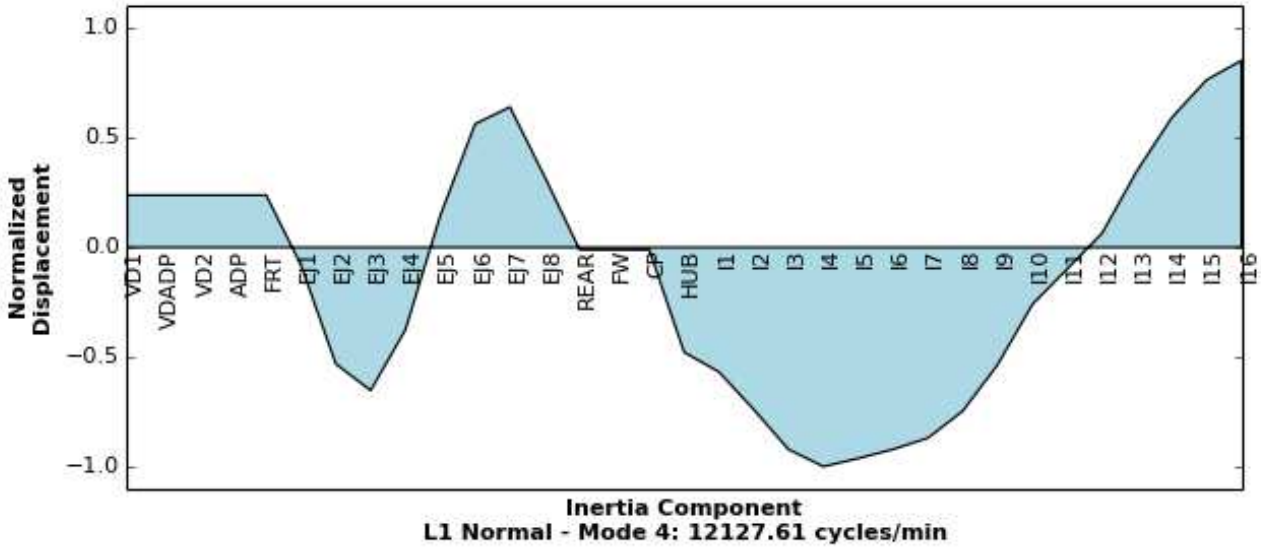


L2 Normal - Mode 2: 4737.86 cycles/min



L2 Normal - Mode 3: 7478.50 cycles/min

Mode Shapes Cont.



Load Case #1

Ariel Performance

7.7.4.0

Company: EXTERRAN
Project #: AP032548 Rev:26
Case 7: Ps-low Pd-high
Customer: XTO ENERGY
Inquiry:
Project: XTO ENERGY

Compressor Data:						Driver Data:	
Elevation,ft:	3600.00	Barmtr,psia:	12.861	Ambient,F:	110.00	Type:	Nat. Gas
Frame: (ELP)	KBZ/6	Stroke, in:	6.75	Rod Dia, in:	2.875	Mfg:	Caterpillar
Max RL Tot, lbf:	150000	Max RL Tens, lbf:	75000	Max RL Comp, lbf:	80000	Model:	G3616 A4
Rated RPM:	1000	Rated BHP:	7800.0	Rated PS FPM:	1125.0	BHP:	5000
Calc RPM:	1000.0	BHP:	4337	Calc PS FPM:	1125.0	Avail:	5000

Services	Service 1					
Gas Model	VMG					
Stage Data:	**1 (SG)**	---	**2**	---	**3**	**4**
Target Flow, MMSCFD	25.000	---	25.000	---	25.000	25.000
Flow Calc, MMSCFD	18.111	---	18.111	---	18.111	18.051
BHP per Stage	1124.6	---	1302.2	---	964.1	877.6
Specific Gravity	0.7500	---	0.7500	---	0.7500	0.7467
Ratio of Sp Ht (N)	1.2321	---	1.2166	---	1.2316	1.2487
Comp Suct (Zs)	0.9903	---	0.9838	---	0.9520	0.8952
Comp Disch (Zd)	0.9856	---	0.9765	---	0.9412	0.8976
Pres Suct Line, psig	20.00	---	N/A	---	N/A	N/A
Pres Suct Flg, psig	19.67	---	73.58	---	246.79	584.22
Pres Disch Flg, psig	76.09	---	253.22	---	600.74	1428.26
Pres Disch Line, psig	N/A	---	N/A	---	N/A	1400.00
Pres Ratio F/F	2.734	---	3.078	---	2.363	2.414
Temp Suct, F	50.00	---	130.00	---	130.00	130.00
Temp Clr Disch, F	130.00	---	130.00	---	130.00	120.00
Cylinder Data:	**Throw 3**	**Throw 5**	**Throw 4**	**Throw 6**	**Throw 1**	**Throw 2**
Cyl Model	24-1/8Z:10	24-1/8Z:10	17-7/8Z:10	17-7/8Z:10	14-1/8Z:10	9-1/4ZK
Cyl Bore, in	24.125	24.125	17.375	17.375	13.625	9.250
Cyl RDP (API), psig	250.0	250.0	577.3	577.3	1154.5	2181.8
Cyl MAWP, psig	275.0	275.0	635.0	635.0	1270.0	2400.0
Cyl Action	DBL	DBL	DBL	DBL	DBL	DBL
Cyl Disp, CFM	3545.8	3545.8	1827.0	1827.0	1113.7	499.6
Pres Suct Intl, psig	15.98	15.98	68.73	68.73	232.20	571.48
Temp Suct Intl, F	60	60	139	139	136	135
Pres Disch Intl, psig	84.46	84.46	267.05	267.05	629.03	1461.49
Temp Disch Intl, F	194	194	285	285	254	255
HE Suct Gas Vel, FPM	9976	9976	7550	7550	7481	4594
HE Disch Gas Vel, FPM	8467	8467	6733	6733	6147	4370
HE Spcrs Used/Max	0/0	0/0	0/6	0/6	0/4	0/4
HE Vol Pkt Avail	0.66+44.90	0.66+44.90	0.76+48.69	0.76+48.69	0.71+40.40	0.36+53.03
Vol Pkt Used	0.00 (V) %	0.00 (V) %	0.00 (V) %	0.00 (V) %	0.00 (V) %	0.00 (V) %
HE Min Clr, %	13.20	13.20	18.03	18.03	24.35	29.34
HE Total Clr, %	13.87	13.87	18.79	18.79	25.06	29.70
CE Suct Gas Vel, FPM	9834	9834	7343	7343	7148	4150
CE Disch Gas Vel, FPM	8347	8347	6548	6548	5874	3947
CE Spcrs Used/Max	0/0	0/0	0/6	0/6	0/4	0/4
CE Min Clr, %	13.59	13.59	18.99	18.99	26.09	33.52
CE Total Clr, %	13.59	13.59	18.99	18.99	26.09	33.52
Suct Vol Eff HE/CE, %	77.7/78.0	77.7/78.0	65.5/65.2	65.5/65.2	69.6/68.5	64.7/60.6
Disch Event HE/CE, ms	11.2/12.8	11.2/12.8	9.5/11.0	9.5/11.0	11.2/12.8	10.7/11.8
Suct Pseudo-Q HE/CE	7.9/7.7	7.9/7.7	5.4/5.1	5.4/5.1	4.0/3.7	2.6/2.1
Gas Rod Ld Comp, %	39.3 C	39.3 C	59.4 C	59.4 C	74.3 C	79.6 C
Gas Rod Ld Tens, %	41.0 T	41.0 T	60.3 T	60.3 T	71.6 T	66.9 T
Gas Rod Ld Total, %	41.4	41.4	61.8	61.8	75.4	75.9
Xhd Pin Deg/%Rvrsl lbf	170/84.0	170/84.0	179/99.0	179/99.0	144/74.5	155/56.6
Flow Calc, MMSCFD	9.055	9.055	9.055	9.055	18.111	18.051
Cyl BHP	562.3	562.3	651.1	651.1	964.1	877.6

01/08/2018 08:17:07 Note: BOLD=Out of Limits, *ITALIC*=Special Appl, ***BOLD***=Review Base: 14.70 psia, 60.0 F Page: 1 of 10
File: C:\Users\Deb\AppData\Local\Microsoft\Windows\Temporary Internet Files\Content.Outlook\1IEDZ846\AP032548.run Gathering Case:7 - Pkg:1

Single Order Results		Order	Predicted	Recommended Limit
FRT	Angular Displacement (deg)	0.5	0.108	1.000
	Angular Displacement (deg)	1.0	0.083	1.000
	Angular Displacement (deg)	1.5	0.077	0.250
	Angular Displacement (deg)	2.0	0.195*	0.150
	Angular Displacement (deg)	2.5	0.078	0.150
	Angular Displacement (deg)	3.0	0.190*	0.150
	Angular Displacement (deg)	6.0	0.044	0.150
I16	Angular Velocity (rpm)	1.0	0.8	40.0
	Angular Velocity (rpm)	2.0	12.8	40.0
	Angular Velocity (rpm)	3.0	9.6	40.0
	Angular Velocity (rpm)	4.0	4.7	40.0
	Angular Velocity (rpm)	5.0	4.1	40.0
	Angular Velocity (rpm)	6.0	20.2	40.0
	Angular Velocity (rpm)	7.0	1.1	40.0
	Angular Velocity (rpm)	8.0	1.8	40.0
	Angular Velocity (rpm)	9.0	0.9	40.0
	Angular Velocity (rpm)	10.0	0.1	40.0
	Angular Velocity (rpm)	11.0	0.7	40.0
	Angular Velocity (rpm)	12.0	2.4	40.0

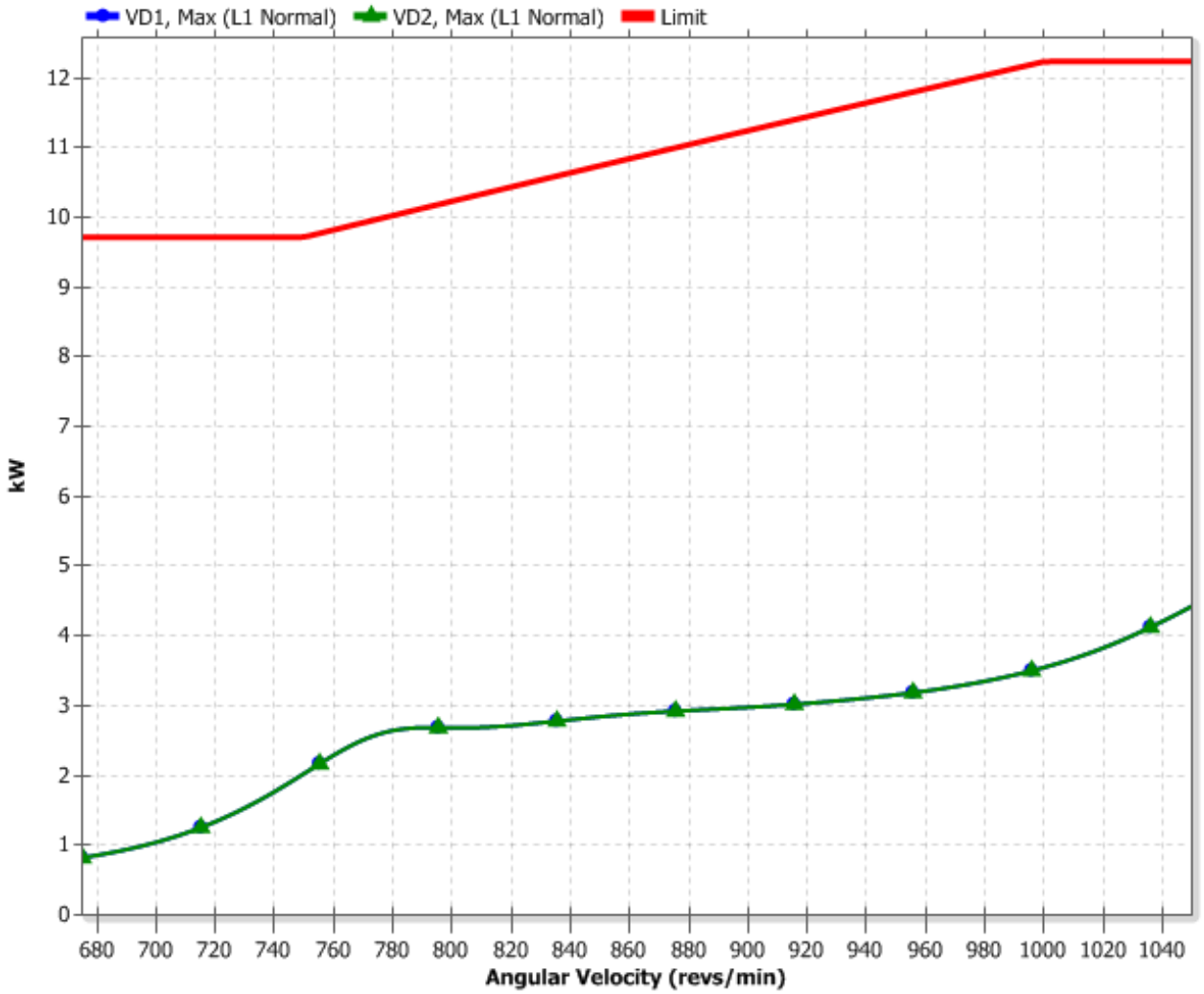
*Vibratory amplitude at the front of the engine crankshaft is used as an indicator for potentially damaging torsional vibrations throughout the system. While the engine excited 2.0 order and 3.0 order vibratory displacement amplitudes at the front of the engine crankshaft are above the recommended limit, additional details of the analysis show that these orders will not cause damage to the driven system.

Combined Order Results		Predicted	Recommended Limit
VD1	Maximum Power Loss (kW)	4.428	12.233
VD2	Maximum Power Loss (kW)	4.428	12.233
EK3	Vibratory Stress (MPa)	40.58	48.00
CPK	Maximum Torque (Nm)	83125	103900
	Minimum Torque (Nm)	-22073	-51900
CSK	Vibratory Torque (Nm)	50627	86404
K4	Vibratory Torque (Nm)	56691	86404
I16	Vibratory Angular Velocity (rpm)	30.5	55.0

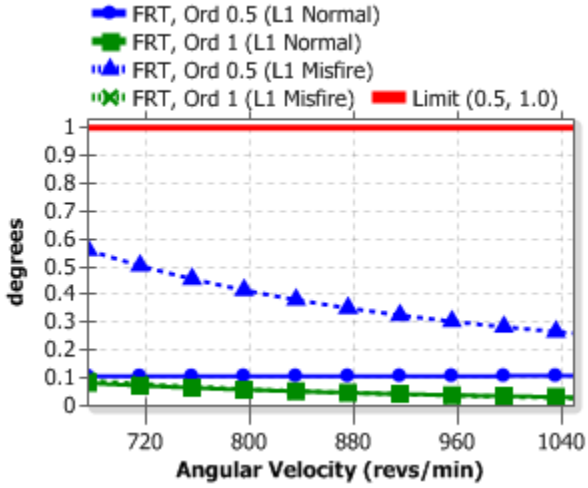
Single Order Misfire Results		Order	Predicted	Recommended Limit
FRT	Angular Displacement (deg)	0.5	0.561	1.000
	Angular Displacement (deg)	1.0	0.092	1.000
	Angular Displacement (deg)	1.5	0.077	0.250
	Angular Displacement (deg)	2.0	0.195*	0.150
	Angular Displacement (deg)	2.5	0.078	0.150
	Angular Displacement (deg)	3.0	0.190*	0.150
	Angular Displacement (deg)	6.0	0.044	0.150

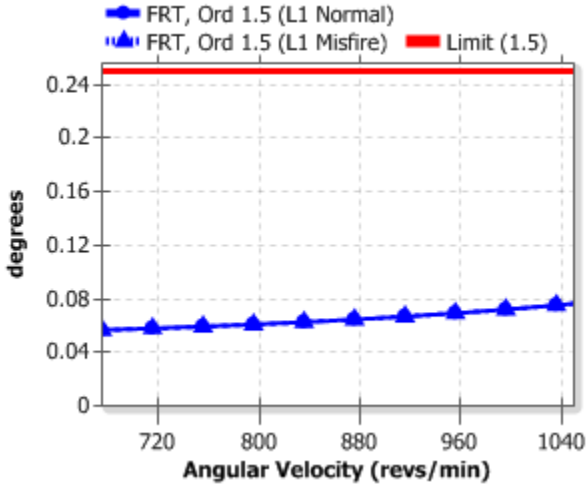
*Vibratory amplitude at the front of the engine crankshaft is used as an indicator for potentially damaging torsional vibrations throughout the system. While the engine excited 2.0 order and 3.0 order vibratory displacement amplitudes at the front of the engine crankshaft are above the recommended limit, additional details of the analysis show that these orders will not cause damage to the driven system.

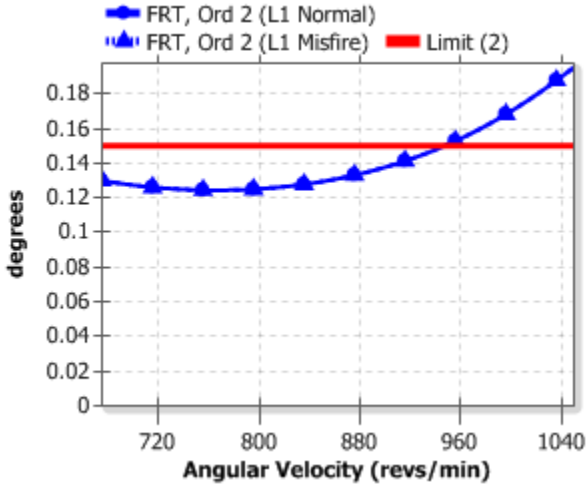
Damper Combined Order Power Loss

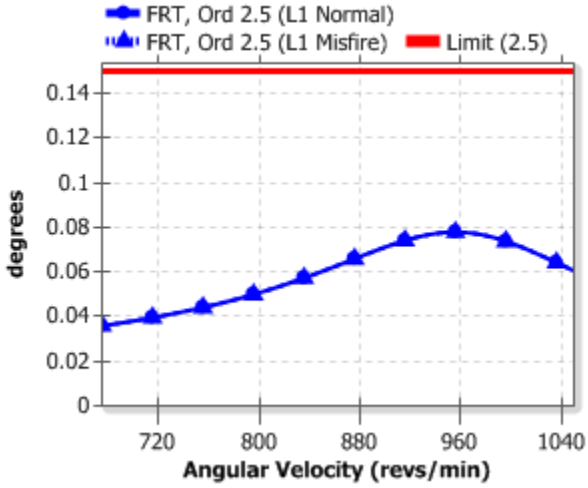


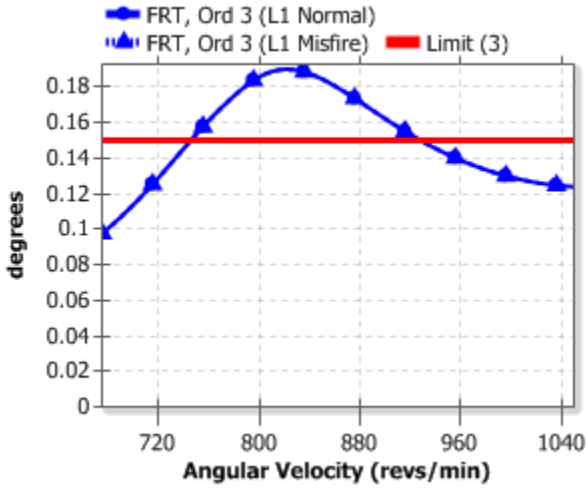
Front Crankshaft Single Order Displacement

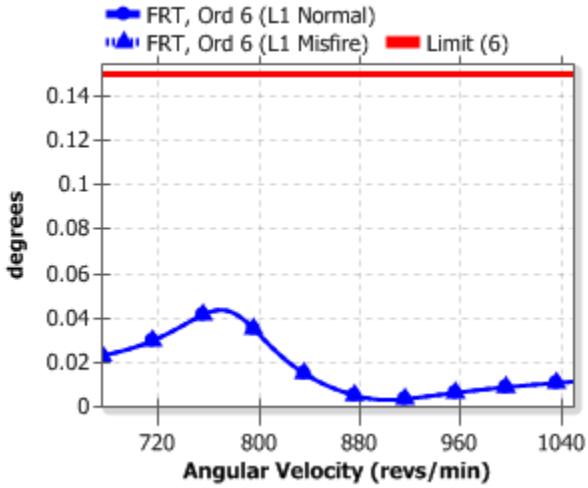




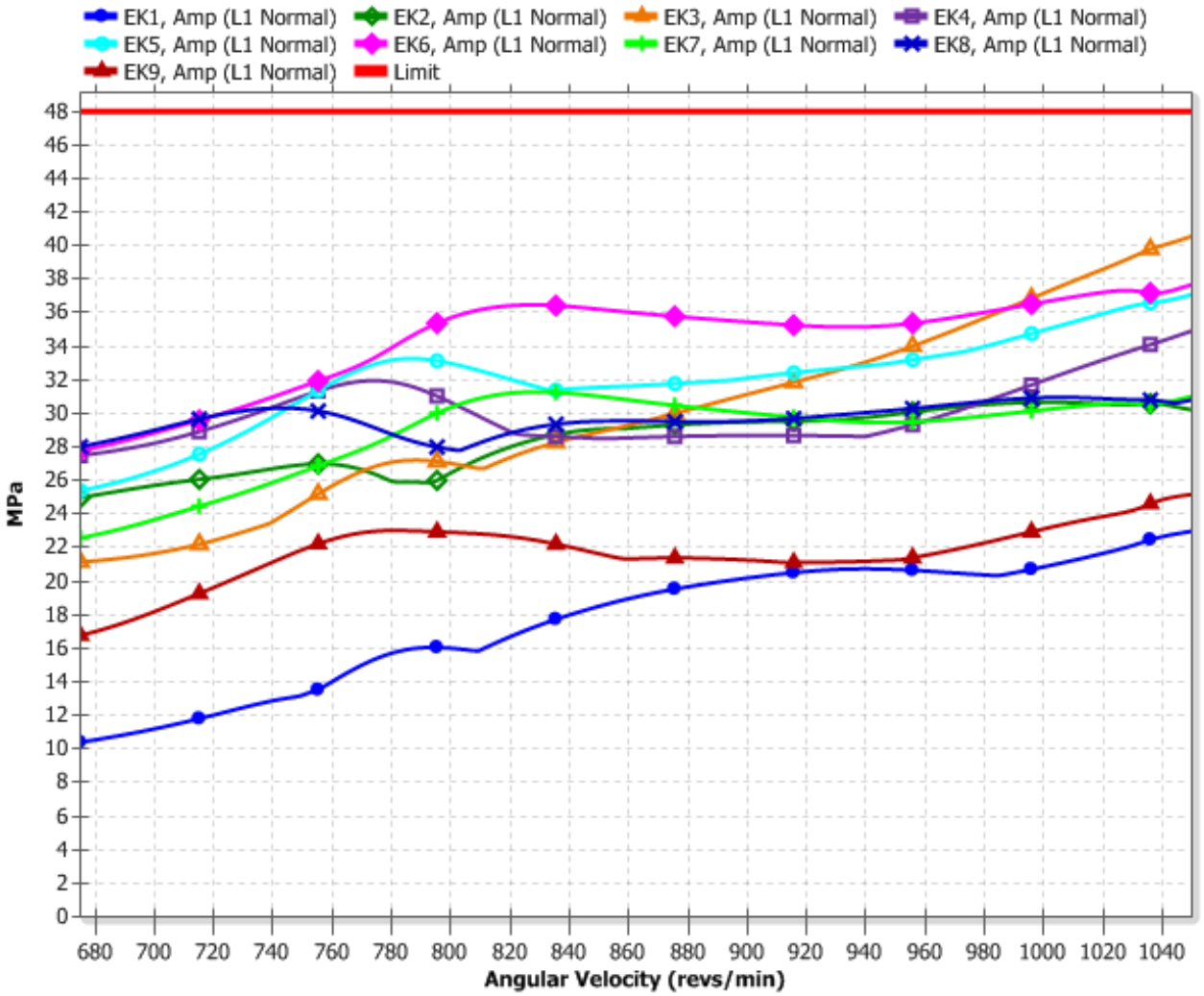




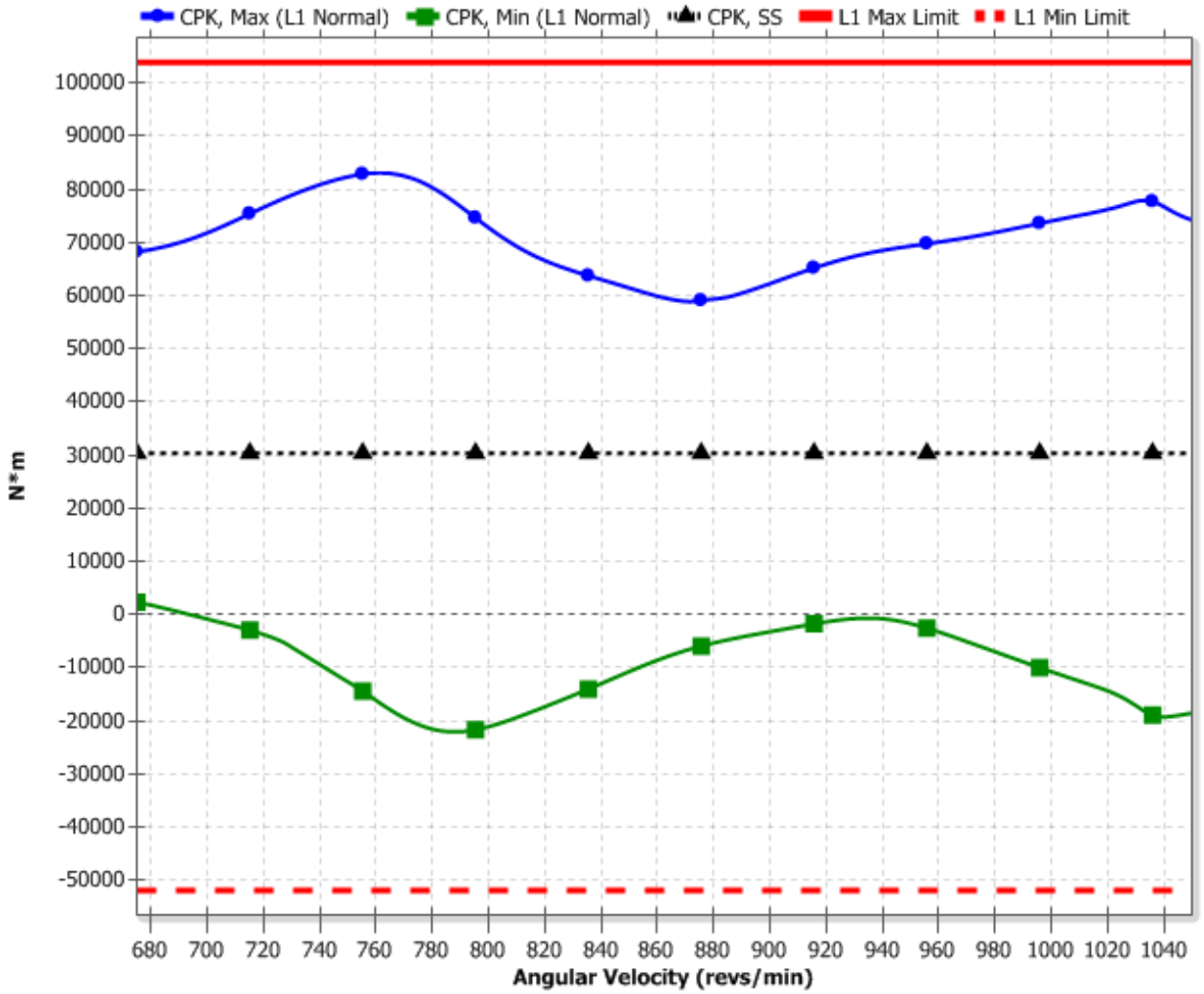




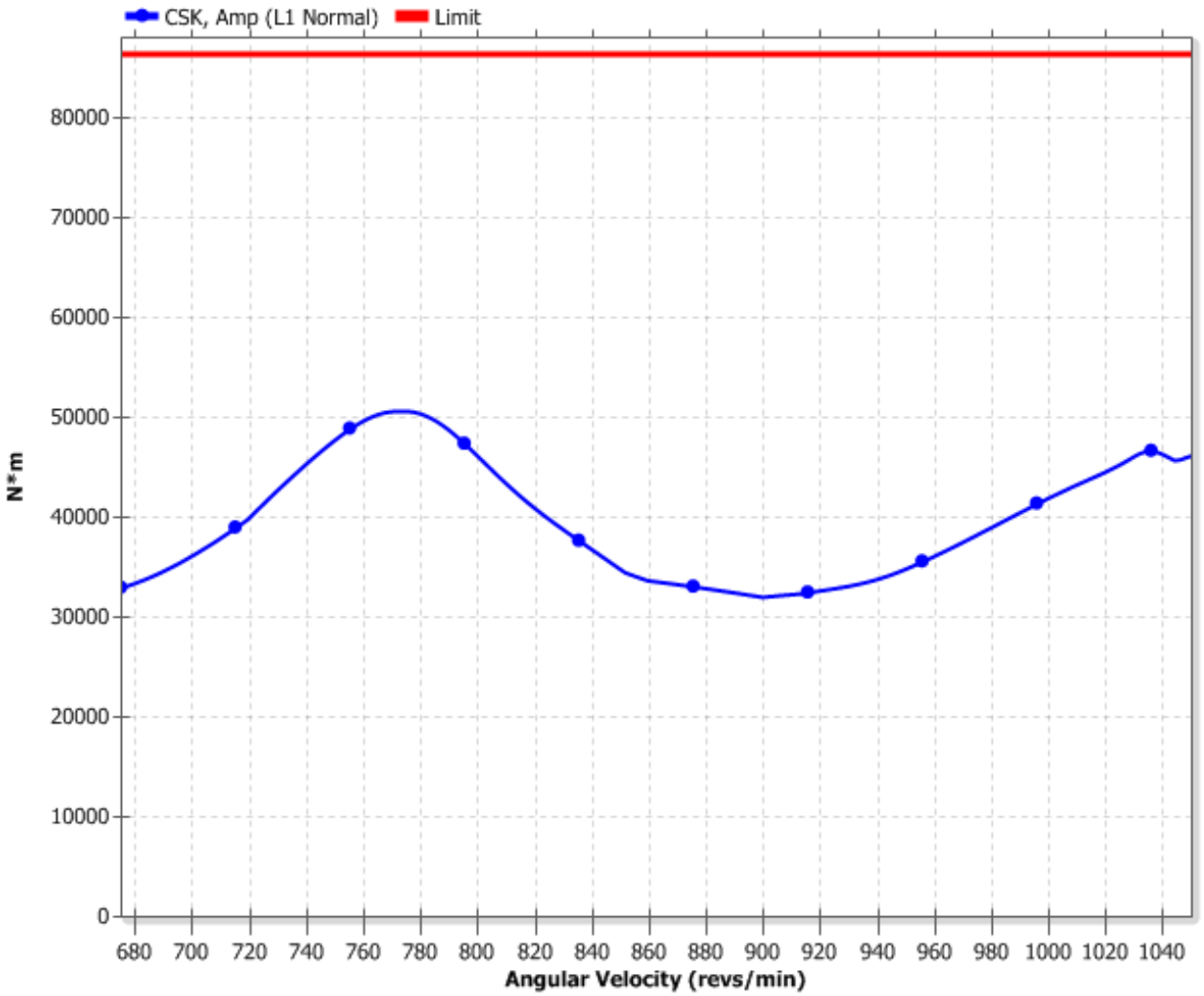
Crankshaft Combined Order Vibratory Stress



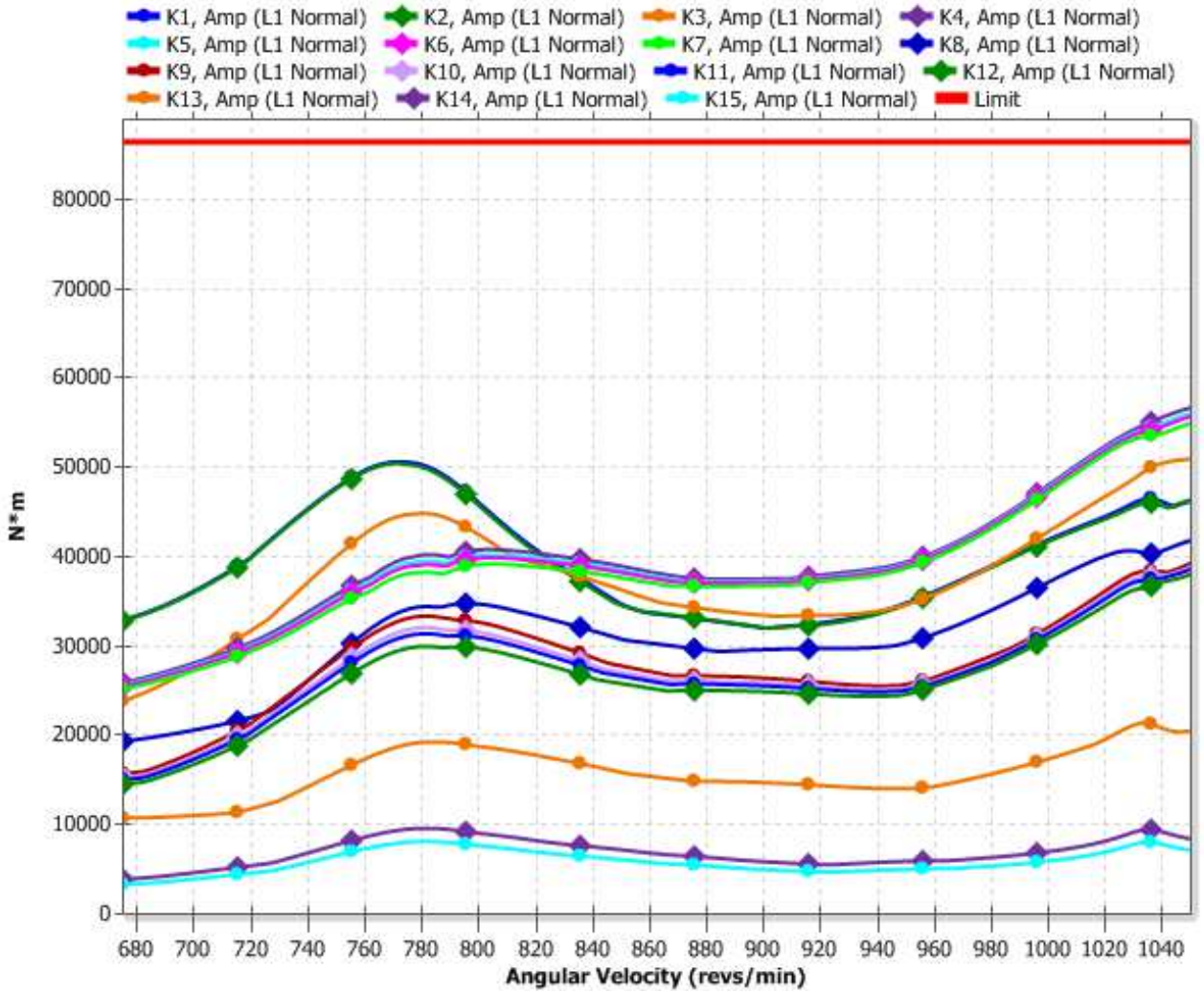
Coupling Combined Order Torque



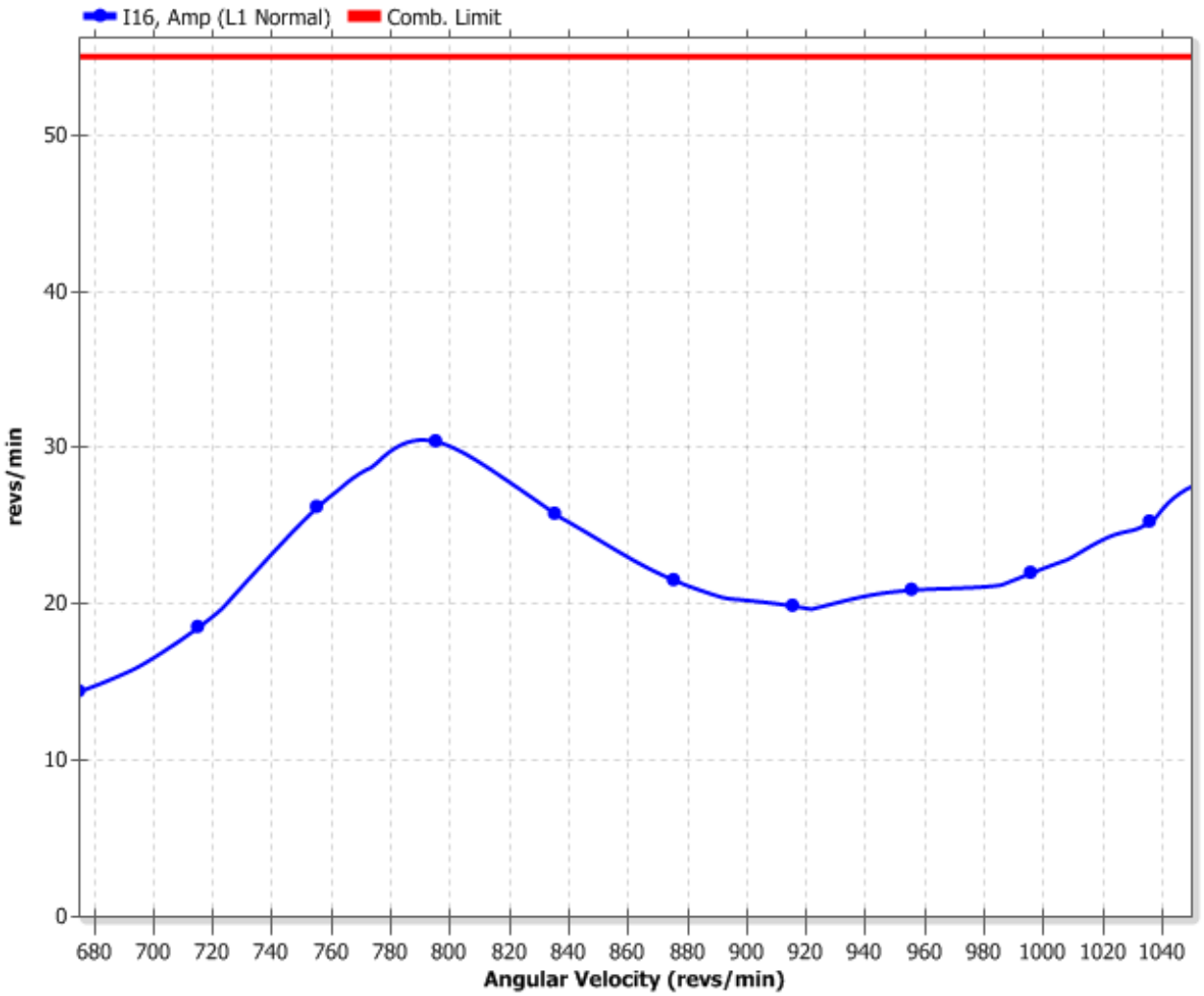
Compressor Stub Combined Order Vibratory Torque



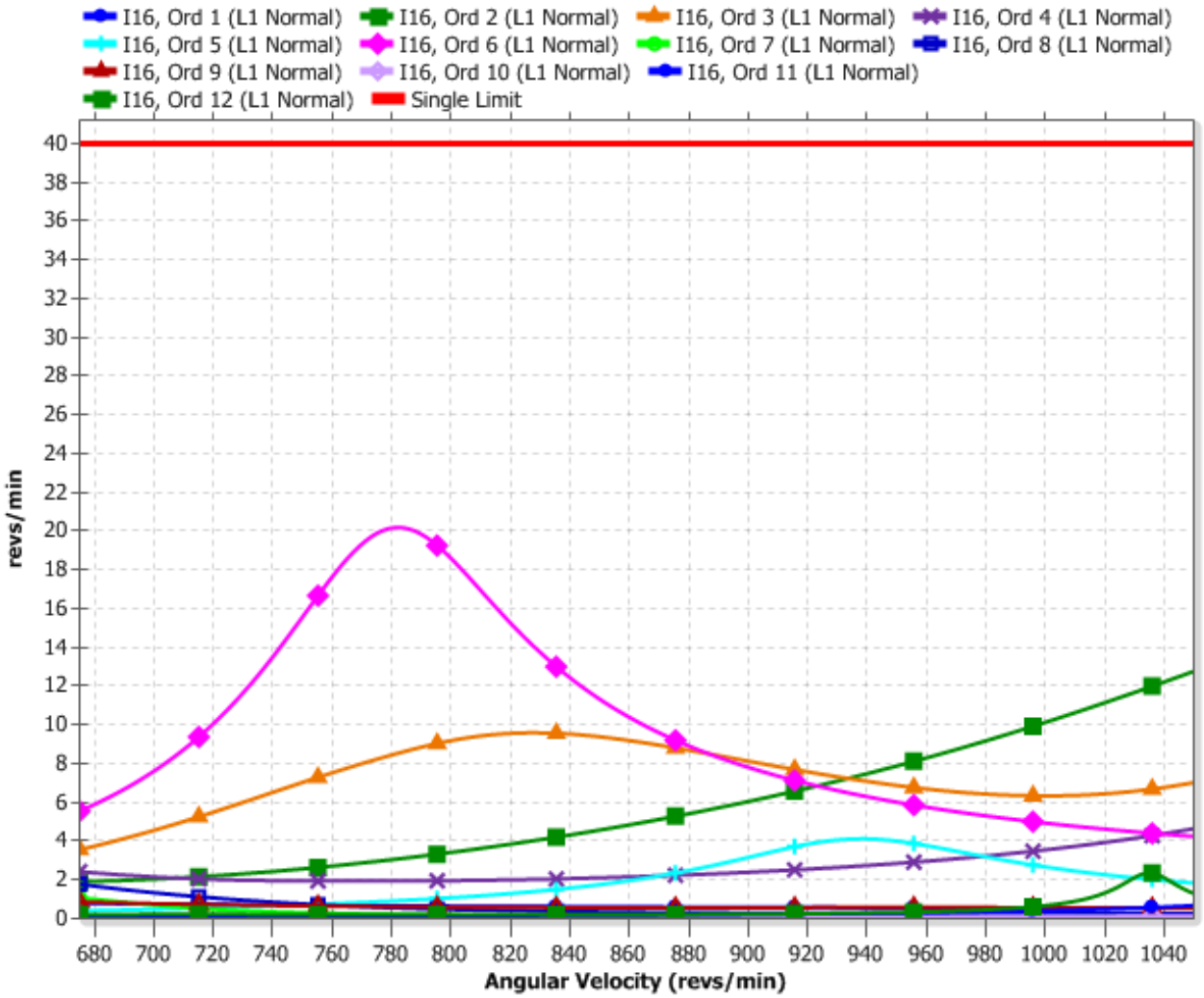
Compressor Shaft Combined Order Vibratory Torque



Aux End Combined Order Velocity



Aux End Single Order Velocity



Load Case #2

Ariel Performance

7.7.4.0	Company:	EXTERRAN	Customer:	XTO ENERGY	
	Project #:	AP032548 Rev:26	Inquiry:		
	Case 24:	Ps-high, Pd-low-3BS-Winter	Project:	XTO ENERGY	

Compressor Data:

Elevation,ft:	3600.00	Barmtr,psia:	12.861	Ambient,F:	110.00	**Driver Data:**	
Frame: **(ELP)**	KBZ/6	Stroke, in:	6.75	Rod Dia, in:	2.875	Type:	Nat. Gas
Max RL Tot, lbf:	150000	Max RL Tens, lbf:	75000	Max RL Comp, lbf:	80000	Mfg:	Caterpillar
Rated RPM:	1000	Rated BHP:	7800.0	Rated PS FPM:	1125.0	Model:	G3616 A4
Calc RPM:	1000.0	BHP:	4885	Calc PS FPM:	1125.0	BHP:	5000
						Avail:	5000

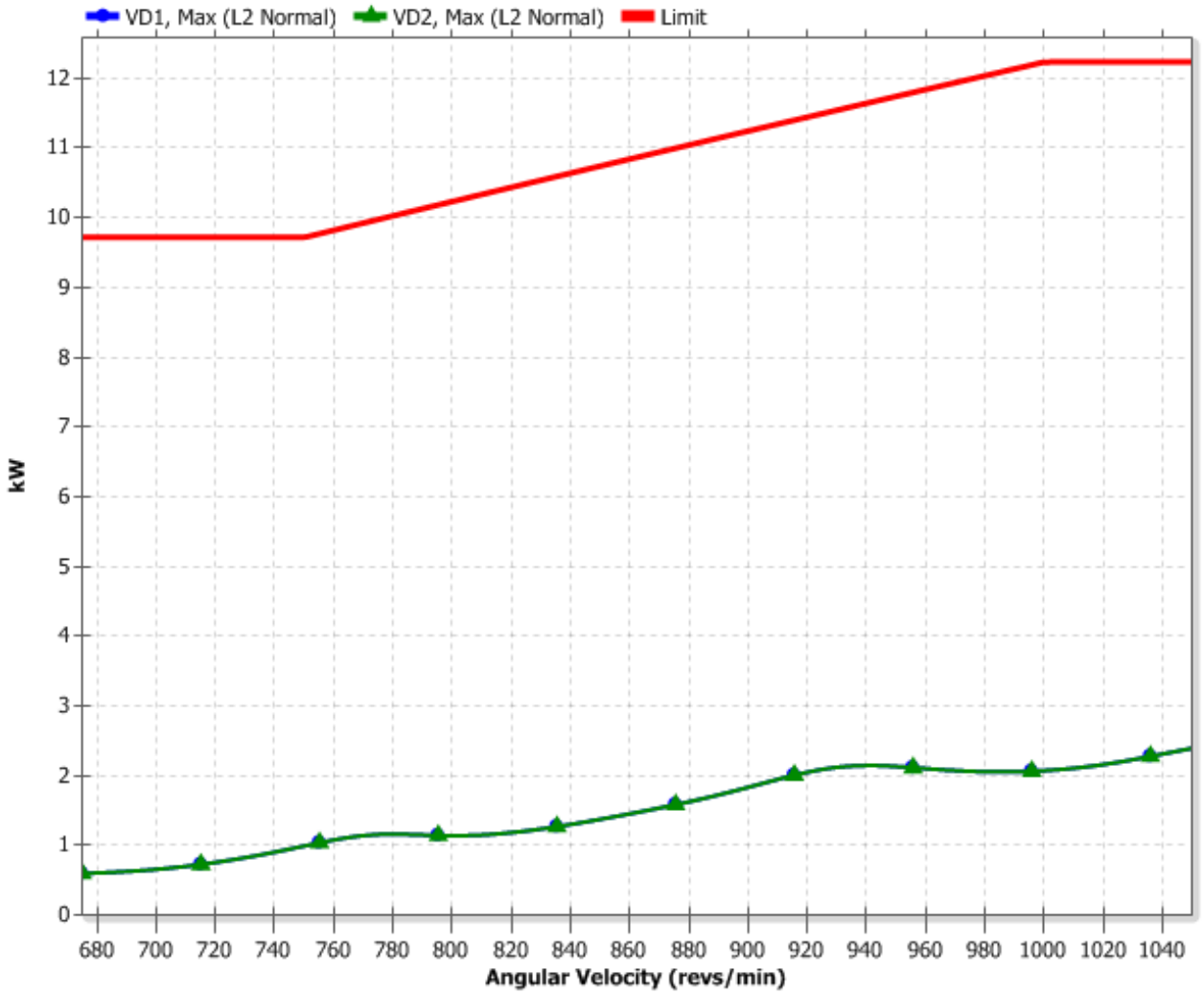
Services	**Service 1**					
Gas Model	VMG					
Stage Data:	**1**	---	**2**	---	**3**	**4**
Target Flow, MMSCFD	25.000	---	25.000	---	25.000	25.000
Flow Calc, MMSCFD	28.560	---	28.560	---	28.560	28.560
BHP per Stage	1652.2	---	1560.1	---	1060.1	543.5
Specific Gravity	0.7914	---	0.7914	---	0.7914	0.7914
Ratio of Sp Ht (N)	1.2316	---	1.2196	---	1.2382	1.2564
Comp Suct (Zs)	0.9753	---	0.9621	---	0.9134	0.8506
Comp Disch (Zd)	0.9644	---	0.9496	---	0.9012	0.8467
Pres Suct Line, psig	60.00	---	N/A	---	N/A	N/A
Pres Suct Flg, psig	59.27	---	162.39	---	394.34	714.11
Pres Disch Flg, psig	166.58	---	402.45	---	729.81	1020.26
Pres Disch Line, psig	N/A	---	N/A	---	N/A	1000.00
Pres Ratio F/F	2.488	---	2.370	---	1.824	1.421
Temp Suct, F	50.00	---	130.00	---	130.00	130.00
Temp Clr Disch, F	130.00	---	130.00	---	130.00	120.00
Cylinder Data:	**Throw 3**	**Throw 5**	**Throw 4**	**Throw 6**	**Throw 1**	**Throw 2**
Cyl Model	24-1/8Z:10	24-1/8Z:10	17-7/8Z:10	17-7/8Z:10	14-1/8Z:10	9-1/4ZK
Cyl Bore, in	24.125	24.125	17.375	17.375	13.625	9.250
Cyl RDP (API), psig	250.0	250.0	577.3	577.3	1154.5	2181.8
Cyl MAWP, psig	275.0	275.0	635.0	635.0	1270.0	2400.0
Cyl Action	DBL	*CE(HEVR)*	DBL	DBL	DBL	DBL
Cyl Disp, CFM	3545.8	1760.2	1827.0	1827.0	1113.7	499.6
Pres Suct Intl, psig	50.48	50.68	151.75	151.75	369.10	696.72
Temp Suct Intl, F	59	64	137	137	134	132
Pres Disch Intl, psig	185.08	184.68	426.95	426.95	769.32	1050.03
Temp Disch Intl, F	183	188	252	252	222	183
HE Suct Gas Vel, FPM	9976	N/A	7550	7550	7481	4594
HE Disch Gas Vel, FPM	8467	N/A	6733	6733	6147	4370
HE Spcrs Used/Max	0/0	N/A	0/6	0/6	0/4	0/4
HE Vol Pkt Avail	0.66+44.90	N/A	0.76+48.69	0.76+48.69	0.71+40.40	0.36+53.03
Vol Pkt Used	40.57 (V) %	N/A %	100.00 (V) %	100.00 (V) %	100.00 (V) %	100.00 (V) %
HE Min Clr, %	13.20	N/A	18.03	18.03	24.35	29.34
HE Total Clr, %	32.08	N/A	67.49	67.49	65.46	82.73
CE Suct Gas Vel, FPM	9834	9834	7343	7343	7148	4150
CE Disch Gas Vel, FPM	8347	8347	6548	6548	5874	3947
CE Spcrs Used/Max	0/0	0/0	0/6	0/6	0/4	0/4
CE Min Clr, %	13.59	13.59	18.99	18.99	26.09	33.52
CE Total Clr, %	13.59	13.59	18.99	18.99	26.09	33.52
Suct Vol Eff HE/CE, %	59.8/80.5	N/A/80.5	24.5/75.6	24.5/75.6	54.2/79.6	69.8/85.9
Disch Event HE/CE, ms	10.0/13.7	N/A/13.7	6.3/13.5	6.3/13.5	11.0/15.7	14.7/18.7
Suct Pseudo-Q HE/CE	8.5/8.3	N/A/8.2	4.7/5.5	4.7/5.5	4.5/4.1	2.9/2.4
Gas Rod Ld Comp, %	77.4 C	6.1 C	82.9 C	82.9 C	76.1 C	35.4 C
Gas Rod Ld Tens, %	80.4 T	75.4 T	83.2 T	83.2 T	71.0 T	22.5 T
Gas Rod Ld Total, %	81.5	41.0	85.8	85.8	76.1	30.1
Xhd Pin Deg/%Rvrsl lbf	161/94.8	119/56.3	143/85.3	143/85.3	151/97.8	154/78.4
Flow Calc, MMSCFD	18.363	10.198	14.280	14.280	28.560	28.560
Cyl BHP	1041.0	611.2	780.0	780.0	1060.1	543.5

Single Order Results		Order	Predicted	Recommended Limit
FRT	Angular Displacement (deg)	0.5	0.119	1.000
	Angular Displacement (deg)	1.0	0.304	1.000
	Angular Displacement (deg)	1.5	0.084	0.250
	Angular Displacement (deg)	2.0	0.108	0.150
	Angular Displacement (deg)	2.5	0.087	0.150
	Angular Displacement (deg)	3.0	0.108	0.150
	Angular Displacement (deg)	5.0	0.033	0.150
I16	Angular Velocity (rpm)	1.0	2.2	40.0
	Angular Velocity (rpm)	2.0	7.1	40.0
	Angular Velocity (rpm)	3.0	5.0	40.0
	Angular Velocity (rpm)	4.0	2.7	40.0
	Angular Velocity (rpm)	5.0	14.1	40.0
	Angular Velocity (rpm)	6.0	13.2	40.0
	Angular Velocity (rpm)	7.0	2.3	40.0
	Angular Velocity (rpm)	8.0	3.3	40.0
	Angular Velocity (rpm)	9.0	0.6	40.0
	Angular Velocity (rpm)	10.0	0.4	40.0
	Angular Velocity (rpm)	11.0	0.6	40.0
	Angular Velocity (rpm)	12.0	2.1	40.0

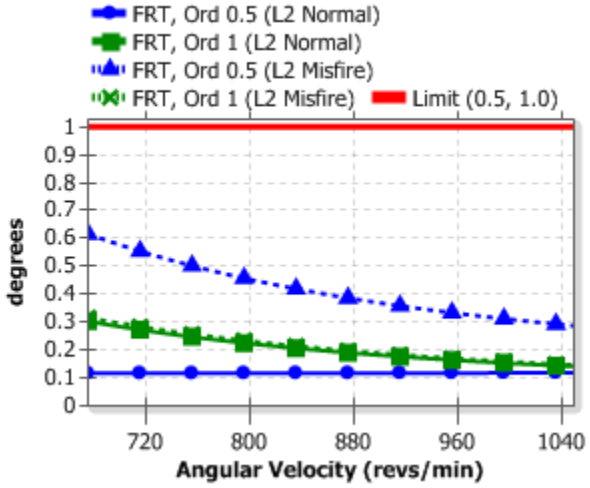
Combined Order Results		Predicted	Recommended Limit
VD1	Maximum Power Loss (kW)	2.393	12.233
VD2	Maximum Power Loss (kW)	2.393	12.233
EK8	Vibratory Stress (MPa)	33.69	48.00
CPK	Maximum Torque (Nm)	72538	103900
	Minimum Torque (Nm)	-6710	-51900
CSK	Vibratory Torque (Nm)	39423	86404
K1	Vibratory Torque (Nm)	39416	86404
I16	Vibratory Angular Velocity (rpm)	24.9	55.0

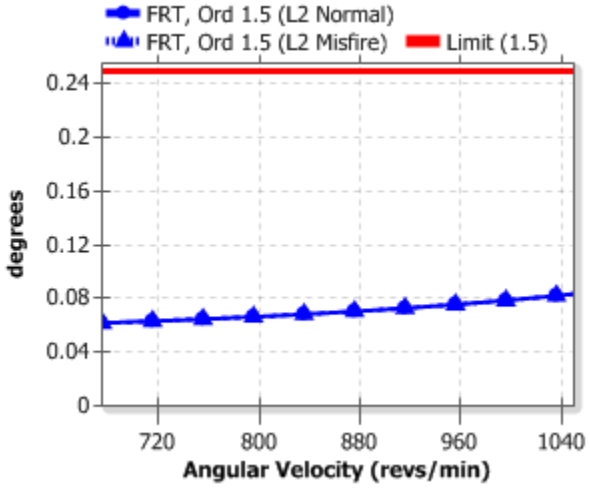
Single Order Misfire Results		Order	Predicted	Recommended Limit
FRT	Angular Displacement (deg)	0.5	0.617	1.000
	Angular Displacement (deg)	1.0	0.317	1.000
	Angular Displacement (deg)	1.5	0.084	0.250
	Angular Displacement (deg)	2.0	0.108	0.150
	Angular Displacement (deg)	2.5	0.087	0.150
	Angular Displacement (deg)	3.0	0.108	0.150
	Angular Displacement (deg)	5.0	0.033	0.150

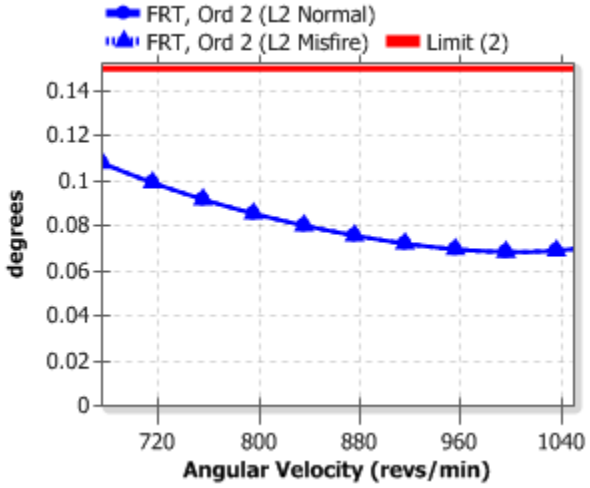
Damper Combined Order Power Loss

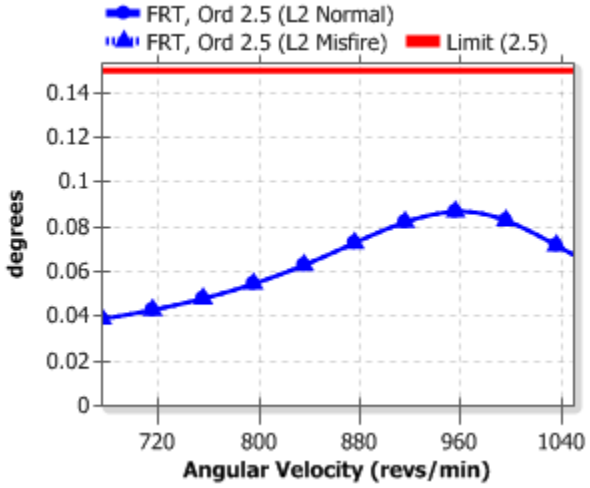


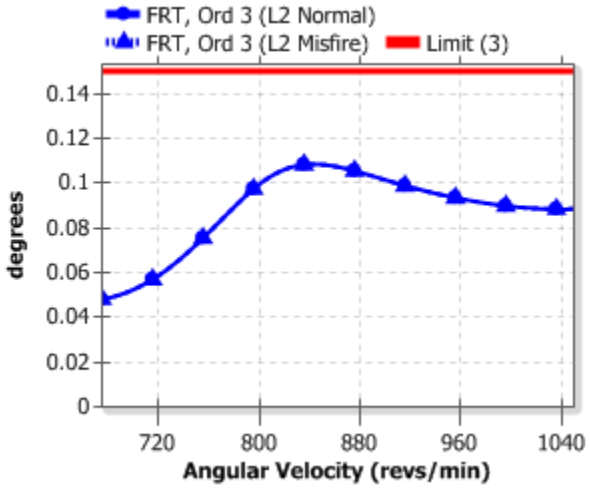
Front Crankshaft Single Order Displacement

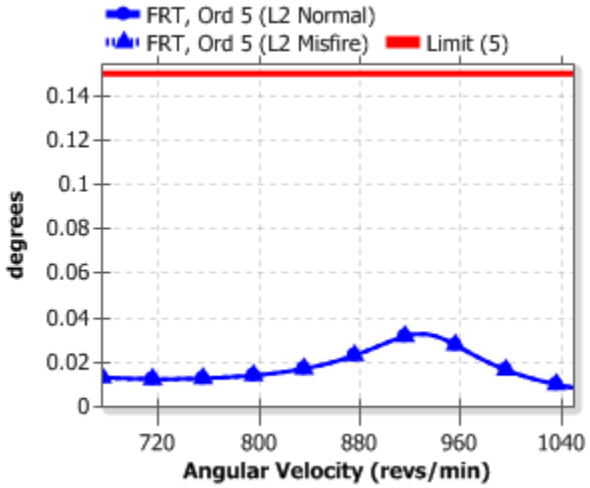




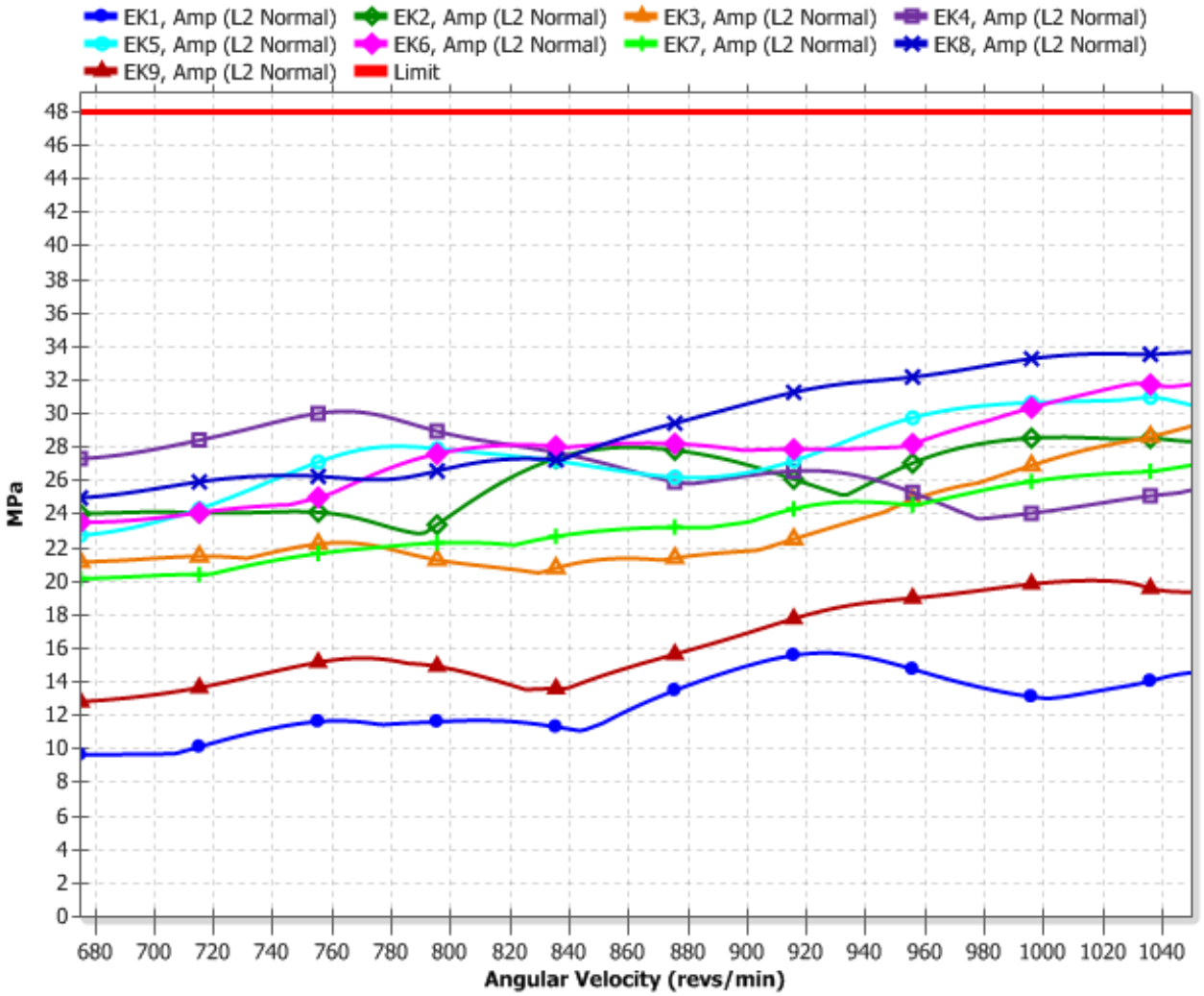




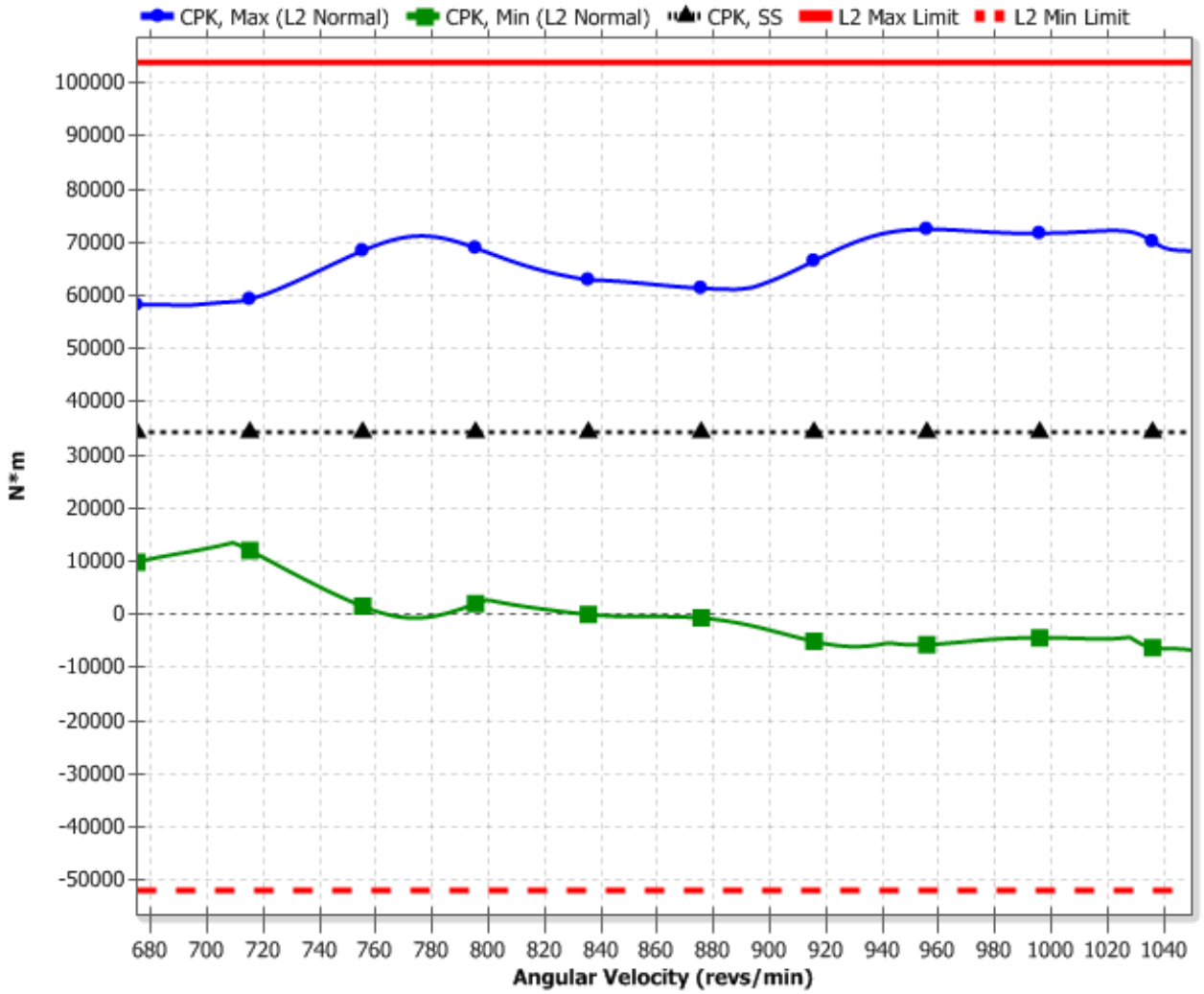




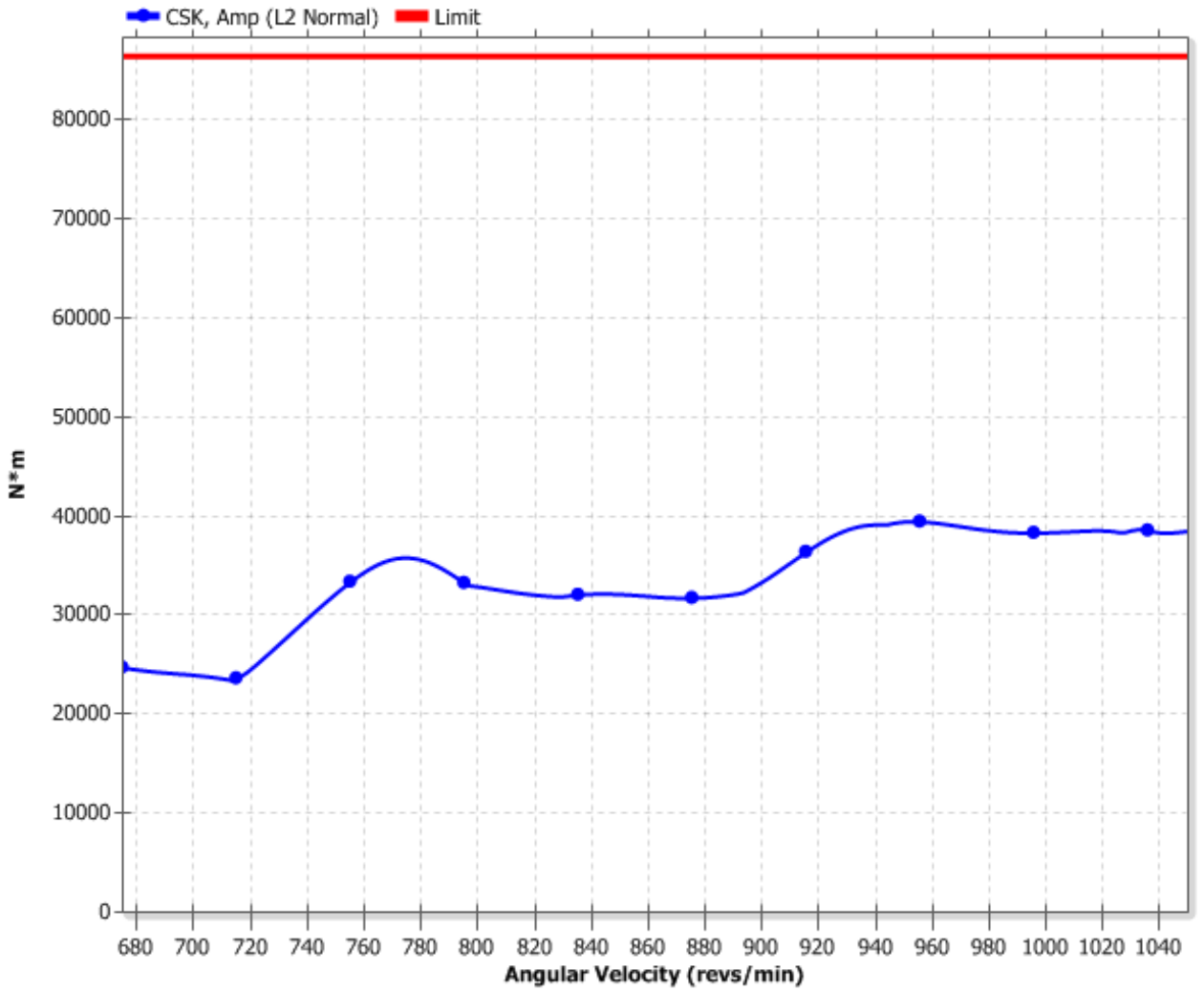
Crankshaft Combined Order Vibratory Stress



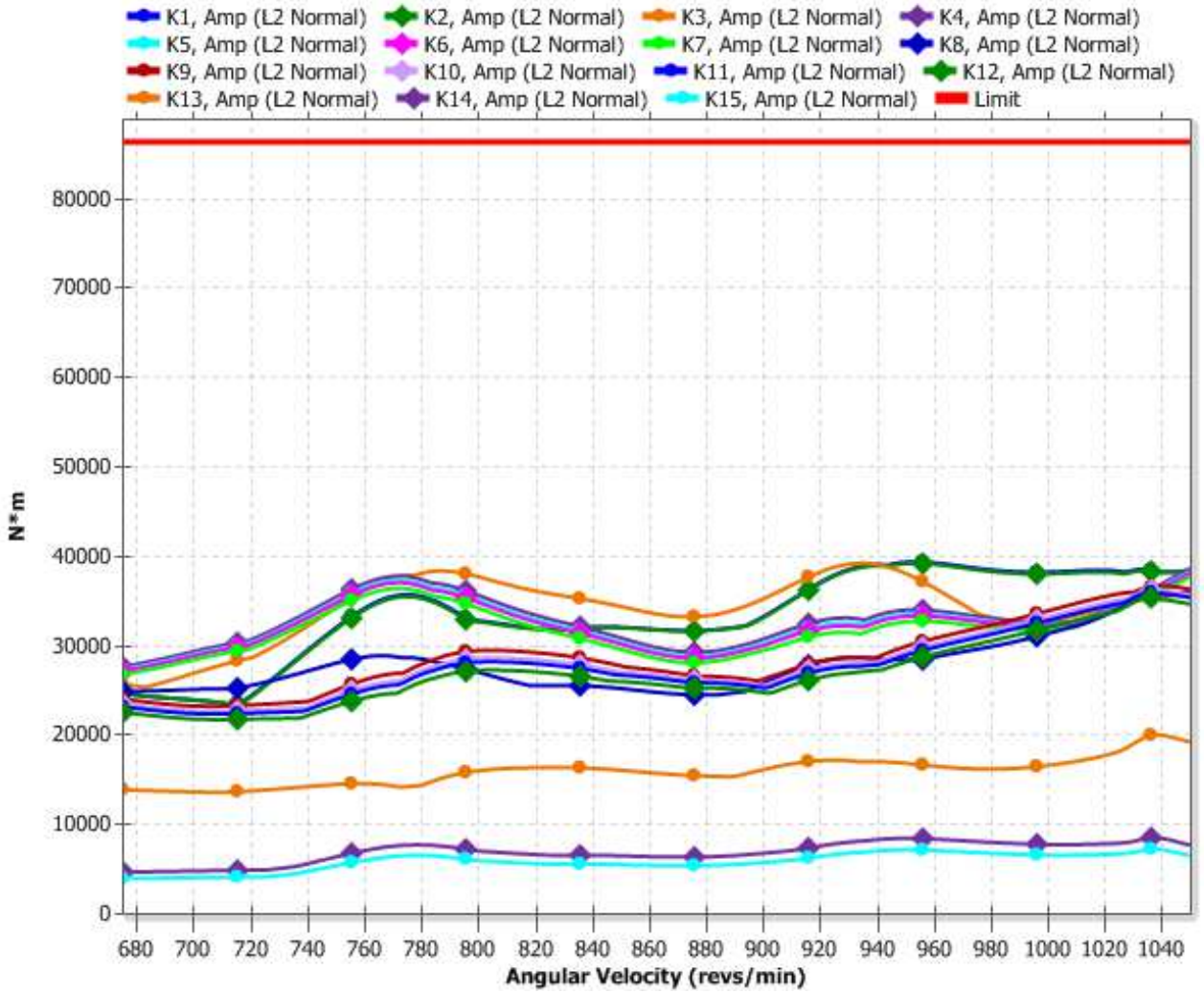
Coupling Combined Order Torque



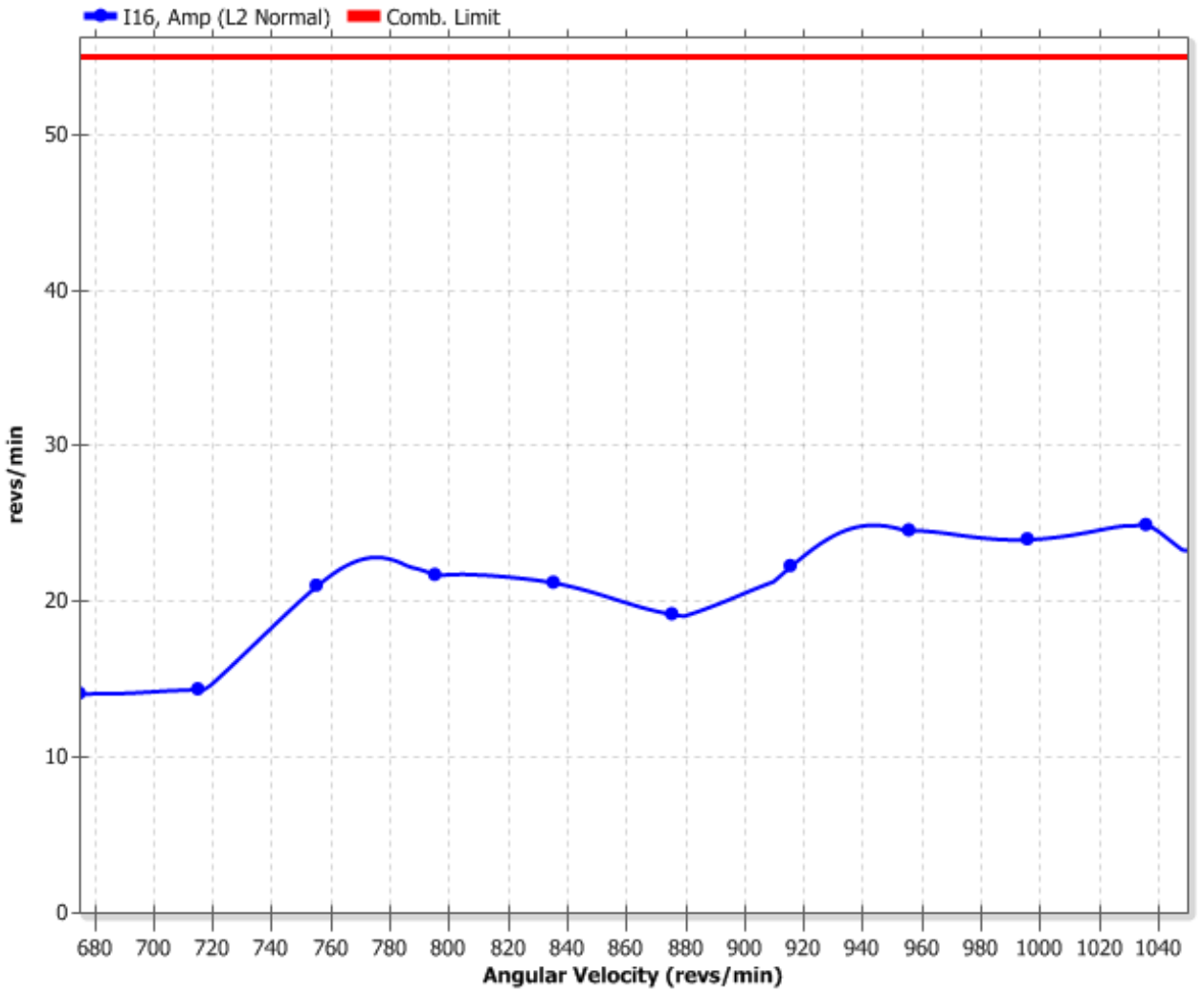
Compressor Stub Combined Order Vibratory Torque



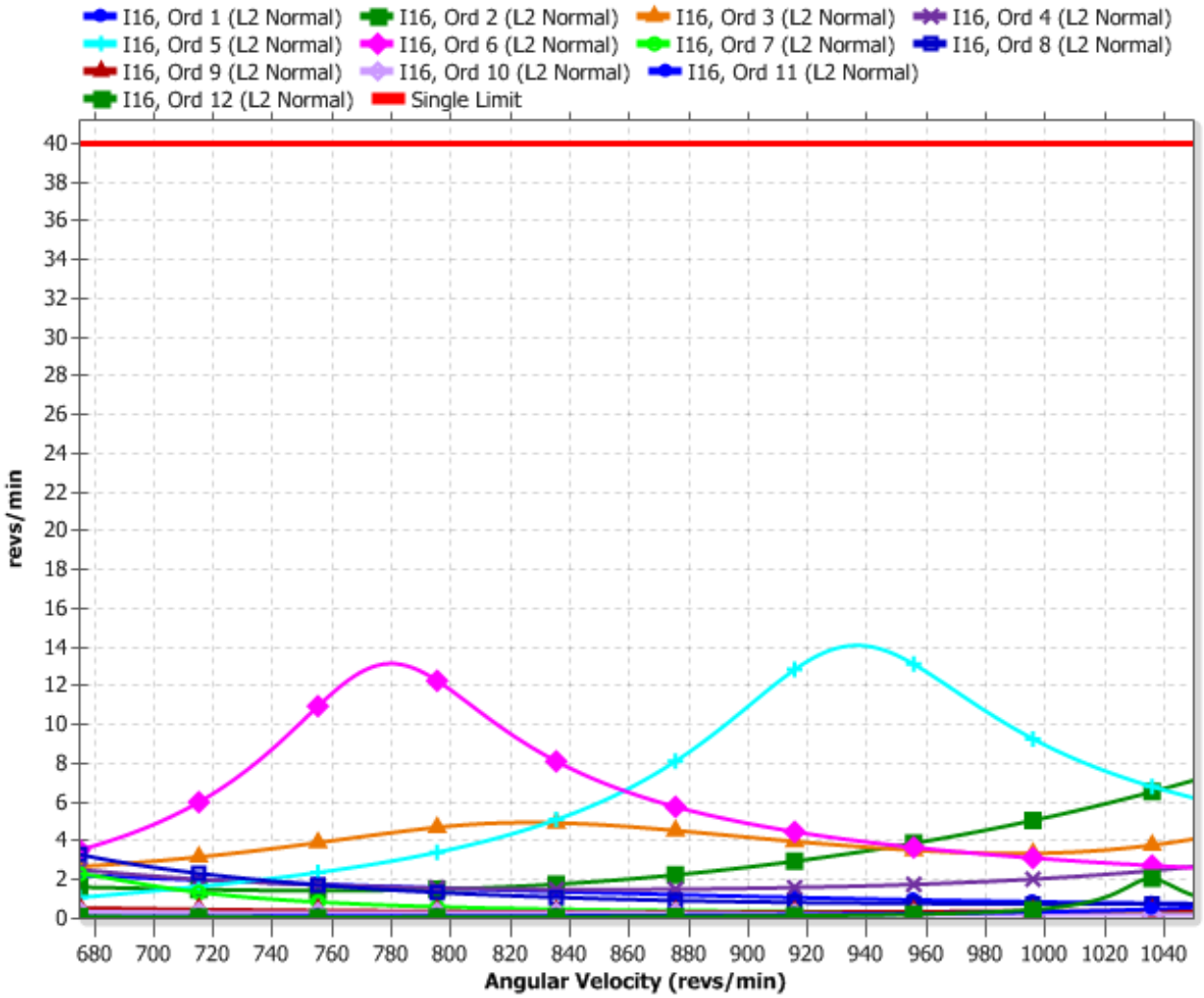
Compressor Shaft Combined Order Vibratory Torque



Aux End Combined Order Velocity



Aux End Single Order Velocity



Load Case #3

Ariel Performance

7.7.4.0	Company:	EXTERRAN	Customer:	XTO ENERGY
	Project #:	AP032548 Rev:26	Inquiry:	
	Case 36:	Ps-high Pd-high-WC XY-Winter	Project:	XTO ENERGY

Compressor Data:

Elevation,ft:	3600.00	Barmtr,psia:	12.861	Ambient,F:	110.00	**Driver Data:**	
Frame: **(ELP)**	KBZ/6	Stroke, in:	6.75	Rod Dia, in:	2.875	Type:	Nat. Gas
Max RL Tot, lbf:	150000	Max RL Tens, lbf:	75000	Max RL Comp, lbf:	80000	Mfg:	Caterpillar
Rated RPM:	1000	Rated BHP:	7800.0	Rated PS FPM:	1125.0	Model:	G3616 A4
Calc RPM:	1000.0	BHP:	4004	Calc PS FPM:	1125.0	BHP:	5000
						Avail:	5000

Services	**Service 1**					
Gas Model	VMG					
Stage Data:	**1**	---	**2**	---	**3**	**4**
Target Flow, MMSCFD	25.000	---	25.000	---	25.000	25.000
Flow Calc, MMSCFD	20.727	---	20.727	---	20.727	20.727
BHP per Stage	1164.0	---	1076.5	---	964.6	730.1
Specific Gravity	0.6968	---	0.6968	---	0.6968	0.6968
Ratio of Sp Ht (N)	1.2502	---	1.2369	---	1.2493	1.2660
Comp Suct (Zs)	0.9796	---	0.9705	---	0.9378	0.8769
Comp Disch (Zd)	0.9724	---	0.9633	---	0.9296	0.8828
Pres Suct Line, psig	60.00	---	N/A	---	N/A	N/A
Pres Suct Flg, psig	59.27	---	154.07	---	346.12	735.72
Pres Disch Flg, psig	158.62	---	355.70	---	755.87	1428.26
Pres Disch Line, psig	N/A	---	N/A	---	N/A	1400.00
Pres Ratio F/F	2.377	---	2.208	---	2.141	1.925
Temp Suct, F	50.00	---	130.00	---	130.00	130.00
Temp Clr Disch, F	130.00	---	130.00	---	130.00	120.00
Cylinder Data:	**Throw 3**	**Throw 5**	**Throw 4**	**Throw 6**	**Throw 1**	**Throw 2**
Cyl Model	24-1/8Z:10	24-1/8Z:10	17-7/8Z:10	17-7/8Z:10	14-1/8Z:10	9-1/4ZK
Cyl Bore, in	24.125	24.125	17.375	17.375	13.625	9.250
Cyl RDP (API), psig	250.0	250.0	577.3	577.3	1154.5	2181.8
Cyl MAWP, psig	275.0	275.0	635.0	635.0	1270.0	2400.0
Cyl Action	*CE(HEVR)*	*CE(HEVR)*	*CE(HEVR)*	*CE(HEVR)*	DBL	DBL
Cyl Disp, CFM	1760.2	1760.2	900.8	900.8	1113.7	499.6
Pres Suct Intl, psig	51.74	51.74	145.50	145.50	327.08	720.47
Temp Suct Intl, F	63	63	139	139	136	134
Pres Disch Intl, psig	173.76	173.76	374.10	374.10	789.55	1461.05
Temp Disch Intl, F	187	187	250	250	247	227
HE Suct Gas Vel, FPM	N/A	N/A	N/A	N/A	7481	4594
HE Disch Gas Vel, FPM	N/A	N/A	N/A	N/A	6147	4370
HE Spcrs Used/Max	N/A	N/A	N/A	N/A	0/4	0/4
HE Vol Pkt Avail	N/A	N/A	N/A	N/A	0.71+40.40	0.36+53.03
Vol Pkt Used	N/A %	N/A %	N/A %	N/A %	100.00 (V) %	100.00 (V) %
HE Min Clr, %	N/A	N/A	N/A	N/A	24.35	29.34
HE Total Clr, %	N/A	N/A	N/A	N/A	65.46	82.73
CE Suct Gas Vel, FPM	9834	9834	7343	7343	7148	4150
CE Disch Gas Vel, FPM	8347	8347	6548	6548	5874	3947
CE Spcrs Used/Max	0/0	0/0	0/6	0/6	0/4	0/4
CE Min Clr, %	13.59	13.59	18.99	18.99	26.09	33.52
CE Total Clr, %	13.59	13.59	18.99	18.99	26.09	33.52
Suct Vol Eff HE/CE, %	N/A/82.1	N/A/82.1	N/A/78.6	N/A/78.6	39.9/73.5	40.8/73.4
Disch Event HE/CE, ms	N/A/14.2	N/A/14.2	N/A/14.2	N/A/14.2	8.5/14.0	9.2/14.7
Suct Pseudo-Q HE/CE	N/A/7.2	N/A/7.2	N/A/4.8	N/A/4.8	3.6/3.5	2.4/2.0
Gas Rod Ld Comp, %	5.4 C	5.4 C	4.2 C	4.2 C	87.1 C	68.2 C
Gas Rod Ld Tens, %	68.8 T	68.8 T	66.6 T	66.6 T	83.0 T	53.6 T
Gas Rod Ld Total, %	37.3	37.3	35.5	35.5	87.9	63.2
Xhd Pin Deg/%Rvrsl lbf	134/58.3	134/58.3	129/54.6	129/54.6	164/96.1	170/62.2
Flow Calc, MMSCFD	10.363	10.363	10.363	10.363	20.727	20.727
Cyl BHP	582.0	582.0	538.3	538.3	964.6	730.1

Single Order Results		Order	Predicted	Recommended Limit
FRT	Angular Displacement (deg)	0.5	0.102	1.000
	Angular Displacement (deg)	1.0	0.542	1.000
	Angular Displacement (deg)	1.5	0.072	0.250
	Angular Displacement (deg)	2.0	0.279*	0.150
	Angular Displacement (deg)	2.5	0.073	0.150
	Angular Displacement (deg)	3.0	0.192*	0.150
	Angular Displacement (deg)	6.0	0.026	0.150
I16	Angular Velocity (rpm)	1.0	4.1	40.0
	Angular Velocity (rpm)	2.0	16.1	40.0
	Angular Velocity (rpm)	3.0	10.4	40.0
	Angular Velocity (rpm)	4.0	1.3	40.0
	Angular Velocity (rpm)	5.0	6.8	40.0
	Angular Velocity (rpm)	6.0	12.2	40.0
	Angular Velocity (rpm)	7.0	0.4	40.0
	Angular Velocity (rpm)	8.0	2.2	40.0
	Angular Velocity (rpm)	9.0	0.7	40.0
	Angular Velocity (rpm)	10.0	0.2	40.0
	Angular Velocity (rpm)	11.0	0.4	40.0
	Angular Velocity (rpm)	12.0	4.2	40.0

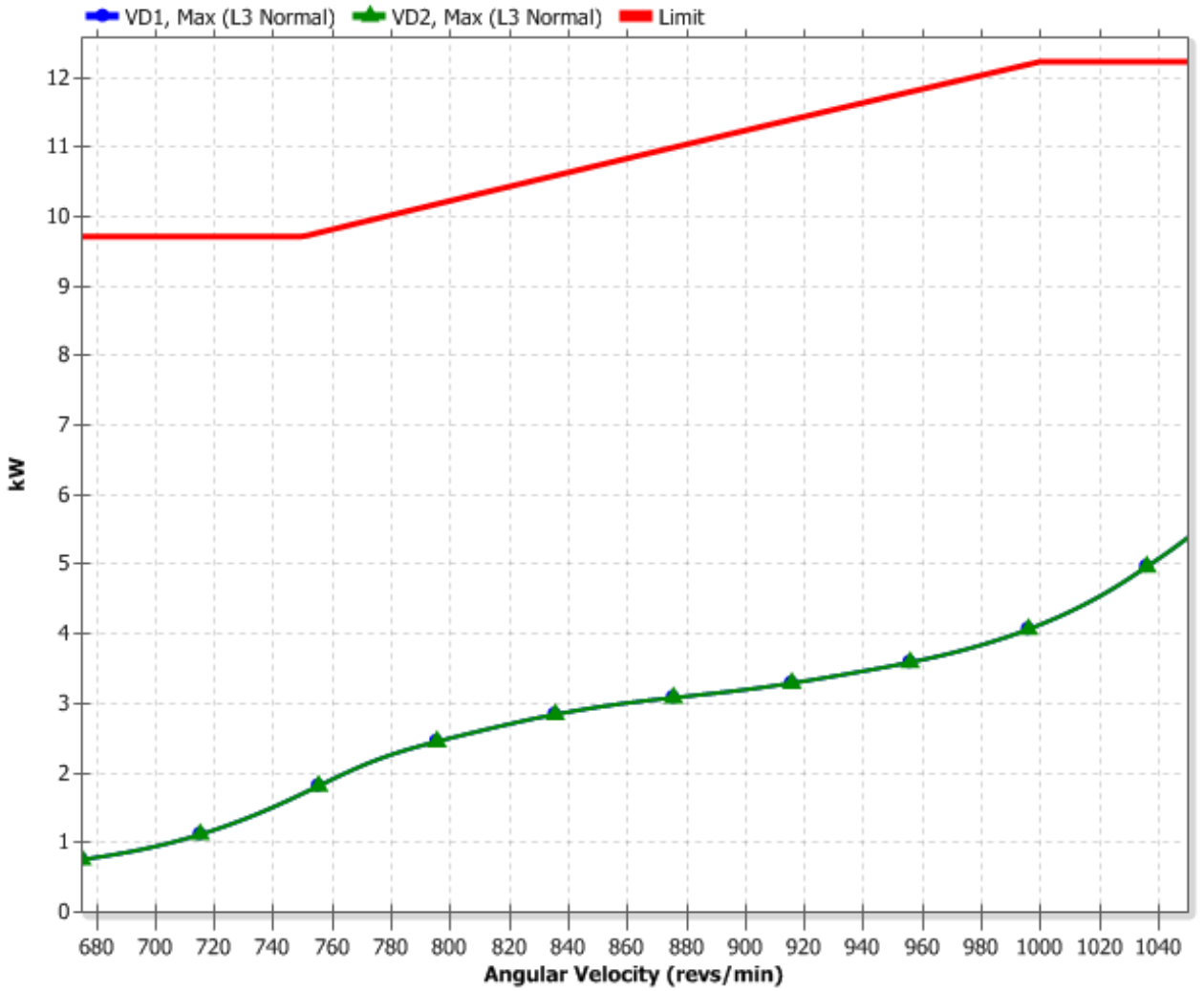
*Vibratory amplitude at the front of the engine crankshaft is used as an indicator for potentially damaging torsional vibrations throughout the system. While the engine excited 2.0 order and 3.0 order vibratory displacement amplitudes at the front of the engine crankshaft are above the recommended limit, additional details of the analysis show that these orders will not cause damage to the driven system.

Combined Order Results		Predicted	Recommended Limit
VD1	Maximum Power Loss (kW)	5.391	12.233
VD2	Maximum Power Loss (kW)	5.391	12.233
EK3	Vibratory Stress (MPa)	44.24	48.00
CPK	Maximum Torque (Nm)	84226	103900
	Minimum Torque (Nm)	-23474	-51900
CSK	Vibratory Torque (Nm)	52481	86404
K4	Vibratory Torque (Nm)	60102	86404
I16	Vibratory Angular Velocity (rpm)	28.8	55.0

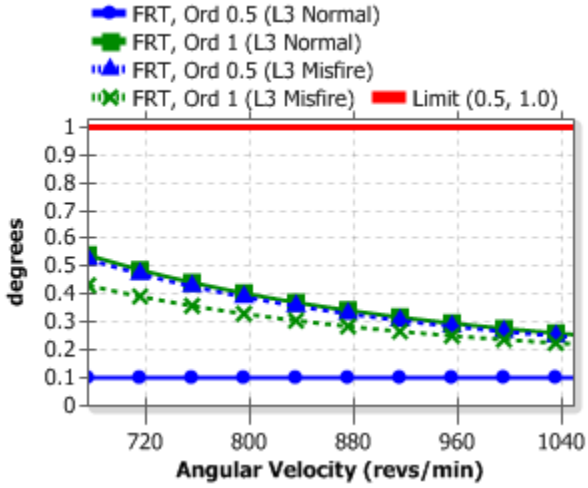
Single Order Misfire Results		Order	Predicted	Recommended Limit
FRT	Angular Displacement (deg)	0.5	0.527	1.000
	Angular Displacement (deg)	1.0	0.433	1.000
	Angular Displacement (deg)	1.5	0.072	0.250
	Angular Displacement (deg)	2.0	0.279*	0.150
	Angular Displacement (deg)	2.5	0.073	0.150
	Angular Displacement (deg)	3.0	0.192*	0.150
	Angular Displacement (deg)	6.0	0.026	0.150

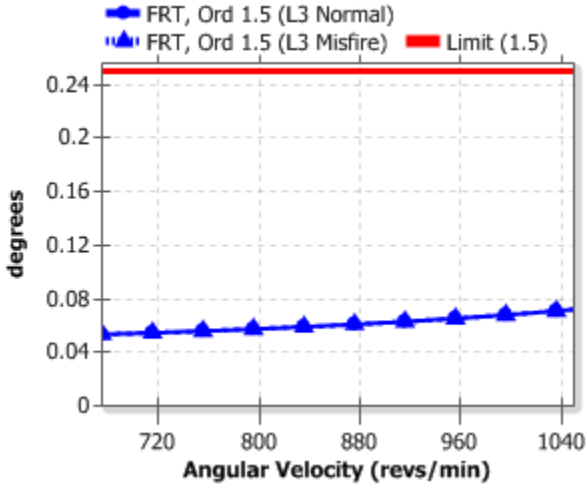
*Vibratory amplitude at the front of the engine crankshaft is used as an indicator for potentially damaging torsional vibrations throughout the system. While the engine excited 2.0 order and 3.0 order vibratory displacement amplitudes at the front of the engine crankshaft are above the recommended limit, additional details of the analysis show that these orders will not cause damage to the driven system.

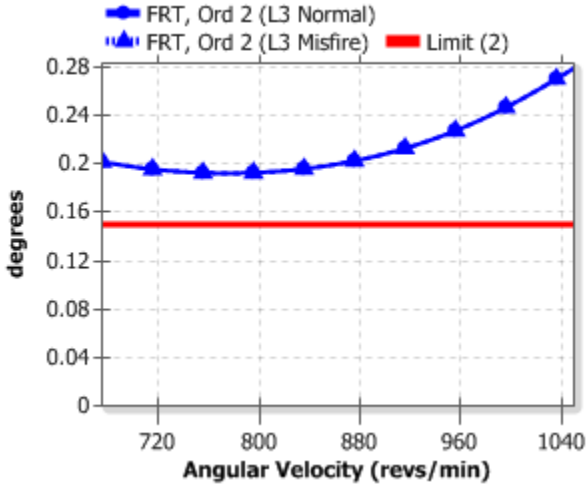
Damper Combined Order Power Loss

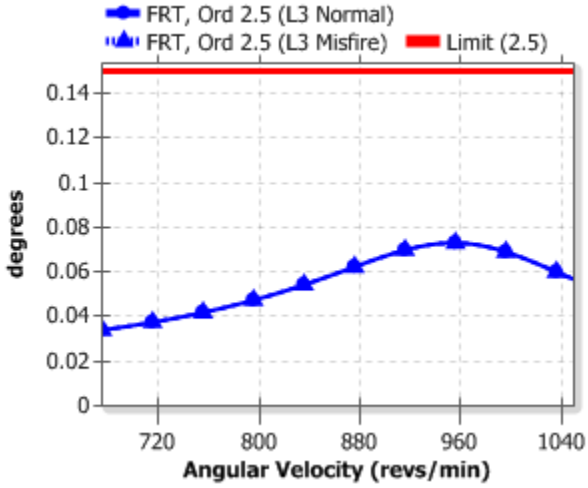


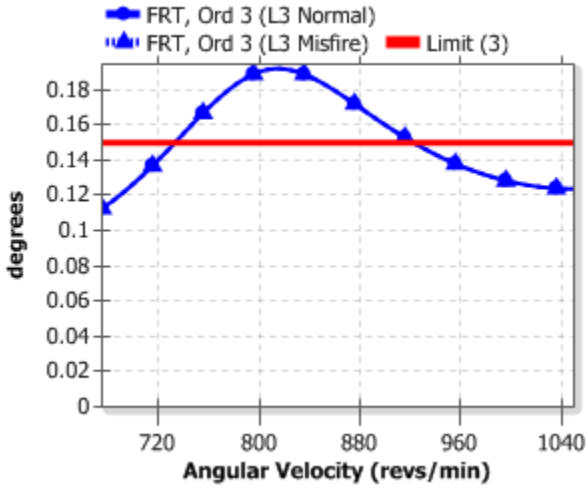
Front Crankshaft Single Order Displacement

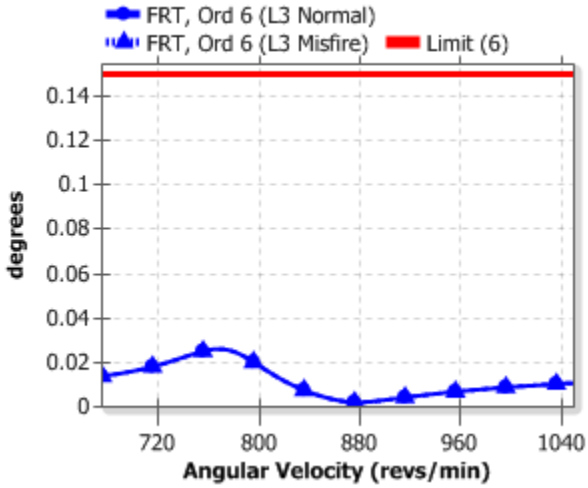




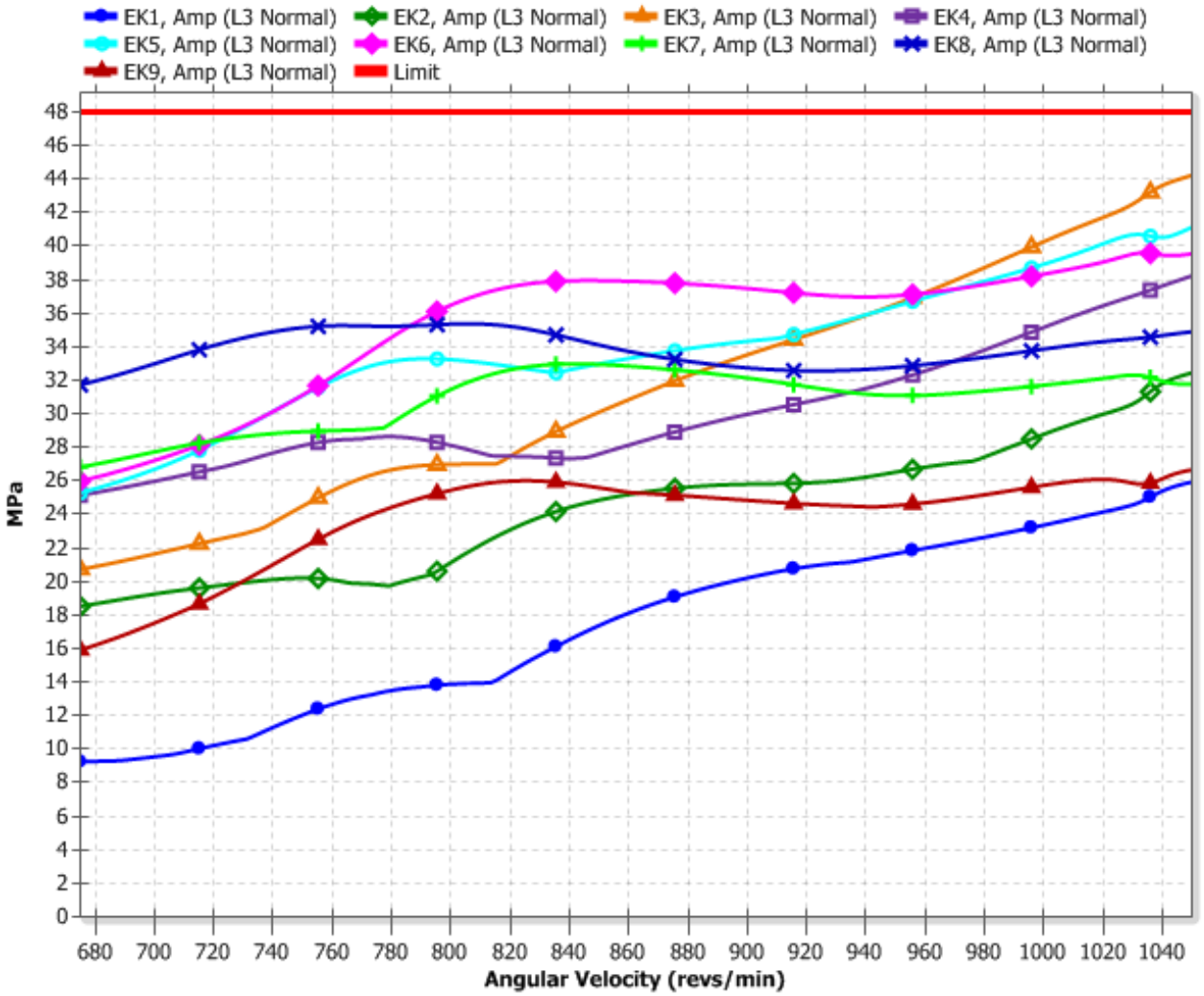




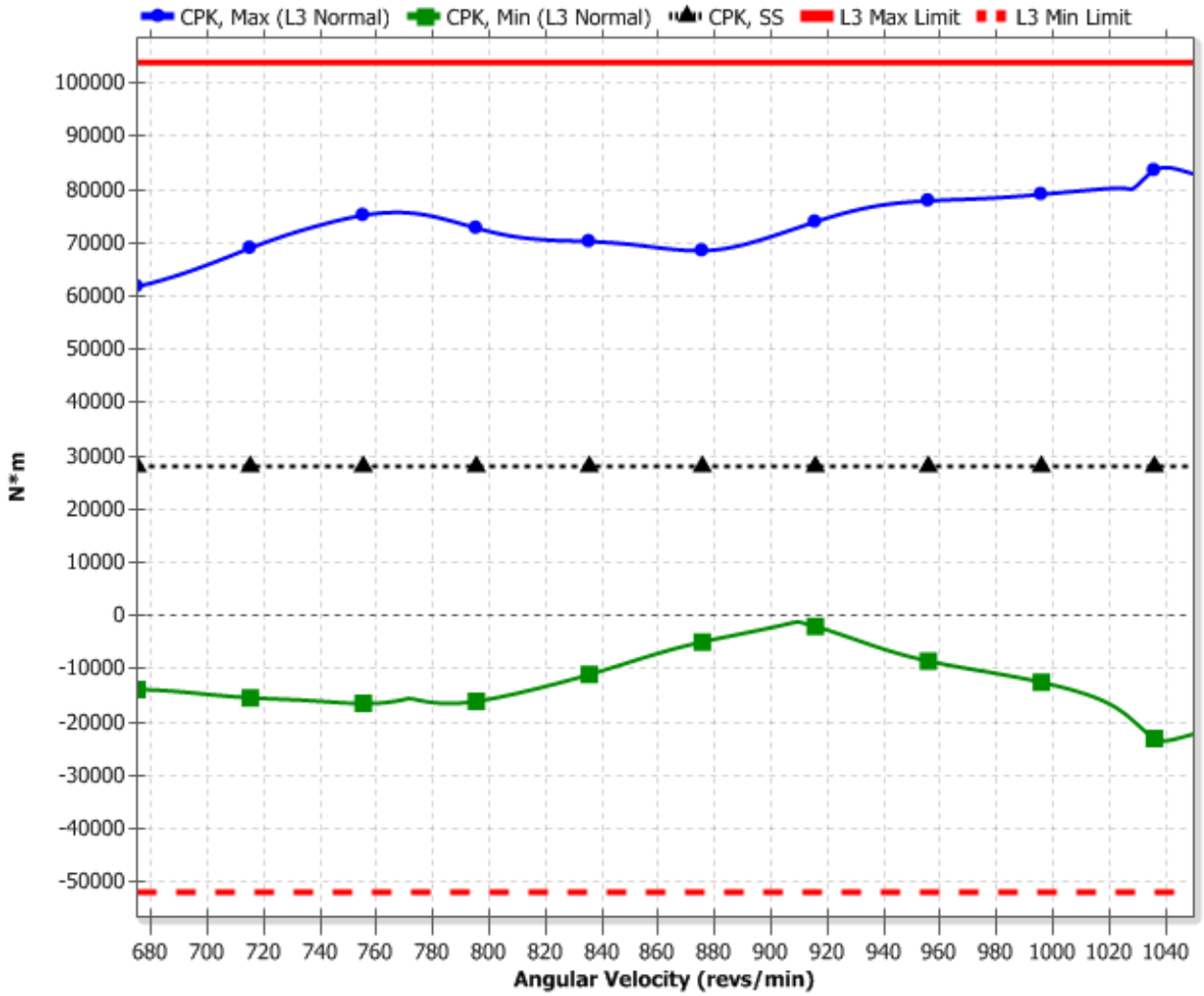




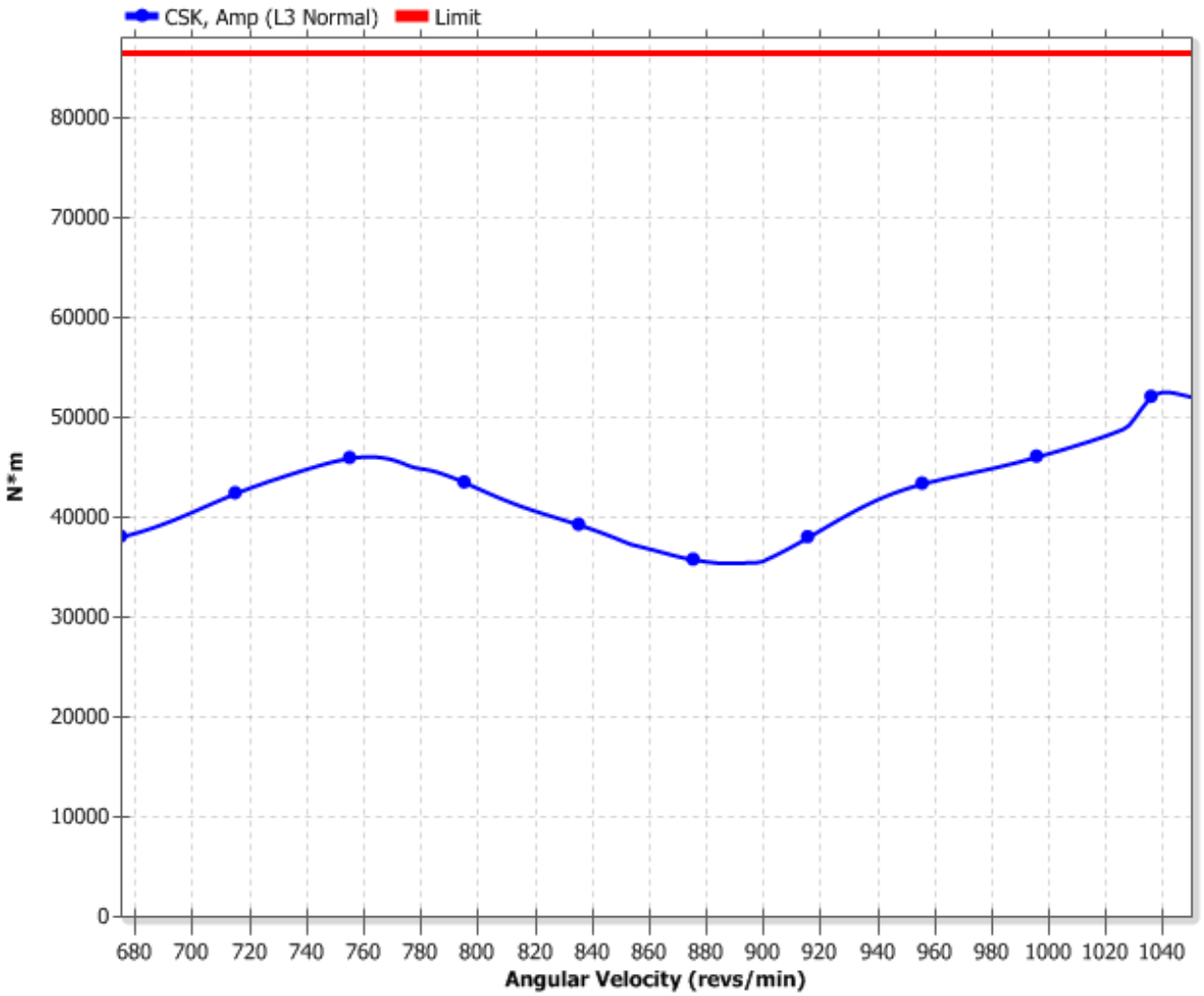
Crankshaft Combined Order Vibratory Stress



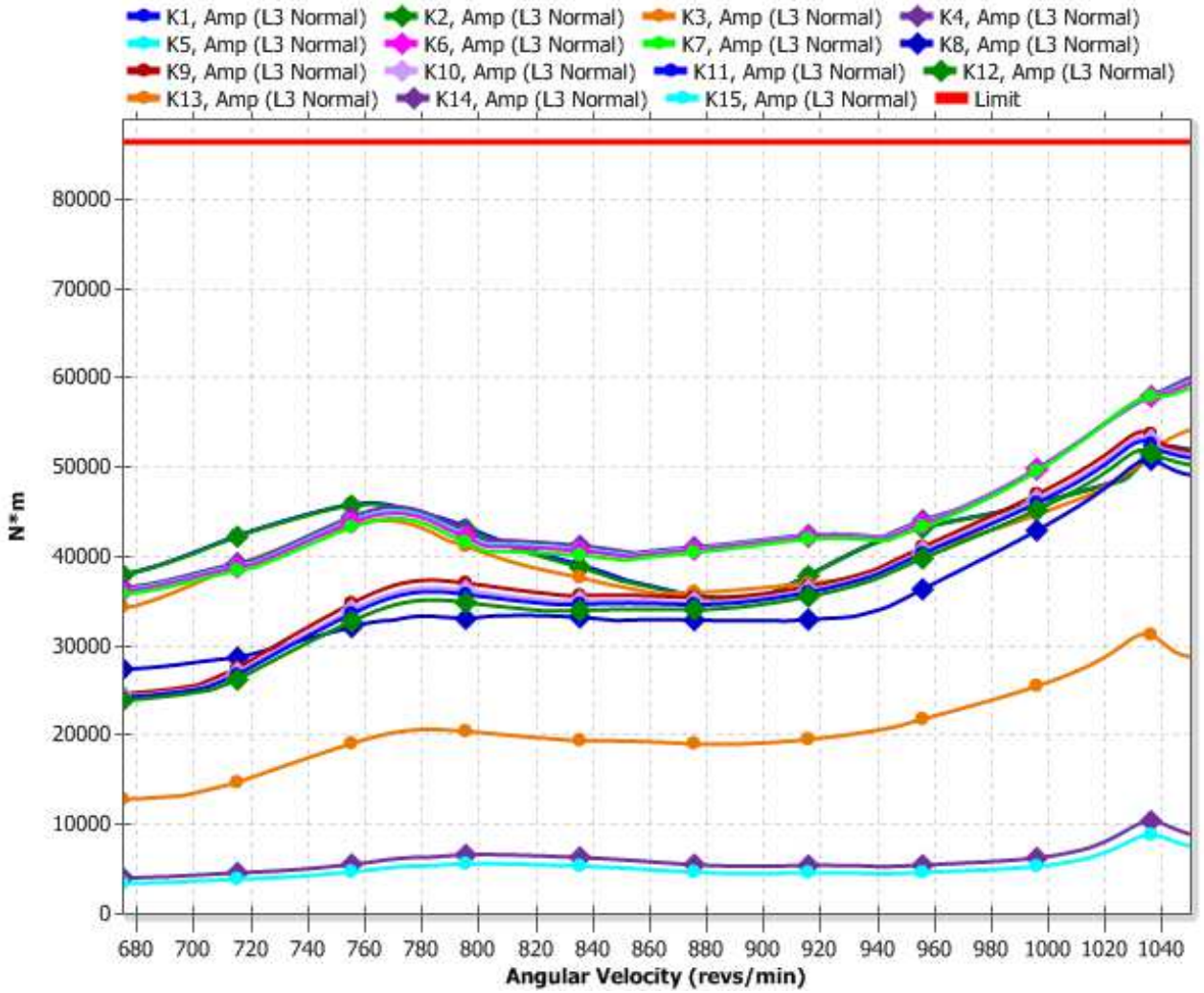
Coupling Combined Order Torque



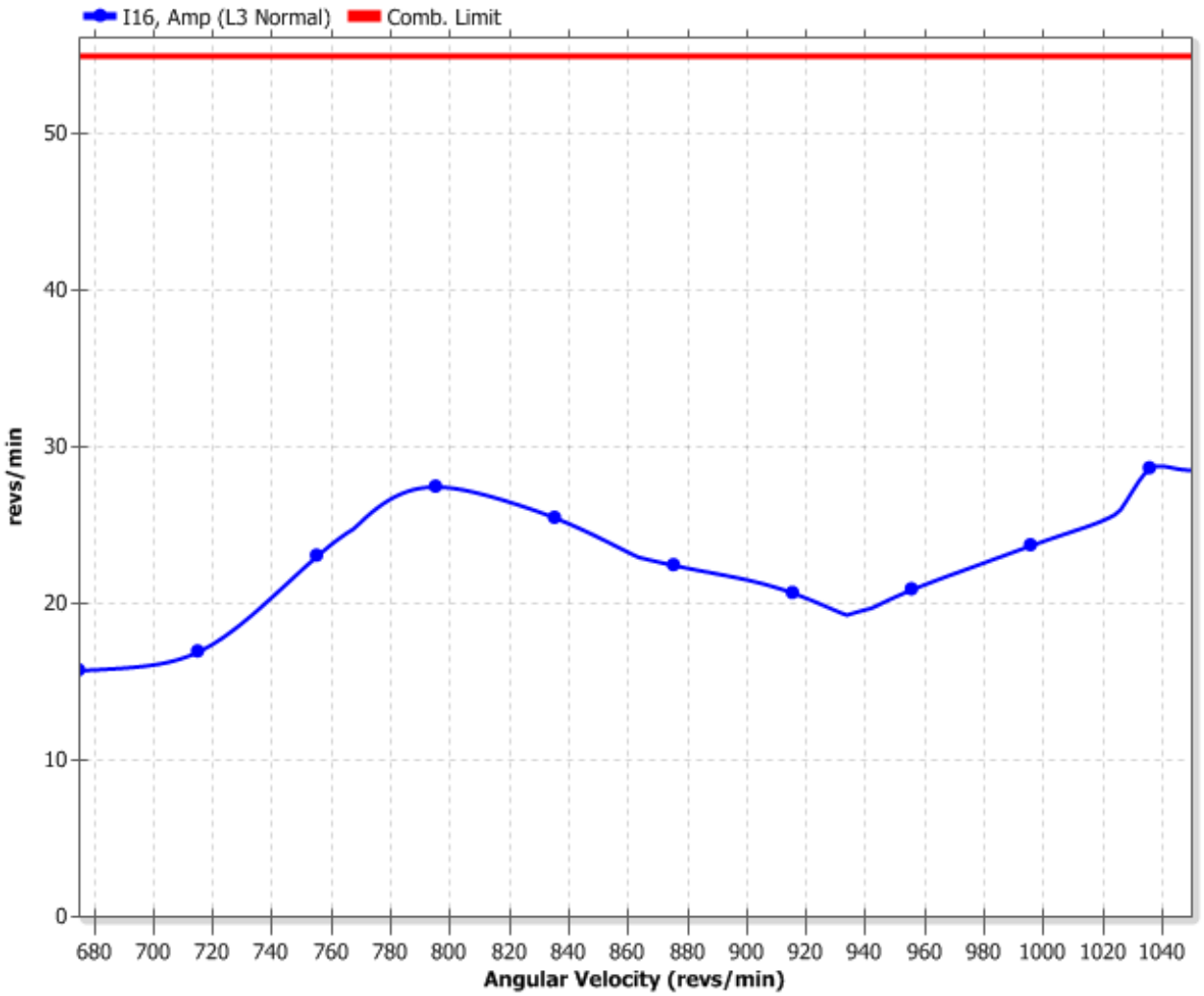
Compressor Stub Combined Order Vibratory Torque



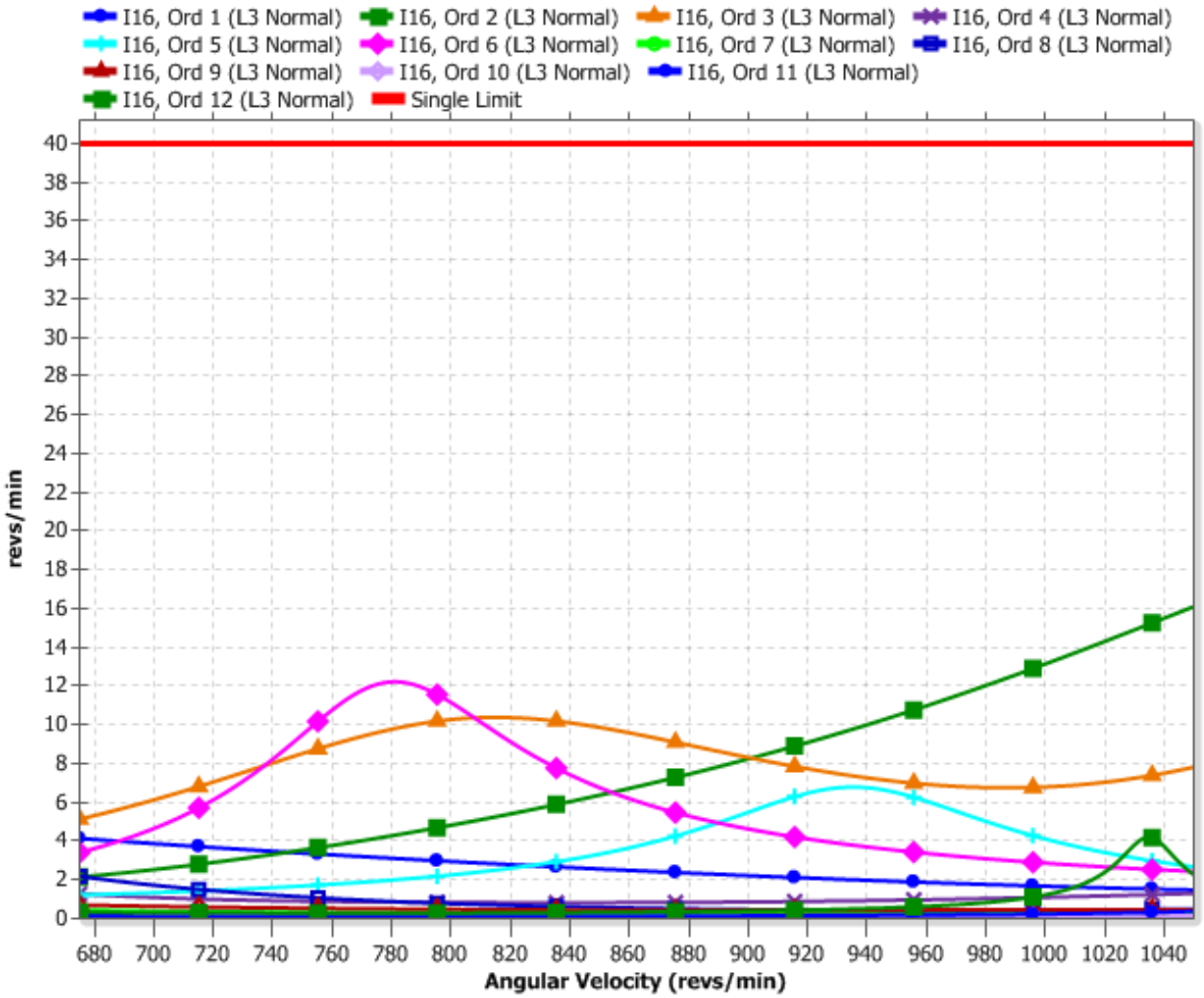
Compressor Shaft Combined Order Vibratory Torque



Aux End Combined Order Velocity



Aux End Single Order Velocity



Load Case #4

Ariel Performance

7.7.4.0

Company: EXTERRAN
Project #: AP032548 Rev:26
Case 50: Ps-design, Pd-low-3BS-Summer
Customer: XTO ENERGY
Inquiry:
Project: XTO ENERGY

Compressor Data:

						Driver Data:	
Elevation,ft:	3600.00	Barmtr,psia:	12.861	Ambient,F:	110.00	Type:	Nat. Gas
Frame: **(ELP)**	KBZ/6	Stroke, in:	6.75	Rod Dia, in:	2.875	Mfg:	Caterpillar
Max RL Tot, lbf:	150000	Max RL Tens, lbf:	75000	Max RL Comp, lbf:	80000	Model:	G3616 A4
Rated RPM:	1000	Rated BHP:	7800.0	Rated PS FPM:	1125.0	BHP:	5000
Calc RPM:	1000.0	BHP:	4905	Calc PS FPM:	1125.0	Avail:	5000

Services	**Service 1**					
Gas Model	VMG					
Stage Data:	**1**	---	**2**	---	**3**	**4**
Target Flow, MMSCFD	25.000	---	25.000	---	25.000	25.000
Flow Calc, MMSCFD	24.778	---	24.778	---	24.772	24.613
BHP per Stage	1432.0	---	1659.5	---	1067.5	677.2
Specific Gravity	0.8016	---	0.8016	---	0.8016	0.7976
Ratio of Sp Ht (N)	1.2209	---	1.2107	---	1.2295	1.2491
Comp Suct (Zs)	0.9852	---	0.9750	---	0.9306	0.8689
Comp Disch (Zd)	0.9785	---	0.9632	---	0.9162	0.8614
Pres Suct Line, psig	35.00	---	N/A	---	N/A	N/A
Pres Suct Flg, psig	34.52	---	99.59	---	302.64	606.18
Pres Disch Flg, psig	102.64	---	309.22	---	620.31	1020.26
Pres Disch Line, psig	N/A	---	N/A	---	N/A	1000.00
Pres Ratio F/F	2.438	---	2.864	---	2.007	1.669
Temp Suct, F	70.00	---	130.00	---	130.00	130.00
Temp Clr Disch, F	130.00	---	130.00	---	130.00	120.00
Cylinder Data:	**Throw 3**	**Throw 5**	**Throw 4**	**Throw 6**	**Throw 1**	**Throw 2**
Cyl Model	24-1/8Z:10	24-1/8Z:10	17-7/8Z:10	17-7/8Z:10	14-1/8Z:10	9-1/4ZK
Cyl Bore, in	24.125	24.125	17.375	17.375	13.625	9.250
Cyl RDP (API), psig	250.0	250.0	577.3	577.3	1154.5	2181.8
Cyl MAWP, psig	275.0	275.0	635.0	635.0	1270.0	2400.0
Cyl Action	DBL	DBL	DBL	DBL	DBL	DBL
Cyl Disp, CFM	3545.8	3545.8	1827.0	1827.0	1113.7	499.6
Pres Suct Intl, psig	28.94	28.94	92.77	92.77	283.22	591.58
Temp Suct Intl, F	79	79	138	138	135	133
Pres Disch Intl, psig	114.25	114.25	327.66	327.66	653.39	1048.84
Temp Disch Intl, F	199	199	273	273	232	203
HE Suct Gas Vel, FPM	9976	9976	7550	7550	7481	4594
HE Disch Gas Vel, FPM	8467	8467	6733	6733	6147	4370
HE Spcrs Used/Max	0/0	0/0	0/6	0/6	0/4	0/4
HE Vol Pkt Avail	0.66+44.90	0.66+44.90	0.76+48.69	0.76+48.69	0.71+40.40	0.36+53.03
Vol Pkt Used	21.44 (V) %	21.44 (V) %	0.00 (V) %	0.00 (V) %	0.00 (V) %	0.00 (V) %
HE Min Clr, %	13.20	13.20	18.03	18.03	24.35	29.34
HE Total Clr, %	23.49	23.49	18.79	18.79	25.06	29.70
CE Suct Gas Vel, FPM	9834	9834	7343	7343	7148	4150
CE Disch Gas Vel, FPM	8347	8347	6548	6548	5874	3947
CE Spcrs Used/Max	0/0	0/0	0/6	0/6	0/4	0/4
CE Min Clr, %	13.59	13.59	18.99	18.99	26.09	33.52
CE Total Clr, %	13.59	13.59	18.99	18.99	26.09	33.52
Suct Vol Eff HE/CE, %	70.2/81.0	70.2/81.0	68.3/68.0	68.3/68.0	76.4/75.6	81.1/79.0
Disch Event HE/CE, ms	11.0/13.8	11.0/13.8	10.0/11.7	10.0/11.7	12.8/14.5	14.8/16.3
Suct Pseudo-Q HE/CE	8.2/8.0	8.2/8.0	5.8/5.5	5.8/5.5	4.4/4.0	2.9/2.3
Gas Rod Ld Comp, %	49.0 C	49.0 C	70.5 C	70.5 C	69.9 C	43.3 C
Gas Rod Ld Tens, %	51.0 T	51.0 T	71.3 T	71.3 T	66.2 T	31.8 T
Gas Rod Ld Total, %	51.6	51.6	73.2	73.2	70.4	39.0
Xhd Pin Deg/%Rvrsl lbf	173/95.8	173/95.8	159/88.2	159/88.2	163/73.4	158/82.0
Flow Calc, MMSCFD	12.389	12.389	12.389	12.389	24.772	24.613
Cyl BHP	716.0	716.0	829.8	829.8	1067.5	677.2

Single Order Results		Order	Predicted	Recommended Limit
FRT	Angular Displacement (deg)	0.5	0.119	1.000
	Angular Displacement (deg)	1.0	0.089	1.000
	Angular Displacement (deg)	1.5	0.084	0.250
	Angular Displacement (deg)	2.0	0.054	0.150
	Angular Displacement (deg)	2.5	0.086	0.150
	Angular Displacement (deg)	3.0	0.184*	0.150
	Angular Displacement (deg)	6.0	0.046	0.150
I16	Angular Velocity (rpm)	1.0	0.8	40.0
	Angular Velocity (rpm)	2.0	8.4	40.0
	Angular Velocity (rpm)	3.0	9.5	40.0
	Angular Velocity (rpm)	4.0	4.9	40.0
	Angular Velocity (rpm)	5.0	5.1	40.0
	Angular Velocity (rpm)	6.0	21.6	40.0
	Angular Velocity (rpm)	7.0	3.1	40.0
	Angular Velocity (rpm)	8.0	1.6	40.0
	Angular Velocity (rpm)	9.0	0.9	40.0
	Angular Velocity (rpm)	10.0	0.2	40.0
	Angular Velocity (rpm)	11.0	0.3	40.0
	Angular Velocity (rpm)	12.0	0.5	40.0

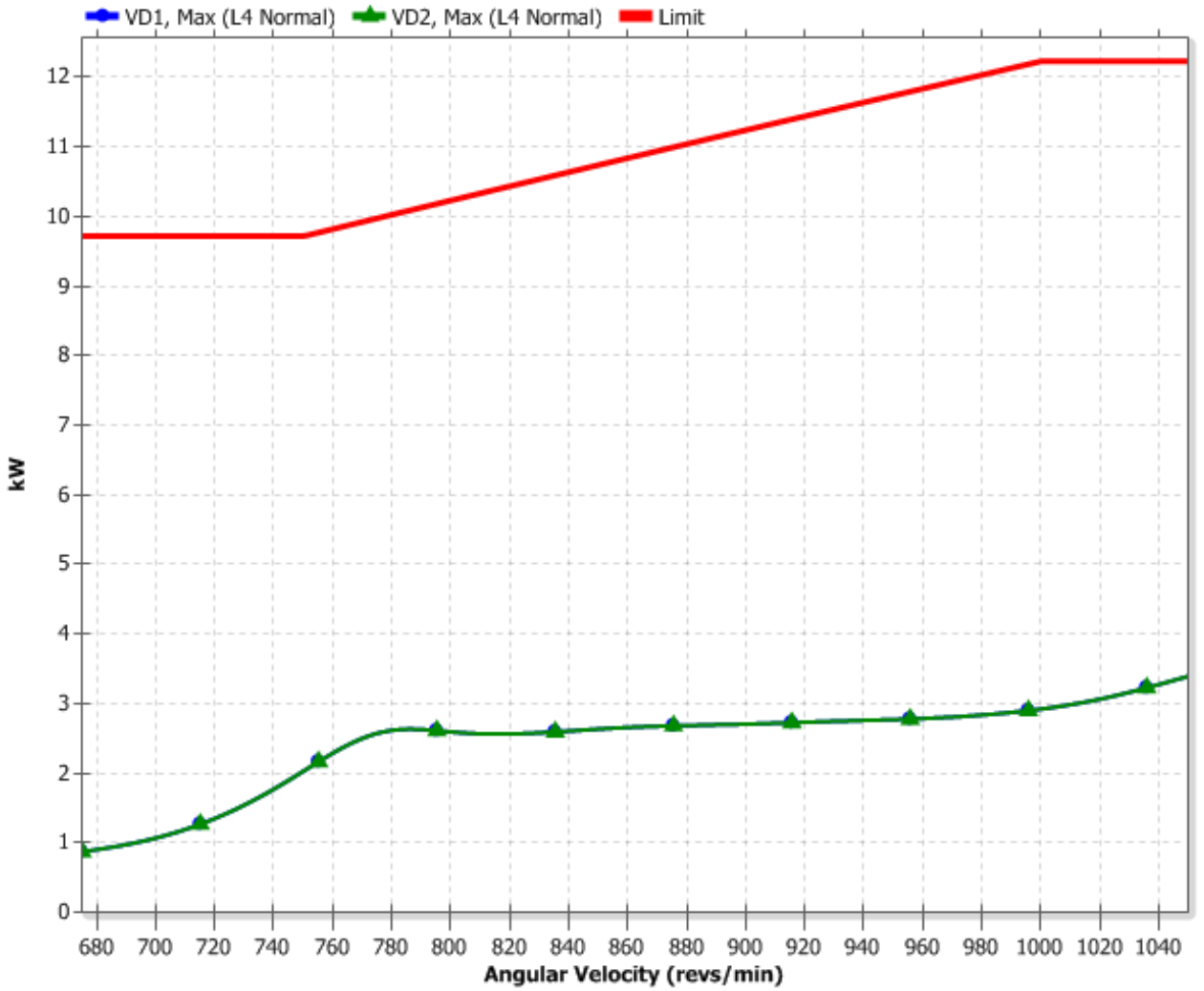
*Vibratory amplitude at the front of the engine crankshaft is used as an indicator for potentially damaging torsional vibrations throughout the system. While the engine excited 3.0 order vibratory displacement amplitude at the front of the engine crankshaft is above the recommended limit, additional details of the analysis show that this order will not cause damage to the driven system.

Combined Order Results		Predicted	Recommended Limit
VD1	Maximum Power Loss (kW)	3.394	12.233
VD2	Maximum Power Loss (kW)	3.394	12.233
EK3	Vibratory Stress (MPa)	35.51	48.00
CPK	Maximum Torque (Nm)	76976	103900
	Minimum Torque (Nm)	-13951	-51900
CSK	Vibratory Torque (Nm)	44580	86404
K4	Vibratory Torque (Nm)	53243	86404
I16	Vibratory Angular Velocity (rpm)	31.7	55.0

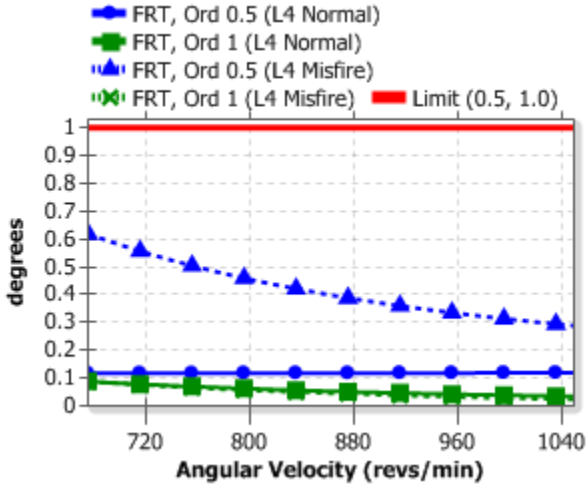
Single Order Misfire Results		Order	Predicted	Recommended Limit
FRT	Angular Displacement (deg)	0.5	0.619	1.000
	Angular Displacement (deg)	1.0	0.088	1.000
	Angular Displacement (deg)	1.5	0.084	0.250
	Angular Displacement (deg)	2.0	0.054	0.150
	Angular Displacement (deg)	2.5	0.086	0.150
	Angular Displacement (deg)	3.0	0.184*	0.150
	Angular Displacement (deg)	6.0	0.046	0.150

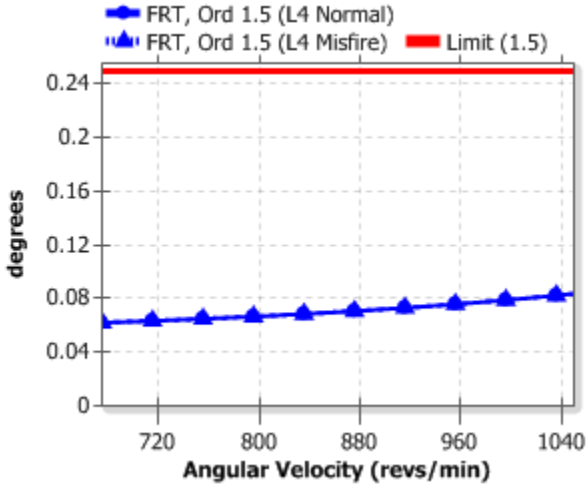
*Vibratory amplitude at the front of the engine crankshaft is used as an indicator for potentially damaging torsional vibrations throughout the system. While the engine excited 3.0 order vibratory displacement amplitude at the front of the engine crankshaft is above the recommended limit, additional details of the analysis show that this order will not cause damage to the driven system.

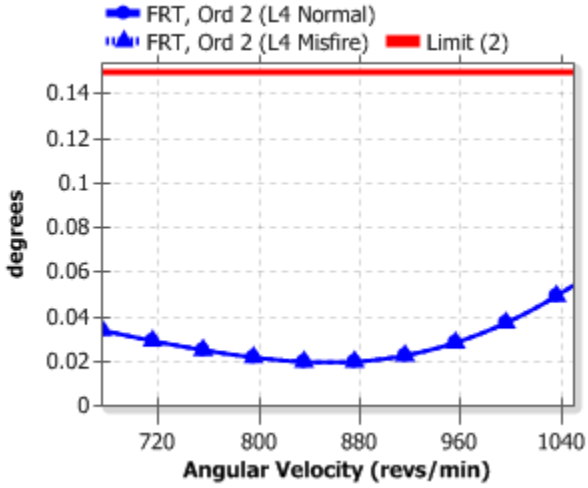
Damper Combined Order Power Loss

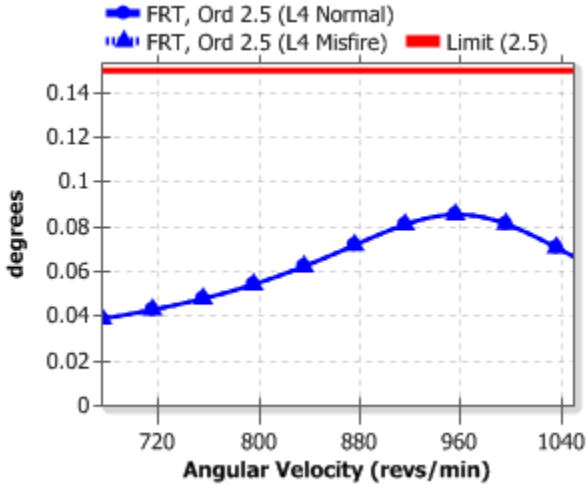


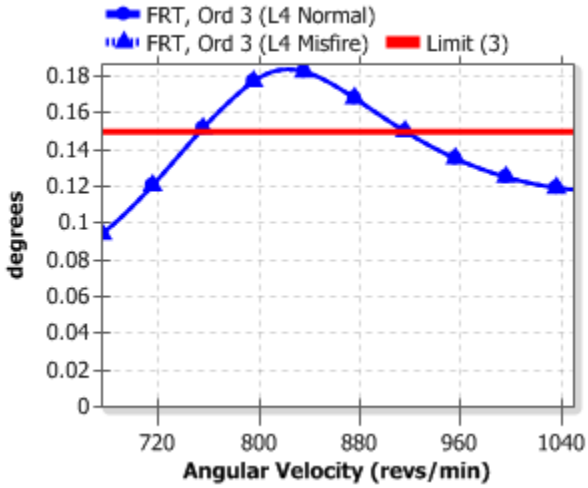
Front Crankshaft Single Order Displacement

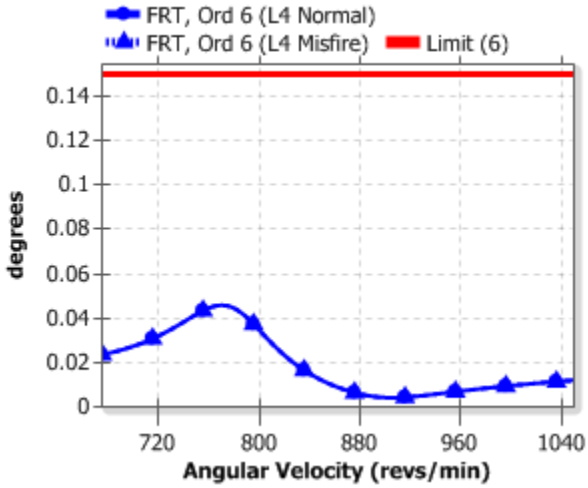




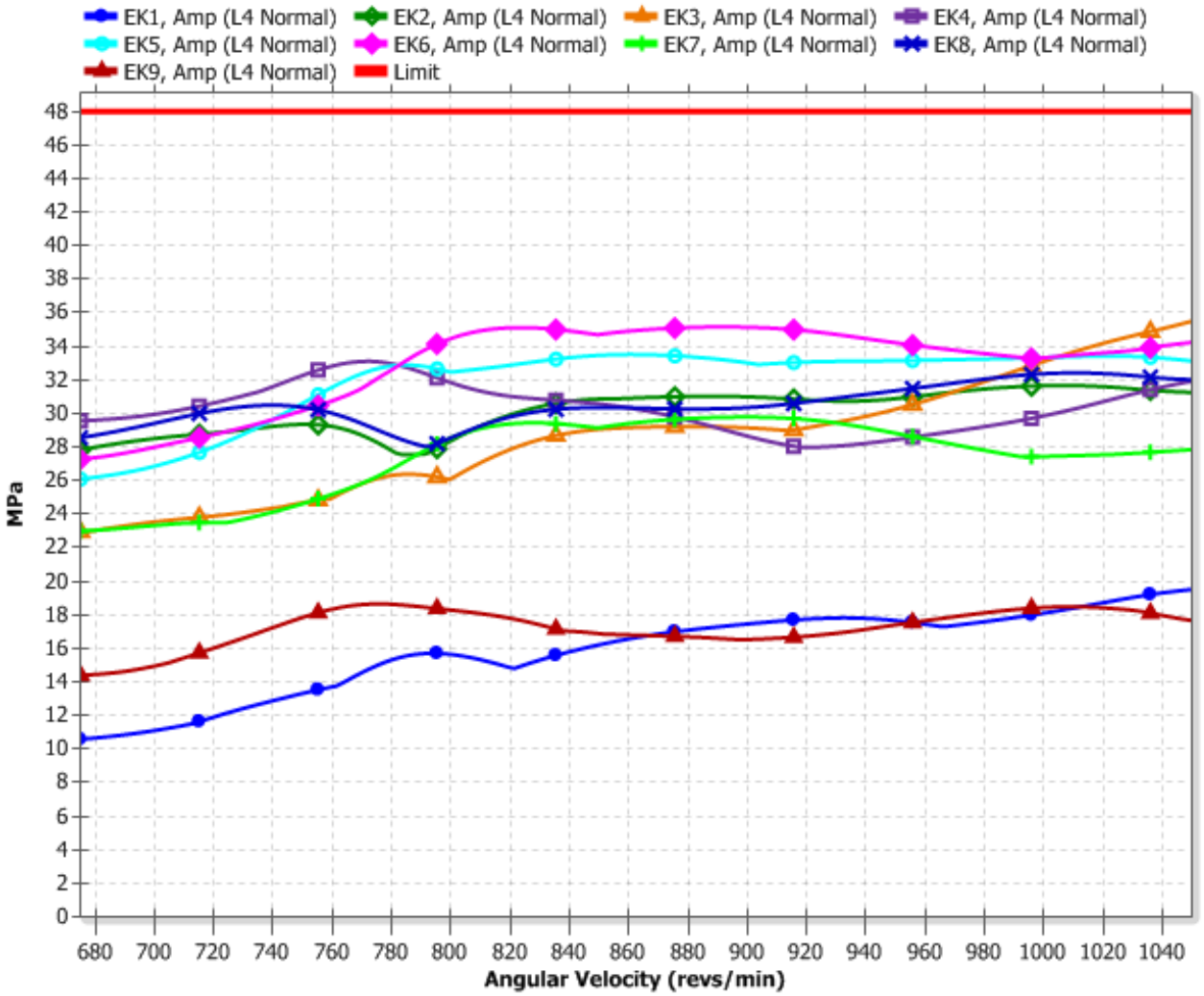




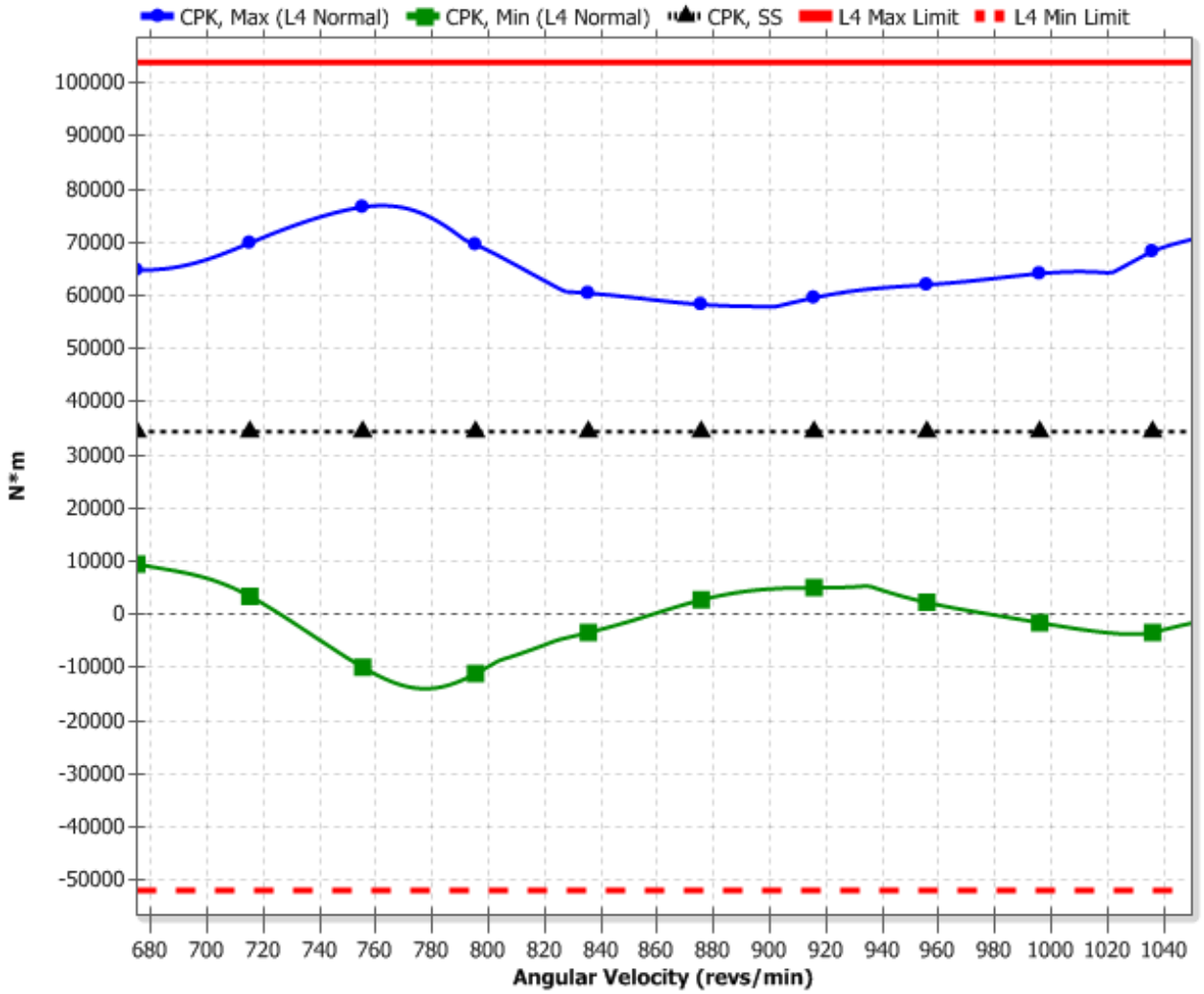




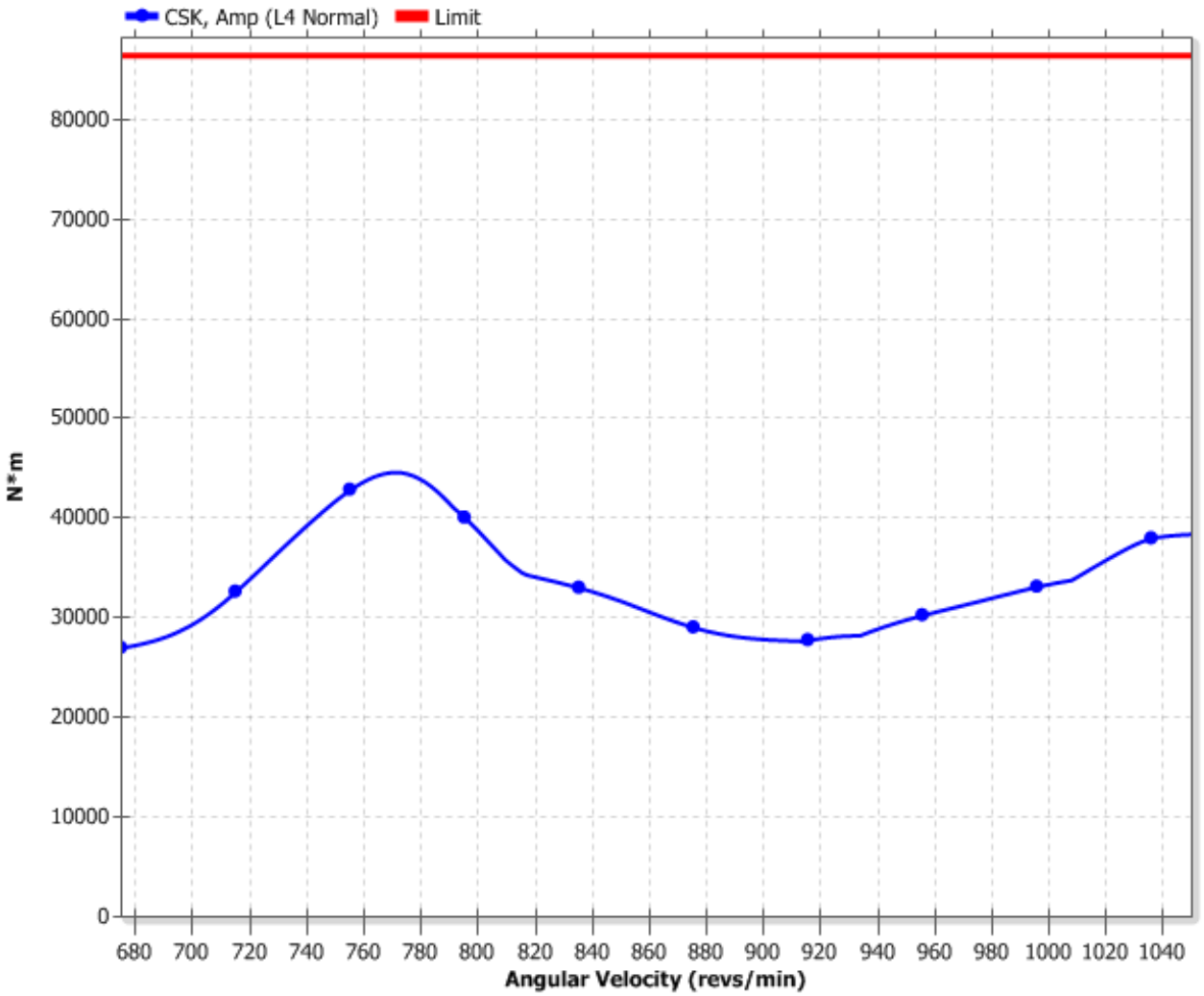
Crankshaft Combined Order Vibratory Stress



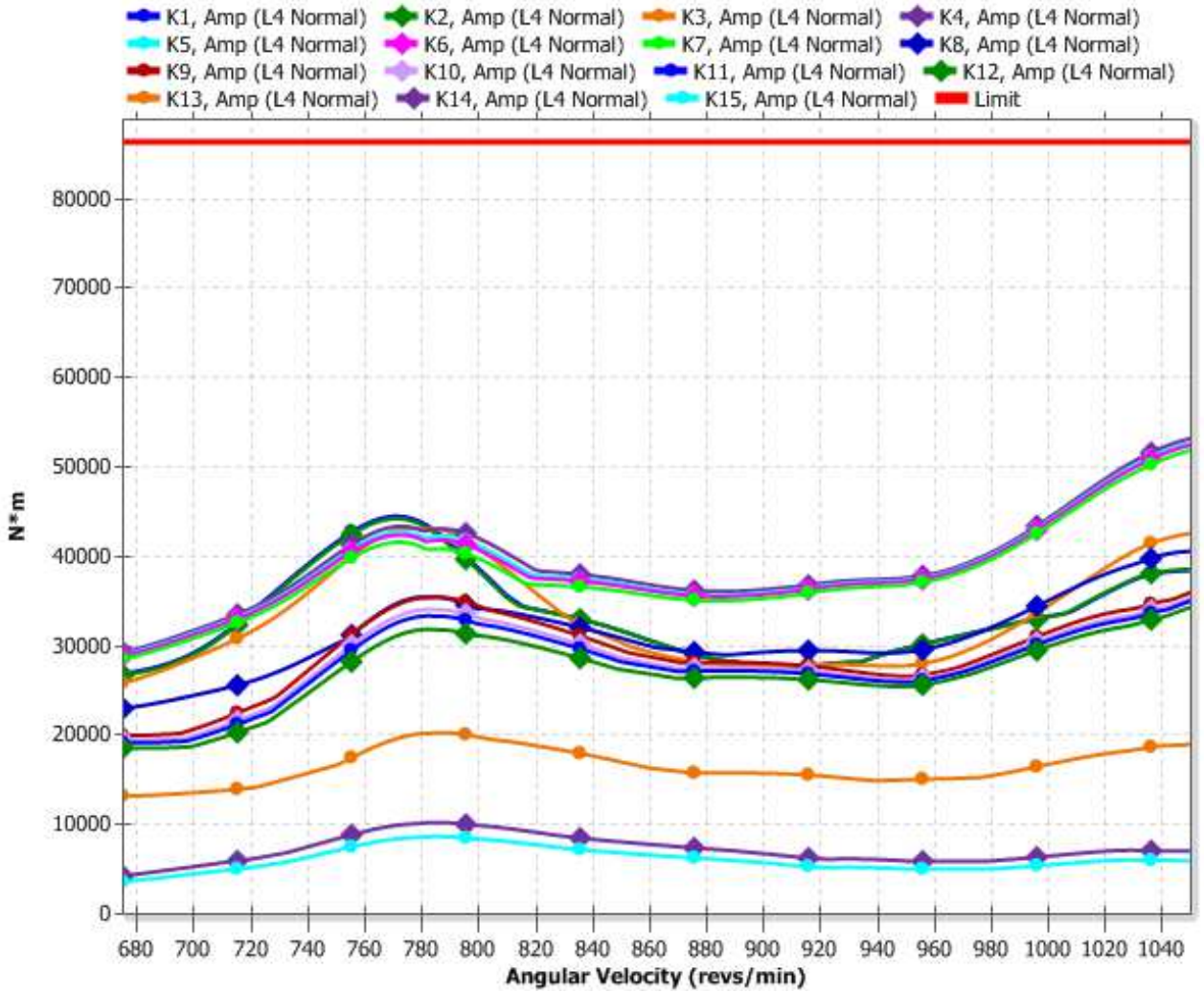
Coupling Combined Order Torque



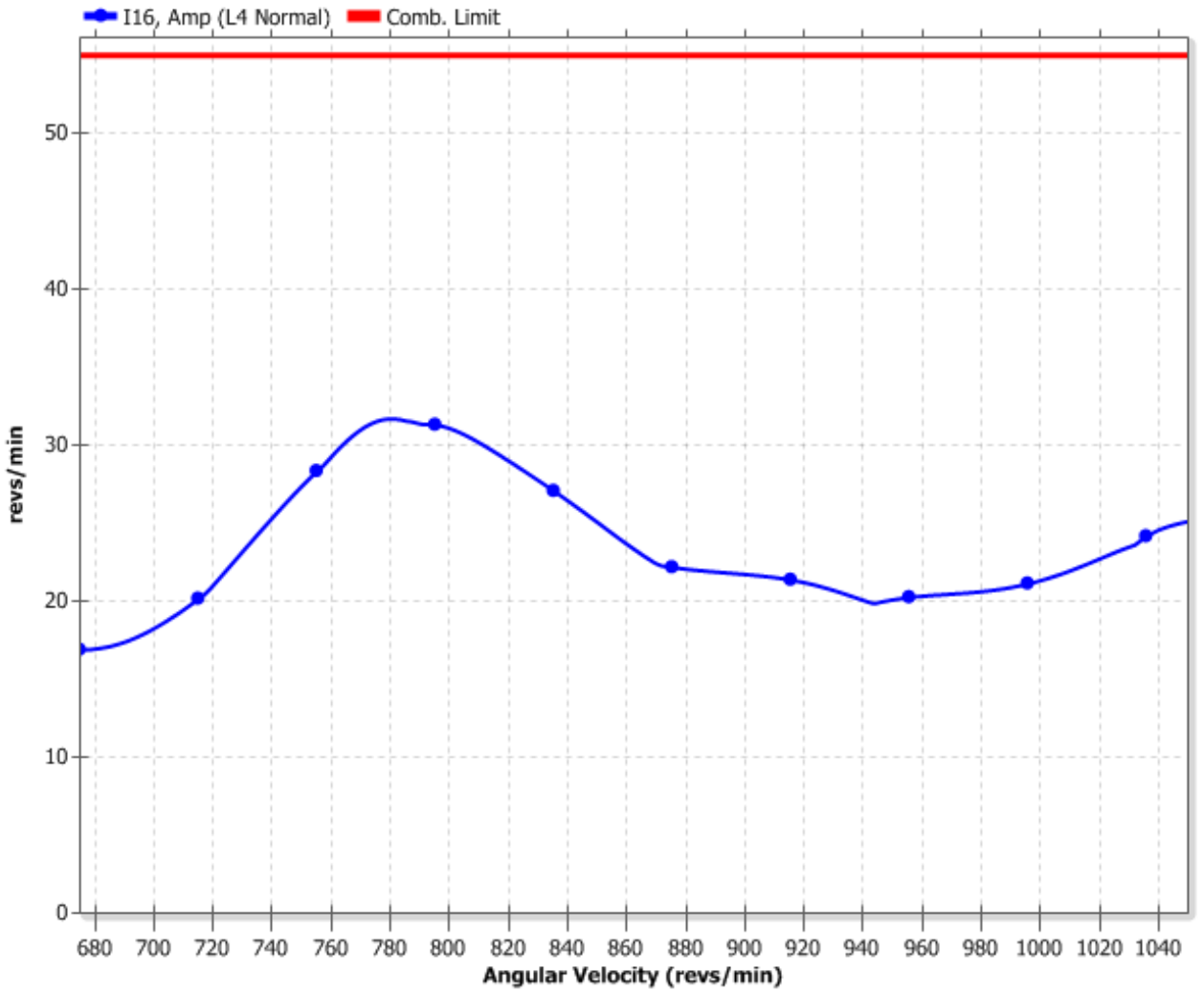
Compressor Stub Combined Order Vibratory Torque



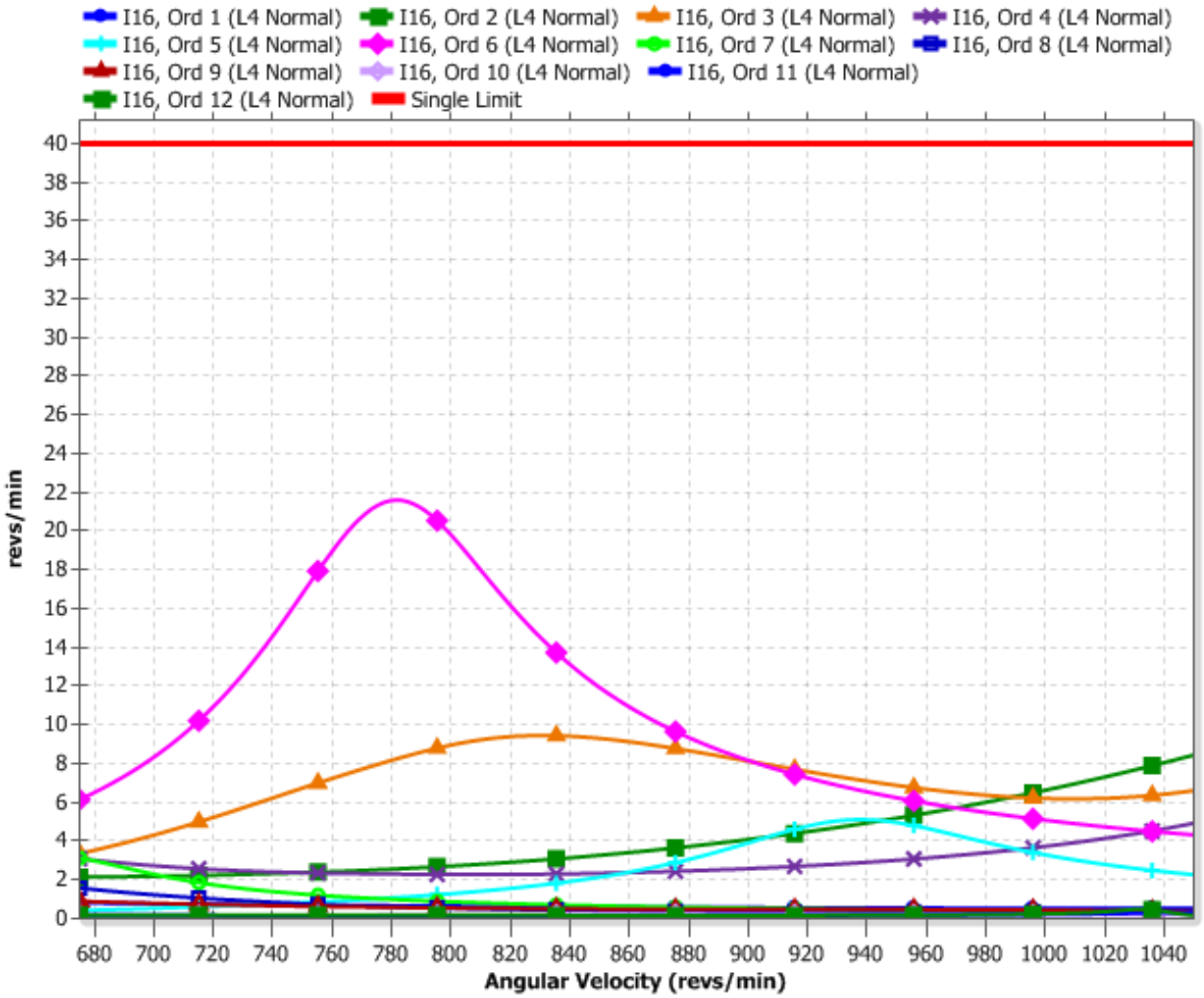
Compressor Shaft Combined Order Vibratory Torque



Aux End Combined Order Velocity



Aux End Single Order Velocity



Load Case #5

Ariel Performance

7.7.4.0

Company: EXTERRAN
Project #: AP032548 Rev:26
Case 67:

Customer: XTO ENERGY
Inquiry:
Project: XTO ENERGY

Compressor Data:						Driver Data:	
Elevation,ft:	3600.00	Barmtr,psia:	12.861	Ambient,F:	110.00	Type:	Nat. Gas
Frame: (ELP)	KBZ/6	Stroke, in:	6.75	Rod Dia, in:	2.875	Mfg:	Caterpillar
Max RL Tot, lbf:	150000	Max RL Tens, lbf:	75000	Max RL Comp, lbf:	80000	Model:	G3616 A4
Rated RPM:	1000	Rated BHP:	7800.0	Rated PS FPM:	1125.0	BHP:	5000
Calc RPM:	1000.0	BHP:	4883	Calc PS FPM:	1125.0	Avail:	5000

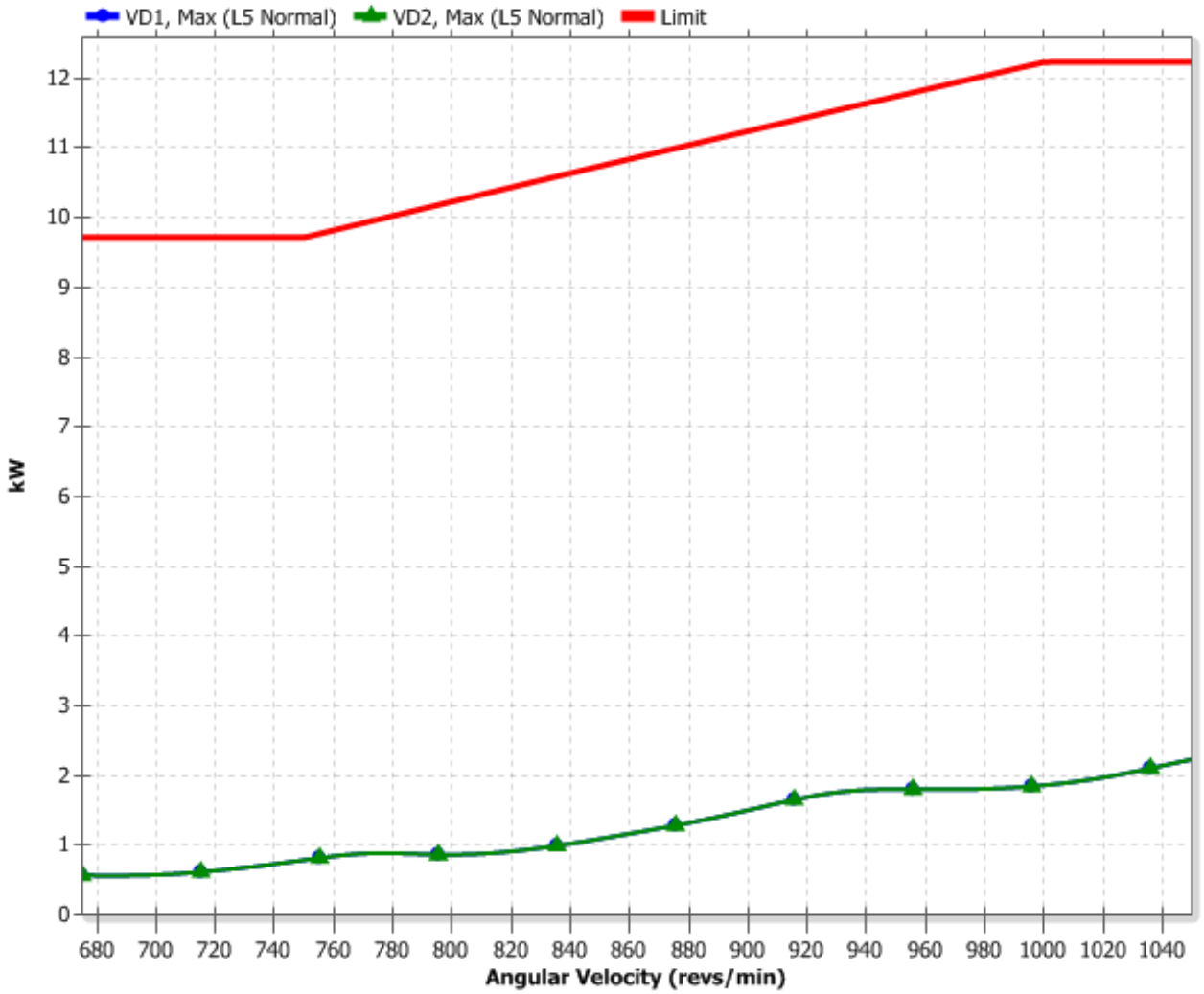
Services	Service 1					
Gas Model	VMG					
Stage Data:	**1**	---	**2**	---	**3**	**4**
Target Flow, MMSCFD	25.000	---	25.000	---	25.000	25.000
Flow Calc, MMSCFD	27.845	---	27.845	---	27.844	27.845
BHP per Stage	1524.3	---	1662.4	---	1075.1	551.9
Specific Gravity	0.8268	---	0.8268	---	0.8268	0.8268
Ratio of Sp Ht (N)	1.2507	---	1.2359	---	1.2546	1.2721
Comp Suct (Zs)	0.9783	---	0.9695	---	0.9260	0.8714
Comp Disch (Zd)	0.9709	---	0.9609	---	0.9182	0.8701
Pres Suct Line, psig	60.00	---	N/A	---	N/A	N/A
Pres Suct Flg, psig	59.27	---	148.99	---	388.38	710.98
Pres Disch Flg, psig	153.18	---	396.49	---	726.67	1020.26
Pres Disch Line, psig	N/A	---	N/A	---	N/A	1000.00
Pres Ratio F/F	2.302	---	2.529	---	1.843	1.427
Temp Suct, F	50.00	---	130.00	---	130.00	130.00
Temp Clr Disch, F	130.00	---	130.00	---	130.00	120.00
Cylinder Data:	**Throw 3**	**Throw 5**	**Throw 4**	**Throw 6**	**Throw 1**	**Throw 2**
Cyl Model	24-1/8Z:10	24-1/8Z:10	17-7/8Z:10	17-7/8Z:10	14-1/8Z:10	9-1/4ZK
Cyl Bore, in	24.125	24.125	17.375	17.375	13.625	9.250
Cyl RDP (API), psig	250.0	250.0	577.3	577.3	1154.5	2181.8
Cyl MAWP, psig	275.0	275.0	635.0	635.0	1270.0	2400.0
Cyl Action	*CE(HEVR)*	DBL	DBL	DBL	DBL	DBL
Cyl Disp, CFM	1760.2	3545.8	1827.0	1827.0	1113.7	499.6
Pres Suct Intl, psig	50.33	50.12	138.82	138.82	362.76	693.32
Temp Suct Intl, F	64	59	138	138	135	132
Pres Disch Intl, psig	170.55	170.94	420.81	420.81	766.58	1050.37
Temp Disch Intl, F	189	183	270	270	229	186
HE Suct Gas Vel, FPM	N/A	9976	7550	7550	7481	4594
HE Disch Gas Vel, FPM	N/A	8467	6733	6733	6147	4370
HE Spcrs Used/Max	N/A	0/0	0/6	0/6	0/4	0/4
HE Vol Pkt Avail	N/A	0.66+44.90	0.76+48.69	0.76+48.69	0.71+40.40	0.36+53.03
Vol Pkt Used	N/A %	75.00 (V) %	75.00 (V) %	75.00 (V) %	100.00 (V) %	100.00 (V) %
HE Min Clr, %	N/A	13.20	18.03	18.03	24.35	29.34
HE Total Clr, %	N/A	47.54	55.31	55.31	65.46	82.73
CE Suct Gas Vel, FPM	9834	9834	7343	7343	7148	4150
CE Disch Gas Vel, FPM	8347	8347	6548	6548	5874	3947
CE Spcrs Used/Max	0/0	0/0	0/6	0/6	0/4	0/4
CE Min Clr, %	13.59	13.59	18.99	18.99	26.09	33.52
CE Total Clr, %	13.59	13.59	18.99	18.99	26.09	33.52
Suct Vol Eff HE/CE, %	N/A/83.0	50.3/83.0	32.5/73.8	32.5/73.8	54.5/79.7	70.2/86.1
Disch Event HE/CE, ms	N/A/14.5	9.5/14.5	7.2/13.0	7.2/13.0	11.0/15.7	14.7/18.7
Suct Pseudo-Q HE/CE	N/A/8.5	8.8/8.6	5.5/5.7	5.5/5.7	4.6/4.2	3.0/2.4
Gas Rod Ld Comp, %	6.4 C	69.5 C	84.8 C	84.8 C	76.7 C	35.7 C
Gas Rod Ld Tens, %	67.0 T	72.1 T	85.4 T	85.4 T	71.8 T	22.8 T
Gas Rod Ld Total, %	36.9	73.1	87.9	87.9	76.8	30.5
Xhd Pin Deg/%Rvrsl lbf	140/59.8	175/84.5	143/93.0	143/93.0	151/96.7	155/77.8
Flow Calc, MMSCFD	10.470	17.375	13.922	13.922	27.844	27.845
Cyl BHP	594.2	930.1	831.2	831.2	1075.1	551.9

Single Order Results		Order	Predicted	Recommended Limit
FRT	Angular Displacement (deg)	0.5	0.119	1.000
	Angular Displacement (deg)	1.0	0.256	1.000
	Angular Displacement (deg)	1.5	0.084	0.250
	Angular Displacement (deg)	2.0	0.079	0.150
	Angular Displacement (deg)	2.5	0.088	0.150
	Angular Displacement (deg)	3.0	0.094	0.150
	Angular Displacement (deg)	4.0	0.029	0.150
I16	Angular Velocity (rpm)	1.0	2.1	40.0
	Angular Velocity (rpm)	2.0	7.4	40.0
	Angular Velocity (rpm)	3.0	4.2	40.0
	Angular Velocity (rpm)	4.0	2.9	40.0
	Angular Velocity (rpm)	5.0	11.4	40.0
	Angular Velocity (rpm)	6.0	11.4	40.0
	Angular Velocity (rpm)	7.0	5.3	40.0
	Angular Velocity (rpm)	8.0	2.8	40.0
	Angular Velocity (rpm)	9.0	0.6	40.0
	Angular Velocity (rpm)	10.0	0.6	40.0
	Angular Velocity (rpm)	11.0	0.2	40.0
	Angular Velocity (rpm)	12.0	2.2	40.0

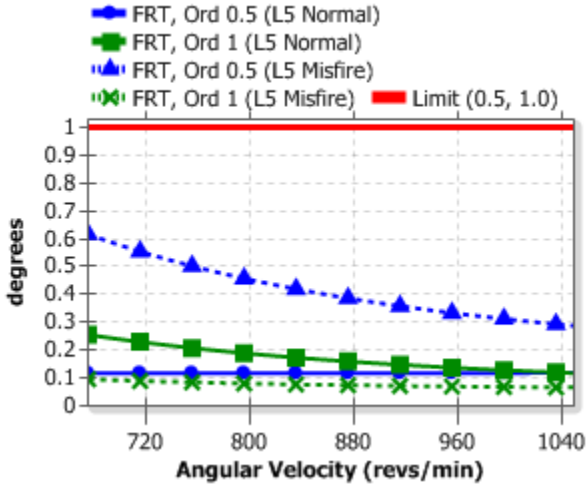
Combined Order Results		Predicted	Recommended Limit
VD1	Maximum Power Loss (kW)	2.234	12.233
VD2	Maximum Power Loss (kW)	2.234	12.233
EK4	Vibratory Stress (MPa)	31.91	48.00
CPK	Maximum Torque (Nm)	68433	103900
	Minimum Torque (Nm)	-2866	-51900
CSK	Vibratory Torque (Nm)	33866	86404
K4	Vibratory Torque (Nm)	52519	86404
I16	Vibratory Angular Velocity (rpm)	21.8	55.0

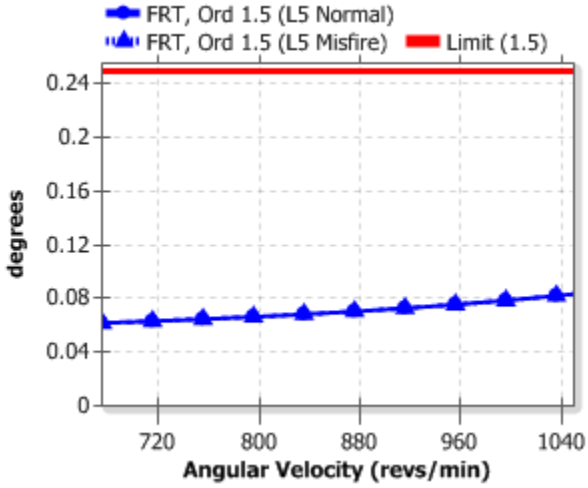
Single Order Misfire Results		Order	Predicted	Recommended Limit
FRT	Angular Displacement (deg)	0.5	0.617	1.000
	Angular Displacement (deg)	1.0	0.096	1.000
	Angular Displacement (deg)	1.5	0.084	0.250
	Angular Displacement (deg)	2.0	0.079	0.150
	Angular Displacement (deg)	2.5	0.088	0.150
	Angular Displacement (deg)	3.0	0.094	0.150
	Angular Displacement (deg)	4.0	0.029	0.150

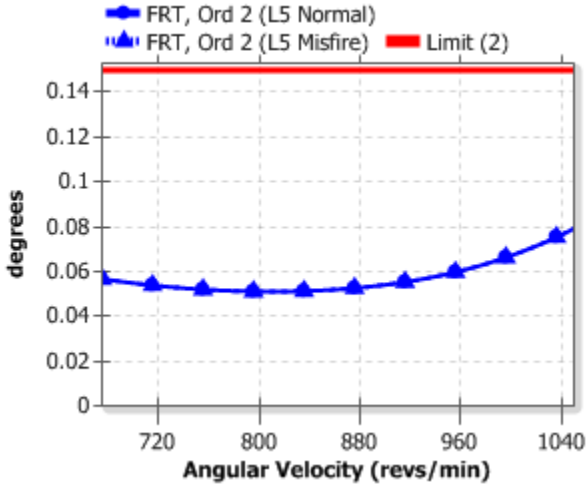
Damper Combined Order Power Loss

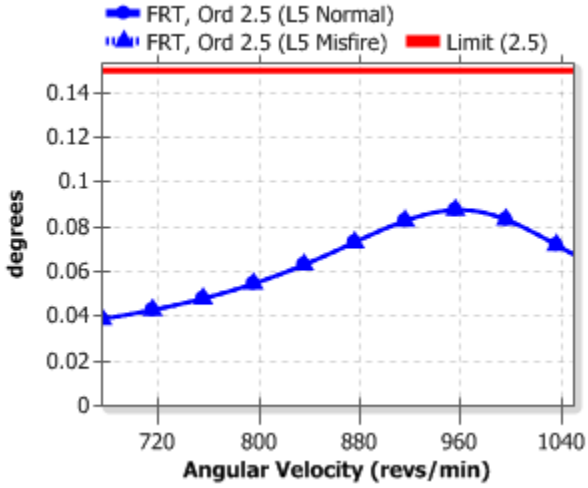


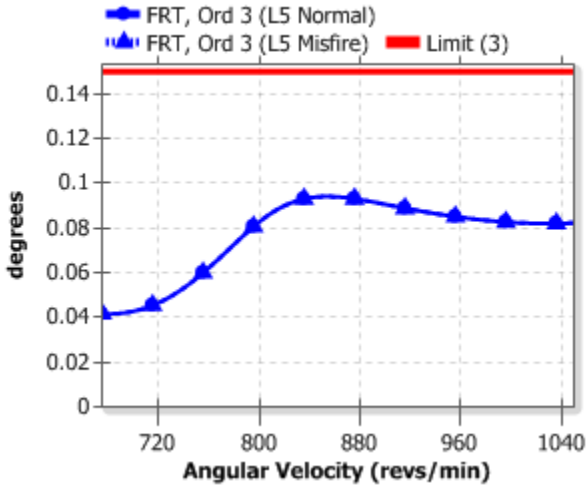
Front Crankshaft Single Order Displacement

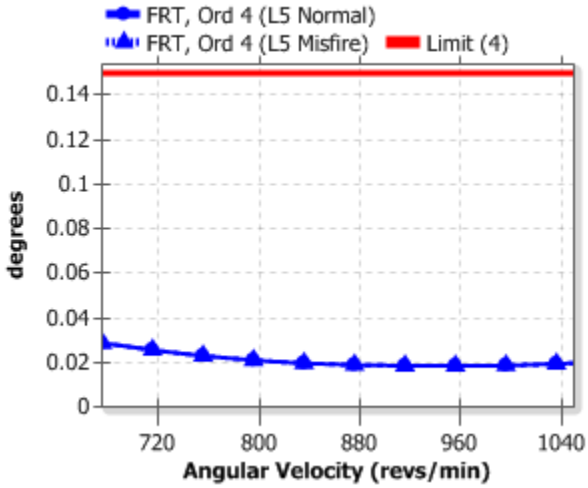




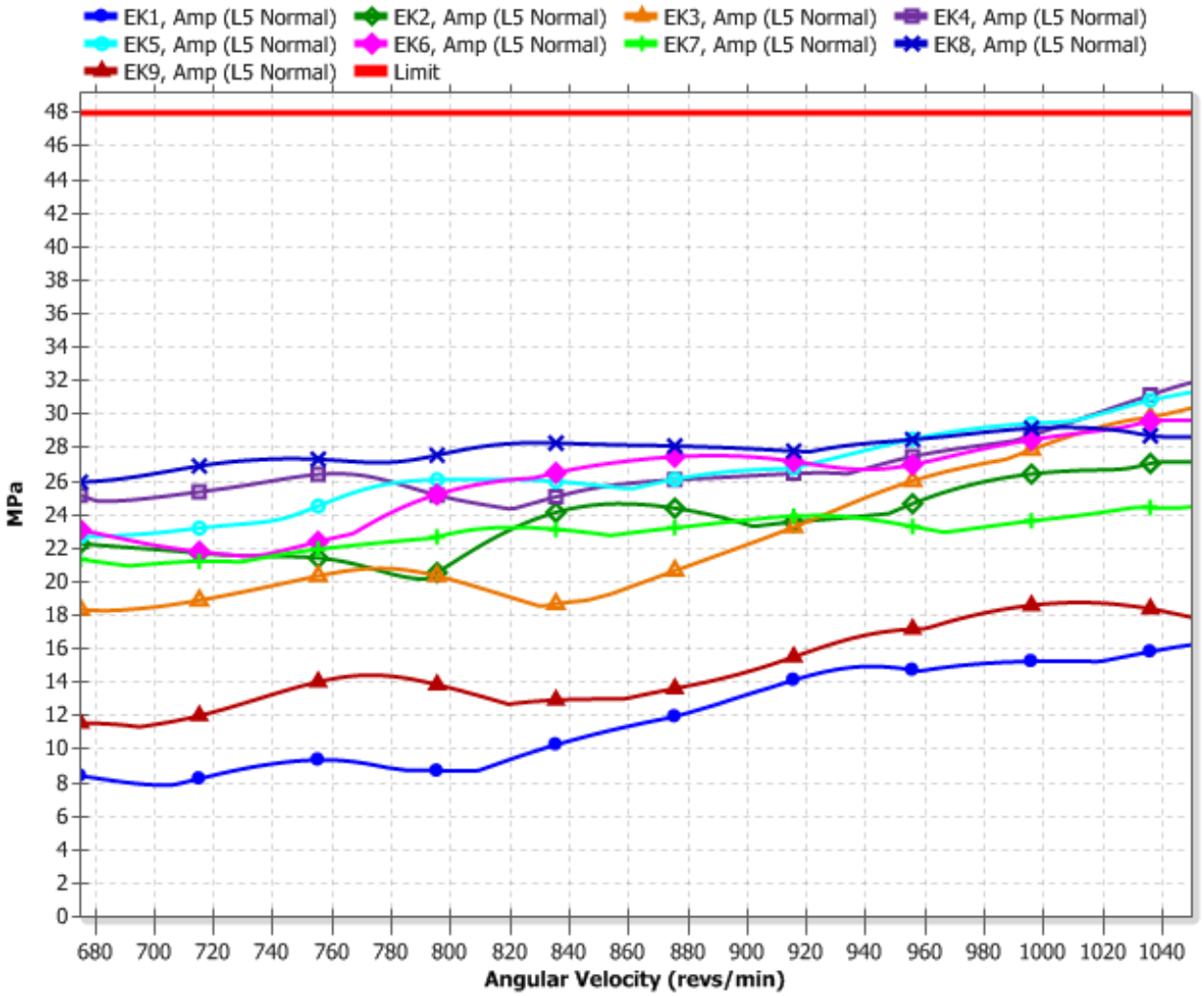




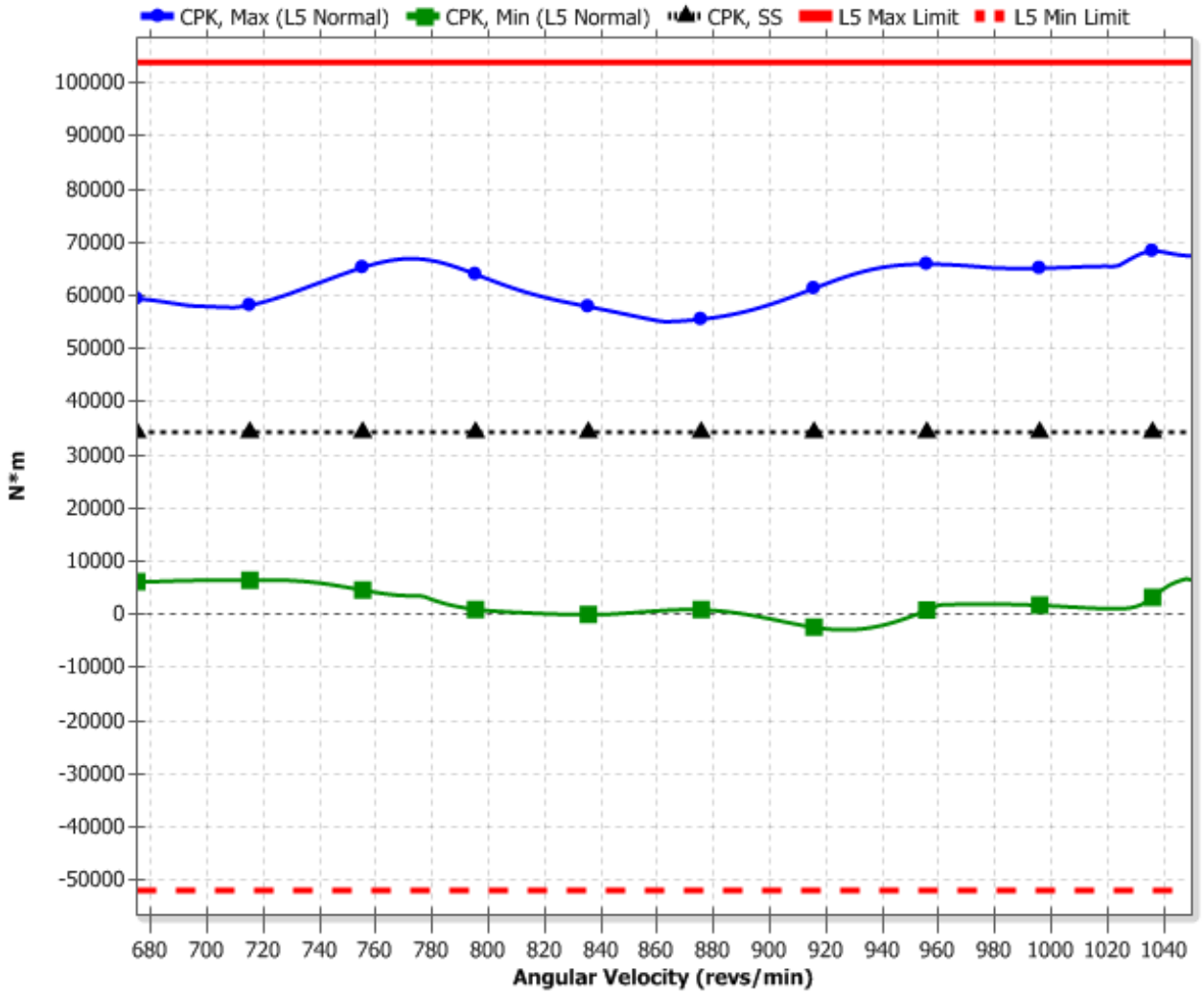




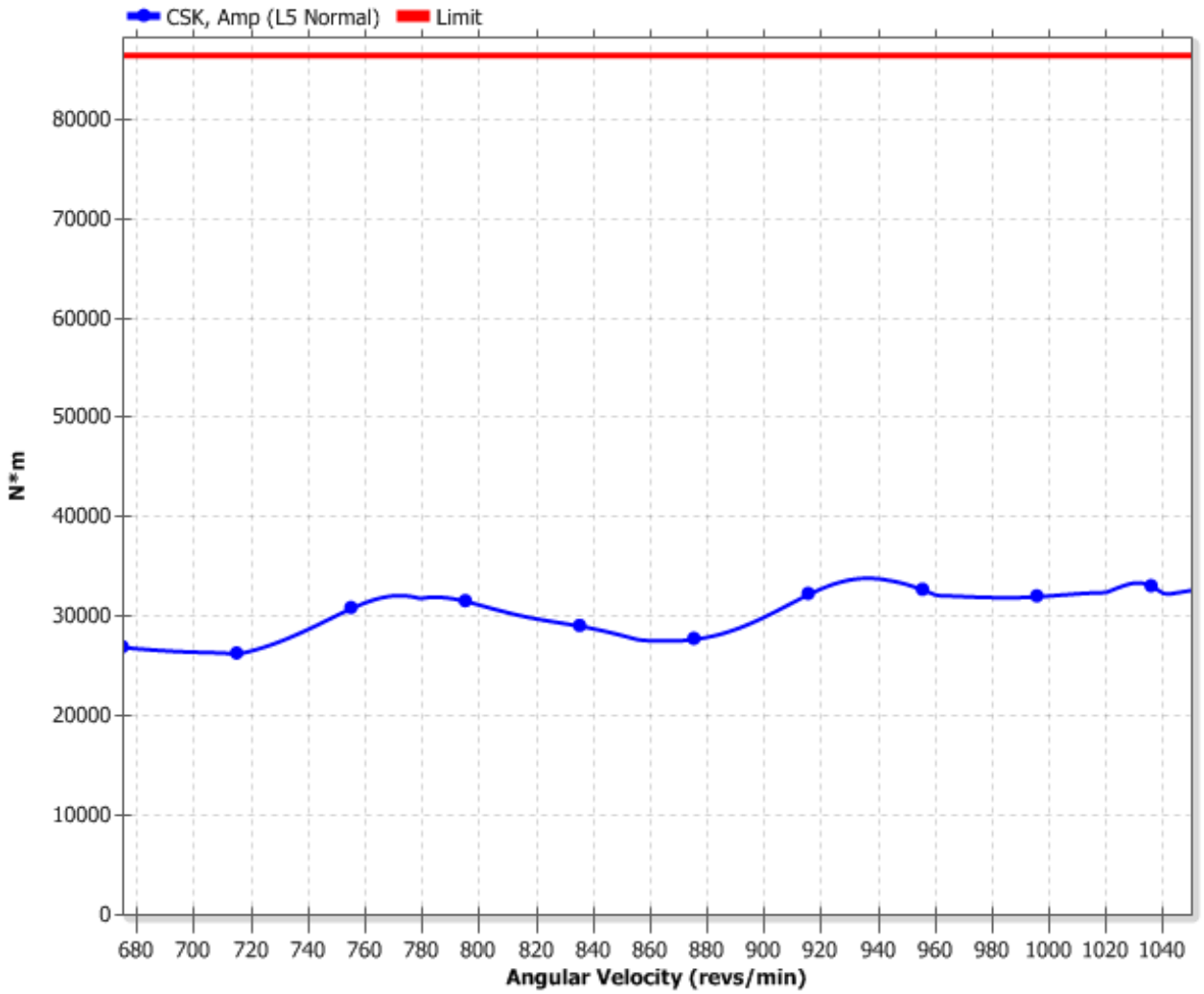
Crankshaft Combined Order Vibratory Stress



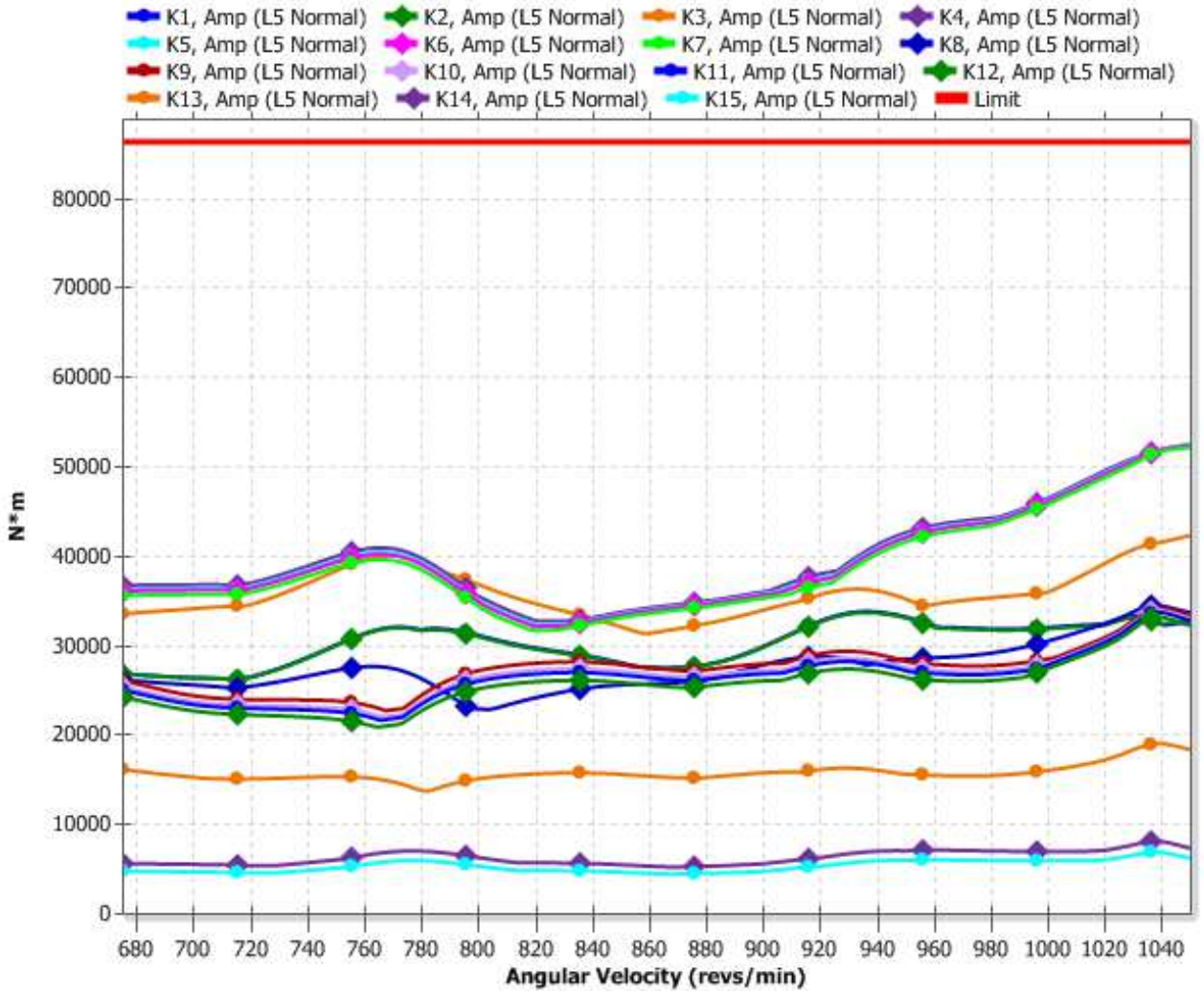
Coupling Combined Order Torque



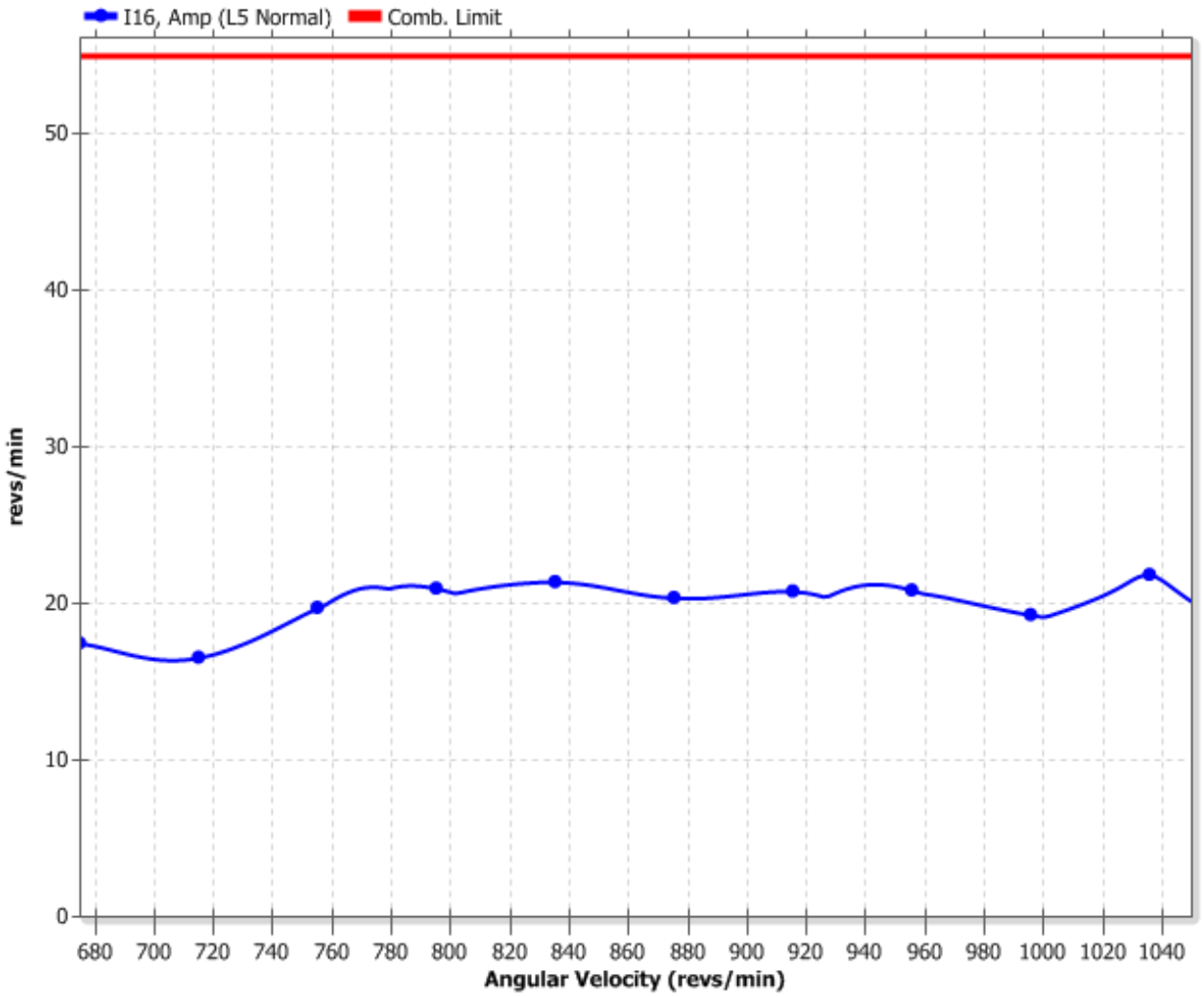
Compressor Stub Combined Order Vibratory Torque



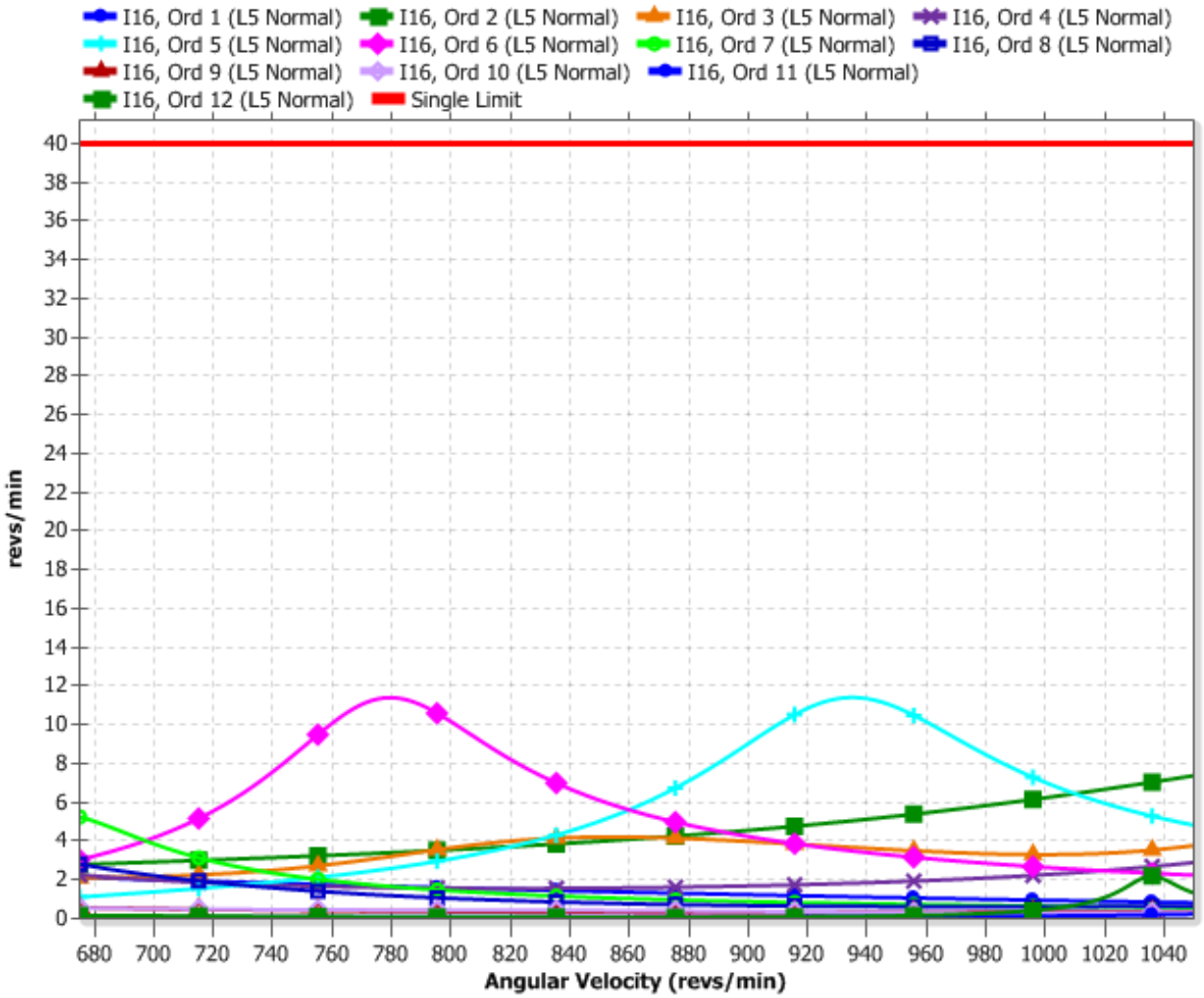
Compressor Shaft Combined Order Vibratory Torque



Aux End Combined Order Velocity



Aux End Single Order Velocity



Load Case #6

Ariel Performance

Company: EXTERRAN
Project #: AP032548 Rev:26
7.7.4.0 Case 71:
Customer: XTO ENERGY
Inquiry:
Project: XTO ENERGY

Compressor Data:						Driver Data:	
Elevation,ft:	3600.00	Barmtr,psia:	12.861	Ambient,F:	110.00	Type:	Nat. Gas
Frame: (ELP)	KBZ/6	Stroke, in:	6.75	Rod Dia, in:	2.875	Mfg:	Caterpillar
Max RL Tot, lbf:	150000	Max RL Tens, lbf:	75000	Max RL Comp, lbf:	80000	Model:	G3616 A4
Rated RPM:	1000	Rated BHP:	7800.0	Rated PS FPM:	1125.0	BHP:	5000
Calc RPM:	1000.0	BHP:	2316	Calc PS FPM:	1125.0	Avail:	5000

Services	Service 1					
Gas Model	VMG					
Stage Data:	**1**	---	**2**	---	**3**	**4**
Target Flow, MMSCFD	25.000	---	25.000	---	25.000	25.000
Flow Calc, MMSCFD	9.073	---	9.073	---	9.073	9.073
BHP per Stage	563.6	---	564.8	---	500.4	618.3
Specific Gravity	0.8285	---	0.8285	---	0.8285	0.8285
Ratio of Sp Ht (N)	1.2445	---	1.2290	---	1.2382	1.2502
Comp Suct (Zs)	0.9902	---	0.9849	---	0.9637	0.9182
Comp Disch (Zd)	0.9862	---	0.9797	---	0.9546	0.9173
Pres Suct Line, psig	20.00	---	N/A	---	N/A	N/A
Pres Suct Flg, psig	19.67	---	66.11	---	179.18	429.71
Pres Disch Flg, psig	68.62	---	185.61	---	446.22	1428.26
Pres Disch Line, psig	N/A	---	N/A	---	N/A	1400.00
Pres Ratio F/F	2.505	---	2.513	---	2.391	3.256
Temp Suct, F	50.00	---	130.00	---	130.00	130.00
Temp Clr Disch, F	130.00	---	130.00	---	130.00	120.00
Cylinder Data:	**Throw 3**	**Throw 5**	**Throw 4**	**Throw 6**	**Throw 1**	**Throw 2**
Cyl Model	24-1/8Z:10	24-1/8Z:10	17-7/8Z:10	17-7/8Z:10	14-1/8Z:10	9-1/4ZK
Cyl Bore, in	24.125	24.125	17.375	17.375	13.625	9.250
Cyl RDP (API), psig	250.0	250.0	577.3	577.3	1154.5	2181.8
Cyl MAWP, psig	275.0	275.0	635.0	635.0	1270.0	2400.0
Cyl Action	*CE(HEVR)*	*CE(HEVR)*	*CE(HEVR)*	*CE(HEVR)*	DBL	DBL
Cyl Disp, CFM	1760.2	1760.2	900.8	900.8	1113.7	499.6
Pres Suct Intl, psig	15.68	15.68	61.38	61.38	167.40	419.52
Temp Suct Intl, F	65	65	140	140	136	137
Pres Disch Intl, psig	76.92	76.92	196.91	196.91	469.08	1462.09
Temp Disch Intl, F	197	197	268	268	260	303
HE Suct Gas Vel, FPM	N/A	N/A	N/A	N/A	7481	4594
HE Disch Gas Vel, FPM	N/A	N/A	N/A	N/A	6147	4370
HE Spcrs Used/Max	N/A	N/A	N/A	N/A	0/4	0/4
HE Vol Pkt Avail	N/A	N/A	N/A	N/A	0.71+40.40	0.36+53.03
Vol Pkt Used	N/A %	N/A %	N/A %	N/A %	100.00 (V) %	0.00 (V) %
HE Min Clr, %	N/A	N/A	N/A	N/A	24.35	29.34
HE Total Clr, %	N/A	N/A	N/A	N/A	65.46	29.70
CE Suct Gas Vel, FPM	9834	9834	7343	7343	7148	4150
CE Disch Gas Vel, FPM	8347	8347	6548	6548	5874	3947
CE Spcrs Used/Max	0/0	0/0	0/6	0/6	0/4	0/4
CE Min Clr, %	13.59	13.59	18.99	18.99	26.09	33.52
CE Total Clr, %	13.59	13.59	18.99	18.99	26.09	33.52
Suct Vol Eff HE/CE, %	N/A/80.8	N/A/80.8	N/A/74.0	N/A/74.0	27.4/68.3	46.6/40.4
Disch Event HE/CE, ms	N/A/13.7	N/A/13.7	N/A/13.0	N/A/13.0	6.7/12.7	7.8/8.5
Suct Pseudo-Q HE/CE	N/A/8.4	N/A/8.4	N/A/5.6	N/A/5.6	3.7/4.0	2.8/2.3
Gas Rod Ld Comp, %	2.8 C	2.8 C	2.1 C	2.1 C	56.4 C	91.2 C
Gas Rod Ld Tens, %	34.5 T	34.5 T	39.8 T	39.8 T	54.5 T	80.6 T
Gas Rod Ld Total, %	18.7	18.7	21.1	21.1	57.3	88.9
Xhd Pin Deg/%Rvrsl lbf	173/55.1	173/55.1	168/49.6	168/49.6	178/66.7	171/68.5
Flow Calc, MMSCFD	4.537	4.537	4.537	4.537	9.073	9.073
Cyl BHP	281.8	281.8	282.4	282.4	500.4	618.3

01/08/2018 08:17:10 Note: BOLD=Out of Limits, *ITALIC*=Special Appl, ***BOLD***=Review Base: 14.70 psia, 60.0 F Page: 10 of 10
File: C:\Users\Deb\AppData\Local\Microsoft\Windows\Temporary Internet Files\Content.Outlook\1IEDZ846\AP032548.run Gathering Case:71 - Pkg:1

Single Order Results		Order	Predicted	Recommended Limit
FRT	Angular Displacement (deg)	0.5	0.069	1.000
	Angular Displacement (deg)	1.0	0.291	1.000
	Angular Displacement (deg)	1.5	0.050	0.250
	Angular Displacement (deg)	2.0	0.310*	0.150
	Angular Displacement (deg)	2.5	0.052	0.150
	Angular Displacement (deg)	3.0	0.215*	0.150
	Angular Displacement (deg)	4.5	0.017	0.150
I16	Angular Velocity (rpm)	1.0	2.3	40.0
	Angular Velocity (rpm)	2.0	16.7	40.0
	Angular Velocity (rpm)	3.0	11.3	40.0
	Angular Velocity (rpm)	4.0	1.2	40.0
	Angular Velocity (rpm)	5.0	4.9	40.0
	Angular Velocity (rpm)	6.0	7.1	40.0
	Angular Velocity (rpm)	7.0	0.5	40.0
	Angular Velocity (rpm)	8.0	1.4	40.0
	Angular Velocity (rpm)	9.0	0.3	40.0
	Angular Velocity (rpm)	10.0	0.1	40.0
	Angular Velocity (rpm)	11.0	0.2	40.0
	Angular Velocity (rpm)	12.0	2.0	40.0

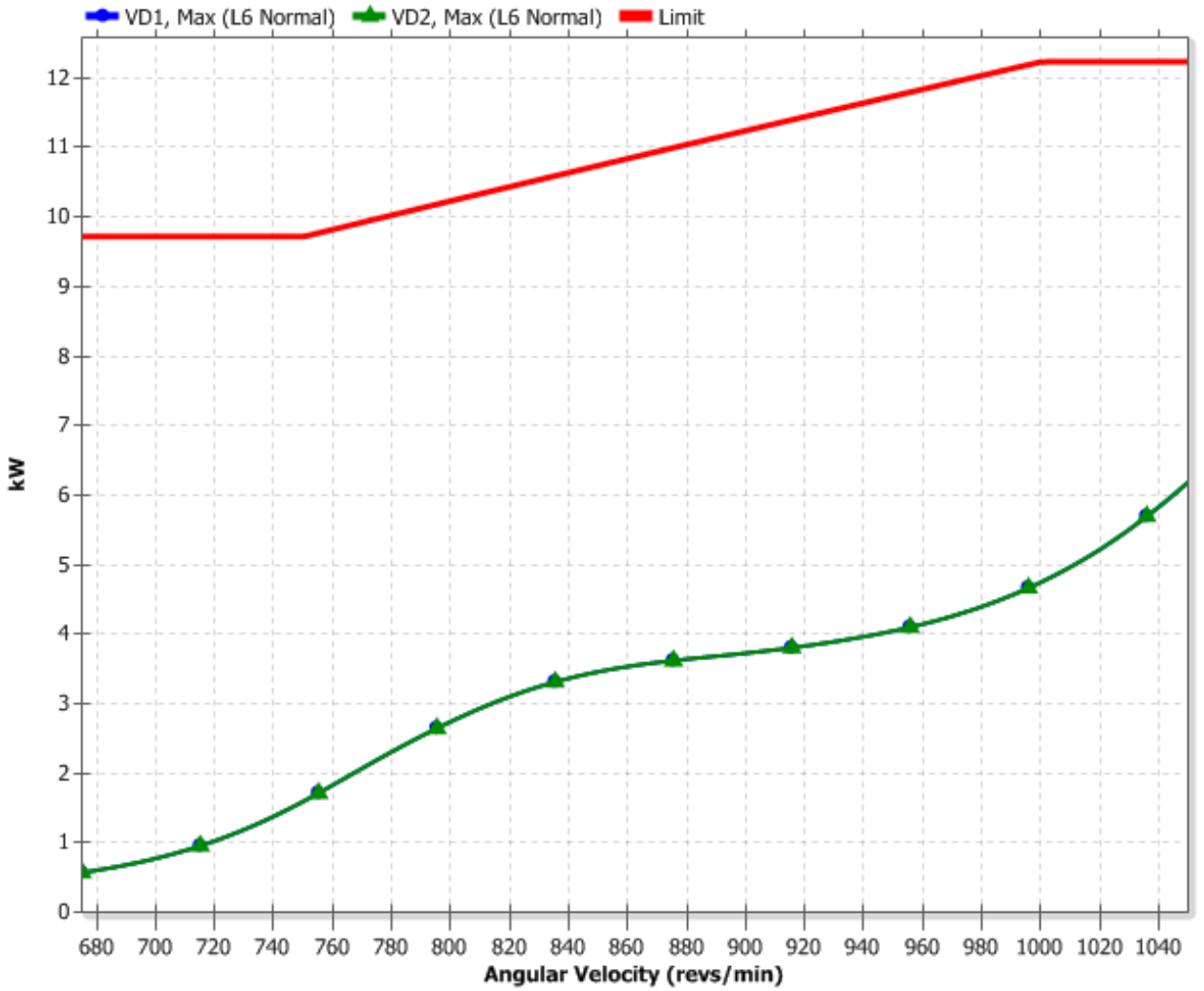
*Vibratory amplitude at the front of the engine crankshaft is used as an indicator for potentially damaging torsional vibrations throughout the system. While the engine excited 2.0 order and 3.0 order vibratory displacement amplitudes at the front of the engine crankshaft are above the recommended limit, additional details of the analysis show that these orders will not cause damage to the driven system.

Combined Order Results		Predicted	Recommended Limit
VD1	Maximum Power Loss (kW)	6.189	12.233
VD2	Maximum Power Loss (kW)	6.189	12.233
EK3	Vibratory Stress (MPa)	44.26	48.00
CPK	Maximum Torque (Nm)	69836	103900
	Minimum Torque (Nm)	-39314	-51900
CSK	Vibratory Torque (Nm)	55030	86404
K4	Vibratory Torque (Nm)	62718	86404
I16	Vibratory Angular Velocity (rpm)	26.9	55.0

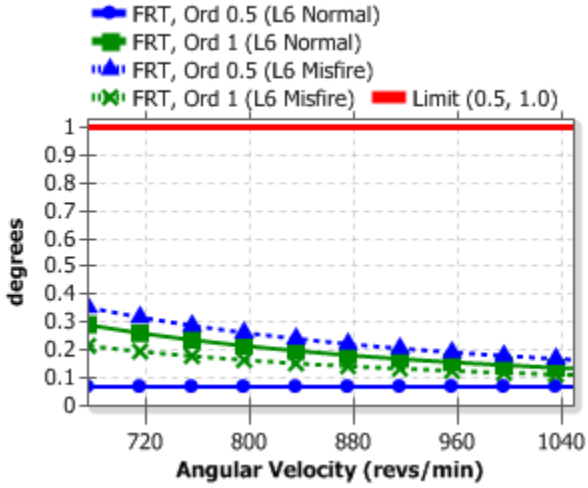
Single Order Misfire Results		Order	Predicted	Recommended Limit
FRT	Angular Displacement (deg)	0.5	0.354	1.000
	Angular Displacement (deg)	1.0	0.216	1.000
	Angular Displacement (deg)	1.5	0.050	0.250
	Angular Displacement (deg)	2.0	0.310*	0.150
	Angular Displacement (deg)	2.5	0.052	0.150
	Angular Displacement (deg)	3.0	0.215*	0.150
	Angular Displacement (deg)	4.5	0.017	0.150

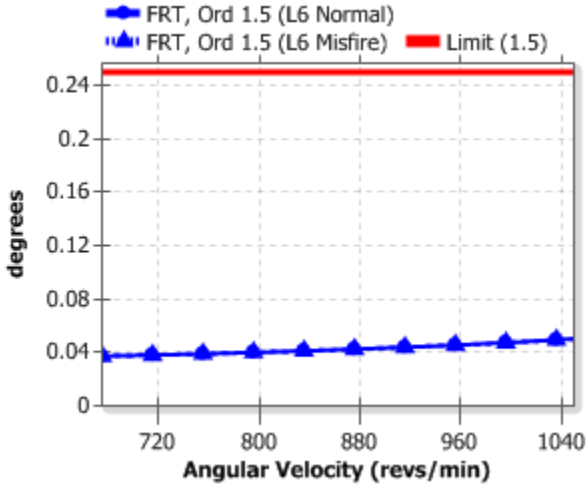
*Vibratory amplitude at the front of the engine crankshaft is used as an indicator for potentially damaging torsional vibrations throughout the system. While the engine excited 2.0 order and 3.0 order vibratory displacement amplitudes at the front of the engine crankshaft are above the recommended limit, additional details of the analysis show that these orders will not cause damage to the driven system.

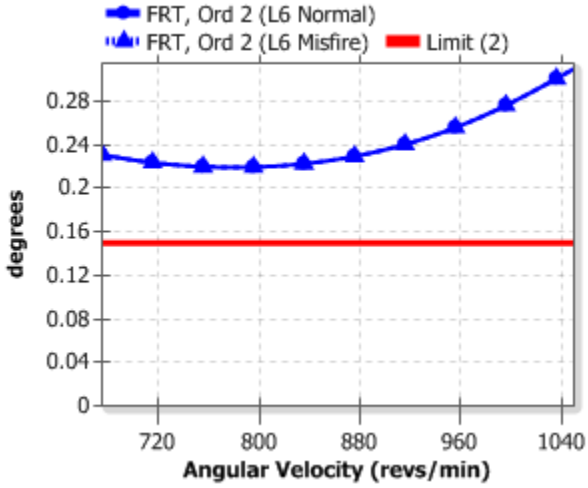
Damper Combined Order Power Loss

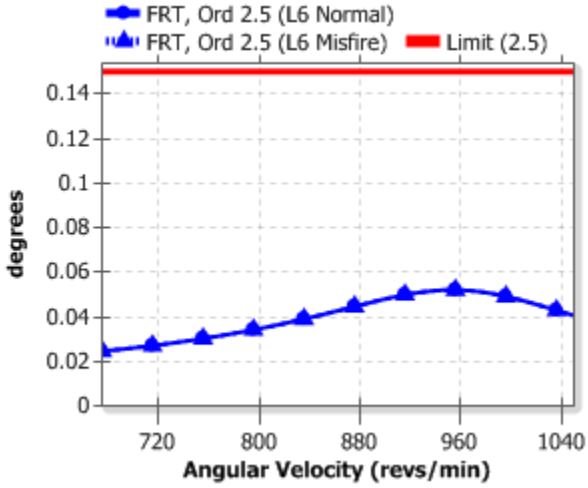


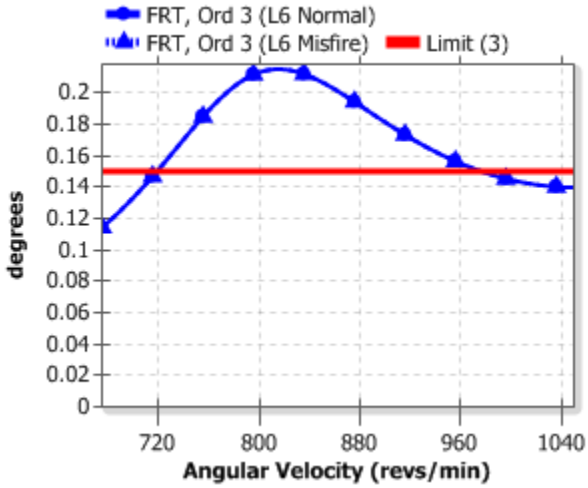
Front Crankshaft Single Order Displacement

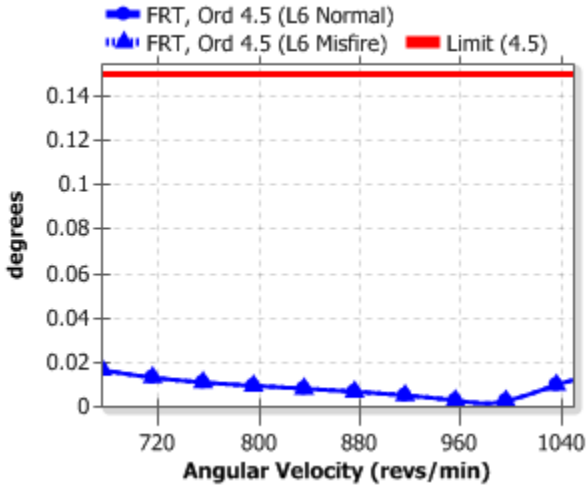




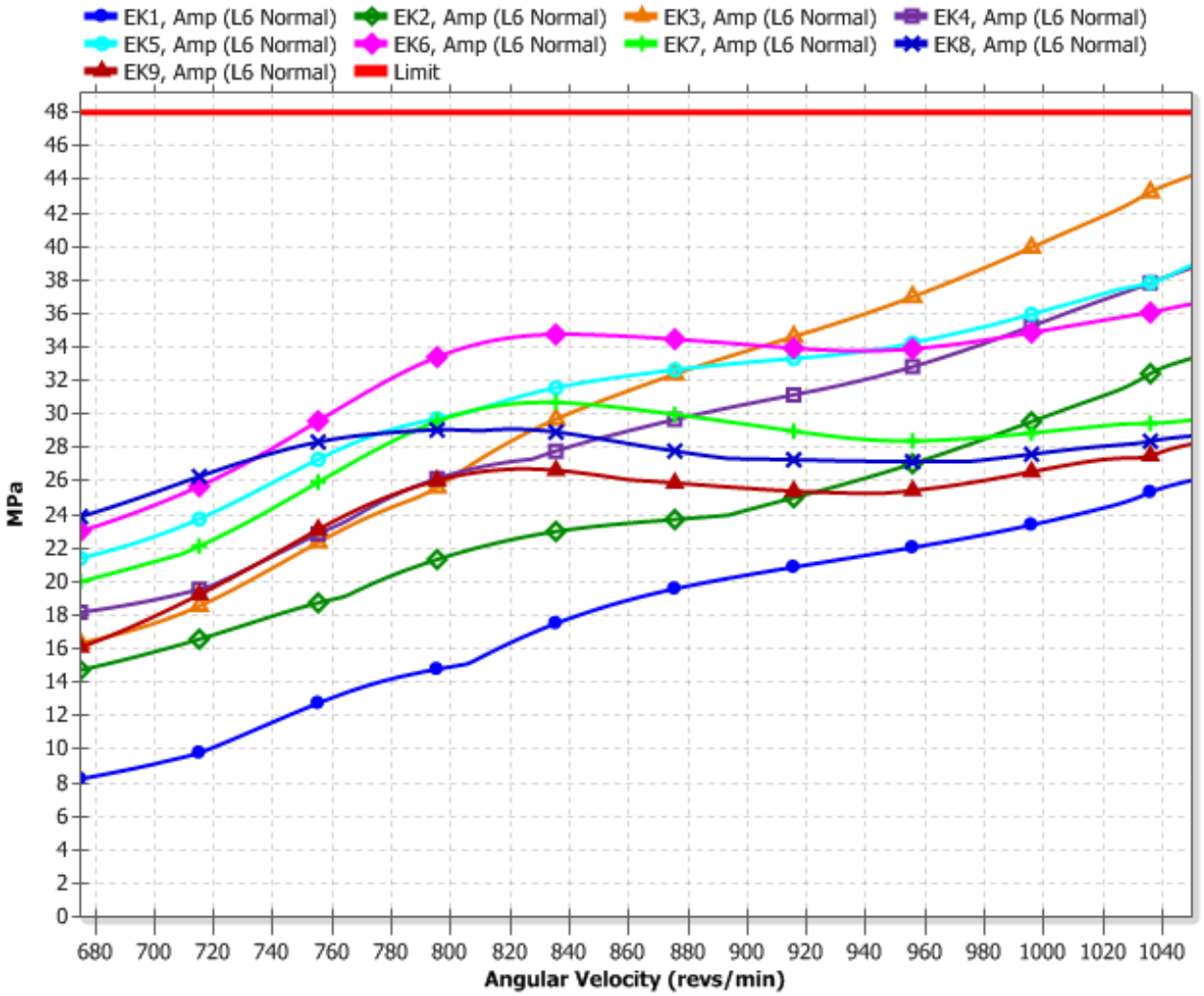




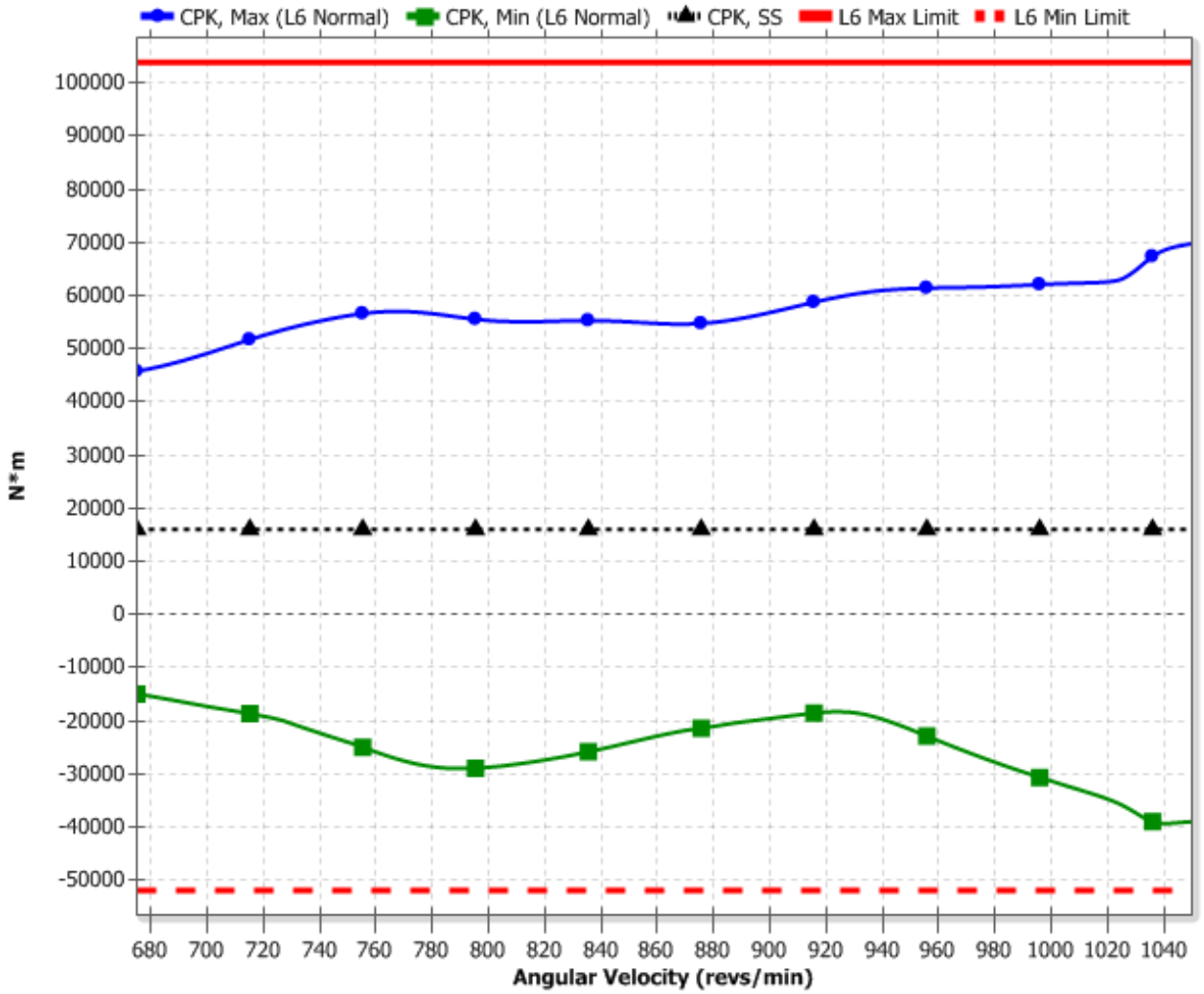




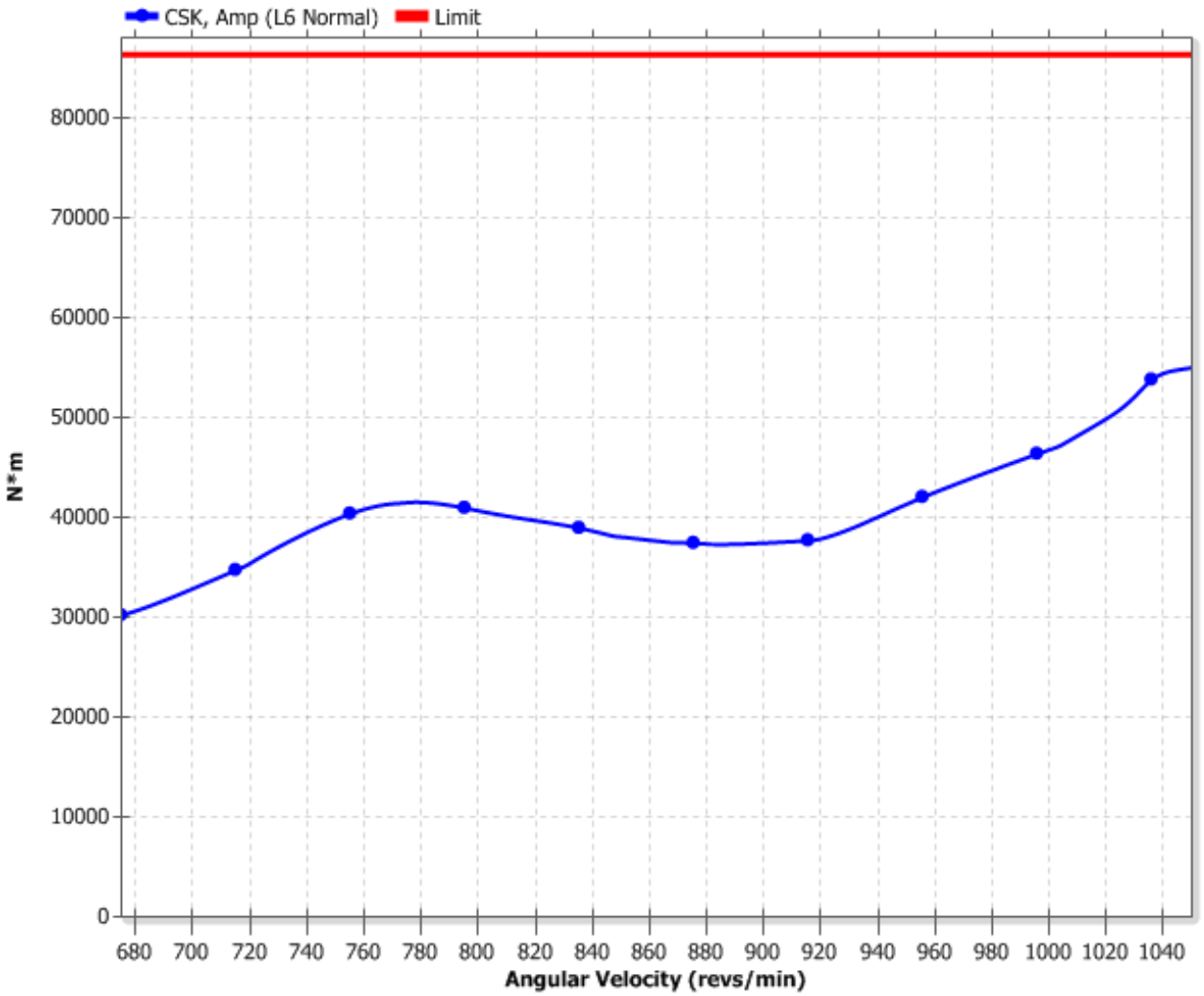
Crankshaft Combined Order Vibratory Stress



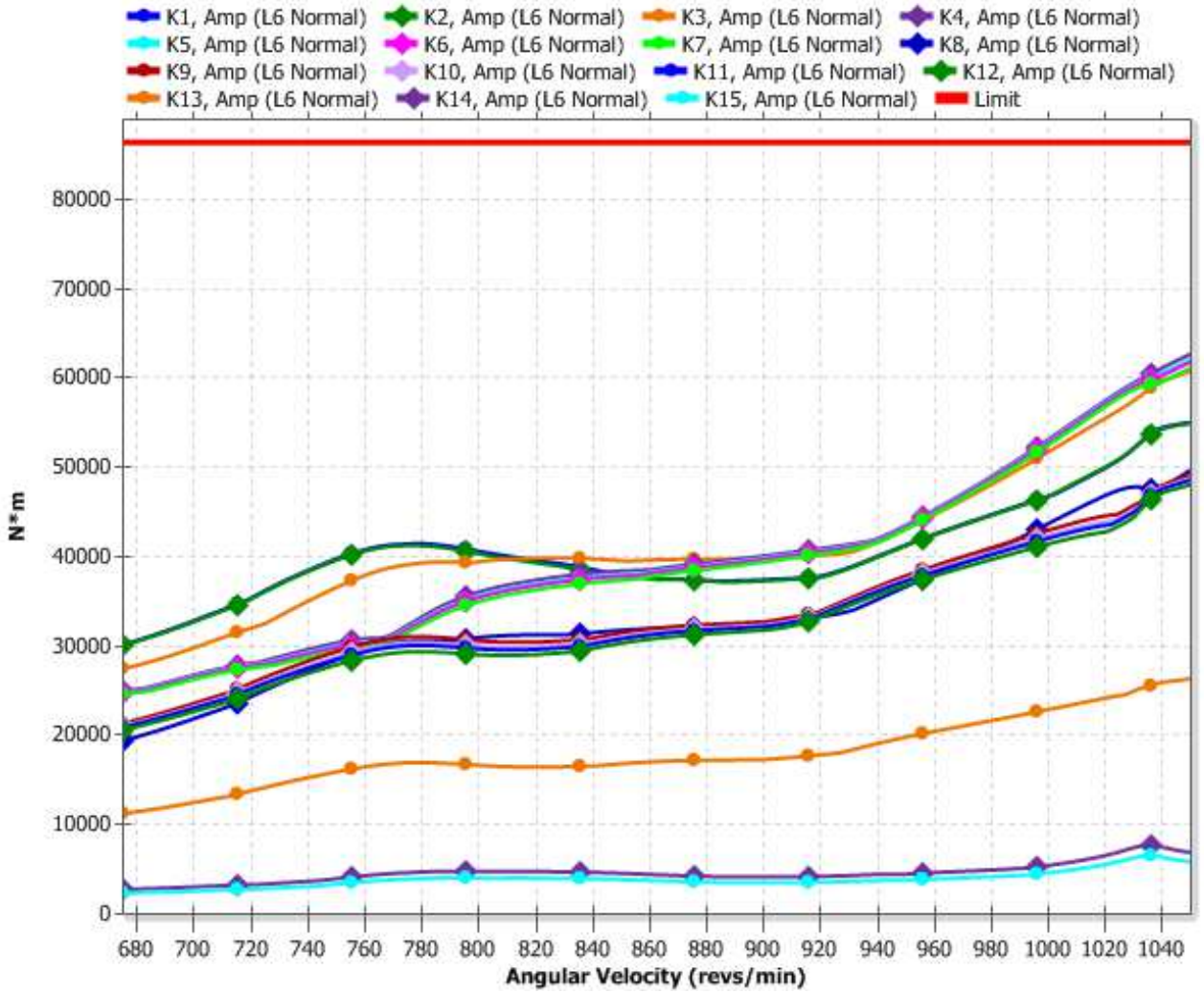
Coupling Combined Order Torque



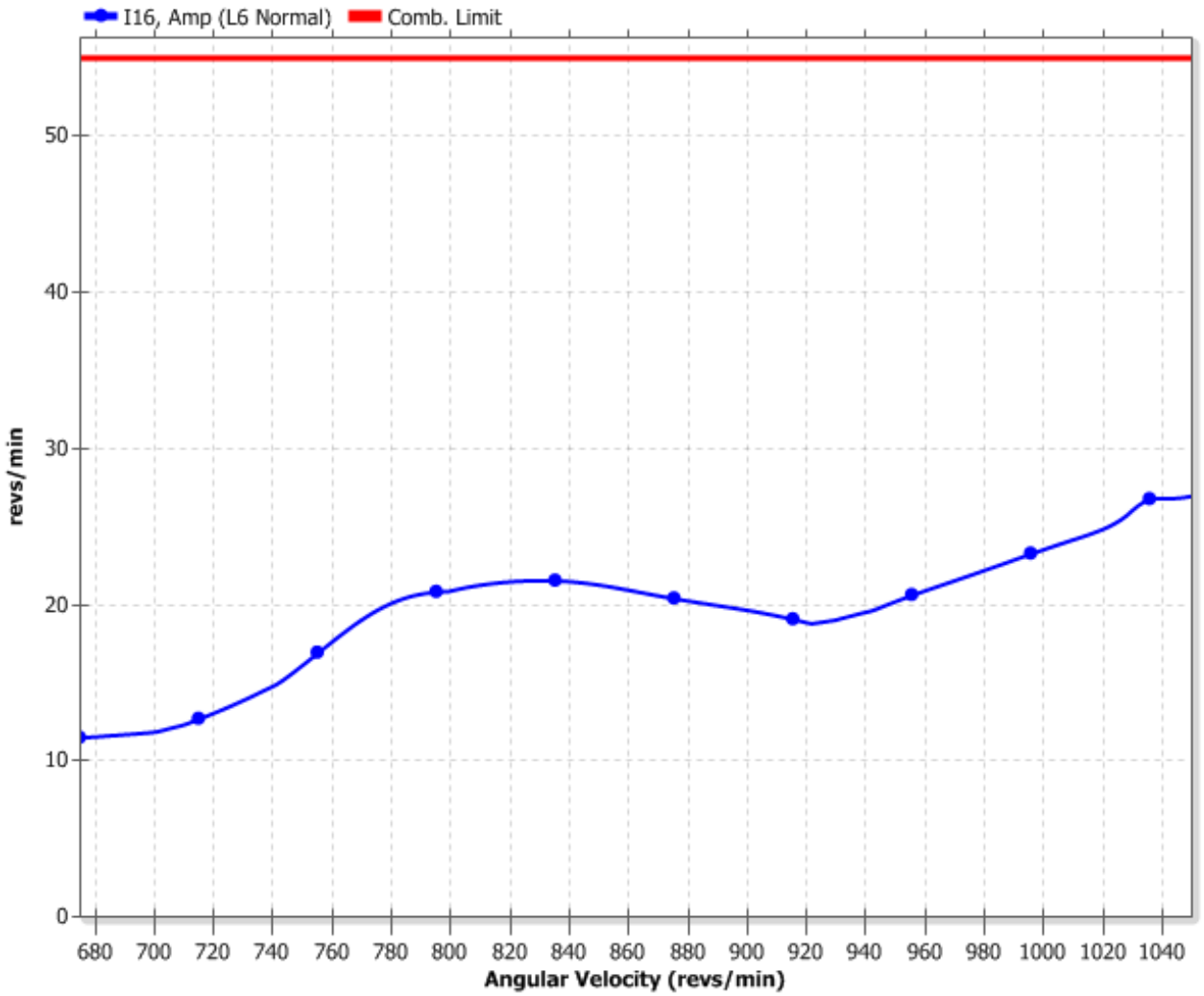
Compressor Stub Combined Order Vibratory Torque



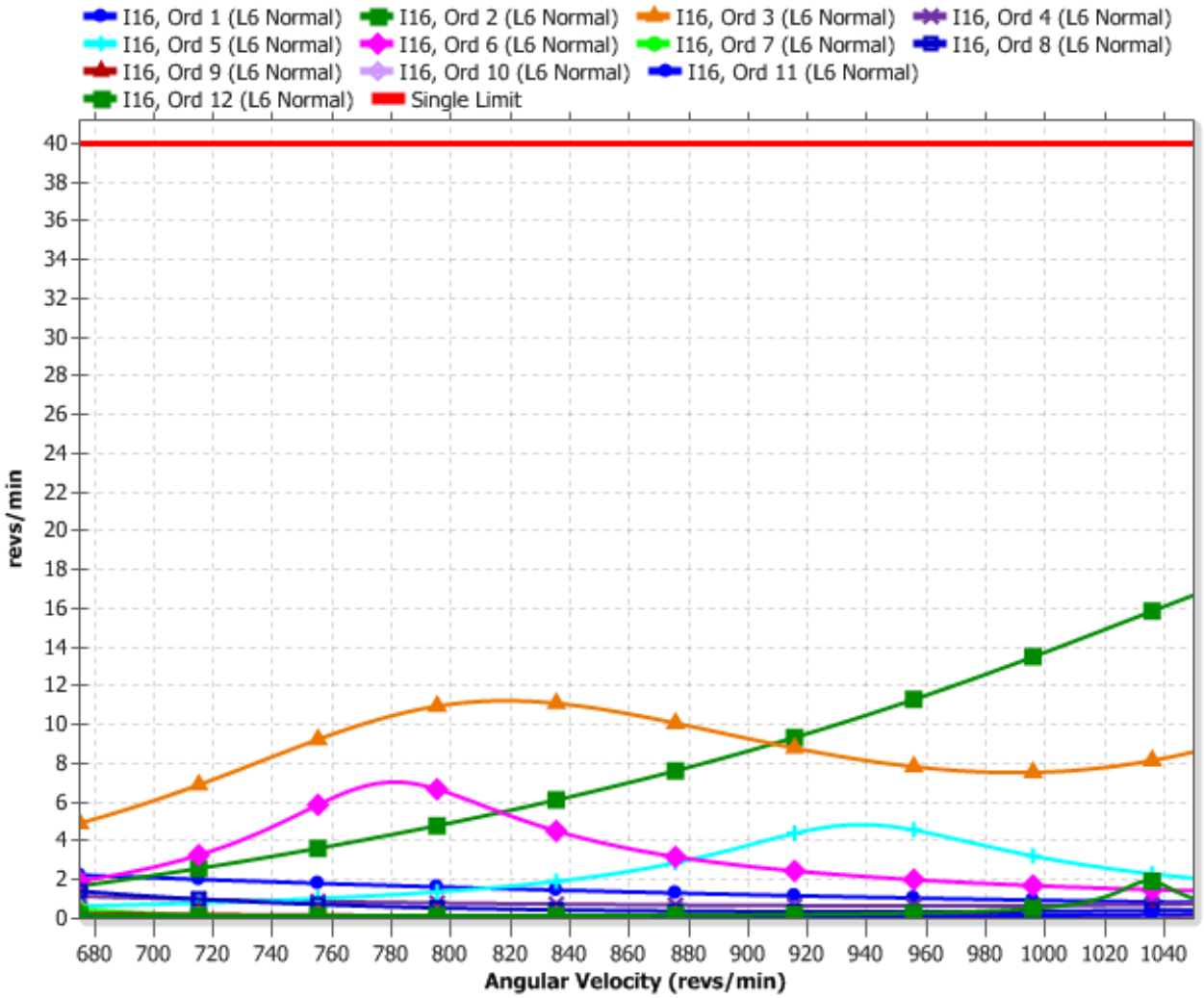
Compressor Shaft Combined Order Vibratory Torque



Aux End Combined Order Velocity



Aux End Single Order Velocity



1. The analysis is based upon information provided by the customer and other manufacturers. Caterpillar is in no way responsible for the accuracy of that information. Caterpillar warrants this analysis to be free from errors in calculations. Any damages arising out of an alleged error by Caterpillar in this report shall be limited to a refund of monies paid by the customer to Caterpillar for the report. This warranty is expressly in lieu of any other warranties, expressed or implied, including any warranty of merchantability or fitness for a particular purpose. Remedies under this warranty are limited to a refund as specified above. Caterpillar is not responsible for incidental or consequential damages. Nothing herein is intended to supersede or alter in any manner any of the terms and conditions of, or any rights the purchaser may have under, Caterpillar's standard product warranty.

2. Caterpillar excludes all liability for or arising from any negligence on its part or on the part of any of its employees, agents or representatives in respect of the manufacture or supply of goods or the provision of services relating to the goods.

3. Satisfactory system operation also depends on factors other than torsional vibration. This report should not be used as a guarantee of a successful system installation.

4. This installation has been analyzed from 90% to 105% of the rated speed.

5. Though all relevant orders of vibration have been analyzed, only significant orders of vibration are included in this report. Combined order results include engine orders 0 through 12. Vibratory amplitudes, stresses and torques are single amplitude, which means they are +/- from zero.

6. System mass-elastic data values are actual values. Mass-elastic values for components driven through a gearbox are not adjusted to engine speed. The viscous damper inertia used to calculate normal modes is an equivalent inertia equal to the damper housing inertia plus one-half of the damper flywheel inertia. Forced response peak amplitudes may appear at speeds that do not correspond to those reported on the Resonant Speed Diagram due to the effects of frequency and torque dependent components or the variation of mean load as a function of speed.

7. This report contains information from two different analysis methods that produce complementary results. The undamped frequency results and the resonant speed diagram contain no damping or excitation. The forced response results shown in the report include system damping and excitation.

8. The analysis considered only the load cases provided by the reciprocating compressor manufacturer/packager at the time of the torsional analysis request. Caterpillar is not responsible for any damages arising from loading the compressor other than as prescribed in the provided load cases. Caterpillar strongly recommends another vibration analysis be performed to verify torsional compatibility of the driveline when the compressor is subjected to loadings other than those listed in this report.

Compressor Mass-Elastic Data

Mass Elastic Data

7.7.4.0

Company: EXTERRAN
Project #: AP032548 Rev:26
Case 7: Ps-low Pd-high
Customer: XTO ENERGY
Inquiry:
Project: XTO ENERGY

Frame: KBZ/6 Stroke: 6.75 in Conrod Center Dist: 18.50 in Rotation: Clockwise
WARNING: Gas Analysis is from Specific Gravity, please use Real Analysis!

Throw #:	1	2	3	4	5	6
Cylinder Model:	14-1/8Z:10	9-1/4ZK	24-1/8Z:10	17-7/8Z:10	24-1/8Z:10	17-7/8Z:10
Cylinder Bore,in	13.625	9.250	24.125	17.375	24.125	17.375
WEIGHTS, lbs:						
Conrod Large End:	156.67	156.67	156.67	156.67	156.67	156.67
Conrod Small End:	117.23	117.23	117.23	117.23	117.23	117.23
Piston & Rod Assembly:	294.20	264.70	368.64	363.80	368.64	363.80
X-Head:	230.60	230.60	230.60	230.60	230.60	230.60
X-Head Pin Assembly:	93.10	93.10	93.10	93.10	93.10	93.10
Balance Nut:	20.00	50.00	20.00	20.00	20.00	20.00
Recip Weight,lbs	755.13	755.63	829.57	824.73	829.57	824.73
THROW INERTIA:						
Crankpin,lb-in2:	7294.450	7294.450	7294.450	7294.450	7294.450	7294.450
Conrod Large End,lb-in2:	1784.578	1784.578	1784.578	1784.578	1784.578	1784.578
Recip Weight,lb-in2:	4336.480	4339.352	4763.967	4736.172	4763.967	4736.172
Total, lb-in2:	13415.508	13418.380	13842.995	13815.200	13842.995	13815.200

MASS ELASTIC DATA

Location	Leading Angle	Station (in)	Symbol	Inertia (lb-in2)	Internal Flywheel (lb-in2)	Symbol	Stiffness (in-lbs/RAD x 10E6)
Shoulder Stop		0.000	I1	1496.370		K1	600.710
Main #1 CL		10.313	I2	4334.600		K2	491.390
Throw #1 CL	0	20.938	I3	13415.508		K3	488.790
Throw #2 CL	0	30.688	I4	13418.380		K4	487.740
Main #2 CL		41.313	I5	4382.140		K5	857.840
Spreader CL		49.813	I6	2191.890		K6	857.840
Main #3 CL		58.313	I7	4382.140		K7	487.740
Throw #3 CL	240	68.938	I8	13842.995		K8	488.790
Throw #4 CL	240	78.688	I9	13815.200		K9	487.740
Main #4 CL		89.313	I10	4382.140		K10	857.840
Spreader CL		97.813	I11	2191.890		K11	857.840
Main #5 CL		106.313	I12	4382.140		K12	487.740
Throw #5 CL	120	116.938	I13	13842.995		K13	488.790
Throw #6 CL	120	126.688	I14	13815.200		K14	487.740
Main #6 CL		137.313	I15	3710.630		K15	820.760
Aux Drive End		142.563	I16	449.300			
			Total:	114053.523	0.000		

Crankshaft Material:
Material: ASTM A668 Class M/AISI 4340 (Forged Alloy Steel)
Yield, psi: 110000
Tensile, psi: 135000

NOTES:
1. Inertia and Stiffness of the drive stub forward of the stop shoulder are not included in this table.
2. Throw Inertias include inertia for the crankshaft, as well as the connecting rod, crosshead, balance nut and piston and rod assembly for that throw.
3. Drive stub stiffness must be calculated appropriately depending upon coupling or flanged hub connection.
4. Mass elastic data listed does not include the added inertia from any optional flywheels or detuners.
5. Refer to the Ariel Packager Standards, section 5 (ER-56.05), for additional information regarding the compressor drive system and the torsional analysis requirements, including specific references to electric motor drive systems.
6. Inertia is for bare compressor only. If an internal auxilliary end flywheel is selected it will show above. Does not include driver, coupling, external flywheel, or internal detuners (donuts).
7. For inertia units of lb-in-sec2, divide the value of lb-in2 by 386.1 in/sec2.

MERCER VALVE CO., INC.®
AUTO SEAT TECHNOLOGY®

July 31, 2015

Technical Bulletin ETB00012

RECOMMENDED MAINTENANCE SCHEDULE

For optimum performance, pressure relief valves must be maintained on a regular basis. Mercer Valve Company, Inc. recommends inspection and testing annually. If required, qualified repair personnel should perform valve repair. Qualified repair personnel performing the annual inspection and testing may alter the maintenance schedule due to service conditions.

In the annual inspection the set pressure should be verified, the valve should be leak checked to the proper specification, the tag information should be verified, and the seal wire should be checked. The tests can be performed on the system or with the pressure relief valve on a test stand. The pressure relief valve can only be tested in place on the system if there is a method and a proper procedure in place to pressurize the pressure relief valve to the set pressure without exceeding the limits of the system. When testing the pressure relief valve the proper fluid will need to be used. Gas/Vapor pressure relief valves should only be tested with a gas/vapor, usually air, and liquid pressure relief valve should be tested only with liquids, usually water. Testing a pressure relief valve with the wrong fluid state can cause inaccurate readings. The set pressure of the pressure relief valve has a tolerance of ±3% of the specified set pressure or ±2psi, which ever is greater, as with accordance with ASME Boiler and Pressure Vessel Code. If the tested set pressure does not fall within these tolerances the pressure relief valve should be reset and possibly repaired by qualified repair personnel. The set pressure definition for a pressure relief valve will vary from each valve line. Below is a chart of the set pressure definition for Mercer Valve Company, Inc. products.

Mercer Valve Co., Inc.® AUTHORIZED BLUE TAG CENTER® "Auto Seat Technology"®

CORPORATE HEADQUARTERS: 9609 NW 4th St., Oklahoma City, OK 73127 • 1-800-833-6402 • Phone: (405) 495-6533 • Fax: (405) 495-8728 • sales@mercervalve.net • www.mercervalve.net

Valve Series	Set Pressure Definitions	
	Gas/Vapor	Liquid
1400 Series	Pop	N/A
8100 Series	Pop	Pop
8500 Series	Pop	N/A
8700 Series	Pop	N/A
9100 Series	Pop	Pop
9500 Series Snap Pilot	Pop	N/A
9500 Series Modulating Pilot	1st Audible Sound from the Outlet of the Main Valve	1st Steady Stream from the Outlet of the Main Valve

If the pressure relief valve does not pass the leak specification or the seal wire has been broken the pressure relief valve will need to be repaired by qualified repair personnel. If the pressure relief valve tag does not indicate the proper service conditions of the pressure relief valve, it will need to be replaced with the proper pressure relief valve for the service conditions. It is always important to comply with all safety precautions when testing a pressure relief valve. Only qualified repair personnel should test and repair the pressure relief valves.

Installation, operation, and maintenance manuals are available for each Mercer Valve Company, Inc. valve line. Request for manuals or other information pertaining to the maintenance of a Mercer Valve Company, Inc. product can be obtained by calling 405-495-6533 or 1-800-833-6402.