



Document No. 19-194-01
September 10, 2019

Torsional Vibration Analysis

for

Kaego Energy & Technology Corp.

Project: 12V275GL+ / KBZ4
Packager: Exterran
Requestor: Vishal Varia
Unit: US-123356-01, US-123356-02

Reported by:

A handwritten signature in black ink that reads 'Crystal K. Zeller'.

Crystal Zeller

Summary

System Description

A Waukesha 12V275GL+ engine is coupled to an Ariel KBZ/4 compressor through a TB Woods FSH 92HT-28 coupling. The compressor manufacturer has provided expected loading conditions for the compressor. A vibration analysis has been performed for these operating conditions plus a no load condition to ensure torsional compatibility of the system.

Conclusion

The following analysis indicates this system is free of serious torsional vibration for the normal and no load operating conditions described. Damper thermal loading and engine crankshaft vibratory stress levels are within manufacturer limits. Damper housing vibration falls within levels that the engine manufacturer has previously approved. Torque levels in the coupling are within manufacturer limits. Torsional vibration levels in the compressor are within manufacturer limits.

The engine manufacturer allows damper displacement amplitudes to exceed the published limit by 30%. Due to 1.5 order damper housing vibrations exceeding the published limit but being within the extended 30% limit, the front end gear/belt wear must be checked at regular service intervals.

IDC Engineering does not recommend operating any system under engine misfire conditions.

For compressor operating conditions other than those analyzed in this report, IDC strongly recommends another vibration analysis be performed to verify torsional compatibility of the driveline.

System Data

Engine: Waukesha 12V275GL+ rated 3750 HP @ 1000 RPM
Operating Speed Range: 750 RPM – 1000 RPM
Coupling: TB Woods FSH 92HT-28, Dwg. No. P003842
Compressor: Ariel KBZ/4, Ref. No. AP035401 Rev:7

Result Highlights

Engine

The highest damper thermal loading occurs under Operating Condition #3 where power loss is 21% of the limit. Damper housing vibration falls within levels that the manufacturer has previously approved. The highest crankshaft stress occurs under Operating Condition #3 where vibratory stress in the crankshaft is 80% of the limit.

Coupling

The highest coupling vibration occurs under Operating Condition #4 where maximum torque is 54% of the limit.

Compressor

The highest compressor crankshaft vibratory torque is 86% of the limit and occurs under Operating Condition #4. The highest compressor aux end velocity occurs under Operating Condition #4 where single order velocity is 63% of the limit for the 7.0 order and where combined order velocity is 62% of the limit.

Report Contents

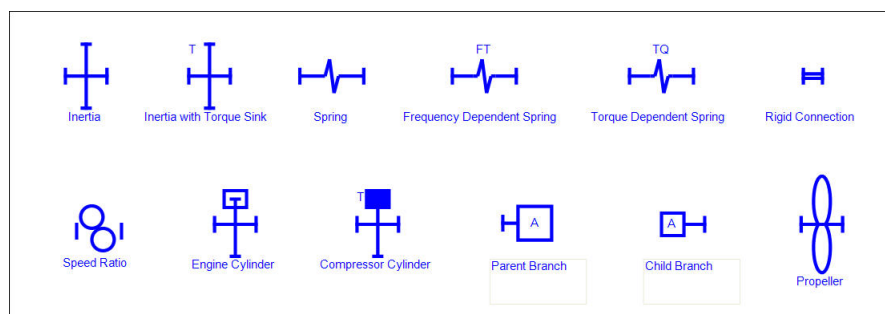
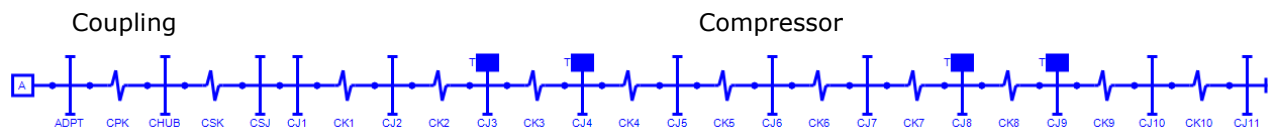
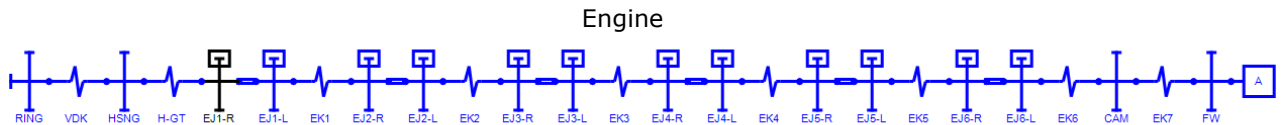
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Mass-Elastic Model

System Diagram

Rated Speed: 1000 rev/min
 Rated Power: 3750 HP
 Speed Sweep: 710 - 1050 rev/min
 Misfire: Off

12V275GL+
 Config



Mass Values

Mass ID	Description	Inertia Value Nms ²	Damping Value Nms/rad
RING	Damper Ring	18.400	0
HSNG	Damper Housing	4.695	0
EJ1-R	Crank Throw 1 Right	7.820	0
EJ1-L	Crank Throw 1 Left	7.820	0
EJ2-R	Crank Throw 2 Right	7.820	0
EJ2-L	Crank Throw 2 Left	7.820	0
EJ3-R	Crank Throw 3 Right	7.820	0
EJ3-L	Crank Throw 3 Left	7.820	0
EJ4-R	Crank Throw 4 Right	7.820	0
EJ4-L	Crank Throw 4 Left	7.820	0
EJ5-R	Crank Throw 5 Right	7.820	0
EJ5-L	Crank Throw 5 Left	7.820	0
EJ6-R	Crank Throw 6 Right	7.922	0
EJ6-L	Crank Throw 6 Left	7.922	0
CAM	Cam Drive	2.949	0
FW	Flywheel	178.290	0
ADPT	Flywheel Adapter	17.531	0
CHUB	Comp Hub	20.669	0
CSJ	Comp Stub	0.318	0
CJ1	Shoulder Stop	1.039	0
CJ2	Main #1 CL	1.818	0
CJ3	Throw #1 CL	3.944	0
CJ4	Throw #2 CL	3.940	0
CJ5	Main #2 CL	1.282	0
CJ6	Spreader CL	0.641	0
CJ7	Main #3 CL	1.282	0
CJ8	Throw #3 CL	3.961	0
CJ9	Throw #4 CL	3.967	0
CJ10	Main #4 CL	1.818	0
CJ11	Aux Drive End	0.727	0

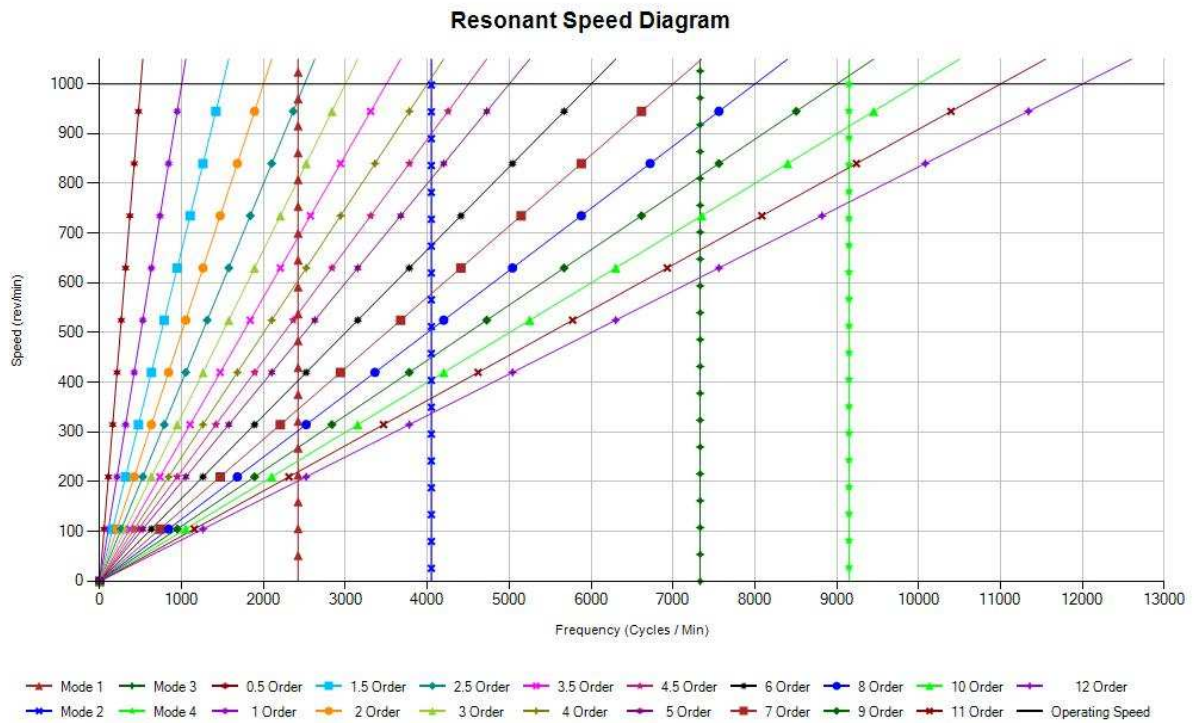
Spring Values

Spring ID	Description	Spring Rate MNm/rad	Damping Rate Nms/rad	Relative Damping Ψ	Outside Diameter mm
VDK	Damper	1.700	2,400	0.000	0.000
H-GT	Engine	40.788	0	0.125	195.072
EK1	Engine	28.133	0	0.125	195.072
EK2	Engine	28.133	0	0.125	195.072
EK3	Engine	28.133	0	0.125	195.072
EK4	Engine	28.133	0	0.125	195.072
EK5	Engine	28.133	0	0.125	195.072
EK6	Engine	40.223	0	0.125	195.072
EK7	Engine	117.053	0	0.125	225.044
CPK	Coupling	139.034	0	0.188	0.000
CSK	Comp Stub	150.628	0	0.188	203.200
CK1	Compressor	64.962	0	0.188	0.000
CK2	Compressor	55.107	0	0.188	0.000
CK3	Compressor	55.226	0	0.188	0.000
CK4	Compressor	55.107	0	0.188	0.000
CK5	Compressor	96.923	0	0.188	0.000
CK6	Compressor	96.923	0	0.188	0.000
CK7	Compressor	55.107	0	0.188	0.000
CK8	Compressor	55.226	0	0.188	0.000
CK9	Compressor	55.107	0	0.188	0.000
CK10	Compressor	15.401	0	0.188	0.000

Normal Modes Analysis

Undamped Frequency Results

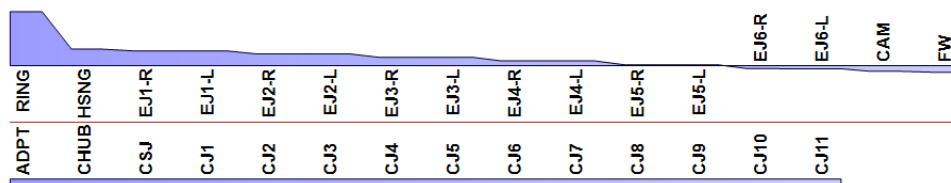
Resonant Speed Diagram



First Natural Frequency

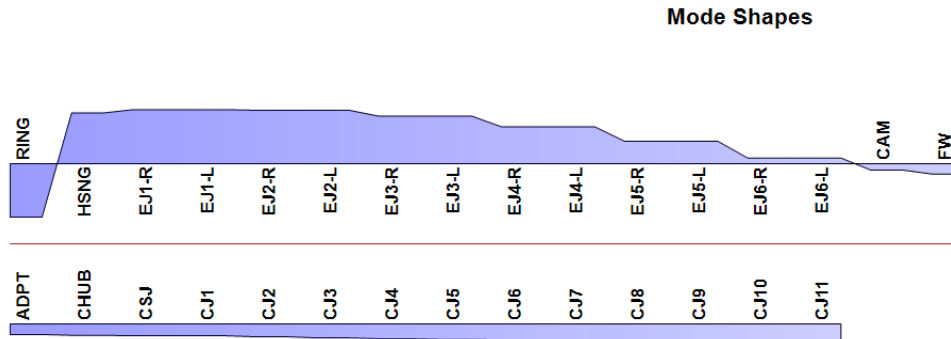
Mode Shape at 2,422 CPM (40.4 Hz)

Mode Shapes



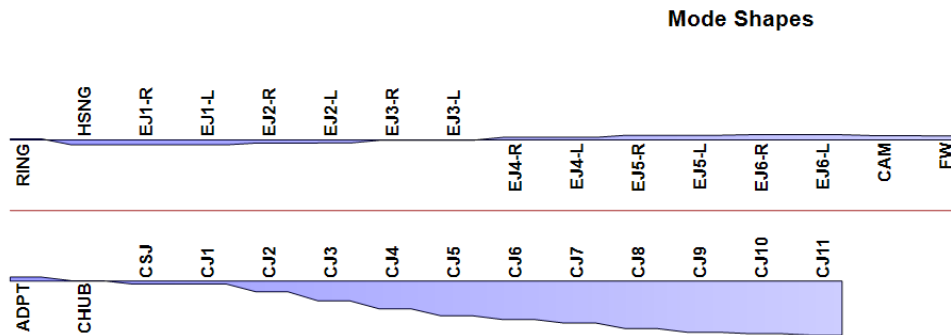
Second Natural Frequency

Mode Shape at 4,049 CPM (67.5 Hz)



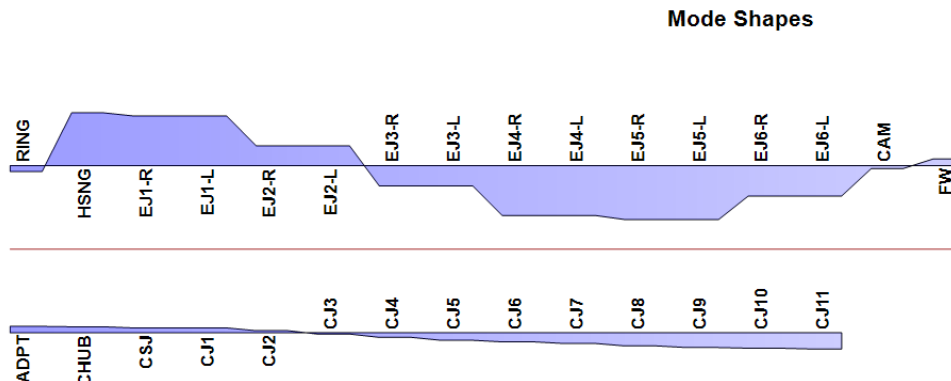
Third Natural Frequency

Mode Shape at 7,331 CPM (122.2 Hz)



Fourth Natural Frequency

Mode Shape at 9,148 CPM (152.5 Hz)



Forced Response Analysis

Operating Condition One



Company: Exterran Energy
Project #: AP035401 Rev:7
7.7.6.0 Case 7:

Ariel Performance

Customer: Kaego Energy & Technology Corp.
Inquiry:
Project:



Compressor Data:

Elevation,ft: 50.00
Frame: (ELP) KBZ/4
Max RL Tot, lbf: 150000
Rated RPM: 1000
Calc RPM: 1000.0

Barmtr,psia: 14.669
Stroke, in: 6.75
Max RL Tens, lbf: 75000
Rated BHP: 5200.0
BHP: 3511

Ambient,F: 100.00
Rod Dia, in: 2.875
Max RL Comp, lbf: 80000
Rated PS FPM: 1125.0
Calc PS FPM: 1125.0

Driver Data:

Type: Nat. Gas
Mfg: Waukesha
Model: 12V275GL+
BHP: 3750
Avail: 3750

Services

Gas Model

Stage Data:

Target Flow, MMSCFD

Flow Calc, MMSCFD

BHP per Stage

Specific Gravity

Ratio of Sp Ht (N)

Comp Suct (Zs)

Comp Disch (Zd)

Pres Suct Line, psig

Pres Suct Flg, psig

Pres Disch Flg, psig

Pres Disch Line, psig

Pres Ratio F/F

Temp Suct, F

Temp Clr Disch, F

Cylinder Data:

Cyl Model

Cyl Bore, in

Cyl RDP (API), psig

Cyl MAWP, psig

Cyl Action

Cyl Disp, CFM

Pres Suct Intl, psig

Temp Suct Intl, F

Pres Disch Intl, psig

Temp Disch Intl, F

HE Suct Gas Vel, FPM

HE Disch Gas Vel, FPM

HE Spcrrs Used/Max

HE Vol Pkt Avail

Vol Pkt Used

HE Min Clr, %

HE Total Clr, %

CE Suct Gas Vel, FPM

CE Disch Gas Vel, FPM

CE Spcrrs Used/Max

CE Min Clr, %

CE Total Clr, %

Suct Vol Eff HE/CE, %

Disch Event HE/CE, ms

Suct Pseudo-Q HE/CE

Gas Rod Ld Comp, %

Gas Rod Ld Tens, %

Gas Rod Ld Total, %

Xhd Pin Deg/%RvrsI lbf

Flow Calc, MMSCFD

Cyl BHP

Service 1

VMG-APRNL2

1

22.500

18.909

1393.1

0.7315

1.2221

0.9866

0.9795

45.00

44.40

176.97

N/A

3.244

100.00

130.00

Throw 1

20-1/8Z:10

20.125

313.6

345.0

DBL

2459.8

39.98

110

188.65

263

8595

7259

0/0

0.62+42.28

0.00 (V) %

13.82

14.44

8420

7111

0/0

14.47

14.47

70.6/70.5

9.7/11.2

6.1/5.8

59.5 C

61.4 T

62.4

168/98.8

9.454

696.5

2

22.500

18.909

1064.6

0.7315

1.2273

0.9644

0.9539

N/A

172.25

451.75

N/A

2.495

130.00

130.00

Throw 3

20-1/8Z:10

20.125

313.6

345.0

DBL

2459.8

39.98

110

188.65

263

8595

7259

0/0

0.62+42.28

0.00 (V) %

13.82

14.44

8420

7111

0/0

14.47

14.47

70.6/70.5

9.7/11.2

6.1/5.8

59.5 C

61.4 T

62.4

171/99.7

9.454

696.5

3

22.500

18.894

1006.9

0.7299

1.2440

0.9156

0.9082

N/A

443.38

1111.15

1100.00

2.458

130.00

120.00

Throw 4

15-7/8Z:10

15.875

768.2

845.0

DBL

1521.0

163.55

137

471.23

258

6904

5946

0/6

0.69+39.74

0.00 (V) %

17.76

18.45

6678

5751

0/6

18.83

18.83

74.5/74.1

11.3/13.0

3.8/3.5

77.5 C

77.0 T

79.9

142/77.8

18.909

1064.6

4

22.500

18.894

1006.9

0.7299

1.2440

0.9156

0.9082

N/A

443.38

1111.15

1100.00

2.458

130.00

120.00

Throw 2

11Z:10

10.500

1545.5

1700.0

DBL

651.1

420.31

135

1158.53

263

7144

5976

0/4

0.67+38.83

0.00 (V) %

24.21

24.88

6609

5528

0/4

26.76

26.76

68.2/66.1

11.0/12.3

4.1/3.5

83.5 C

75.0 T

82.1

152/67.2

18.894

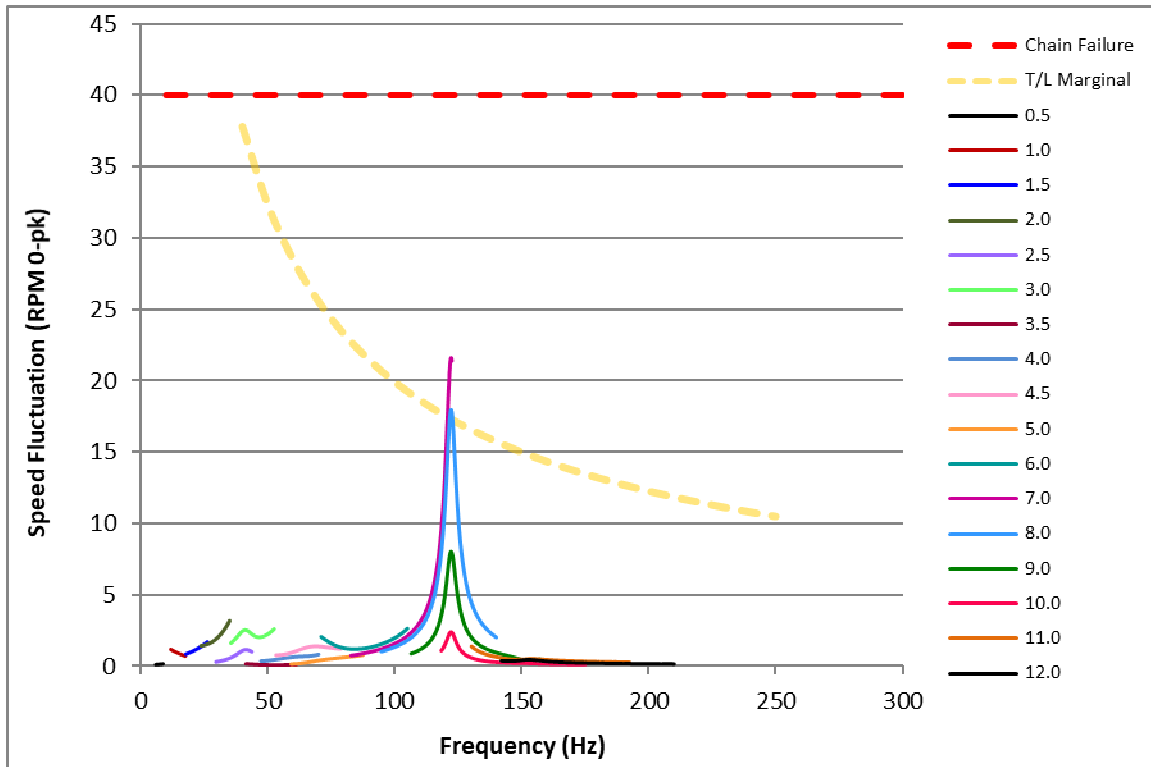
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Forced Response Highlights

Engine Firing Normal

Model Symbol	Component	Measured	Units	Order	Predicted Value	Limit	Comments
VDK	Damper	Power Absorbed	kW	Combined	1.972	10	Acceptable
HSNG	Damper Housing	Absolute Amplitude	deg	1.0	0.130	0.50	Acceptable
				1.5	0.211	0.20	*See Note
EK2	Engine Crankshaft	Vibratory Stress	MPa	Combined	32.984	42.75	Acceptable
CPK	Coupling	Nominal Torque	Nm	Combined	24672	158340	Acceptable
		Minimum Torque			-15989	-62318	Acceptable
		Maximum Torque			65829	124749	Acceptable
CSK	Compressor Crankshaft	Vibratory Torque	Nm	Combined	41715	59660	Acceptable
CK4					47106	59660	Acceptable
CJ11	Aux End	Absolute Velocity	RPM	7.0	21.607	40	Acceptable
				Combined	29.786	55	Acceptable

Compressor Aux End Velocity: Predictions vs. Limits



Forced Response Highlights

Speed Range

The torsional response has been analyzed from 710 RPM to 1050 RPM.

Engine Damper Thermal Loads

The predicted damper thermal loads are within the manufacturer's limits.

Engine Front End Amplitudes

*The predicted front end amplitudes exceed manufacturer allowable limits for normal operation. The engine manufacturer has specified that 1.5 order amplitudes up to 30% above their published limit are acceptable. The predicted front end amplitudes are within 30% above the manufacturer published limits and are therefore acceptable.

Engine Crankshaft Stresses

The predicted engine crankshaft stresses are within the manufacturer's limits.

Coupling Torques

The predicted vibratory torque for the TB Woods FSH 92HT-28 coupling is within the manufacturer's limits.

Compressor Crankshaft Torques

The predicted vibratory torque for the Ariel KBZ/4 compressor is within the manufacturer's limits.

Compressor Auxiliary End Velocity

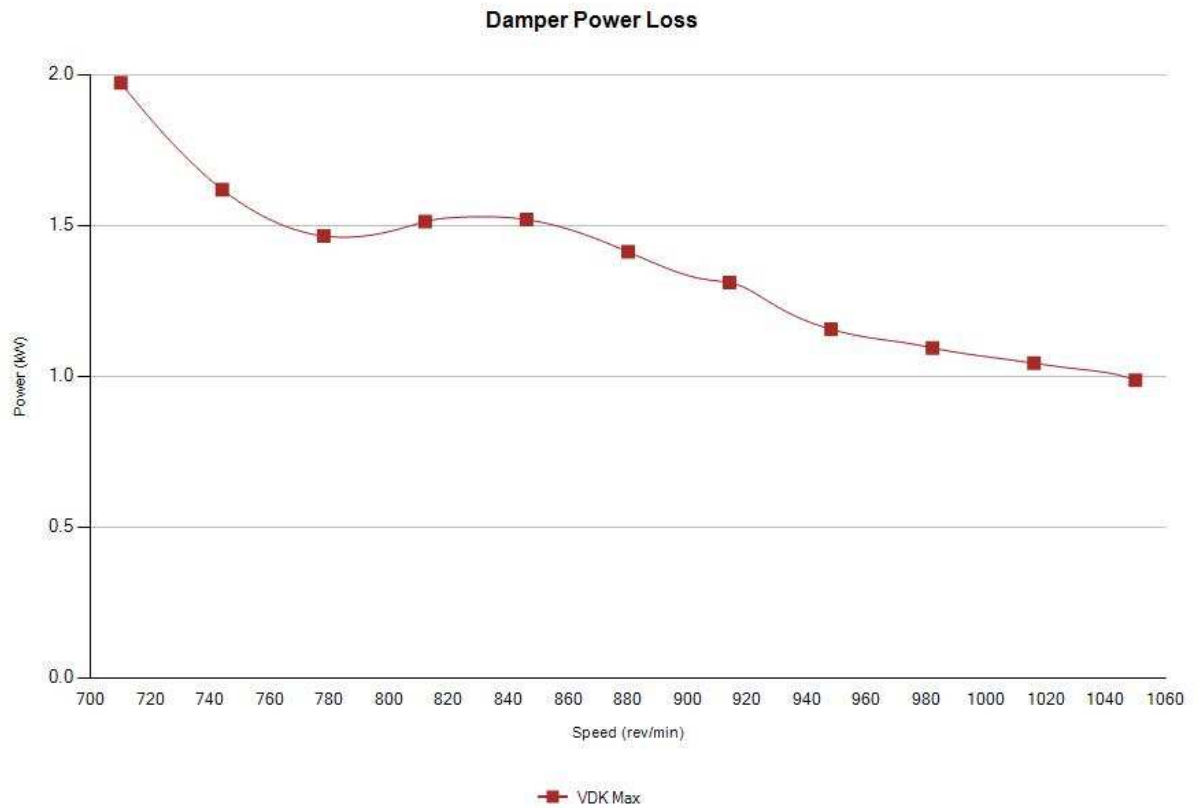
The predicted velocity at the auxiliary end of the Ariel KBZ/4 compressor crankshaft is within the manufacturer's limits.

Compressor Torsional-Lateral Awareness

The torsional-lateral (T/L) curve is intended to reduce high frequency lateral vibration levels by minimizing torsional oscillations. The T/L curve is only a recommendation, not a mechanical limit. Adherence to the T/L curve is not mandated. For more information on torsional-lateral awareness please see Ariel's Engineering Reference in the Appendix.

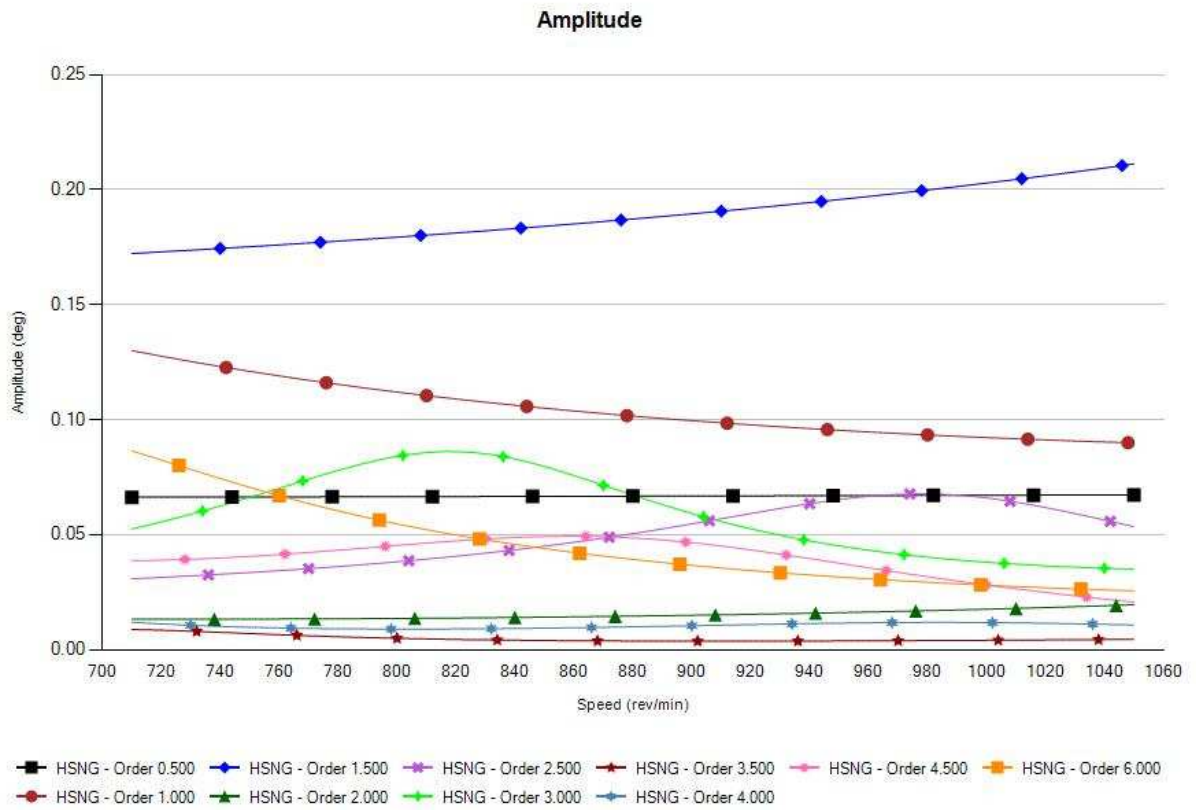
Forced Response Results

Damper Combined Order Thermal Loading



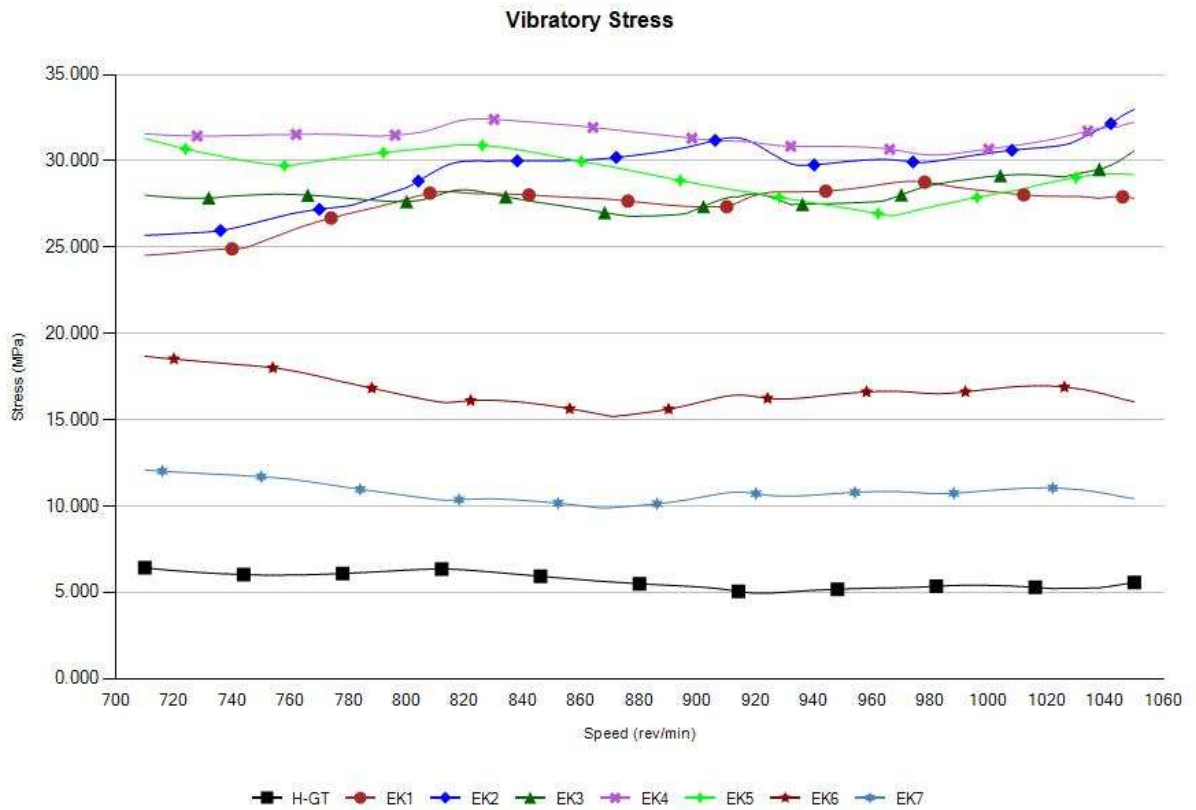
Component	Max Damper Power Loss (kW)
VDK Max	1.972

Front Crank Single Order Amplitude



Component	Max Amplitude (deg)
HSNG - Order 0.500	0.067
HSNG - Order 1.000	0.130
HSNG - Order 1.500	0.211
HSNG - Order 2.000	0.020
HSNG - Order 2.500	0.068
HSNG - Order 3.000	0.086
HSNG - Order 3.500	0.009
HSNG - Order 4.000	0.012
HSNG - Order 4.500	0.049
HSNG - Order 6.000	0.086

Engine Crankshaft Combined Order Vibratory Stress



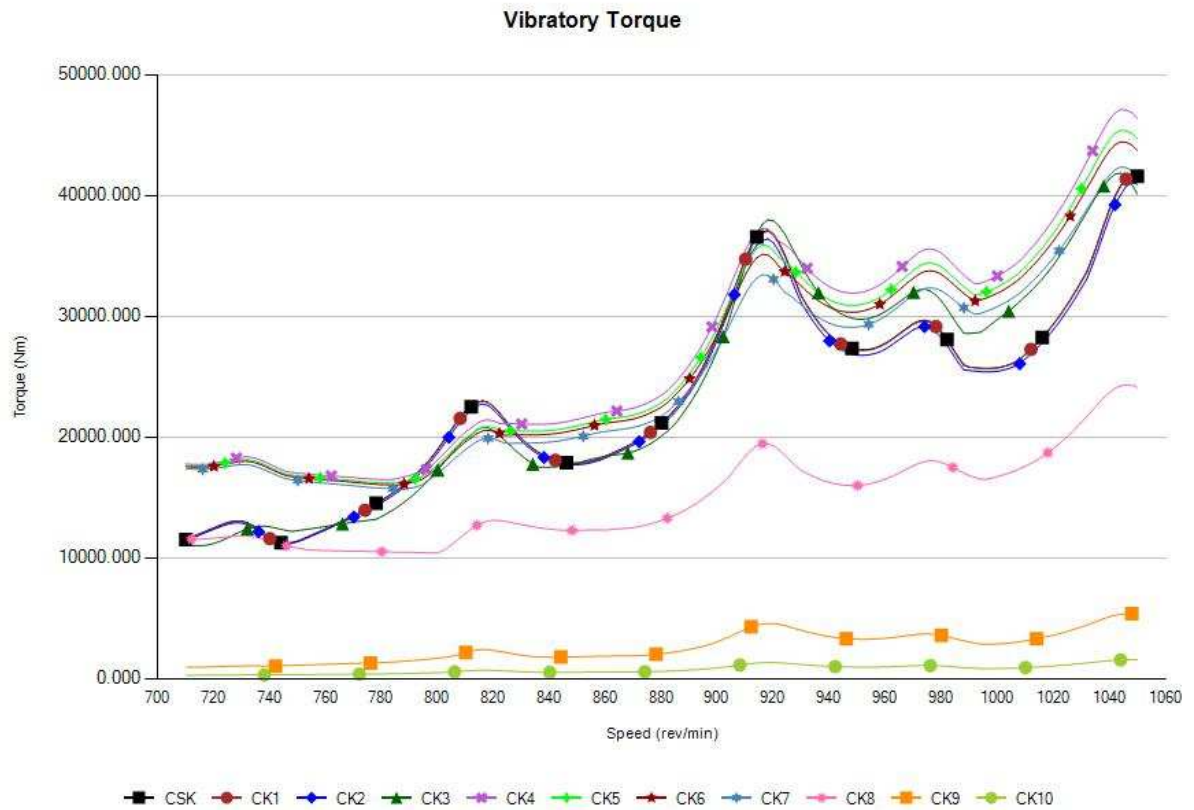
Component	Max Vibratory Stress (MPa)
H-GT	6.419
EK1	28.818
EK2	32.984
EK3	30.569
EK4	32.440
EK5	31.303
EK6	18.685
EK7	12.087

Coupling Combined Order Torque



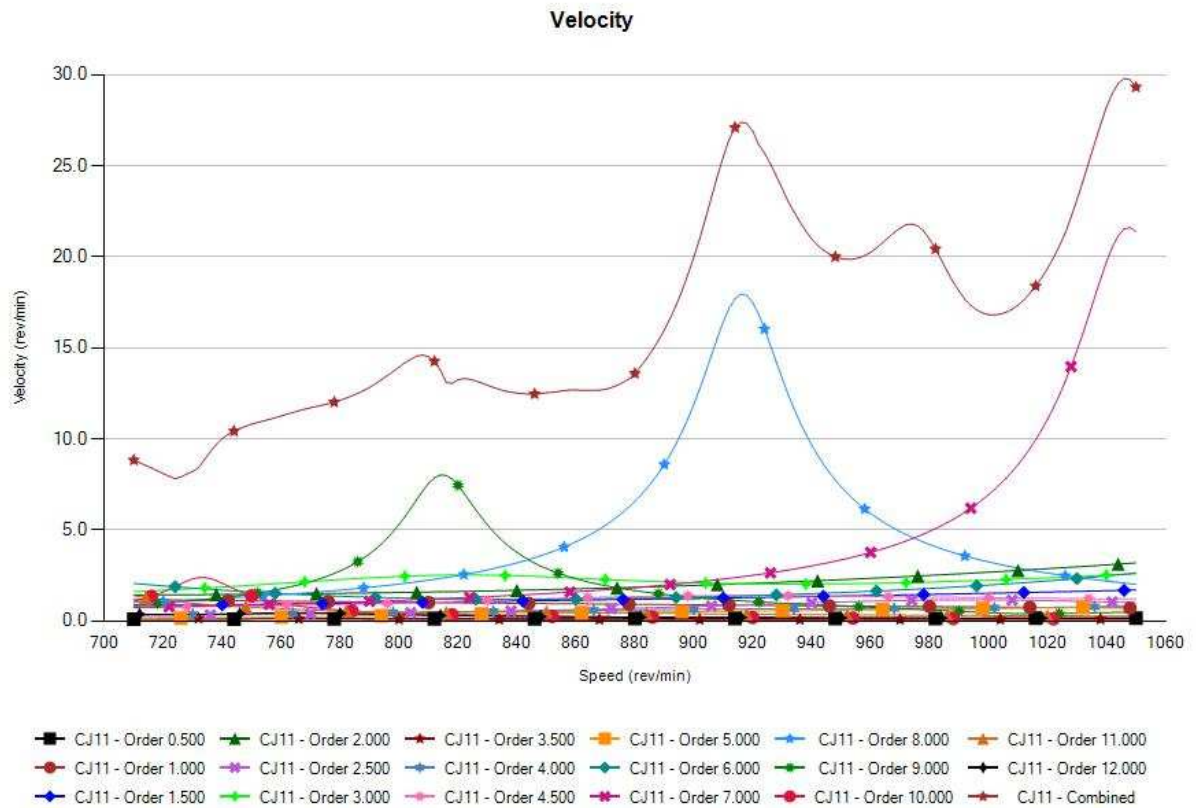
Component	Torque (Nm)
CPK Steady State	24672
CPK Min + SS	-15989
CPK Max + SS	65829

Compressor Shaft Combined Order Vibratory Torque



Component	Max Vibratory Torque (Nm)
CSK	41715
CK1	41660
CK2	41061
CK3	41842
CK4	47106
CK5	45394
CK6	44442
CK7	42353
CK8	24320
CK9	5379
CK10	1565

Compressor Aux End Velocity



Component	Max Velocity (rev/min)
CJ11 - Order 0.500	0.151
CJ11 - Order 1.000	1.171
CJ11 - Order 1.500	1.696
CJ11 - Order 2.000	3.188
CJ11 - Order 2.500	1.154
CJ11 - Order 3.000	2.597
CJ11 - Order 3.500	0.152
CJ11 - Order 4.000	0.821
CJ11 - Order 4.500	1.389
CJ11 - Order 5.000	0.778
CJ11 - Order 6.000	2.634
CJ11 - Order 7.000	21.607
CJ11 - Order 8.000	17.953
CJ11 - Order 9.000	8.018
CJ11 - Order 10.000	2.388
CJ11 - Order 11.000	1.386
CJ11 - Order 12.000	0.454
CJ11 - Combined	29.786

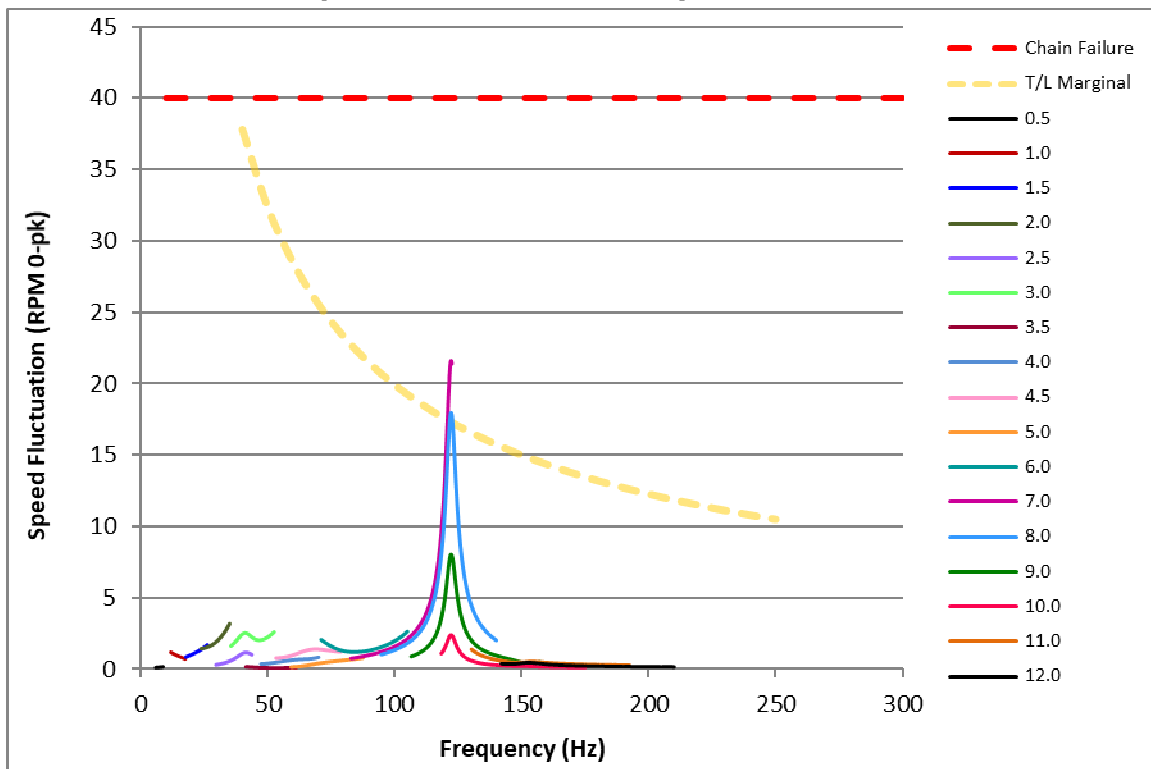
Operating Condition One with Engine Misfire

Forced Response Highlights

Misfire Cylinder 1

Model Symbol	Component	Measured	Units	Order	Predicted Value	Limit	Comments
VDK	Damper	Power Absorbed	kW	Combined	1.849	10	Acceptable
HSNG	Damper Housing	Absolute Amplitude	deg	0.5	0.584	1.75	Acceptable
				1.5	0.201	0.20	*See Note
EK4	Engine Crankshaft	Vibratory Stress	MPa	Combined	32.433	42.75	Acceptable
CPK	Coupling	Nominal Torque	Nm	Combined	24672	158340	Acceptable
		Minimum Torque			-15452	-62318	Acceptable
		Maximum Torque			66446	124749	Acceptable
CSK	Compressor Crankshaft	Vibratory Torque	Nm	Combined	41521	59660	Acceptable
CK4					46791	59660	Acceptable
CJ11	Aux End	Absolute Velocity	RPM	7.0	21.242	40	Acceptable
				Combined	31.669	55	Acceptable

Compressor Aux End Velocity: Predictions vs. Limits



Forced Response Highlights

Speed Range

The torsional response has been analyzed from 710 RPM to 1050 RPM.

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Compressor Auxiliary End Velocity

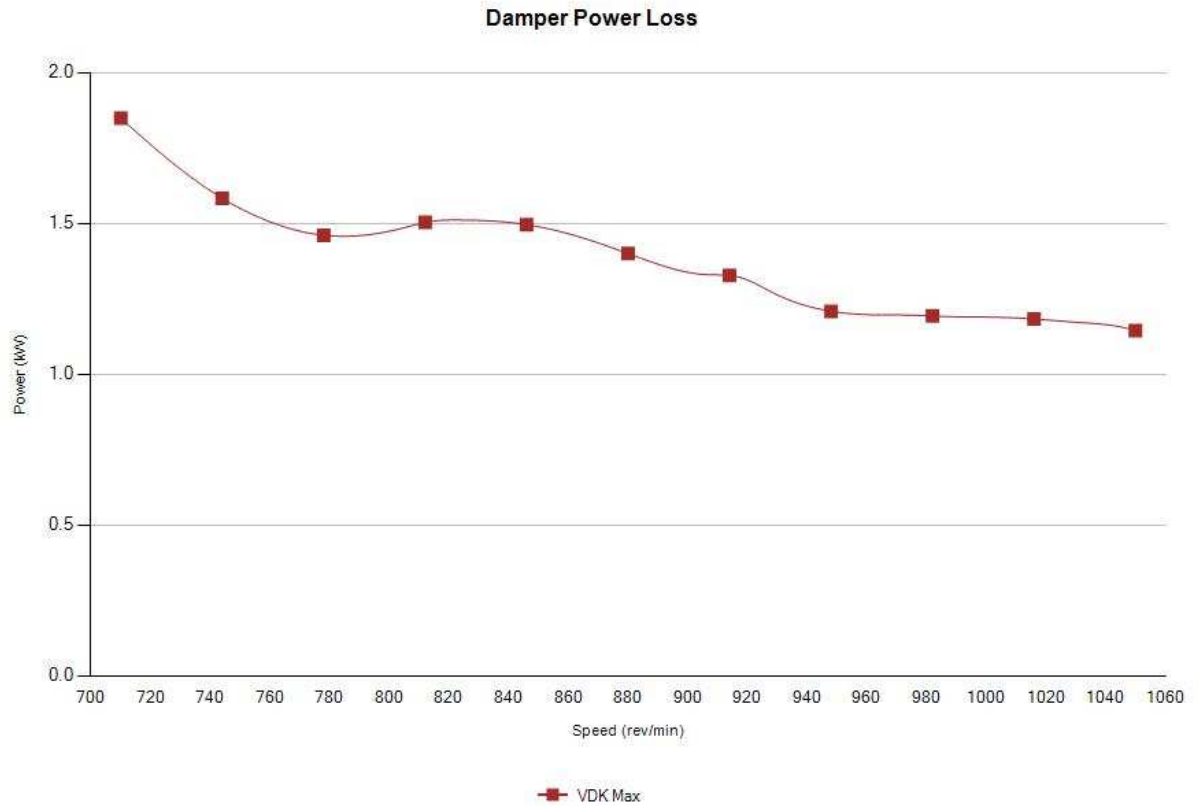
The predicted velocity at the auxiliary end of the Ariel KBZ/4 compressor crankshaft is within the manufacturer's limits.

Compressor Torsional-Lateral Awareness

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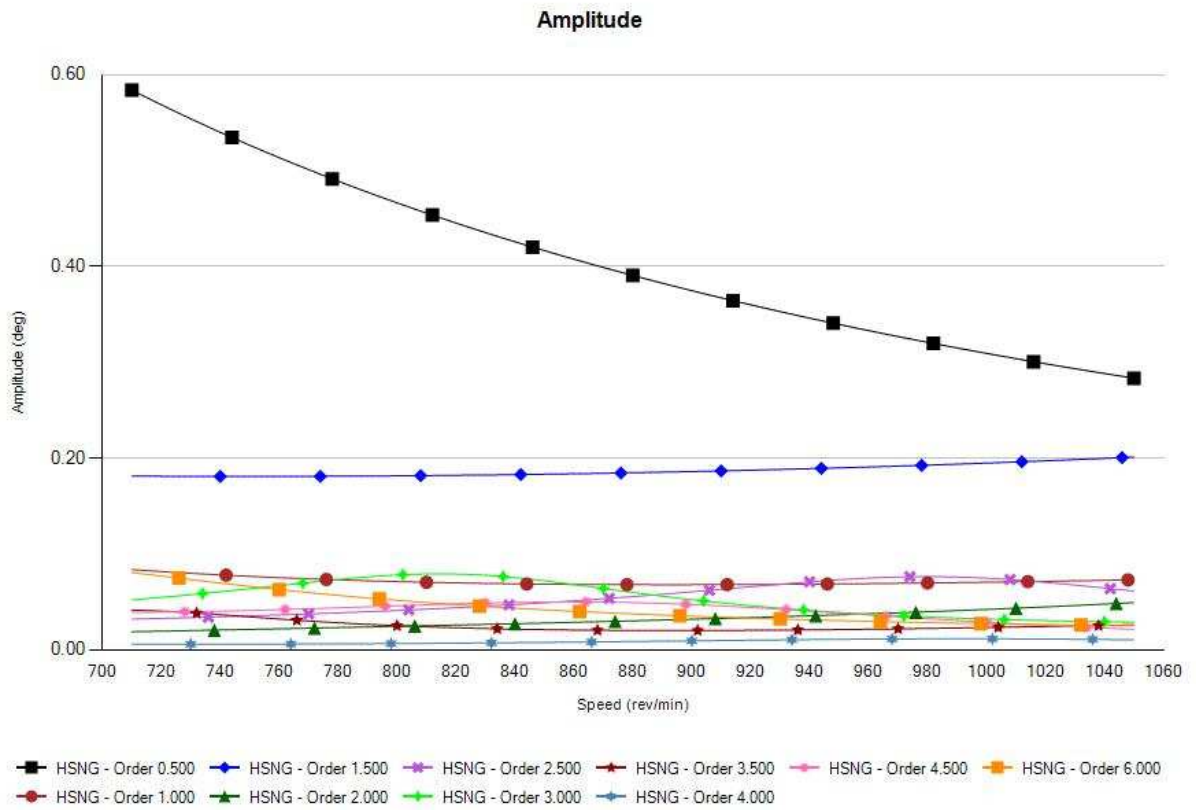
Forced Response Results

Damper Combined Order Thermal Loading



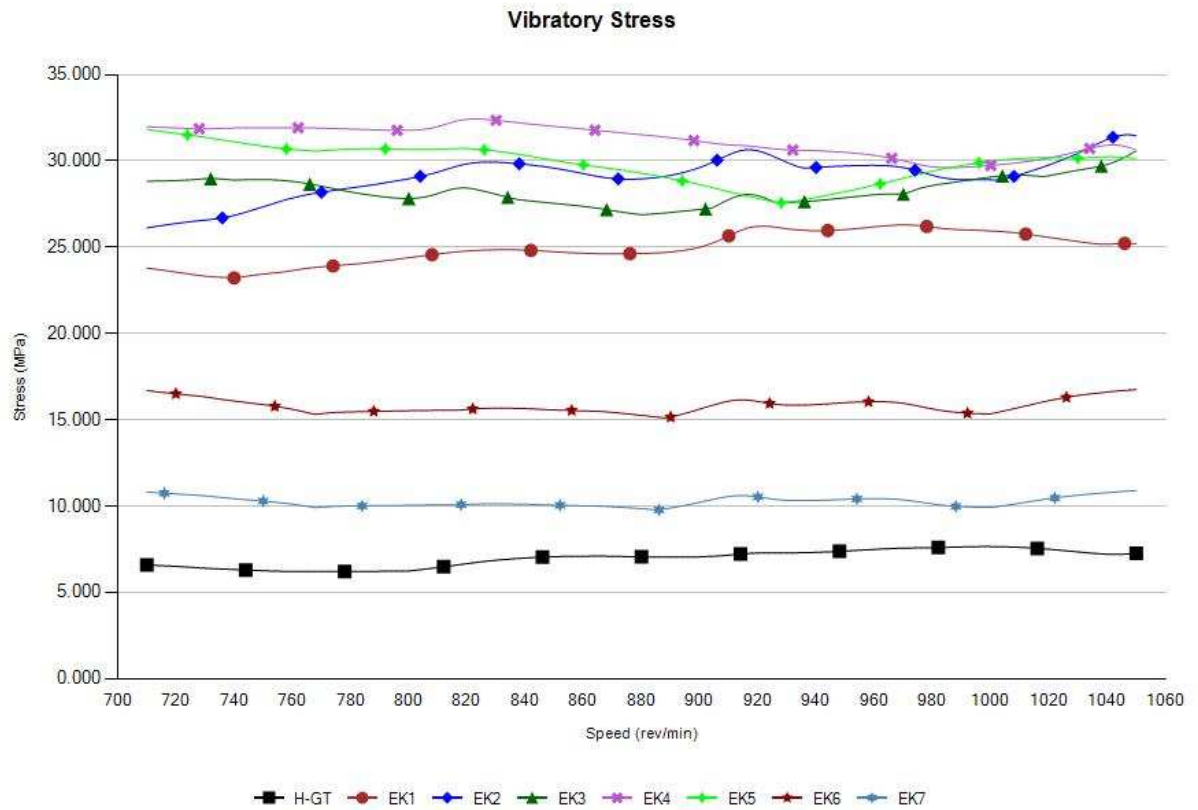
Component	Max Damper Power Loss (kW)
VDK Max	1.849

Front Crank Single Order Amplitude



Component	Max Amplitude (deg)
HSNG - Order 0.500	0.584
HSNG - Order 1.000	0.084
HSNG - Order 1.500	0.201
HSNG - Order 2.000	0.049
HSNG - Order 2.500	0.076
HSNG - Order 3.000	0.079
HSNG - Order 3.500	0.041
HSNG - Order 4.000	0.011
HSNG - Order 4.500	0.050
HSNG - Order 6.000	0.081

Engine Crankshaft Combined Order Vibratory Stress



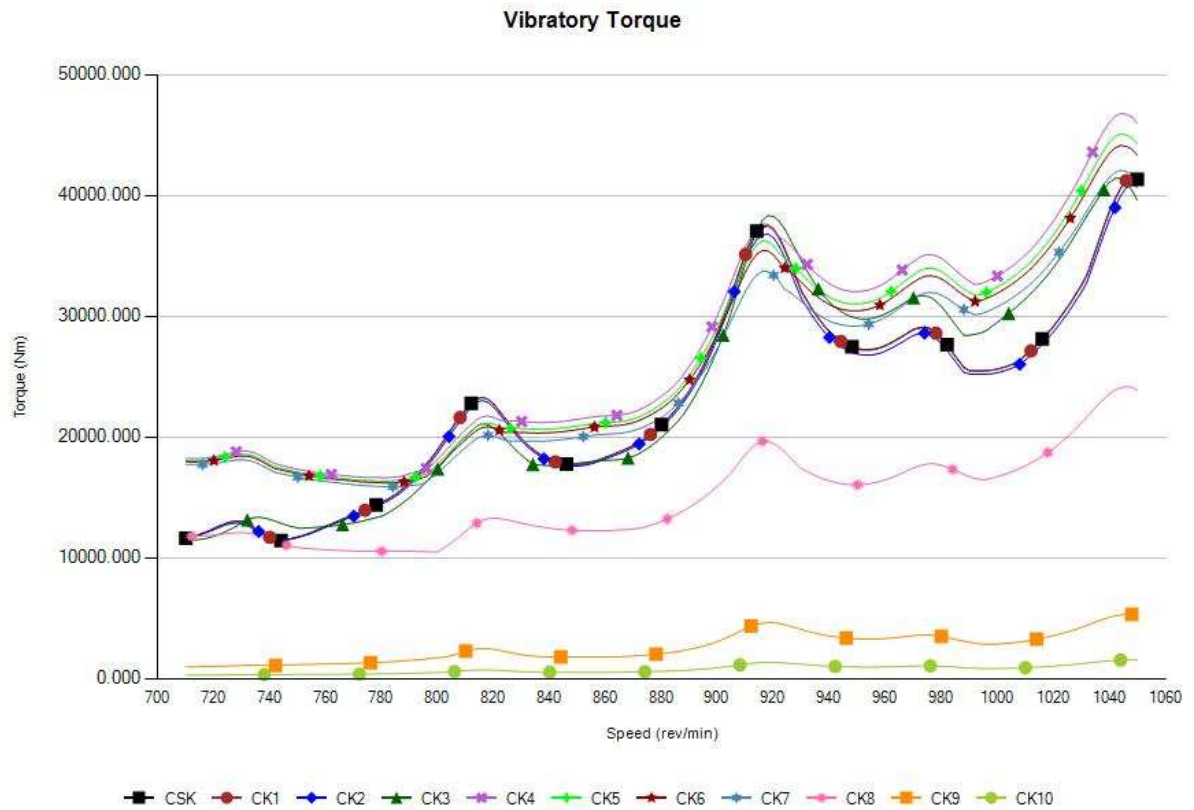
Component	Max Vibratory Stress (MPa)
H-GT	7.652
EK1	26.291
EK2	31.512
EK3	30.579
EK4	32.433
EK5	31.822
EK6	16.749
EK7	10.892

Coupling Combined Order Torque



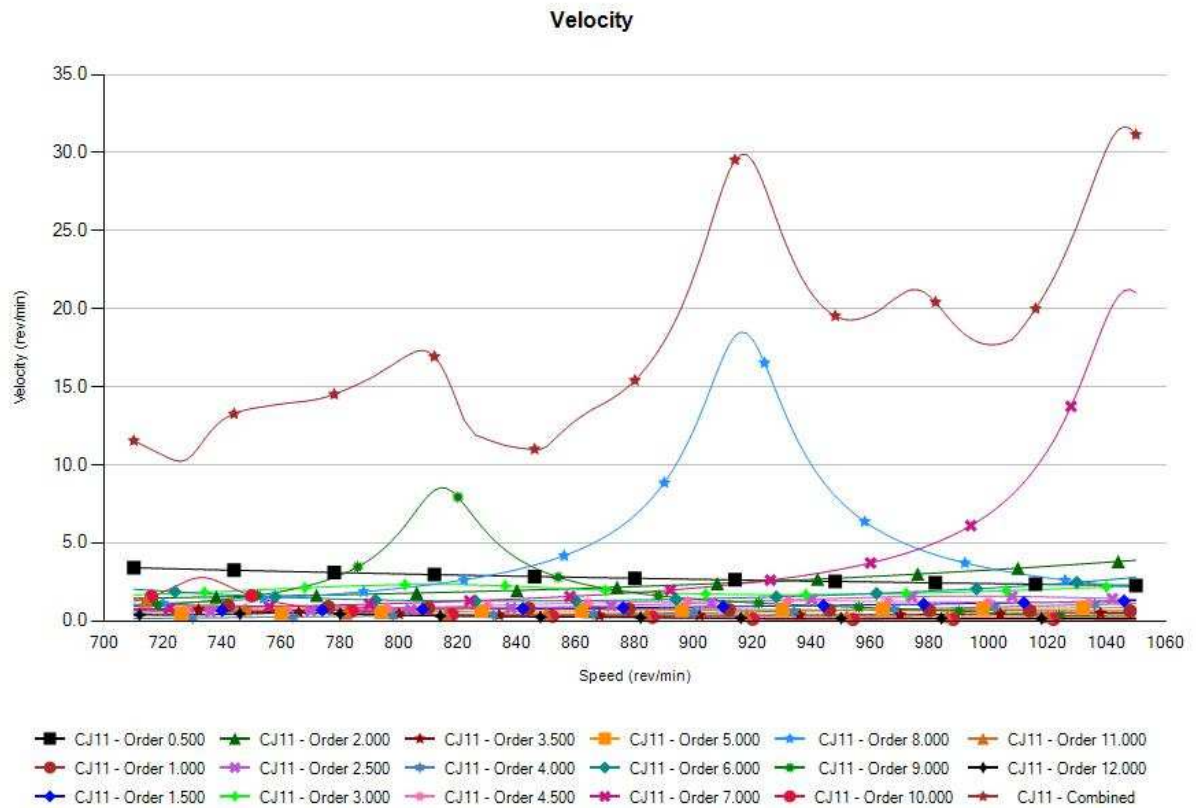
Component	Torque (Nm)
CPK Steady State	24672
CPK Min + SS	-15452
CPK Max + SS	66446

Compressor Shaft Combined Order Vibratory Torque



Component	Max Vibratory Torque (Nm)
CSK	41521
CK1	41466
CK2	40872
CK3	41439
CK4	46791
CK5	45090
CK6	44145
CK7	42072
CK8	24163
CK9	5321
CK10	1548

Compressor Aux End Velocity



Component	Max Velocity (rev/min)
CJ11 - Order 0.500	3.406
CJ11 - Order 1.000	1.042
CJ11 - Order 1.500	1.295
CJ11 - Order 2.000	3.892
CJ11 - Order 2.500	1.591
CJ11 - Order 3.000	2.340
CJ11 - Order 3.500	0.796
CJ11 - Order 4.000	1.116
CJ11 - Order 4.500	1.285
CJ11 - Order 5.000	0.870
CJ11 - Order 6.000	2.796
CJ11 - Order 7.000	21.242
CJ11 - Order 8.000	18.505
CJ11 - Order 9.000	8.535
CJ11 - Order 10.000	2.779
CJ11 - Order 11.000	1.393
CJ11 - Order 12.000	0.517
CJ11 - Combined	31.669

Operating Condition Two

Ariel Performance			
	Company: Exterran Energy	Customer: Kaego Energy & Technology Corp.	
Project #: 7.7.6.0	AP035401 Rev:7	Inquiry:	
Case 13:	30API-CPF-45 Ps,320 Pd	Project:	

Compressor Data:

Elevation,ft: 50.00
 Frame: (ELP) KBZ/4
 Max RL Tot, lbf: 150000
 Rated RPM: 1000
 Calc RPM: 1000.0

Barmtr,psia: 14.669
 Stroke, in: 6.75
 Max RL Tens, lbf: 75000
 Rated BHP: 5200.0
 BHP: 2333

Ambient,F: 100.00
 Rod Dia, in: 2.875
 Max RL Comp, lbf: 80000
 Rated PS FPM: 1125.0
 Calc PS FPM: 1125.0

Driver Data:

Type: Nat. Gas
 Mfg: Waukesha
 Model: 12V275GL+
 BHP: 3750
 Avail: 3750

Services

Gas Model

Stage Data:

Target Flow, MMSCFD
 Flow Calc, MMSCFD
 BHP per Stage
 Specific Gravity
 Ratio of Sp Ht (N)
 Comp Suct (Zs)
 Comp Disch (Zd)
 Pres Suct Line, psig
 Pres Suct Flg, psig
 Pres Disch Flg, psig
 Pres Disch Line, psig
 Pres Ratio F/F
 Temp Suct, F
 Temp Clr Disch, F

Service 1

VMG-APRNL2

1

22.500
 19.647
 1360.7
 0.6978
 1.2319
 0.9877
 0.9823
 45.00
 44.40
 163.83
 N/A
 3.022
 100.00
 130.00

2

22.500
 19.647
 821.4
 0.6978
 1.2375
 0.9697
 0.9635
 N/A
 160.67
 327.82
 N/A
 1.953
 130.00
 130.00

3

22.500
 19.647
 105.0
 0.6978
 1.2538
 0.9426
 0.9425
 N/A
 322.82
 326.69
 320.00
 1.011
 130.00
 120.00

Cylinder Data:

Throw 1
 Cyl Model
 Cyl Bore, in
 Cyl RDP (API), psig
 Cyl MAWP, psig
 Cyl Action
 Cyl Disp, CFM
 Pres Suct Intl, psig
 Temp Suct Intl, F
 Pres Disch Intl, psig
 Temp Disch Intl, F
 HE Suct Gas Vel, FPM
 HE Disch Gas Vel, FPM
 HE Spcra Used/Max
 HE Vol Pkt Avail
 Vol Pkt Used
 HE Min Clr, %
 HE Total Clr, %
 CE Suct Gas Vel, FPM
 CE Disch Gas Vel, FPM
 CE Spcra Used/Max
 CE Min Clr, %
 CE Total Clr, %
 Suct Vol Eff HE/CE, %
 Disch Event HE/CE, ms
 Suct Pseudo-Q HE/CE
 Gas Rod Ld Comp, %
 Gas Rod Ld Tens, %
 Gas Rod Ld Total, %
 Xhd Pin Deg/%Rvsl lbf
 Flow Calc, MMSCFD
 Cyl BHP

Throw 3

20-1/8Z:10
 20.125
 313.6
 345.0
 DBL
 2459.8
 40.19
 110
 174.24
 259
 8595
 7259
 0/0
 0.62+42.28
 0.00 (V) %
 13.82
 14.44
 8420
 7111
 0/0
 14.47
 14.47
 73.4/73.4
 10.3/11.8
 5.8/5.6
 53.7 C
 55.3 T
 56.3
 178/98.9
 9.824
 680.4

Throw 3

20-1/8Z:10
 20.125
 313.6
 345.0
 DBL
 2459.8
 40.19
 110
 174.24
 259
 8595
 7259
 0/0
 0.62+42.28
 0.00 (V) %
 13.82
 14.44
 8420
 7111
 0/0
 14.47
 14.47
 73.4/73.4
 10.3/11.8
 5.8/5.6
 53.7 C
 55.3 T
 56.3
 180/98.1
 9.824
 680.4

Throw 4

15-7/8Z:10
 15.875
 768.2
 845.0
 DBL
 1521.0
 152.90
 135
 341.92
 228
 6904
 5946
 0/6
 0.69+39.74
 0.00 (V) %
 17.76
 18.45
 6678
 5751
 0/6
 18.83
 18.83
 82.9/82.6
 13.8/15.5
 3.6/3.3
 48.1 C
 46.9 T
 49.1
 173/97.6
 19.647
 821.4

Throw 2

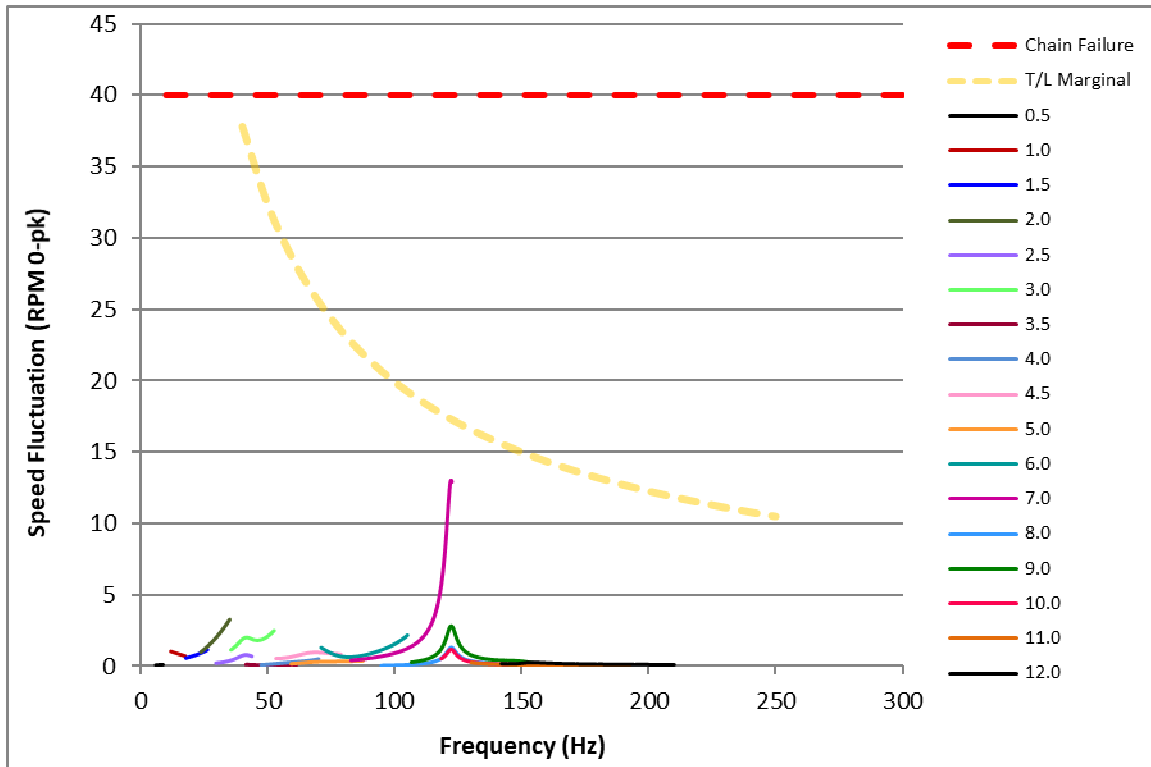
11Z:10
 10.500
 1545.5
 1700.0
 DBL
 651.1
 306.90
 131
 342.57
 143
 7144
 5976
 0/4
 0.67+38.83
 0.00 (V) %
 24.21
 24.88
 6609
 5528
 0/4
 26.76
 26.76
 97.7/97.6
 26.2/26.8
 3.9/3.3
 6.4 C
 1.2 T
 4.0
 158/74.9
 19.647
 105.0

Forced Response Highlights

Engine Firing Normal

Model Symbol	Component	Measured	Units	Order	Predicted Value	Limit	Comments
VDK	Damper	Power Absorbed	kW	Combined	1.097	10	Acceptable
HSNG	Damper Housing	Absolute Amplitude	deg	1.0	0.115	0.50	Acceptable
				1.5	0.142	0.20	Acceptable
EK4	Engine Crankshaft	Vibratory Stress	MPa	Combined	26.764	42.75	Acceptable
CPK	Coupling	Nominal Torque	Nm	Combined	16288	158340	Acceptable
		Minimum Torque			-19002	-62318	Acceptable
		Maximum Torque			45946	124749	Acceptable
CSK	Compressor Crankshaft	Vibratory Torque	Nm	Combined	33409	59660	Acceptable
CK4					41570	59660	Acceptable
CJ11	Aux End	Absolute Velocity	RPM	7.0	13.027	40	Acceptable
				Combined	19.042	55	Acceptable

Compressor Aux End Velocity: Predictions vs. Limits



Forced Response Highlights

Speed Range

The torsional response has been analyzed from 710 RPM to 1050 RPM.

Engine Damper Thermal Loads

The predicted damper thermal loads are within the manufacturer's limits.

Engine Front End Amplitudes

The predicted front end amplitudes are within the manufacturer's limits.

Engine Crankshaft Stresses

The predicted engine crankshaft stresses are within the manufacturer's limits.

Coupling Torques

The predicted vibratory torque for the TB Woods FSH 92HT-28 coupling is within the manufacturer's limits.

Compressor Crankshaft Torques

The predicted vibratory torque for the Ariel KBZ/4 compressor is within the manufacturer's limits.

Compressor Auxiliary End Velocity

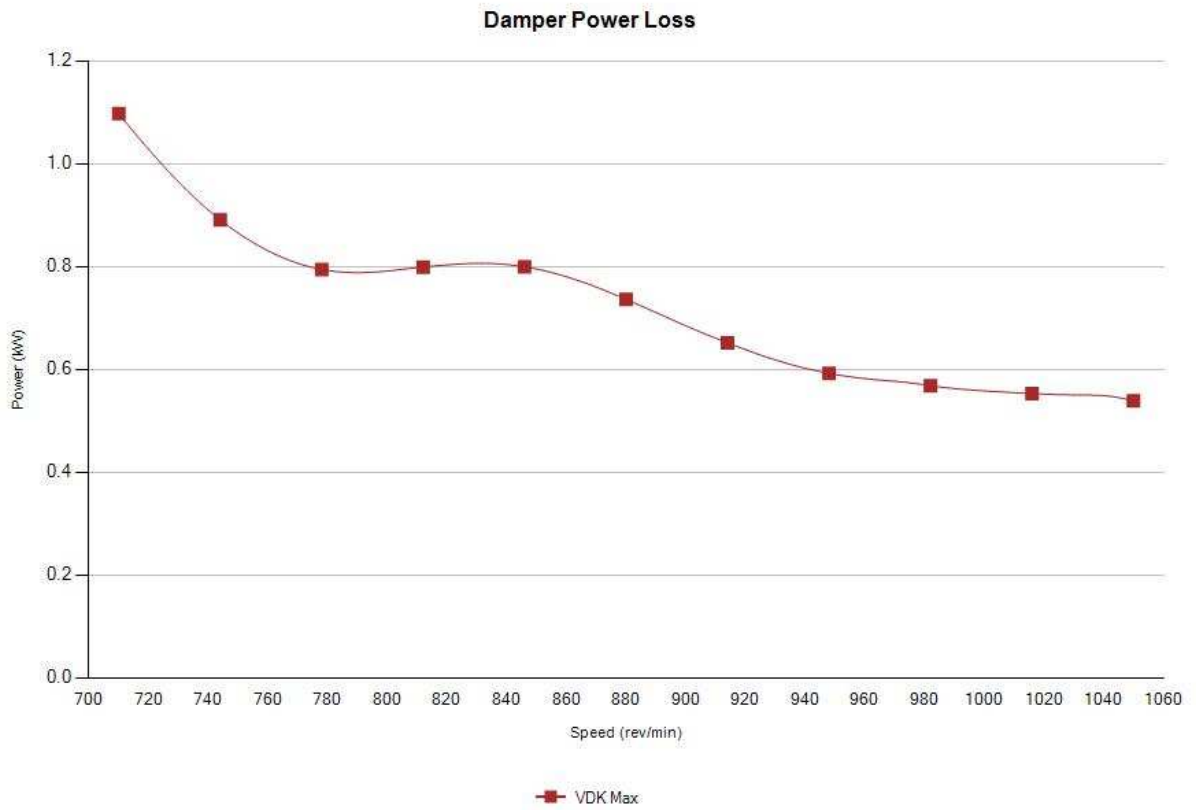
The predicted velocity at the auxiliary end of the Ariel KBZ/4 compressor crankshaft is within the manufacturer's limits.

Compressor Torsional-Lateral Awareness

The torsional-lateral (T/L) curve is intended to reduce high frequency lateral vibration levels by minimizing torsional oscillations. The T/L curve is only a recommendation, not a mechanical limit. Adherence to the T/L curve is not mandated. For more information on torsional-lateral awareness please see Ariel's Engineering Reference in the Appendix.

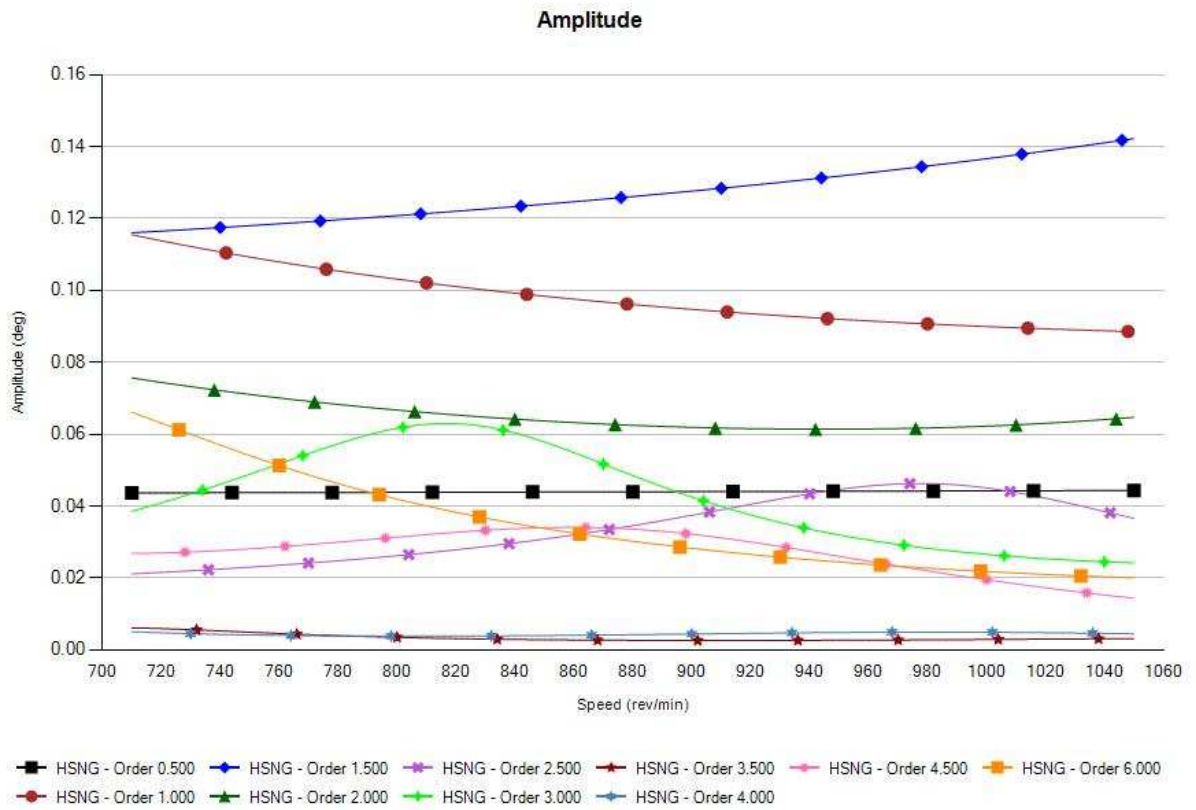
Forced Response Results

Damper Combined Order Thermal Loading



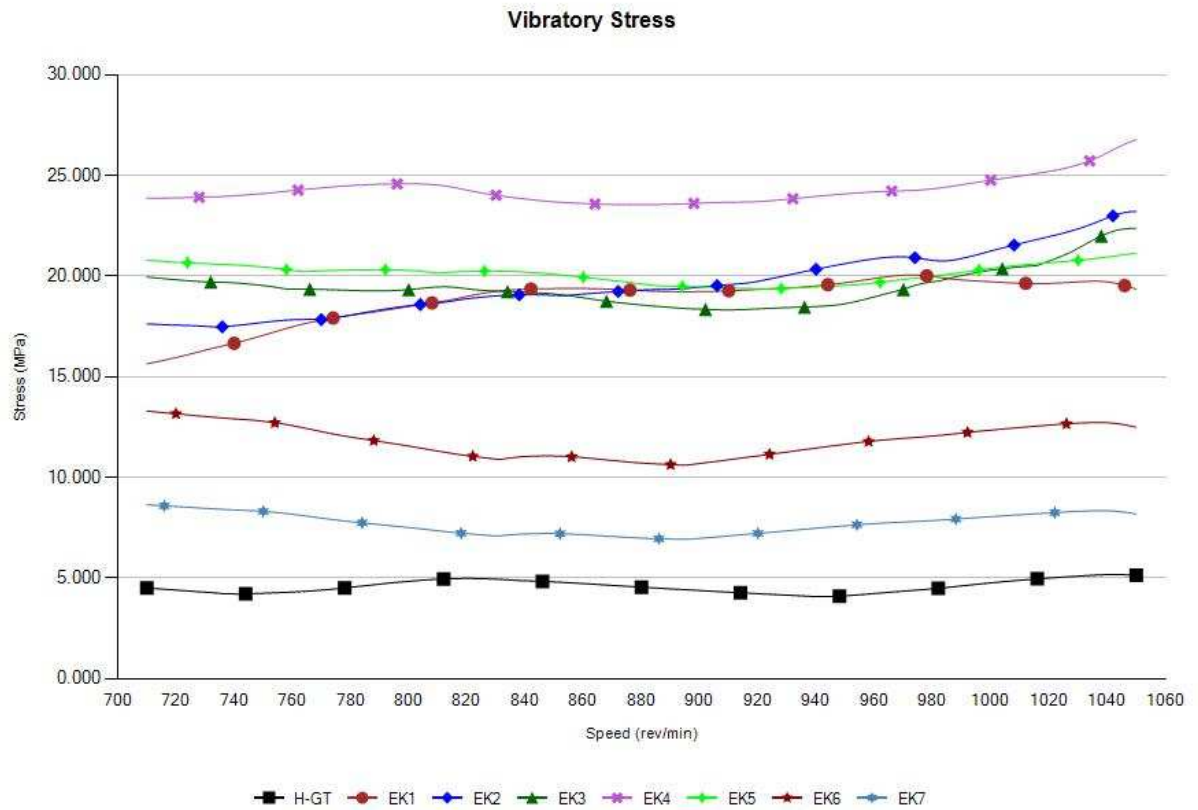
Component	Max Damper Power Loss (kW)
VDK Max	1.097

Front Crank Single Order Amplitude



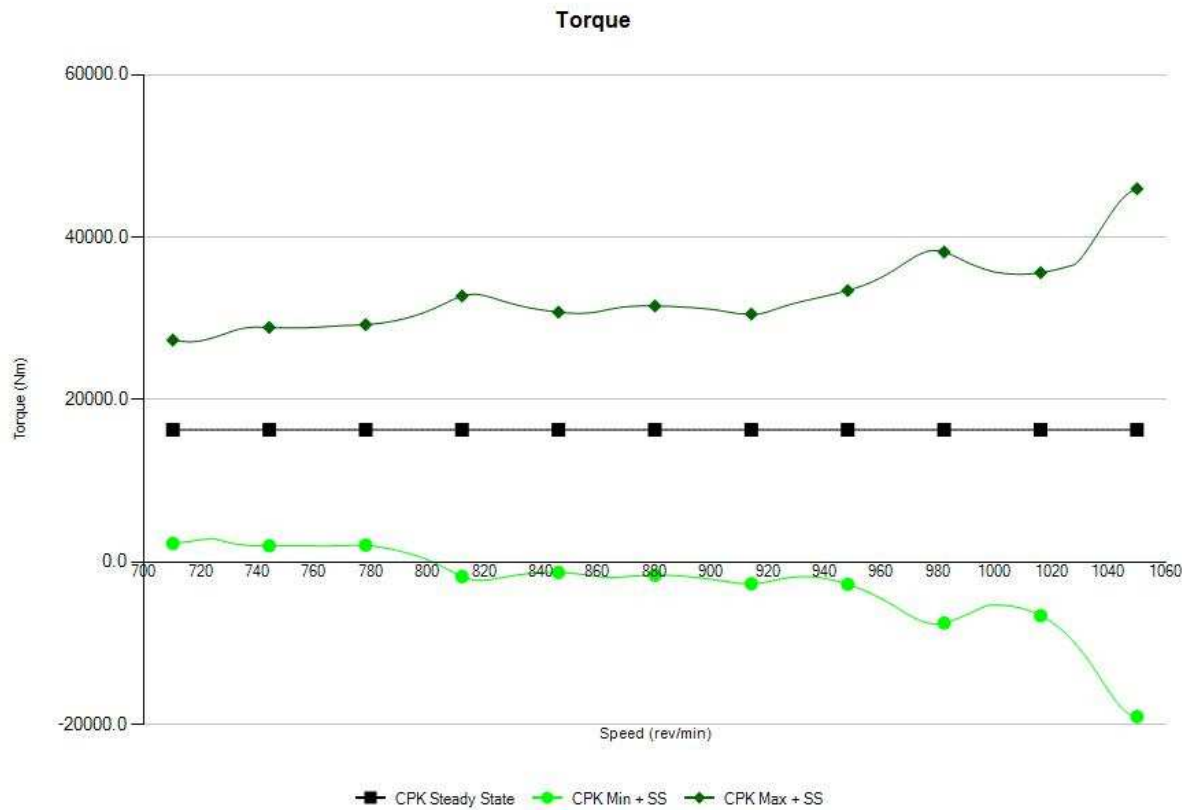
Component	Max Amplitude (deg)
HSNG - Order 0.500	0.044
HSNG - Order 1.000	0.115
HSNG - Order 1.500	0.142
HSNG - Order 2.000	0.076
HSNG - Order 2.500	0.046
HSNG - Order 3.000	0.063
HSNG - Order 3.500	0.006
HSNG - Order 4.000	0.005
HSNG - Order 4.500	0.034
HSNG - Order 6.000	0.066

Engine Crankshaft Combined Order Vibratory Stress



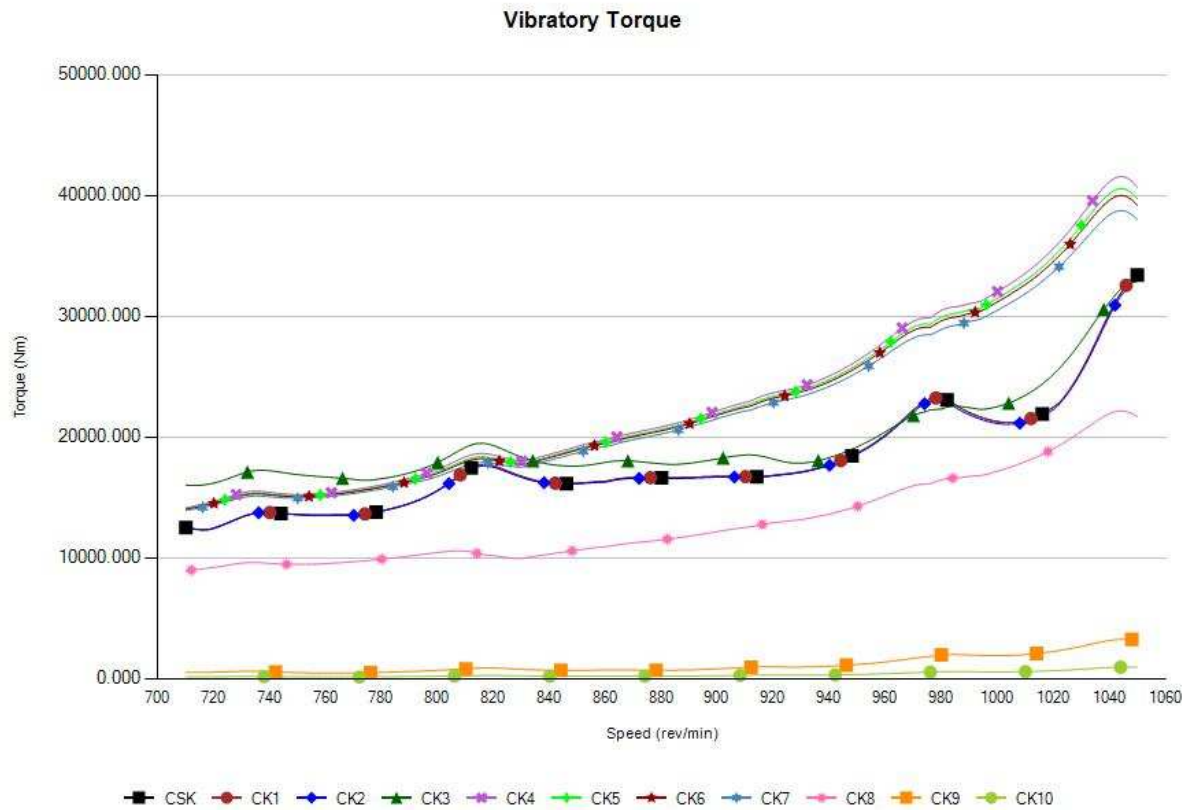
Component	Max Vibratory Stress (MPa)
H-GT	5.167
EK1	20.050
EK2	23.210
EK3	22.360
EK4	26.764
EK5	21.133
EK6	13.290
EK7	8.634

Coupling Combined Order Torque



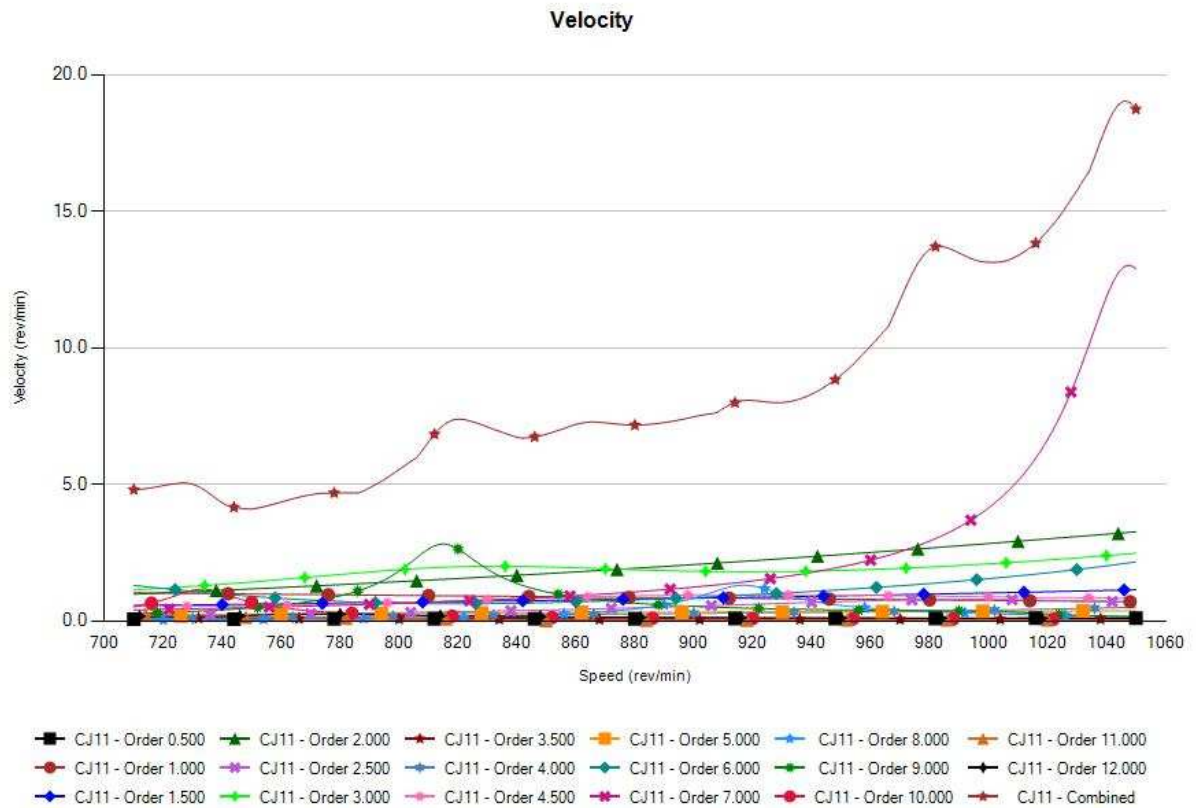
Component	Torque (Nm)
CPK Steady State	16288
CPK Min + SS	-19002
CPK Max + SS	45946

Compressor Shaft Combined Order Vibratory Torque



Component	Max Vibratory Torque (Nm)
CSK	33409
CK1	33374
CK2	33030
CK3	32887
CK4	41570
CK5	40570
CK6	40006
CK7	38757
CK8	22162
CK9	3252
CK10	945

Compressor Aux End Velocity



Component	Max Velocity (rev/min)
CJ11 - Order 0.500	0.100
CJ11 - Order 1.000	1.031
CJ11 - Order 1.500	1.142
CJ11 - Order 2.000	3.262
CJ11 - Order 2.500	0.787
CJ11 - Order 3.000	2.481
CJ11 - Order 3.500	0.105
CJ11 - Order 4.000	0.502
CJ11 - Order 4.500	0.959
CJ11 - Order 5.000	0.372
CJ11 - Order 6.000	2.163
CJ11 - Order 7.000	13.027
CJ11 - Order 8.000	1.305
CJ11 - Order 9.000	2.812
CJ11 - Order 10.000	1.166
CJ11 - Order 11.000	0.254
CJ11 - Order 12.000	0.257
CJ11 - Combined	19.042

Operating Condition Three



Ariel Performance

Company:	Exterran Energy	Customer:	Kaego Energy & Technology Corp.
Project #:	AP035401 Rev:7	Inquiry:	
7.7.6.0 Case 24:	Derate HP Available = 3618 30API-CPF-MAX Ps, MAX Pd	Project:	



Compressor Data:

Elevation,ft:	50.00	Barmtr,psia:	14.669	Ambient,F:	100.00
Frame: (ELP)	KBZ/4	Stroke, in:	6.75	Rod Dia, in:	2.875
Max RL Tot, lbf:	150000	Max RL Tens, lbf:	75000	Max RL Comp, lbf:	80000
Rated RPM:	1000	Rated BHP:	5200.0	Rated PS FPM:	1125.0
Calc RPM:	1000.0	BHP:	3618	Calc PS FPM:	1125.0

Driver Data:

Type:	Nat. Gas
Mfg:	Waukesha
Model:	12V275GL+
BHP:	3750
Avail:	3750

Services

Service 1

Gas Model	VMG-APRNL2			
Stage Data:	1	2	3	
Target Flow, MMSCFD	22.500	22.500	22.500	
Flow Calc, MMSCFD	20.543	20.544	20.538	
BHP per Stage	1401.7	1130.5	1039.8	
Specific Gravity	0.6978	0.6978	0.6972	
Ratio of Sp Ht (N)	1.2329	1.2370	1.2528	
Comp Suct (Zs)	0.9857	0.9654	0.9199	
Comp Disch (Zd)	0.9796	0.9571	0.9161	
Pres Suct Line, psig	55.00	N/A	N/A	
Pres Suct Flg, psig	54.30	185.75	466.17	
Pres Disch Flg, psig	190.75	474.99	1111.15	
Pres Disch Line, psig	N/A	N/A	1100.00	
Pres Ratio F/F	2.978	2.443	2.341	
Temp Suct, F	100.00	130.00	130.00	
Temp Clr Disch, F	130.00	130.00	120.00	
Cylinder Data:	Throw 1	Throw 3	Throw 4	Throw 2
Cyl Model	20-1/8Z:10	20-1/8Z:10	15-7/8Z:10	11Z:10
Cyl Bore, in	20.125	20.125	15.875	10.500
Cyl RDP (API), psig	313.6	313.6	768.2	1545.5
Cyl MAWP, psig	345.0	345.0	845.0	1700.0
Cyl Action	DBL	DBL	DBL	DBL
Cyl Disp, CFM	2459.8	2459.8	1521.0	651.1
Pres Suct Intl, psig	49.37	49.37	176.86	443.14
Temp Suct Intl, F	109	109	137	135
Pres Disch Intl, psig	202.79	202.79	494.39	1156.26
Temp Disch Intl, F	257	257	260	259
HE Suct Gas Vel, FPM	8595	8595	6904	7144
HE Disch Gas Vel, FPM	7259	7259	5946	5976
HE Spcrrs Used/Max	0/0	0/0	0/6	0/4
HE Vol Pkt Avail	0.62+42.28	0.62+42.28	0.69+39.74	0.67+38.83
Vol Pkt Used	27.02 (V) %	27.02 (V) %	0.00 (V) %	0.00 (V) %
HE Min Clr, %	13.82	13.82	17.76	24.21
HE Total Clr, %	25.86	25.86	18.45	24.88
CE Suct Gas Vel, FPM	8420	8420	6678	6609
CE Disch Gas Vel, FPM	7111	7111	5751	5528
CE Spcrrs Used/Max	0/0	0/0	0/6	0/4
CE Min Clr, %	14.47	14.47	18.83	26.76
CE Total Clr, %	14.47	14.47	18.83	26.76
Suct Vol Eff HE/CE, %	57.5/73.9	57.5/73.9	75.6/75.1	70.8/68.9
Disch Event HE/CE, ms	9.0/12.0	9.0/12.0	11.7/13.3	11.5/13.0
Suct Pseudo-Q HE/CE	5.8/5.6	5.8/5.6	3.6/3.3	3.9/3.4
Gas Rod Ld Comp, %	61.5 C	61.5 C	80.1 C	81.0 C
Gas Rod Ld Tens, %	63.3 T	63.3 T	79.4 T	72.2 T
Gas Rod Ld Total, %	64.4	64.4	82.4	79.3
Xhd Pin Deg/%RvrsI lbf	164/73.8	167/75.0	144/78.6	151/67.1
Flow Calc, MMSCFD	10.272	10.272	20.544	20.538
Cyl BHP	700.9	700.9	1130.5	1039.8

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Note: **BOLD**=Out of Limits, **ITALIC**=Special Appl, **BOLD**=Review

Base: 14.70 psia, 80.0 F
Gathering

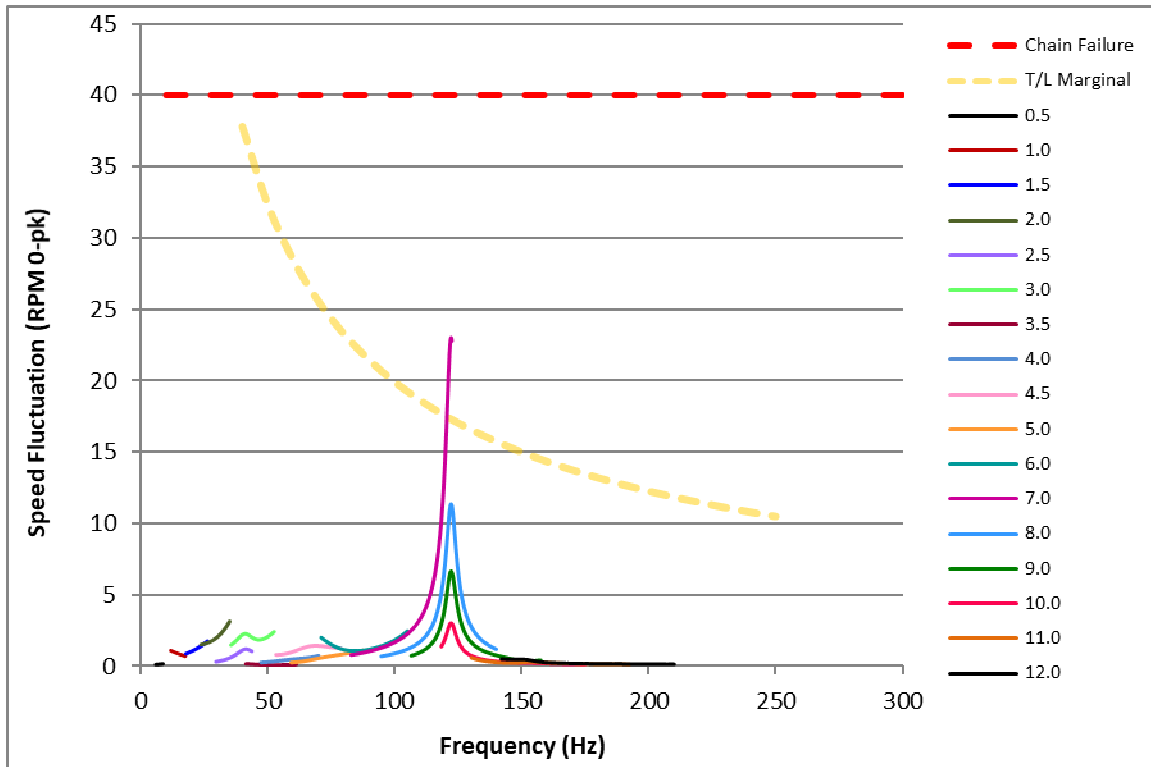
Page: 3 of 8
Case:24 - Pkg:1

Forced Response Highlights

Engine Firing Normal

Model Symbol	Component	Measured	Units	Order	Predicted Value	Limit	Comments
VDK	Damper	Power Absorbed	kW	Combined	2.060	10	Acceptable
HSNG	Damper Housing	Absolute Amplitude	deg	1.0	0.121	0.50	Acceptable
				1.5	0.218	0.20	*See Note
EK2	Engine Crankshaft	Vibratory Stress	MPa	Combined	34.030	42.75	Acceptable
CPK	Coupling	Nominal Torque	Nm	Combined	25438	158340	Acceptable
		Minimum Torque			-14928	-62318	Acceptable
		Maximum Torque			66258	124749	Acceptable
CSK	Compressor Crankshaft	Vibratory Torque	Nm	Combined	41421	59660	Acceptable
CK4					46734	59660	Acceptable
CJ11	Aux End	Absolute Velocity	RPM	7.0	23.016	40	Acceptable
				Combined	30.427	55	Acceptable

Compressor Aux End Velocity: Predictions vs. Limits



Forced Response Highlights

Speed Range

The torsional response has been analyzed from 710 RPM to 1050 RPM.

Engine Damper Thermal Loads

The predicted damper thermal loads are within the manufacturer's limits.

Engine Front End Amplitudes

*The predicted front end amplitudes exceed manufacturer allowable limits for normal operation. The engine manufacturer has specified that 1.5 order amplitudes up to 30% above their published limit are acceptable. The predicted front end amplitudes are within 30% above the manufacturer published limits and are therefore acceptable.

Engine Crankshaft Stresses

The predicted engine crankshaft stresses are within the manufacturer's limits.

Coupling Torques

The predicted vibratory torque for the TB Woods FSH 92HT-28 coupling is within the manufacturer's limits.

Compressor Crankshaft Torques

The predicted vibratory torque for the Ariel KBZ/4 compressor is within the manufacturer's limits.

Compressor Auxiliary End Velocity

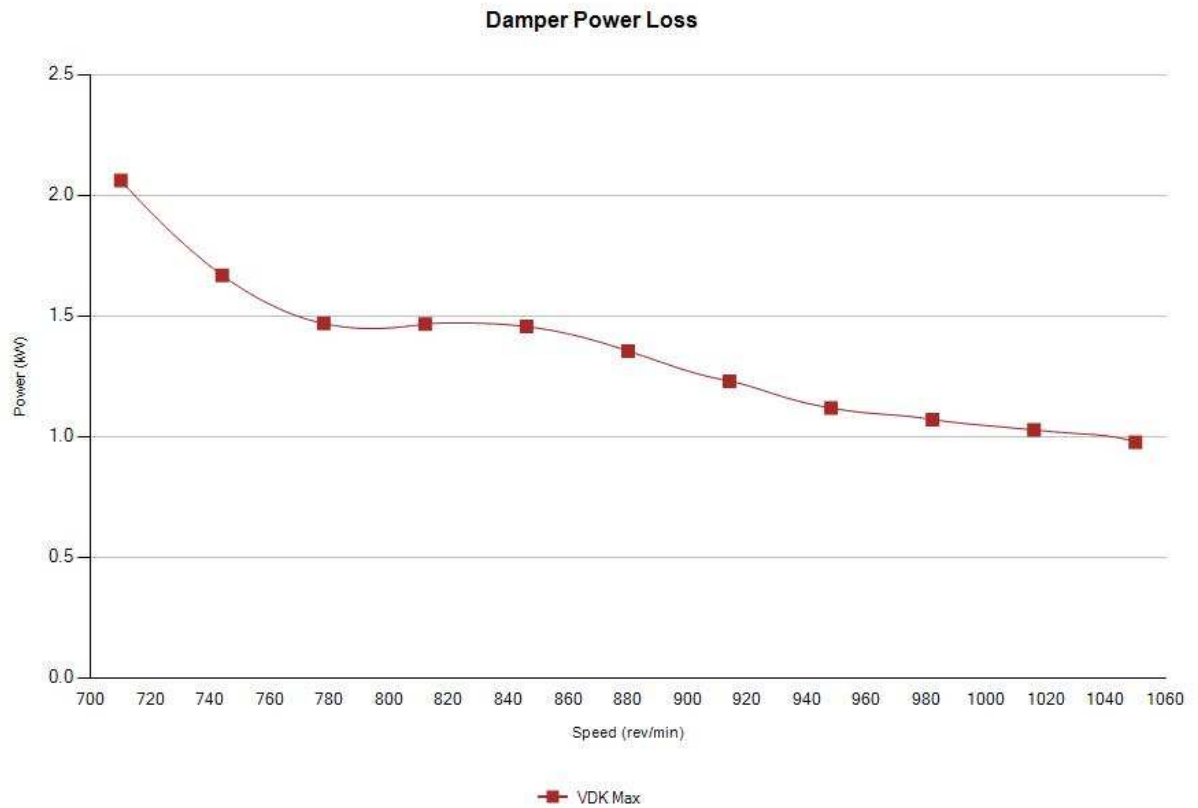
The predicted velocity at the auxiliary end of the Ariel KBZ/4 compressor crankshaft is within the manufacturer's limits.

Compressor Torsional-Lateral Awareness

The torsional-lateral (T/L) curve is intended to reduce high frequency lateral vibration levels by minimizing torsional oscillations. The T/L curve is only a recommendation, not a mechanical limit. Adherence to the T/L curve is not mandated. For more information on torsional-lateral awareness please see Ariel's Engineering Reference in the Appendix.

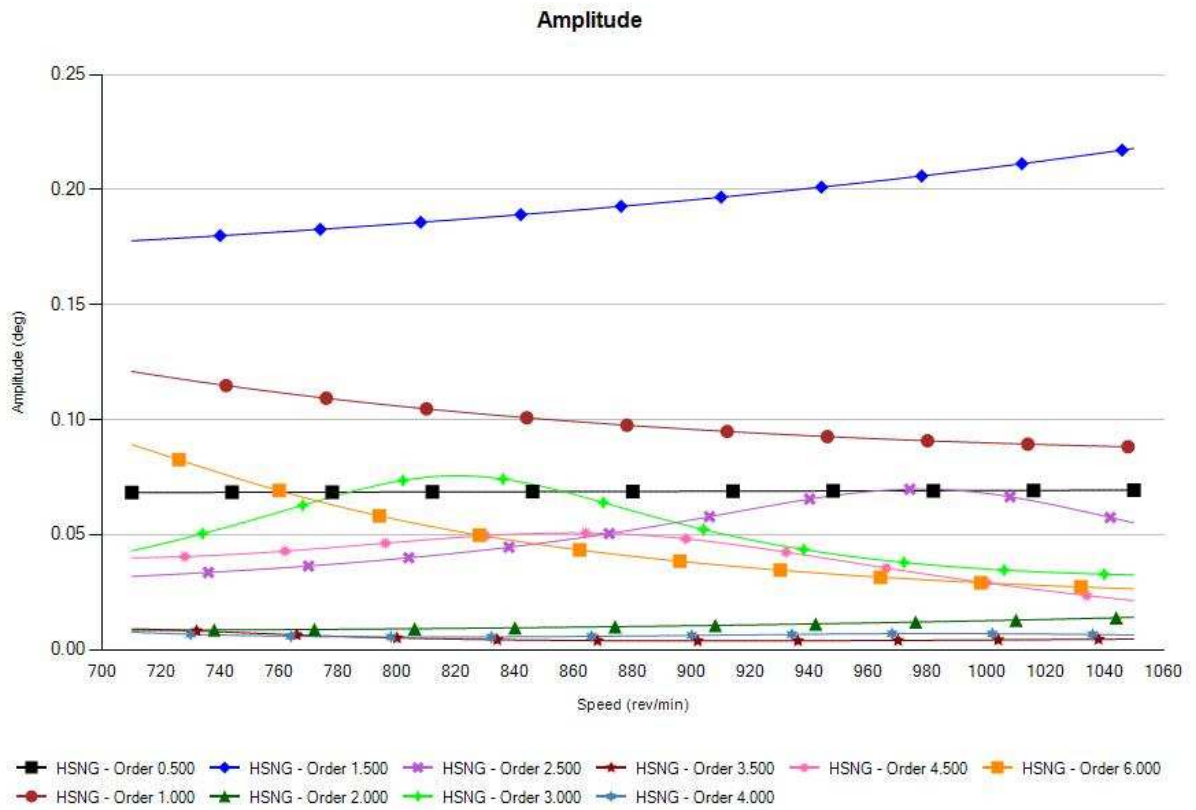
Forced Response Results

Damper Combined Order Thermal Loading



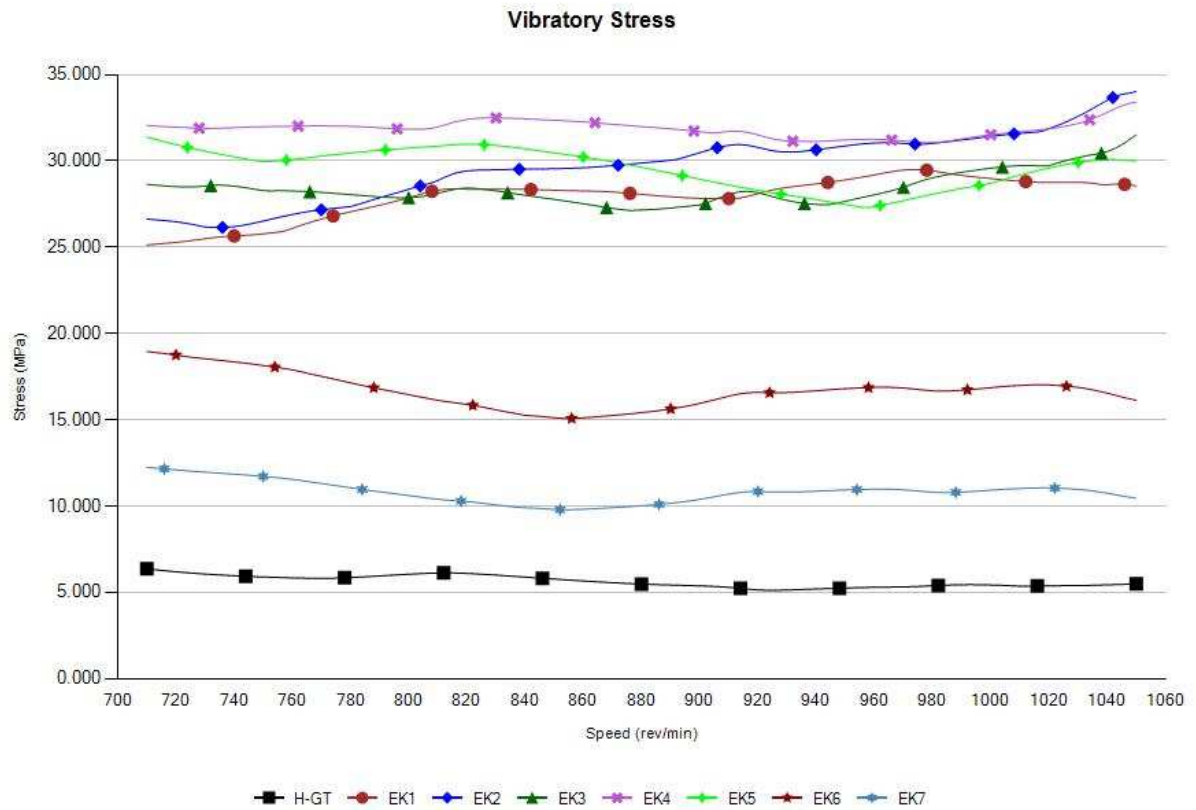
Component	Max Damper Power Loss (kW)
VDK Max	2.060

Front Crank Single Order Amplitude



Component	Max Amplitude (deg)
HSNG - Order 0.500	0.069
HSNG - Order 1.000	0.121
HSNG - Order 1.500	0.218
HSNG - Order 2.000	0.014
HSNG - Order 2.500	0.070
HSNG - Order 3.000	0.076
HSNG - Order 3.500	0.009
HSNG - Order 4.000	0.008
HSNG - Order 4.500	0.051
HSNG - Order 6.000	0.089

Engine Crankshaft Combined Order Vibratory Stress



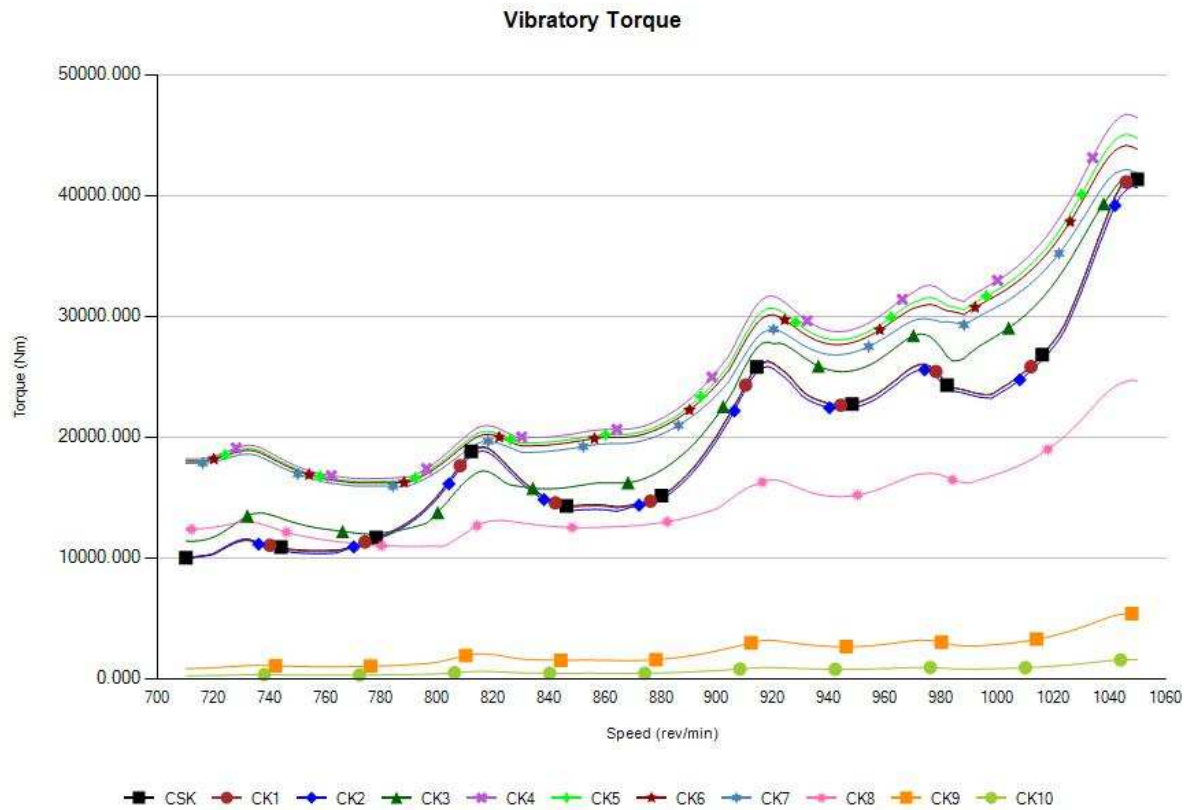
Component	Max Vibratory Stress (MPa)
H-GT	6.365
EK1	29.501
EK2	34.030
EK3	31.509
EK4	33.407
EK5	31.381
EK6	18.958
EK7	12.234

Coupling Combined Order Torque



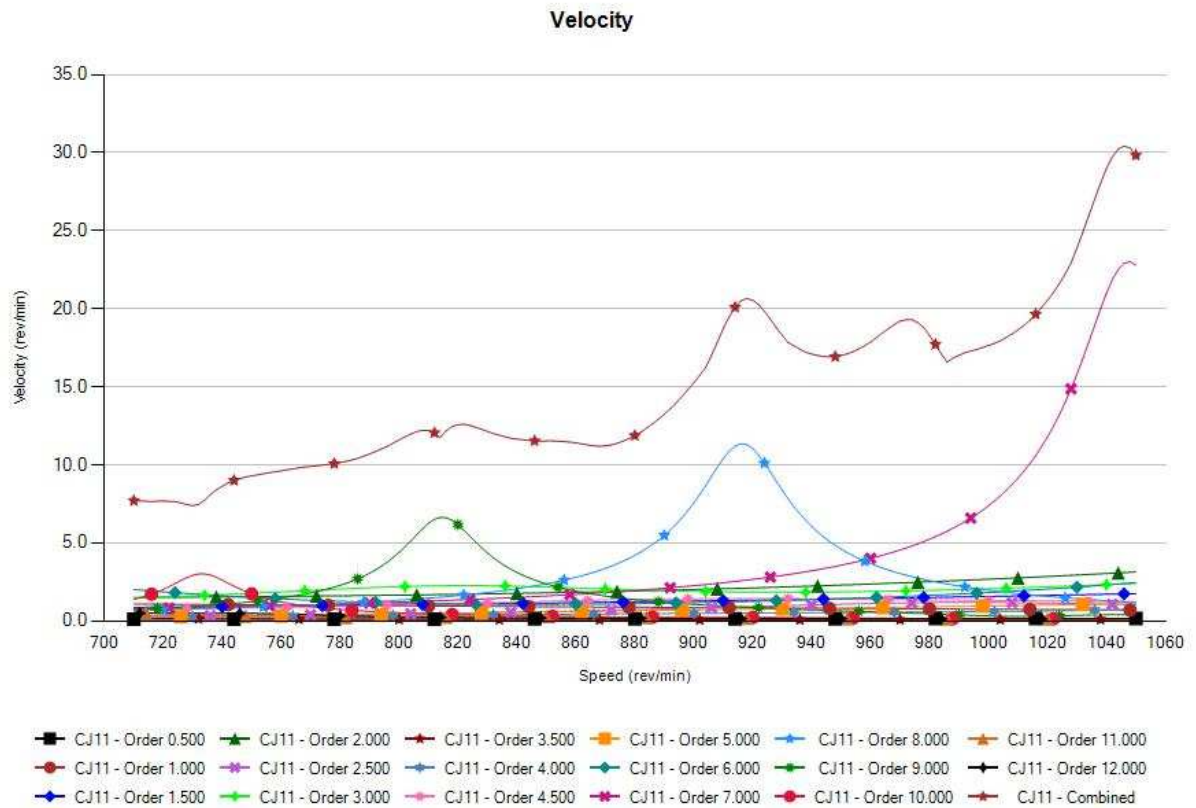
Component	Torque (Nm)
CPK Steady State	25438
CPK Min + SS	-14928
CPK Max + SS	66258

Compressor Shaft Combined Order Vibratory Torque



Component	Max Vibratory Torque (Nm)
CSK	41421
CK1	41358
CK2	40742
CK3	41376
CK4	46734
CK5	45071
CK6	44151
CK7	42155
CK8	24693
CK9	5381
CK10	1566

Compressor Aux End Velocity



Component	Max Velocity (rev/min)
CJ11 - Order 0.500	0.156
CJ11 - Order 1.000	1.089
CJ11 - Order 1.500	1.750
CJ11 - Order 2.000	3.141
CJ11 - Order 2.500	1.189
CJ11 - Order 3.000	2.409
CJ11 - Order 3.500	0.156
CJ11 - Order 4.000	0.736
CJ11 - Order 4.500	1.431
CJ11 - Order 5.000	1.109
CJ11 - Order 6.000	2.462
CJ11 - Order 7.000	23.016
CJ11 - Order 8.000	11.351
CJ11 - Order 9.000	6.634
CJ11 - Order 10.000	3.017
CJ11 - Order 11.000	0.591
CJ11 - Order 12.000	0.496
CJ11 - Combined	30.427

Operating Condition Four



Company: Exterran Energy
Project #: AP035401 Rev:7
7.7.6.0 Case 38:

Ariel Performance

Customer: Kaego Energy & Technology Corp.
Inquiry:
Project:



Compressor Data:

Elevation,ft: 50.00
Frame: (ELP) KBZ/4
Max RL Tot, lbf: 150000
Rated RPM: 1000
Calc RPM: 1000.0

Barmtr,psia: 14.669
Stroke, in: 6.75
Max RL Tens, lbf: 75000
Rated BHP: 5200.0
BHP: 3396

Ambient,F: 100.00
Rod Dia, in: 2.875
Max RL Comp, lbf: 80000
Rated PS FPM: 1125.0
Calc PS FPM: 1125.0

Driver Data:

Type: Nat. Gas
Mfg: Waukesha
Model: 12V275GL+
BHP: 3750
Avail: 3750

Services

Gas Model

Stage Data:

Target Flow, MMSCFD

Flow Calc, MMSCFD

BHP per Stage

Specific Gravity

Ratio of Sp Ht (N)

Comp Suct (Zs)

Comp Disch (Zd)

Pres Suct Line, psig

Pres Suct Flg, psig

Pres Disch Flg, psig

Pres Disch Line, psig

Pres Ratio F/F

Temp Suct, F

Temp Clr Disch, F

Cylinder Data:

Cyl Model

Cyl Bore, in

Cyl RDP (API), psig

Cyl MAWP, psig

Cyl Action

Cyl Disp, CFM

Pres Suct Intl, psig

Temp Suct Intl, F

Pres Disch Intl, psig

Temp Disch Intl, F

HE Suct Gas Vel, FPM

HE Disch Gas Vel, FPM

HE Spcrrs Used/Max

HE Vol Pkt Avail

Vol Pkt Used

HE Min Clr, %

HE Total Clr, %

CE Suct Gas Vel, FPM

CE Disch Gas Vel, FPM

CE Spcrrs Used/Max

CE Min Clr, %

CE Total Clr, %

Suct Vol Eff HE/CE, %

Disch Event HE/CE, ms

Suct Pseudo-Q HE/CE

Gas Rod Ld Comp, %

Gas Rod Ld Tens, %

Gas Rod Ld Total, %

Xhd Pin Deg/%RvrsI lbf

Flow Calc, MMSCFD

Cyl BHP

Service 1

VMG-APRNL2

1

2

3

22.500

19.241

1249.9

0.6978

1.2335

0.9857

0.9799

55.00

54.30

180.10

N/A

2.824

100.00

130.00

Throw 1

20-1/8Z:10

20.125

313.6

345.0

DBL

2459.8

49.37

109

191.63

250

8595

7259

0/0

0.62+42.28

100.00 (V) %

13.82

56.72

8420

7111

0/0

14.47

14.47

19.3/75.7

5.2/12.5

4.2/5.6

57.0 C

58.6 T

59.7

159/64.3

7.390

479.6

Service 2

2

3

22.500

19.241

1081.9

0.6978

1.2361

0.9672

0.9590

N/A

175.10

457.53

N/A

2.488

130.00

130.00

Throw 3

20-1/8Z:10

20.125

313.6

345.0

DBL

2459.8

49.37

109

191.63

250

8595

7259

0/0

0.62+42.28

13.82

14.44

8420

7111

0/0

14.47

14.47

75.7/75.7

10.8/12.5

5.8/5.6

57.0 C

58.6 T

59.7

176/96.6

11.850

770.3

Service 3

3

4

22.500

19.237

1018.0

0.6973

1.2516

0.9226

0.9185

N/A

448.71

1111.15

1100.00

2.430

130.00

120.00

Throw 4

15-7/8Z:10

15.875

768.2

845.0

DBL

1521.0

166.69

137

476.15

262

6904

5946

0/6

0.69+39.74

17.76

18.45

6678

5751

0/6

18.83

18.83

74.9/74.5

11.5/13.0

3.6/3.3

78.0 C

77.5 T

80.3

143/78.0

19.241

1081.9

Service 4

4

5

22.500

19.237

1018.0

0.6973

1.2516

0.9226

0.9185

N/A

448.71

1111.15

1100.00

2.430

130.00

120.00

Throw 2

11Z:10

10.500

1545.5

1700.0

DBL

651.1

426.59

136

1155.84

265

7144

5976

0/4

0.67+38.83

24.21

24.88

6609

5528

0/4

26.76

26.76

69.1/67.1

11.2/12.5

3.9/3.3

82.6 C

74.0 T

81.1

150/67.6

19.237

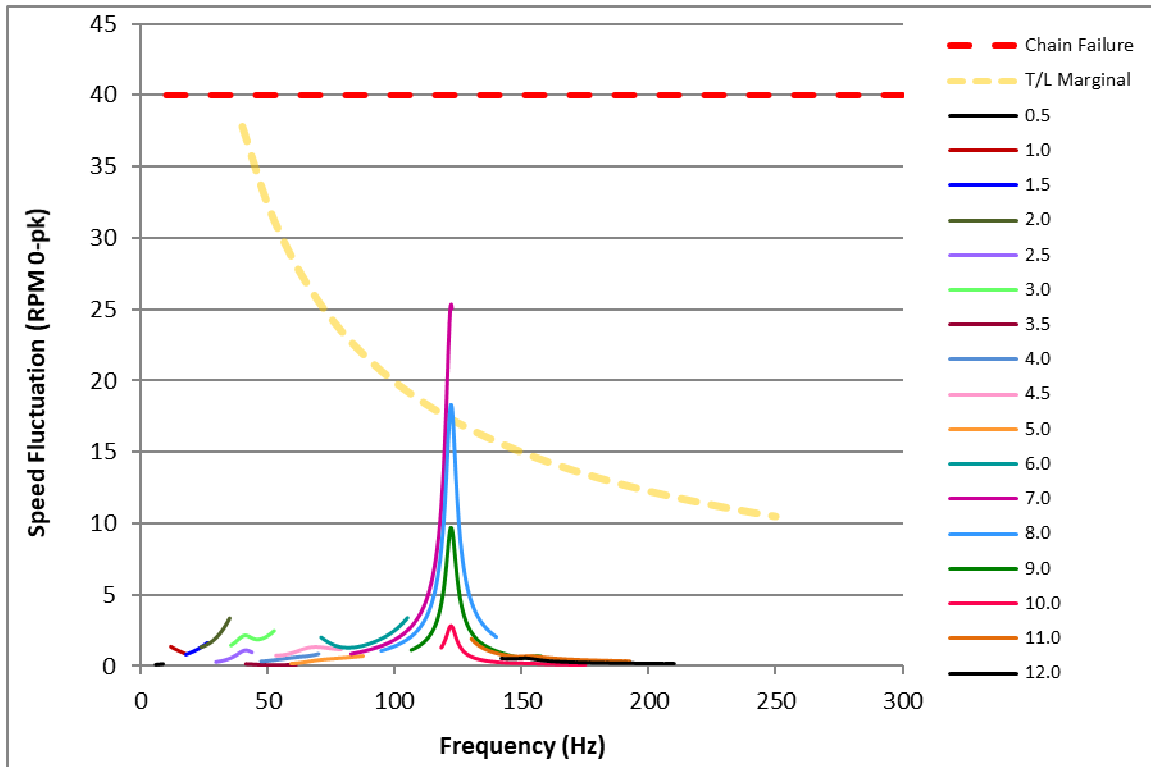
1018.0

Forced Response Highlights

Engine Firing Normal

Model Symbol	Component	Measured	Units	Order	Predicted Value	Limit	Comments
VDK	Damper	Power Absorbed	kW	Combined	1.846	10	Acceptable
HSNG	Damper Housing	Absolute Amplitude	deg	1.0	0.151	0.50	Acceptable
				1.5	0.204	0.20	*See Note
EK2	Engine Crankshaft	Vibratory Stress	MPa	Combined	32.843	42.75	Acceptable
CPK	Coupling	Nominal Torque	Nm	Combined	23855	158340	Acceptable
		Minimum Torque			-18228	-62318	Acceptable
		Maximum Torque			67784	124749	Acceptable
CSK	Compressor Crankshaft	Vibratory Torque	Nm	Combined	44105	59660	Acceptable
CK4					51448	59660	Acceptable
CJ11	Aux End	Absolute Velocity	RPM	7.0	25.340	40	Acceptable
				Combined	34.124	55	Acceptable

Compressor Aux End Velocity: Predictions vs. Limits



Forced Response Highlights

Speed Range

The torsional response has been analyzed from 710 RPM to 1050 RPM.

Engine Damper Thermal Loads

The predicted damper thermal loads are within the manufacturer's limits.

Engine Front End Amplitudes

*The predicted front end amplitudes exceed manufacturer allowable limits for normal operation. The engine manufacturer has specified that 1.5 order amplitudes up to 30% above their published limit are acceptable. The predicted front end amplitudes are within 30% above the manufacturer published limits and are therefore acceptable.

Engine Crankshaft Stresses

The predicted engine crankshaft stresses are within the manufacturer's limits.

Coupling Torques

The predicted vibratory torque for the TB Woods FSH 92HT-28 coupling is within the manufacturer's limits.

Compressor Crankshaft Torques

The predicted vibratory torque for the Ariel KBZ/4 compressor is within the manufacturer's limits.

Compressor Auxiliary End Velocity

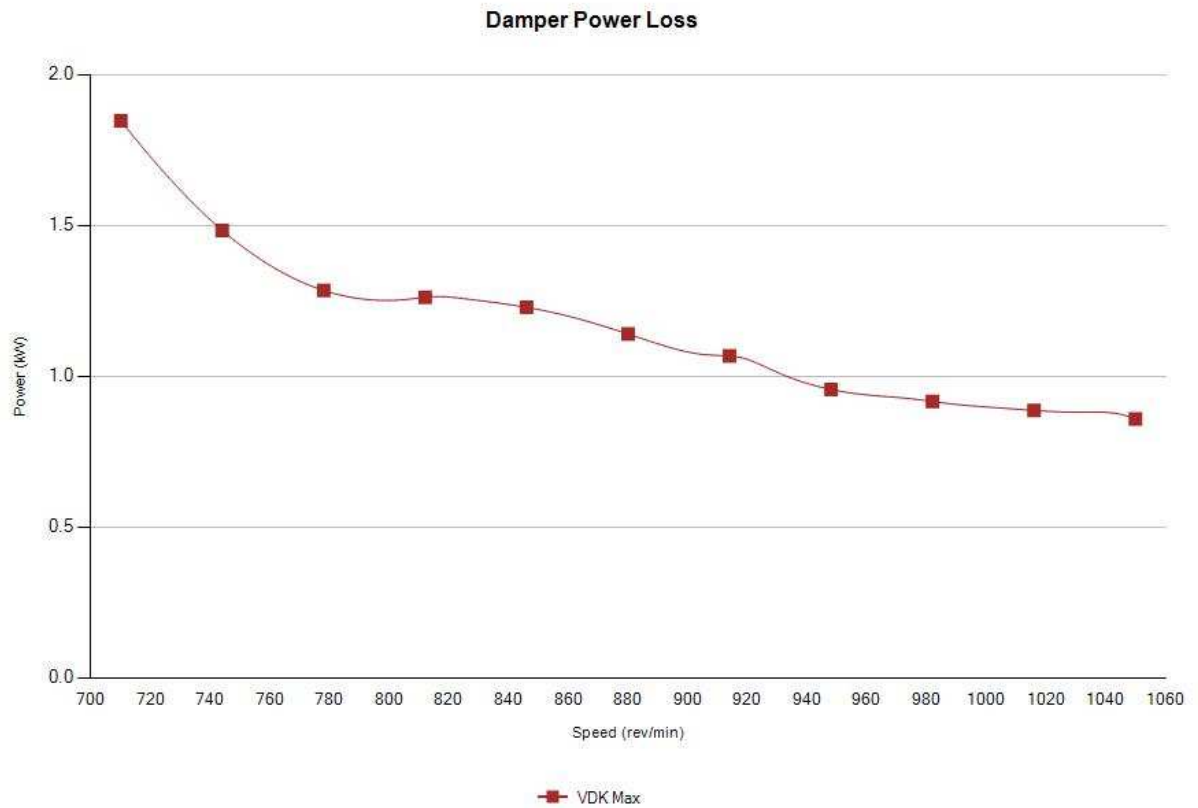
The predicted velocity at the auxiliary end of the Ariel KBZ/4 compressor crankshaft is within the manufacturer's limits.

Compressor Torsional-Lateral Awareness

The torsional-lateral (T/L) curve is intended to reduce high frequency lateral vibration levels by minimizing torsional oscillations. The T/L curve is only a recommendation, not a mechanical limit. Adherence to the T/L curve is not mandated. For more information on torsional-lateral awareness please see Ariel's Engineering Reference in the Appendix.

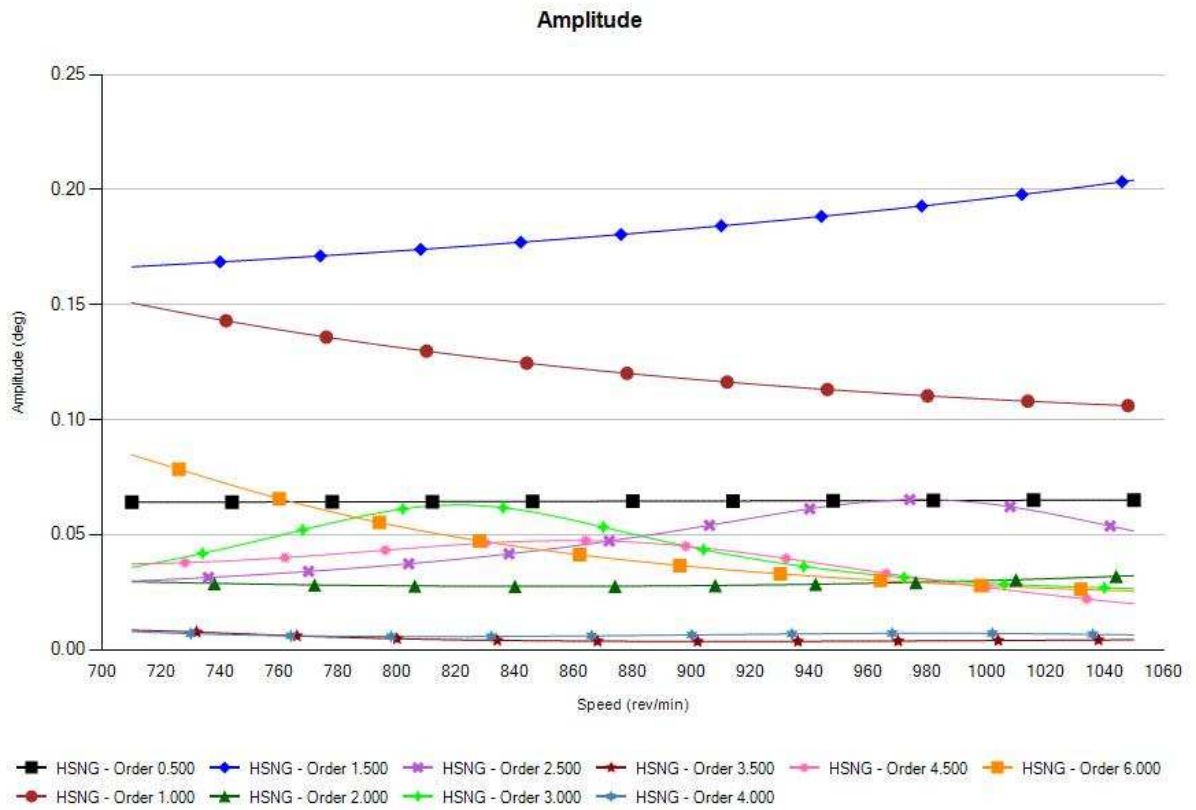
Forced Response Results

Damper Combined Order Thermal Loading



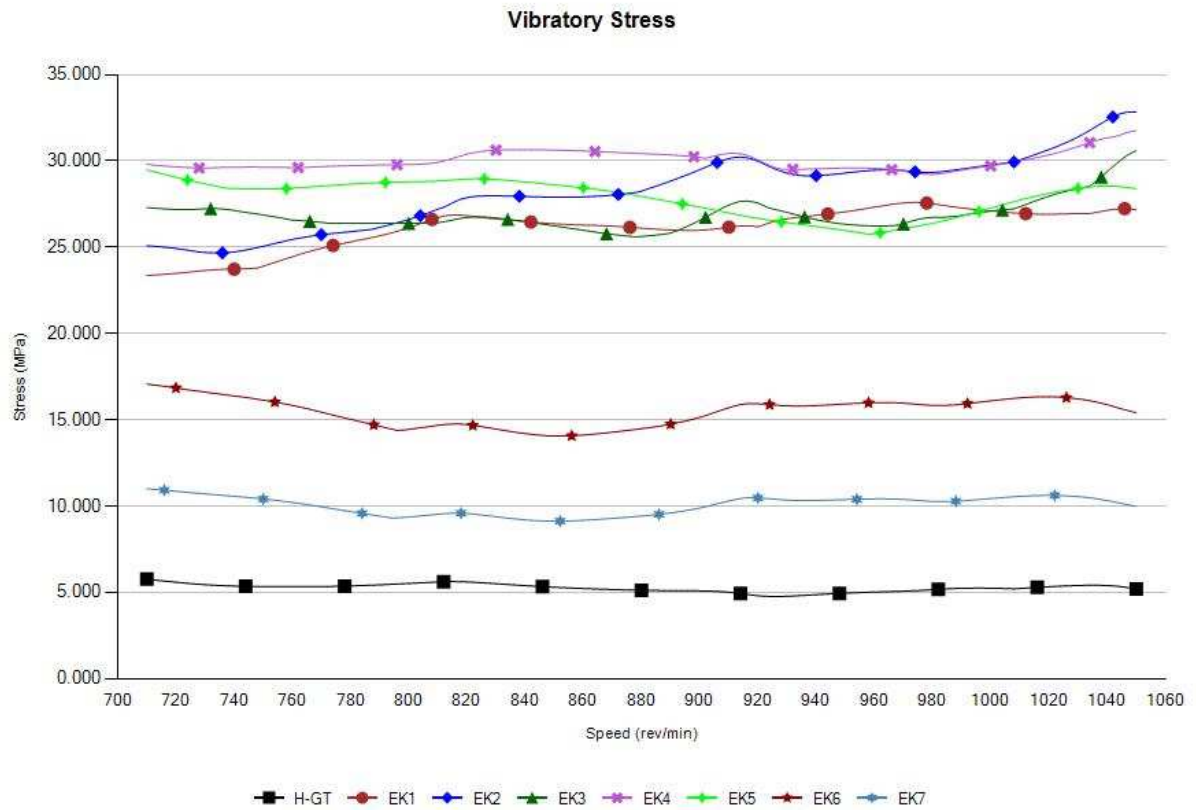
Component	Max Damper Power Loss (kW)
VDK Max	1.846

Front Crank Single Order Amplitude



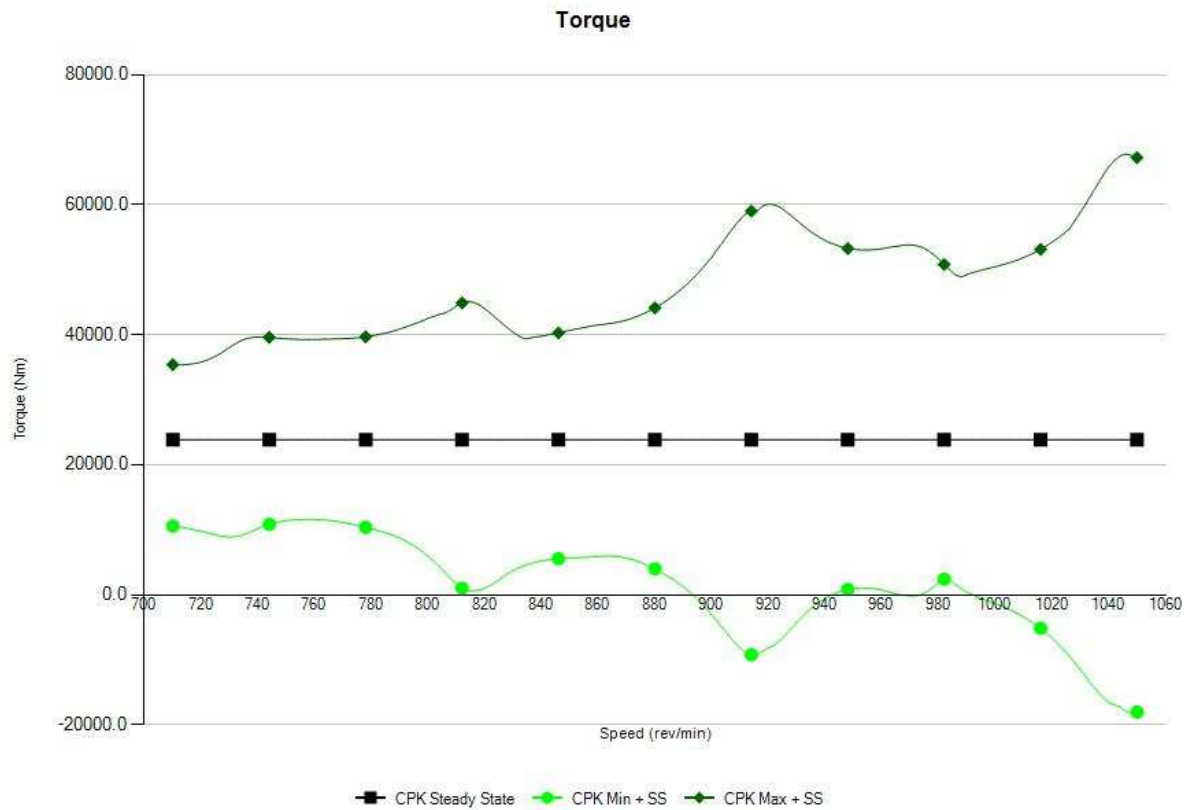
Component	Max Amplitude (deg)
HSNG - Order 0.500	0.065
HSNG - Order 1.000	0.151
HSNG - Order 1.500	0.204
HSNG - Order 2.000	0.032
HSNG - Order 2.500	0.065
HSNG - Order 3.000	0.063
HSNG - Order 3.500	0.008
HSNG - Order 4.000	0.008
HSNG - Order 4.500	0.047
HSNG - Order 6.000	0.085

Engine Crankshaft Combined Order Vibratory Stress



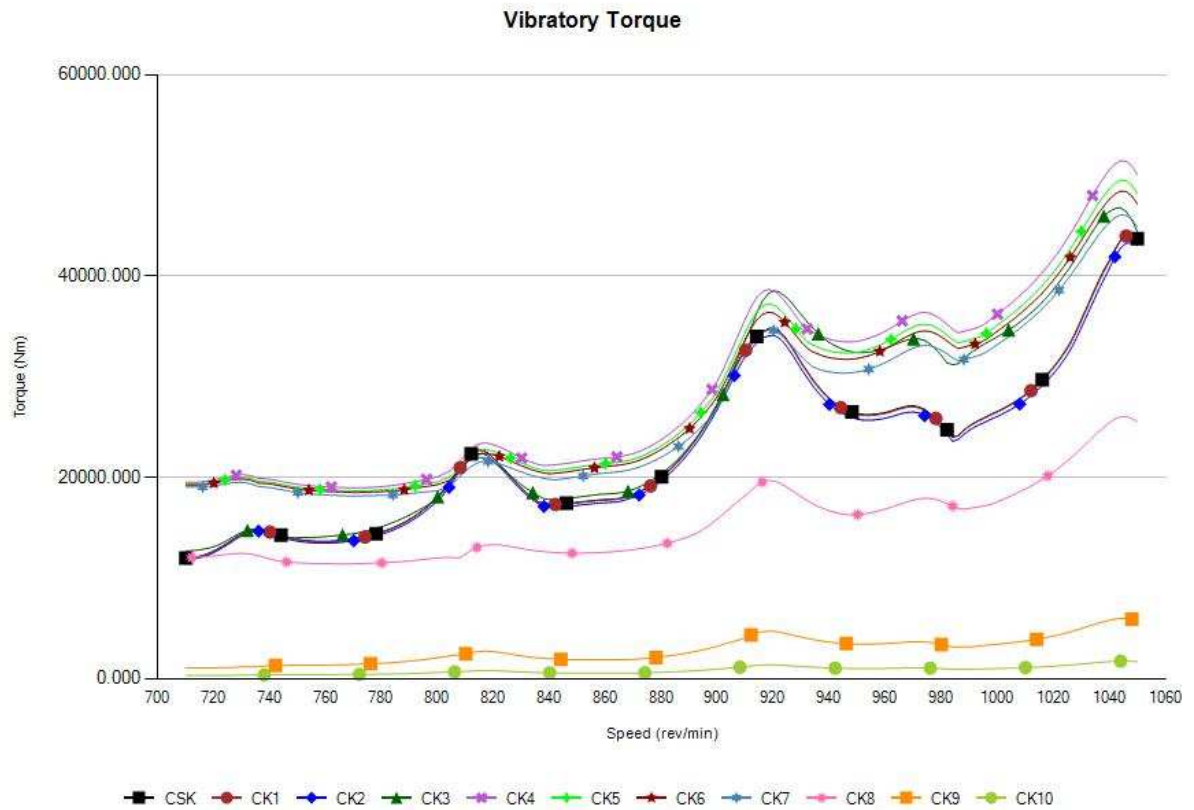
Component	Max Vibratory Stress (MPa)
H-GT	5.767
EK1	27.597
EK2	32.843
EK3	30.593
EK4	31.757
EK5	29.479
EK6	17.069
EK7	11.005

Coupling Combined Order Torque



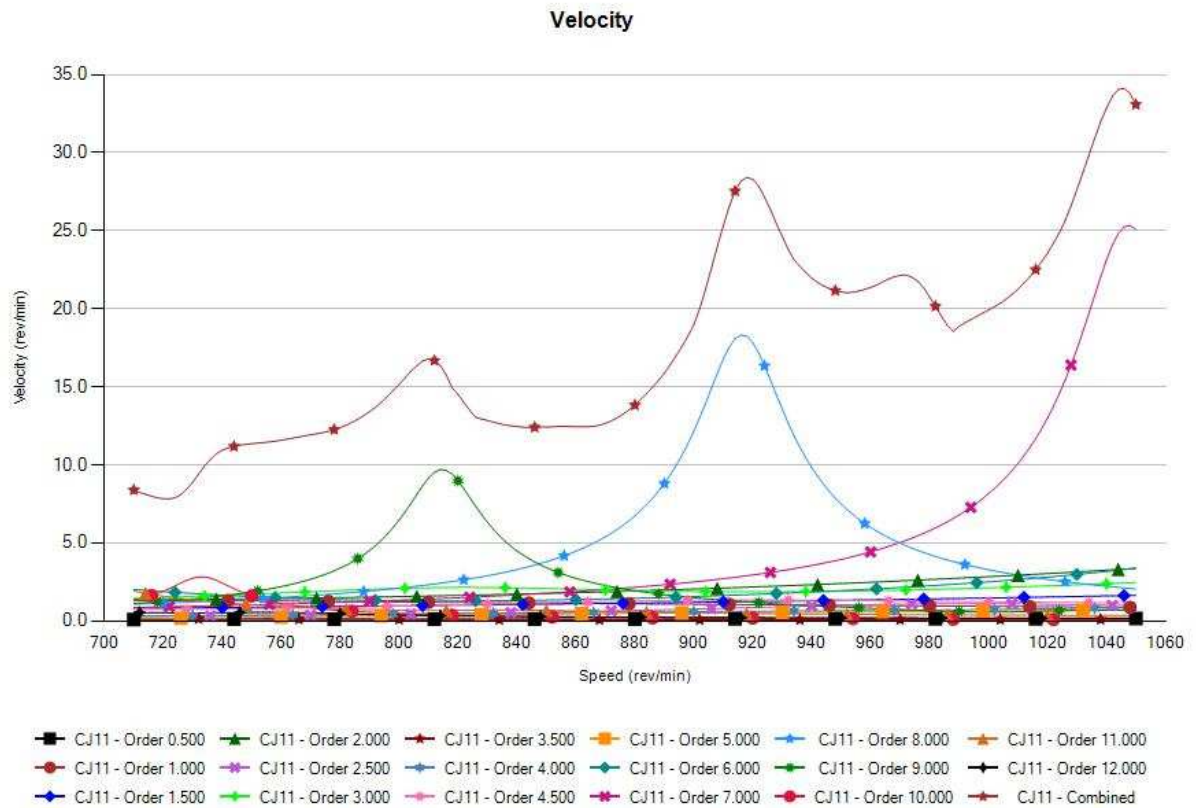
Component	Torque (Nm)
CPK Steady State	23855
CPK Min + SS	-18228
CPK Max + SS	67784

Compressor Shaft Combined Order Vibratory Torque



Component	Max Vibratory Torque (Nm)
CSK	44105
CK1	44002
CK2	43300
CK3	46780
CK4	51448
CK5	49507
CK6	48428
CK7	46066
CK8	26027
CK9	5981
CK10	1740

Compressor Aux End Velocity



Component	Max Velocity (rev/min)
CJ11 - Order 0.500	0.146
CJ11 - Order 1.000	1.363
CJ11 - Order 1.500	1.639
CJ11 - Order 2.000	3.362
CJ11 - Order 2.500	1.112
CJ11 - Order 3.000	2.466
CJ11 - Order 3.500	0.146
CJ11 - Order 4.000	0.855
CJ11 - Order 4.500	1.337
CJ11 - Order 5.000	0.710
CJ11 - Order 6.000	3.388
CJ11 - Order 7.000	25.340
CJ11 - Order 8.000	18.320
CJ11 - Order 9.000	9.697
CJ11 - Order 10.000	2.817
CJ11 - Order 11.000	1.922
CJ11 - Order 12.000	0.553
CJ11 - Combined	34.124

Operating Condition Five

Ariel Performance			
	Company: Exterran Energy	Customer: Kaego Energy & Technology Corp.	
Project #: AP035401 Rev:7	Inquiry:		
7.7.6.0 Case 39:	Project:		

Compressor Data:				Driver Data:	
Elevation,ft:	50.00	Barmtr,psia:	14.669	Ambient,F:	100.00
Frame: (ELP)	KBZ/4	Stroke, in:	6.75	Rod Dia, in:	2.875
Max RL Tot, lbf:	150000	Max RL Tens, lbf:	75000	Max RL Comp, lbf:	80000
Rated RPM:	1000	Rated BHP:	5200.0	Rated PS FPM:	1125.0
Calc RPM:	1000.0	BHP:	2035	Calc PS FPM:	1125.0
Type:	Nat. Gas				
Mfg:	Waukesha				
Model:	12V275GL+				
BHP:	3750				
Avail:	3750				

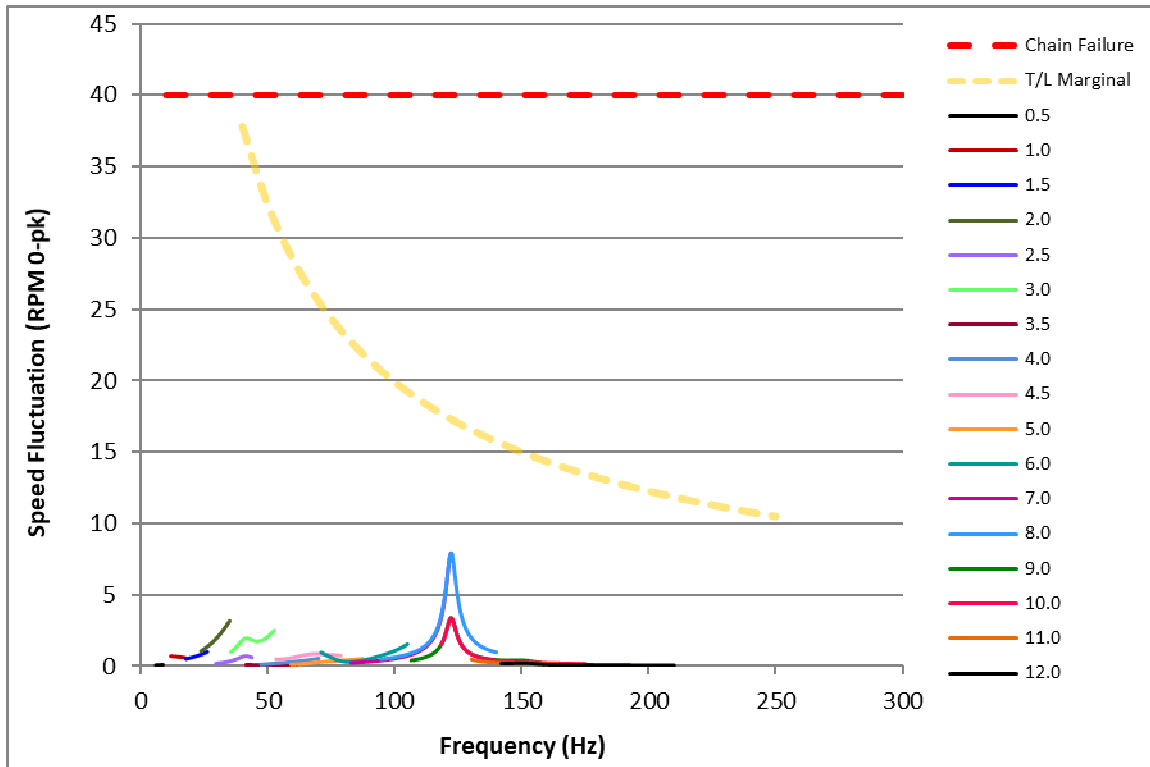
Services	Service 1			
Gas Model	VMG-APRNL2			
Stage Data:	1	2	3	
Target Flow, MMSCFD	22.500	22.500	22.500	
Flow Calc, MMSCFD	17.146	17.145	17.146	
BHP per Stage	1059.4	739.1	190.7	
Specific Gravity	0.7315	0.7315	0.7315	
Ratio of Sp Ht (N)	1.2240	1.2270	1.2420	
Comp Suct (Zs)	0.9866	0.9705	0.9430	
Comp Disch (Zd)	0.9807	0.9632	0.9410	
Pres Suct Line, psig	45.00	N/A	N/A	
Pres Suct Flg, psig	44.40	139.89	288.18	
Pres Disch Flg, psig	143.05	293.18	326.69	
Pres Disch Line, psig	N/A	N/A	320.00	
Pres Ratio F/F	2.670	1.992	1.127	
Temp Suct, F	100.00	130.00	130.00	
Temp Clr Disch, F	130.00	130.00	120.00	
Cylinder Data:	Throw 1	Throw 3	Throw 4	Throw 2
Cyl Model	20-1/8Z:10	20-1/8Z:10	15-7/8Z:10	11Z:10
Cyl Bore, in	20.125	20.125	15.875	10.500
Cyl RDP (API), psig	313.6	313.6	768.2	1545.5
Cyl MAWP, psig	345.0	345.0	845.0	1700.0
Cyl Action	DBL	DBL	DBL	DBL
Cyl Disp, CFM	2459.8	2459.8	1521.0	651.1
Pres Suct Intl, psig	39.97	39.97	132.72	273.23
Temp Suct Intl, F	108	108	135	131
Pres Disch Intl, psig	153.01	153.01	306.49	343.00
Temp Disch Intl, F	238	237	227	157
HE Suct Gas Vel, FPM	8595	8595	6904	7144
HE Disch Gas Vel, FPM	7259	7259	5946	5976
HE Spcrrs Used/Max	0/0	0/0	0/6	0/4
HE Vol Pkt Avail	0.62+42.28	0.62+42.28	0.69+39.74	0.67+38.83
Vol Pkt Used	0.00 (V) %	100.00 (V) %	0.00 (V) %	0.00 (V) %
HE Min Clr, %	13.82	13.82	17.76	24.21
HE Total Clr, %	14.44	56.72	18.45	24.88
CE Suct Gas Vel, FPM	8420	8420	6678	6609
CE Disch Gas Vel, FPM	7111	7111	5751	5528
CE Spcrrs Used/Max	0/0	0/0	0/6	0/4
CE Min Clr, %	14.47	14.47	18.83	26.76
CE Total Clr, %	14.47	14.47	18.83	26.76
Suct Vol Eff HE/CE, %	77.3/77.3	24.7/77.3	82.1/81.8	95.1/94.8
Disch Event HE/CE, ms	11.2/12.8	6.0/12.8	13.5/15.2	22.2/23.3
Suct Pseudo-Q HE/CE	6.1/5.9	5.0/5.9	3.7/3.5	4.0/3.5
Gas Rod Ld Comp, %	45.3 C	45.3 C	44.1 C	9.8 C
Gas Rod Ld Tens, %	46.6 T	46.6 T	43.2 T	5.1 T
Gas Rod Ld Total, %	47.5	47.5	45.1	7.8
Xhd Pin Deg/%Rvrsal lbf	175/95.1	174/90.8	170/98.0	158/77.9
Flow Calc, MMSCFD	10.353	6.793	17.145	17.146
Cyl BHP	640.0	419.3	739.1	190.7

Forced Response Highlights

Engine Firing Normal

Model Symbol	Component	Measured	Units	Order	Predicted Value	Limit	Comments
VDK	Damper	Power Absorbed	kW	Combined	0.854	10	Acceptable
HSNG	Damper Housing	Absolute Amplitude	deg	1.0	0.077	0.50	Acceptable
				1.5	0.125	0.20	Acceptable
EK4	Engine Crankshaft	Vibratory Stress	MPa	Combined	24.317	42.75	Acceptable
CPK	Coupling	Nominal Torque	Nm	Combined	14165	158340	Acceptable
		Minimum Torque			-11672	-62318	Acceptable
		Maximum Torque			38233	124749	Acceptable
CSK	Compressor Crankshaft	Vibratory Torque	Nm	Combined	25795	59660	Acceptable
CK4					36660	59660	Acceptable
CJ11	Aux End	Absolute Velocity	RPM	8.0	7.922	40	Acceptable
				Combined	14.185	55	Acceptable

Compressor Aux End Velocity: Predictions vs. Limits



Forced Response Highlights

Speed Range

The torsional response has been analyzed from 710 RPM to 1050 RPM.

Engine Damper Thermal Loads

The predicted damper thermal loads are within the manufacturer's limits.

Engine Front End Amplitudes

The predicted front end amplitudes are within the manufacturer's limits.

Engine Crankshaft Stresses

The predicted engine crankshaft stresses are within the manufacturer's limits.

Coupling Torques

The predicted vibratory torque for the TB Woods FSH 92HT-28 coupling is within the manufacturer's limits.

Compressor Crankshaft Torques

The predicted vibratory torque for the Ariel KBZ/4 compressor is within the manufacturer's limits.

Compressor Auxiliary End Velocity

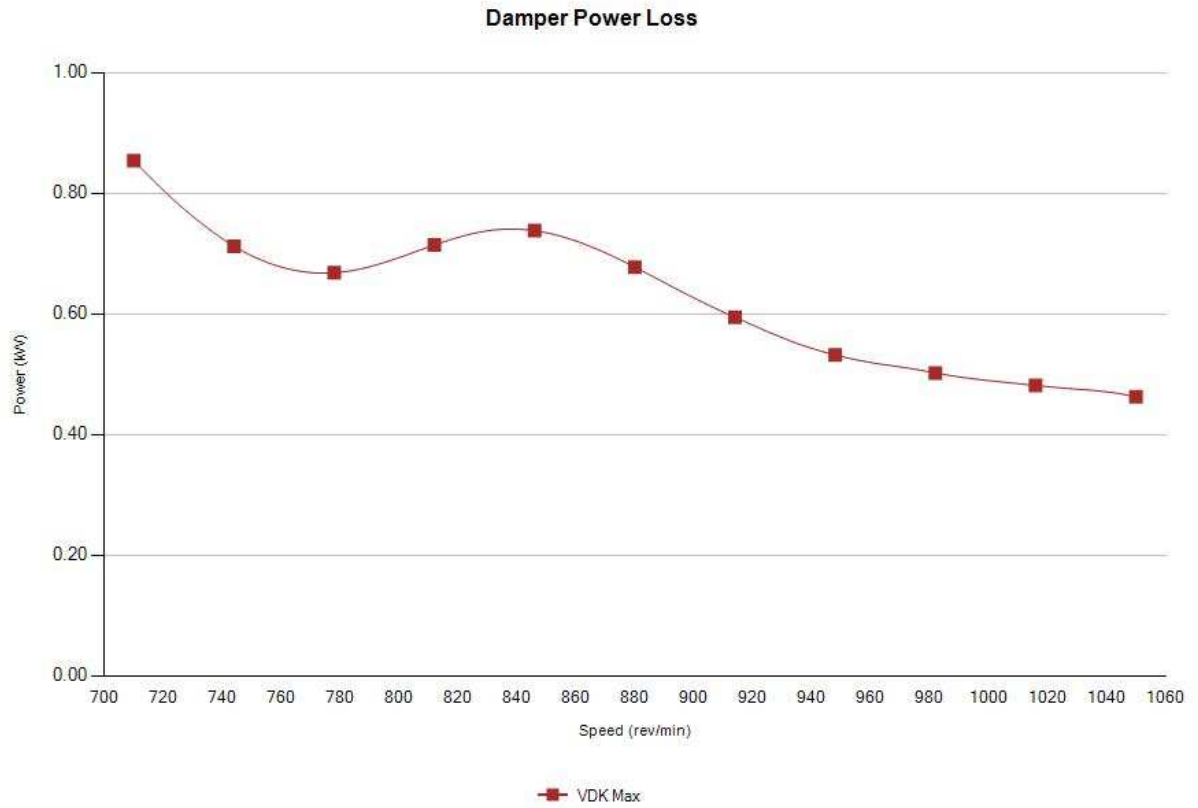
The predicted velocity at the auxiliary end of the Ariel KBZ/4 compressor crankshaft is within the manufacturer's limits.

Compressor Torsional-Lateral Awareness

The torsional-lateral (T/L) curve is intended to reduce high frequency lateral vibration levels by minimizing torsional oscillations. The T/L curve is only a recommendation, not a mechanical limit. Adherence to the T/L curve is not mandated. For more information on torsional-lateral awareness please see Ariel's Engineering Reference in the Appendix.

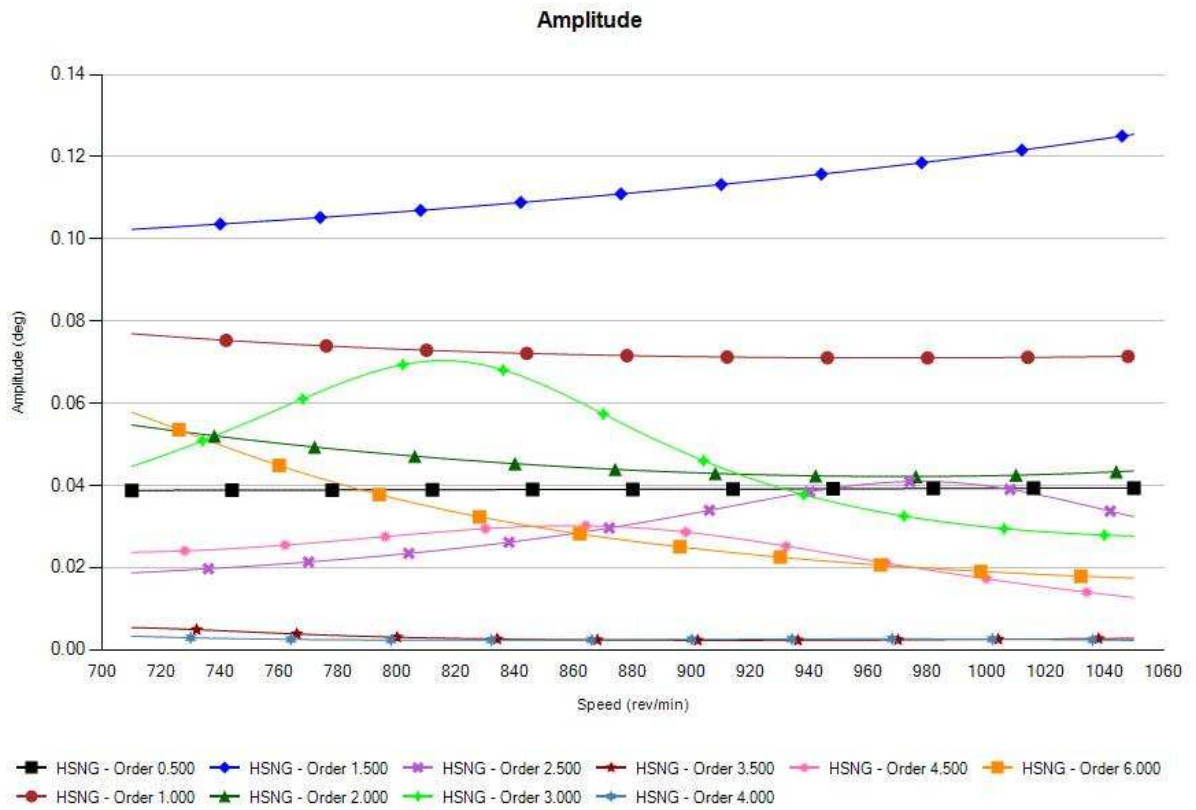
Forced Response Results

Damper Combined Order Thermal Loading



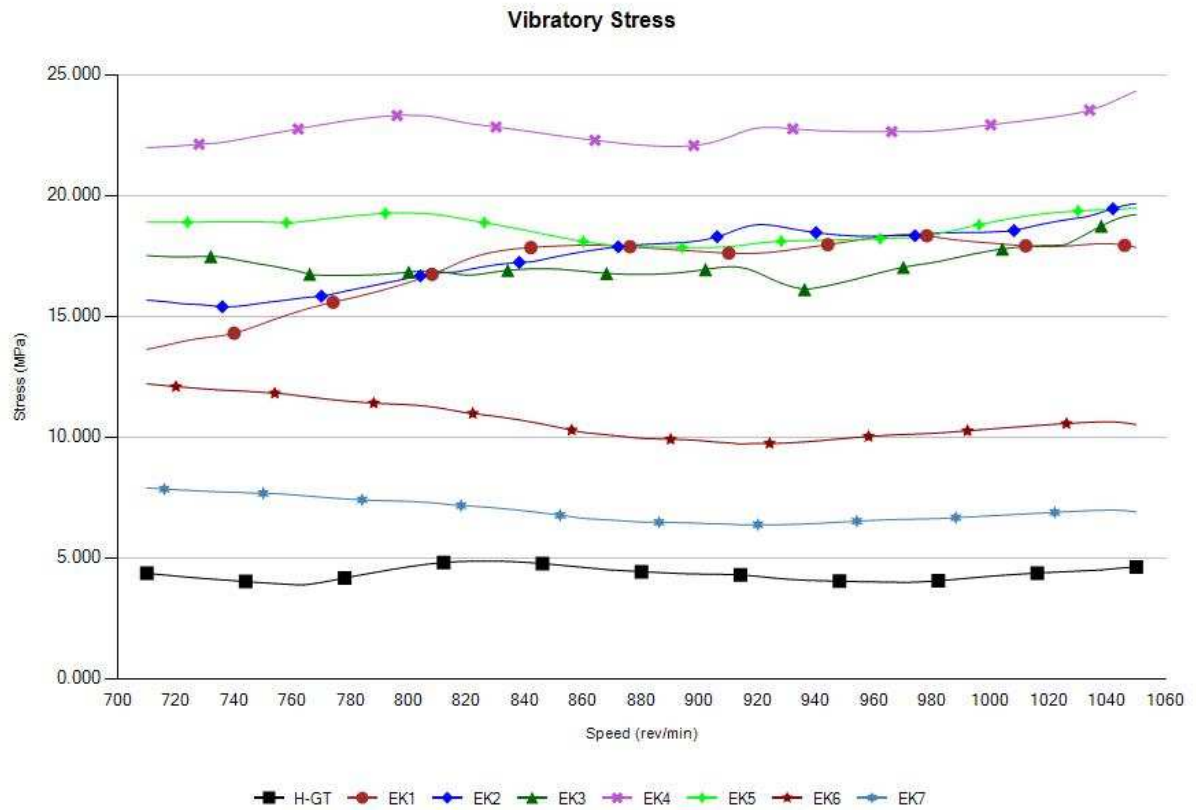
Component	Max Damper Power Loss (kW)
VDK Max	0.854

Front Crank Single Order Amplitude



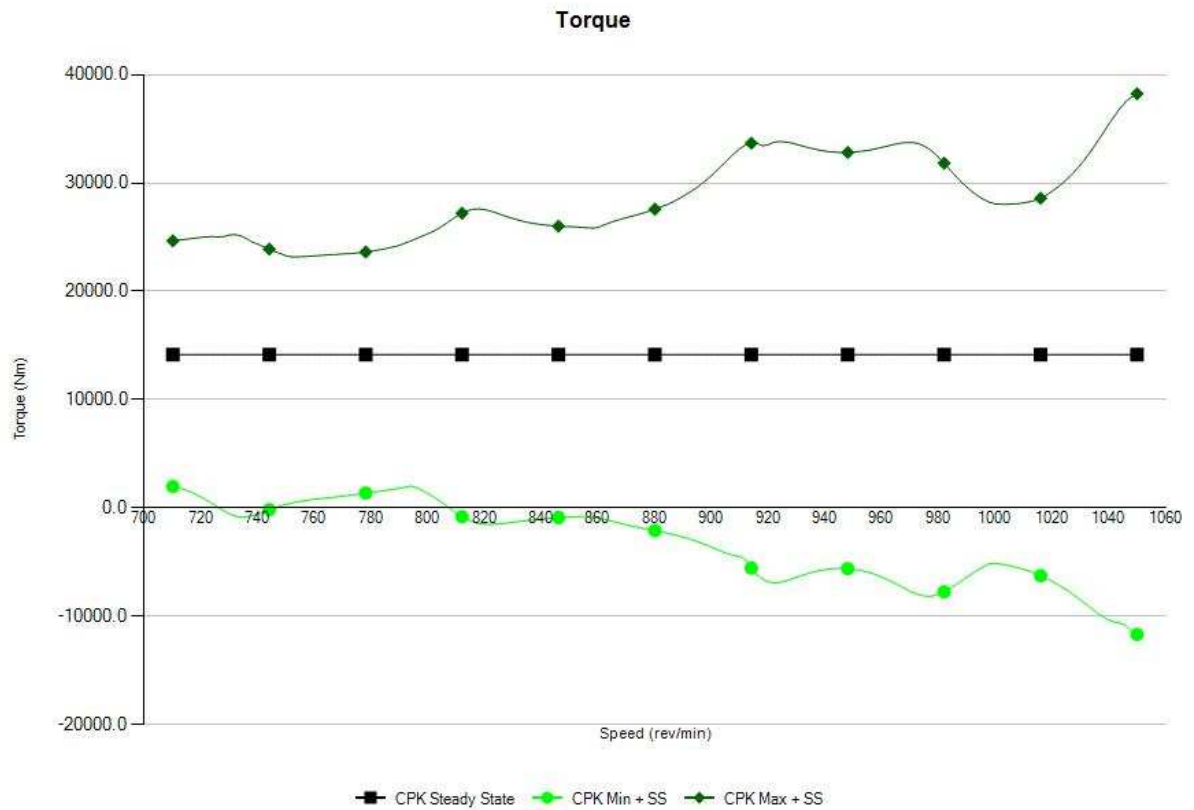
Component	Max Amplitude (deg)
HSNG - Order 0.500	0.039
HSNG - Order 1.000	0.077
HSNG - Order 1.500	0.125
HSNG - Order 2.000	0.055
HSNG - Order 2.500	0.041
HSNG - Order 3.000	0.070
HSNG - Order 3.500	0.005
HSNG - Order 4.000	0.003
HSNG - Order 4.500	0.030
HSNG - Order 6.000	0.058

Engine Crankshaft Combined Order Vibratory Stress



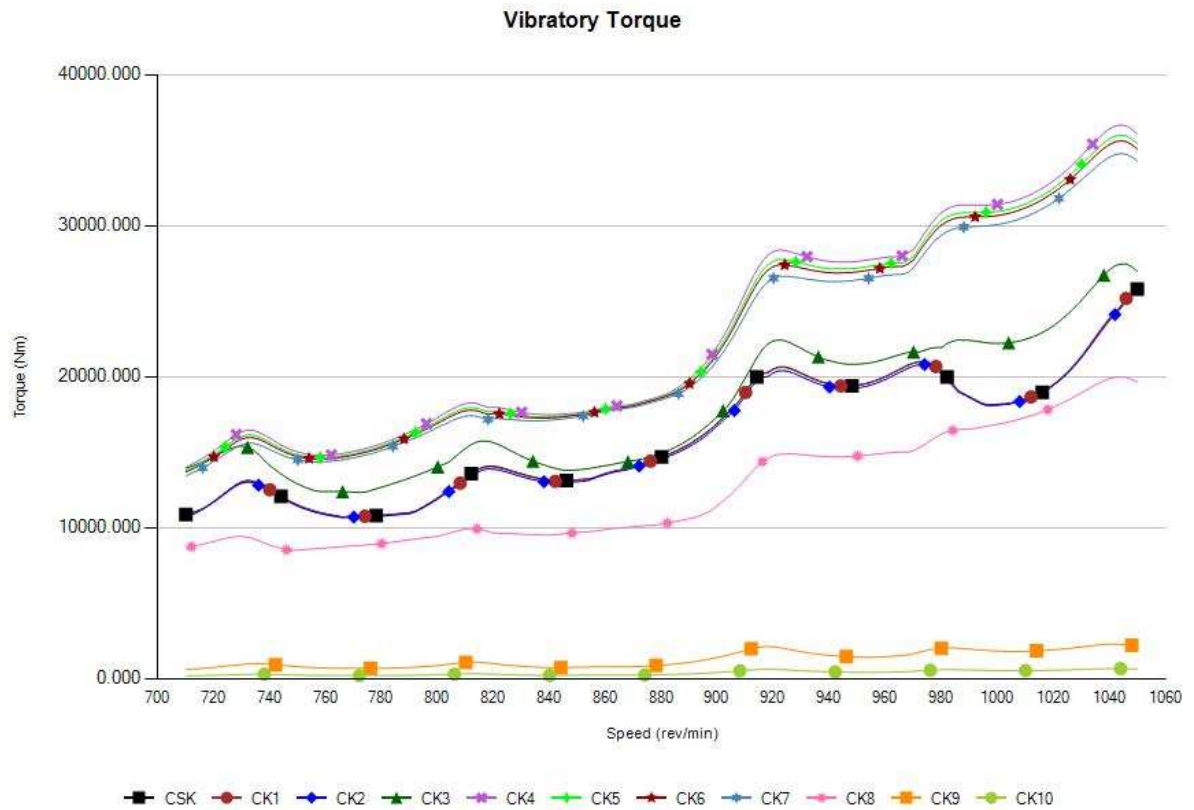
Component	Max Vibratory Stress (MPa)
H-GT	4.864
EK1	18.388
EK2	19.665
EK3	19.205
EK4	24.317
EK5	19.473
EK6	12.200
EK7	7.890

Coupling Combined Order Torque



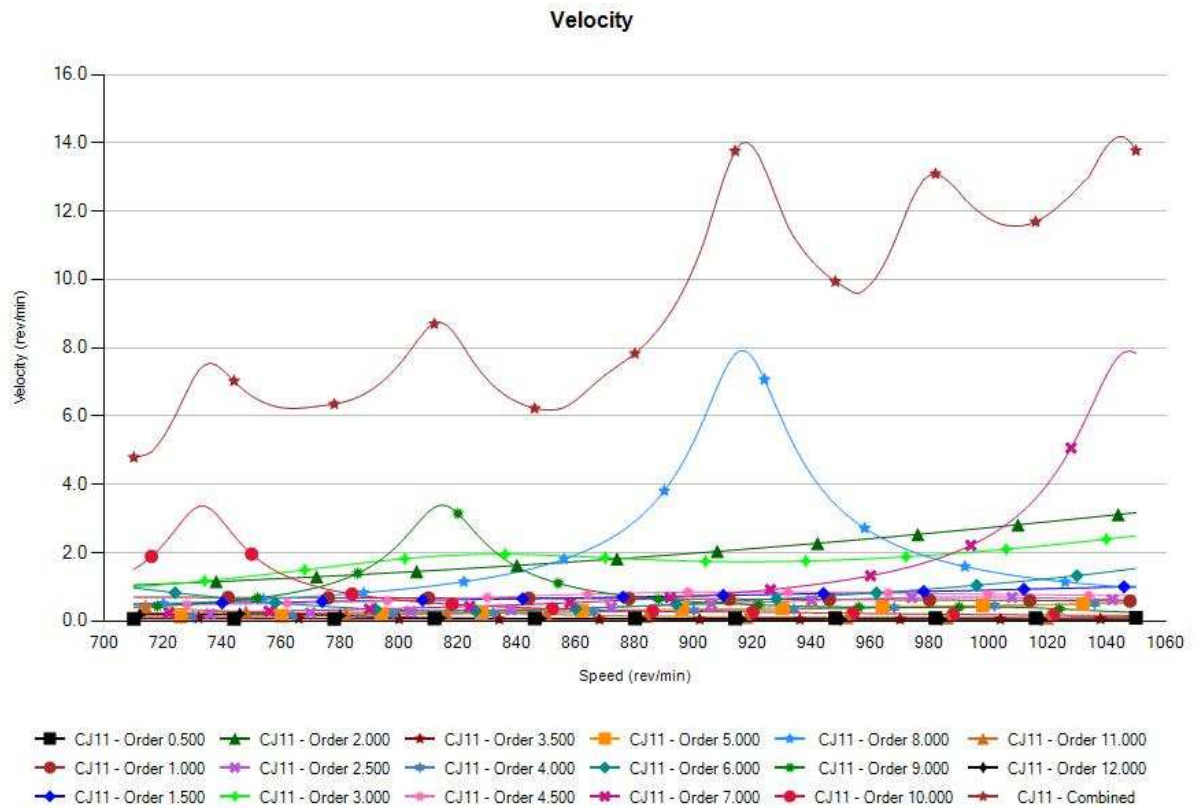
Component	Torque (Nm)
CPK Steady State	14165
CPK Min + SS	-11672
CPK Max + SS	38233

Compressor Shaft Combined Order Vibratory Torque



Component	Max Vibratory Torque (Nm)
CSK	25795
CK1	25783
CK2	25594
CK3	27465
CK4	36660
CK5	35993
CK6	35614
CK7	34769
CK8	19990
CK9	2283
CK10	664

Compressor Aux End Velocity



Component	Max Velocity (rev/min)
CJ11 - Order 0.500	0.088
CJ11 - Order 1.000	0.695
CJ11 - Order 1.500	1.008
CJ11 - Order 2.000	3.172
CJ11 - Order 2.500	0.698
CJ11 - Order 3.000	2.494
CJ11 - Order 3.500	0.093
CJ11 - Order 4.000	0.538
CJ11 - Order 4.500	0.850
CJ11 - Order 5.000	0.517
CJ11 - Order 6.000	1.537
CJ11 - Order 7.000	7.912
CJ11 - Order 8.000	7.922
CJ11 - Order 9.000	3.390
CJ11 - Order 10.000	3.366
CJ11 - Order 11.000	0.467
CJ11 - Order 12.000	0.212
CJ11 - Combined	14.185

Operating Condition Six



Company: Exterran Energy
Project #: AP035401 Rev:7
7.7.6.0 Case 40:

Ariel Performance

Customer: Kaego Energy & Technology Corp.
Inquiry:
Project:



Compressor Data:

Elevation,ft: 50.00
Frame: (ELP) KBZ/4
Max RL Tot, lbf: 150000
Rated RPM: 1000
Calc RPM: 1000.0

Barmtr,psia: 14.669
Stroke, in: 6.75
Max RL Tens, lbf: 75000
Rated BHP: 5200.0
BHP: 2035

Ambient,F: 100.00
Rod Dia, in: 2.875
Max RL Comp, lbf: 80000
Rated PS FPM: 1125.0
Calc PS FPM: 1125.0

Driver Data:

Type: Nat. Gas
Mfg: Waukesha
Model: 12V275GL+
BHP: 3750
Avail: 3750

Services

Gas Model

Stage Data:

Target Flow, MMSCFD

Flow Calc, MMSCFD

BHP per Stage

Specific Gravity

Ratio of Sp Ht (N)

Comp Suct (Zs)

Comp Disch (Zd)

Pres Suct Line, psig

Pres Suct Flg, psig

Pres Disch Flg, psig

Pres Disch Line, psig

Pres Ratio F/F

Temp Suct, F

Temp Clr Disch, F

Cylinder Data:

Cyl Model

Cyl Bore, in

Cyl RDP (API), psig

Cyl MAWP, psig

Cyl Action

Cyl Disp, CFM

Pres Suct Intl, psig

Temp Suct Intl, F

Pres Disch Intl, psig

Temp Disch Intl, F

HE Suct Gas Vel, FPM

HE Disch Gas Vel, FPM

HE Spcra Used/Max

HE Vol Pkt Avail

Vol Pkt Used

HE Min Clr, %

HE Total Clr, %

CE Suct Gas Vel, FPM

CE Disch Gas Vel, FPM

CE Spcra Used/Max

CE Min Clr, %

CE Total Clr, %

Suct Vol Eff HE/CE, %

Disch Event HE/CE, ms

Suct Pseudo-Q HE/CE

Gas Rod Ld Comp, %

Gas Rod Ld Tens, %

Gas Rod Ld Total, %

Xhd Pin Deg/%RvrsI lbf

Flow Calc, MMSCFD

Cyl BHP

Service 1

VMG-APRNL2

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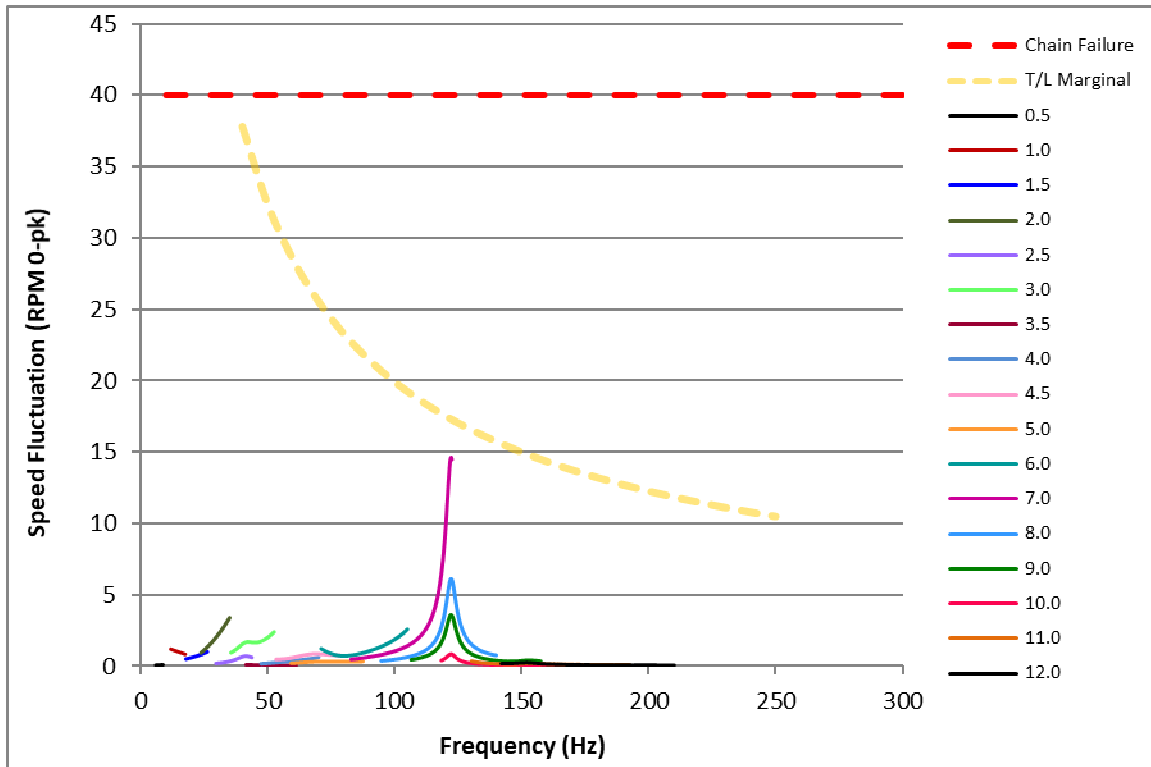
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Forced Response Highlights

Engine Firing Normal

Model Symbol	Component	Measured	Units	Order	Predicted Value	Limit	Comments
VDK	Damper	Power Absorbed	kW	Combined	0.889	10	Acceptable
HSNG	Damper Housing	Absolute Amplitude	deg	1.0	0.131	0.50	Acceptable
				1.5	0.125	0.20	Acceptable
EK4	Engine Crankshaft	Vibratory Stress	MPa	Combined	24.865	42.75	Acceptable
CPK	Coupling	Nominal Torque	Nm	Combined	14165	158340	Acceptable
		Minimum Torque			-22530	-62318	Acceptable
		Maximum Torque			46768	124749	Acceptable
CSK	Compressor Crankshaft	Vibratory Torque	Nm	Combined	35571	59660	Acceptable
CK4					43860	59660	Acceptable
CJ11	Aux End	Absolute Velocity	RPM	7.0	14.619	40	Acceptable
				Combined	21.546	55	Acceptable

Compressor Aux End Velocity: Predictions vs. Limits



Forced Response Highlights

Speed Range

The torsional response has been analyzed from 710 RPM to 1050 RPM.

Engine Damper Thermal Loads

The predicted damper thermal loads are within the manufacturer's limits.

Engine Front End Amplitudes

The predicted front end amplitudes are within the manufacturer's limits.

Engine Crankshaft Stresses

The predicted engine crankshaft stresses are within the manufacturer's limits.

Coupling Torques

The predicted vibratory torque for the TB Woods FSH 92HT-28 coupling is within the manufacturer's limits.

Compressor Crankshaft Torques

The predicted vibratory torque for the Ariel KBZ/4 compressor is within the manufacturer's limits.

Compressor Auxiliary End Velocity

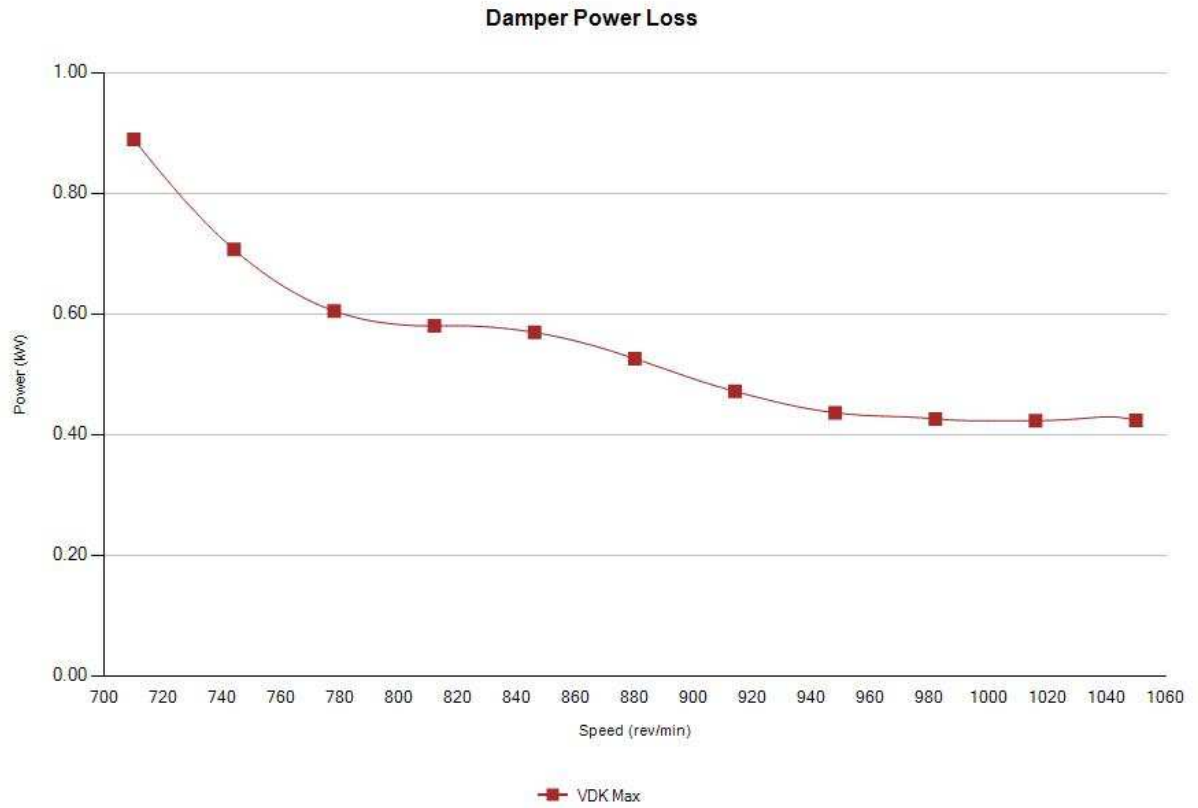
The predicted velocity at the auxiliary end of the Ariel KBZ/4 compressor crankshaft is within the manufacturer's limits.

Compressor Torsional-Lateral Awareness

The torsional-lateral (T/L) curve is intended to reduce high frequency lateral vibration levels by minimizing torsional oscillations. The T/L curve is only a recommendation, not a mechanical limit. Adherence to the T/L curve is not mandated. For more information on torsional-lateral awareness please see Ariel's Engineering Reference in the Appendix.

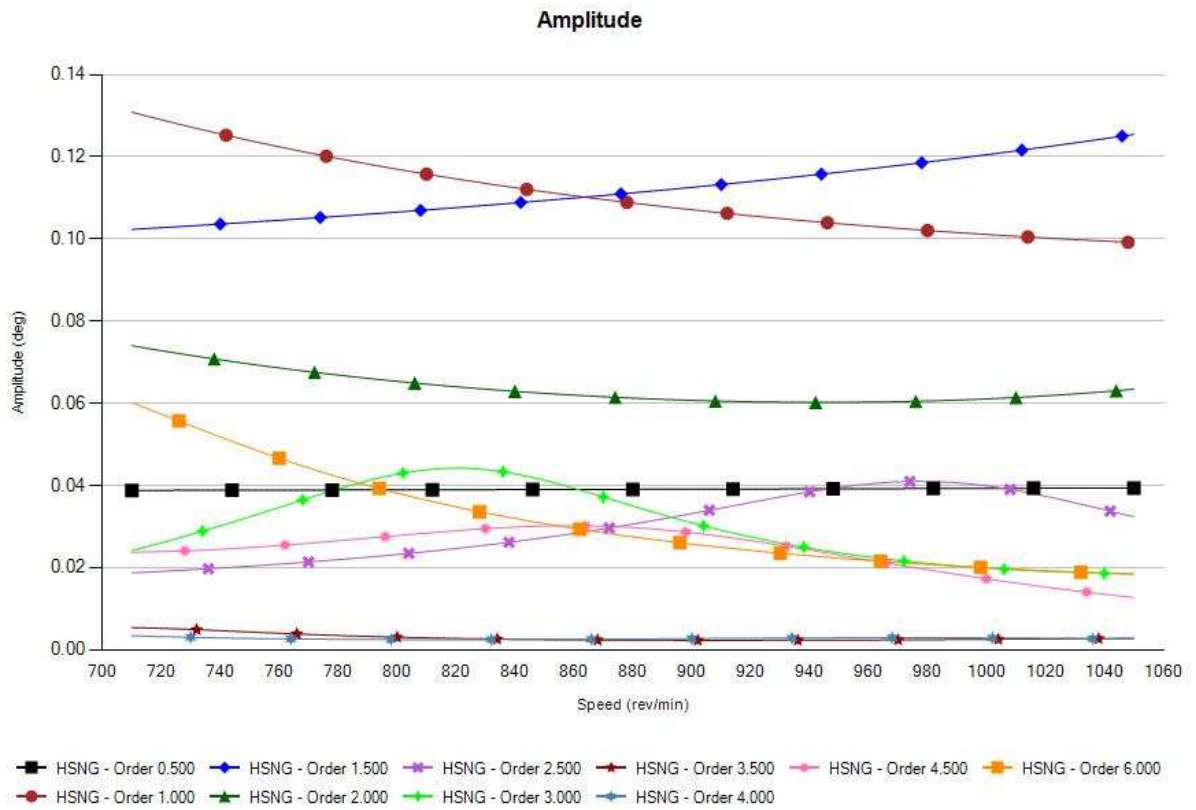
Forced Response Results

Damper Combined Order Thermal Loading



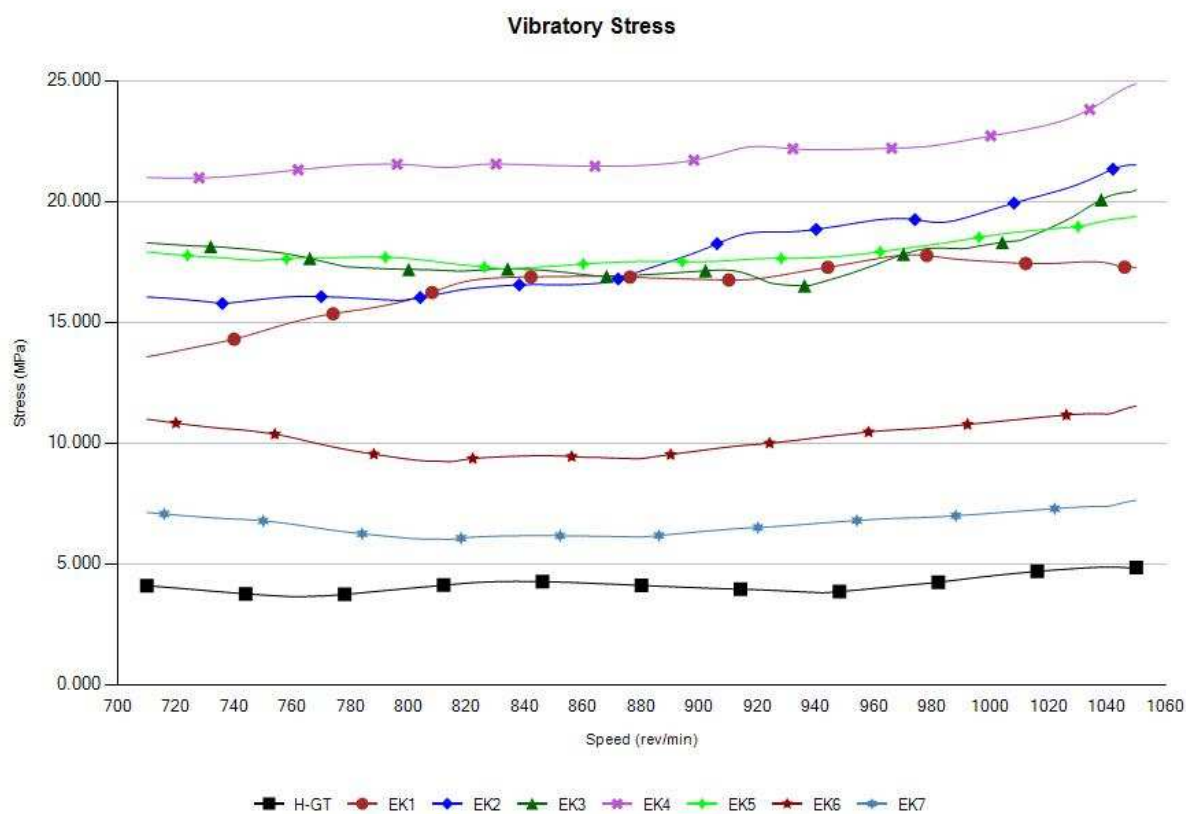
Component	Max Damper Power Loss (kW)
VDK Max	0.889

Front Crank Single Order Amplitude



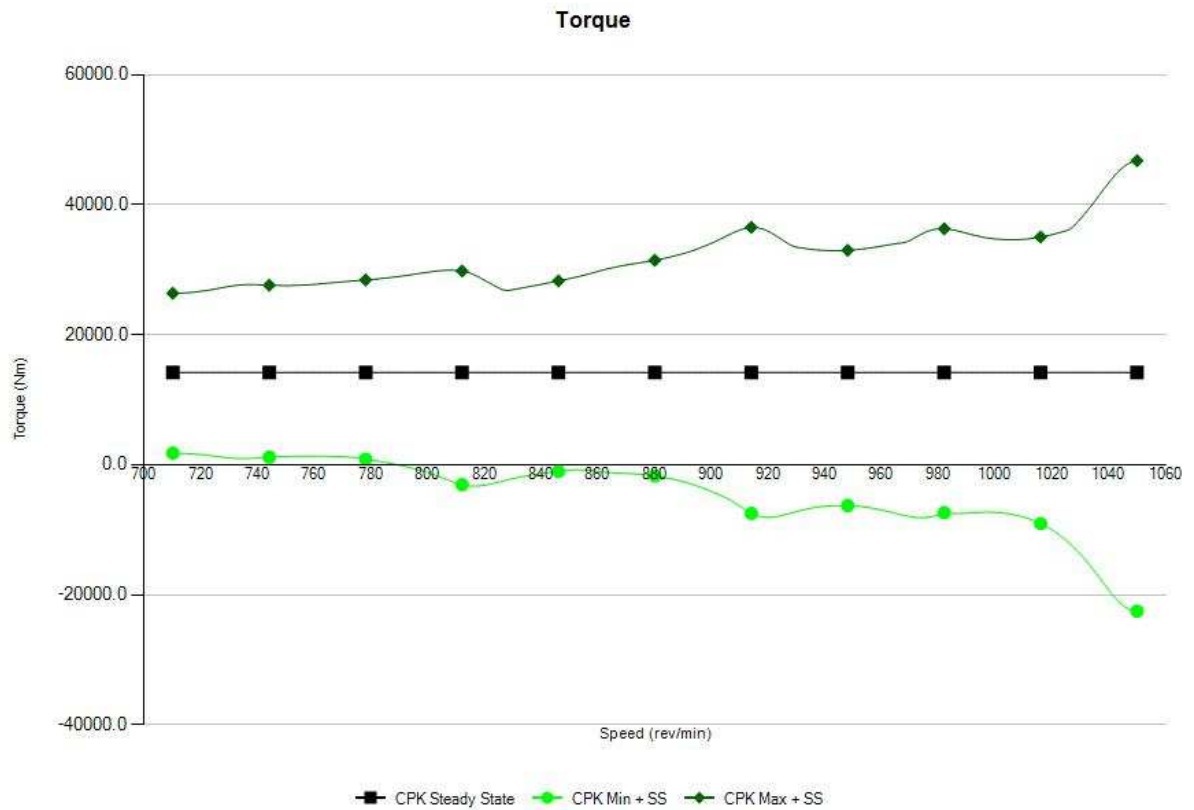
Component	Max Amplitude (deg)
HSNG - Order 0.500	0.039
HSNG - Order 1.000	0.131
HSNG - Order 1.500	0.125
HSNG - Order 2.000	0.074
HSNG - Order 2.500	0.041
HSNG - Order 3.000	0.044
HSNG - Order 3.500	0.005
HSNG - Order 4.000	0.003
HSNG - Order 4.500	0.030
HSNG - Order 6.000	0.060

Engine Crankshaft Combined Order Vibratory Stress



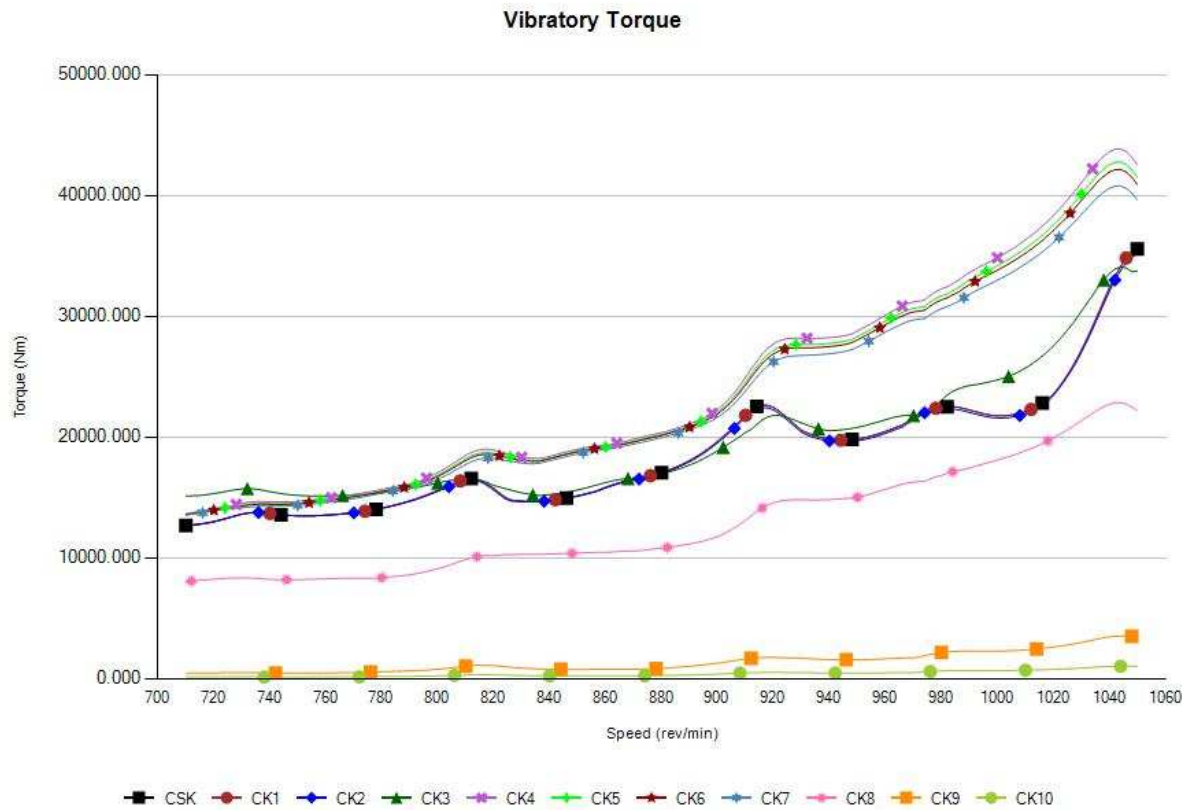
Component	Max Vibratory Stress (MPa)
H-GT	4.864
EK1	17.791
EK2	21.512
EK3	20.485
EK4	24.865
EK5	19.359
EK6	11.528
EK7	7.633

Coupling Combined Order Torque



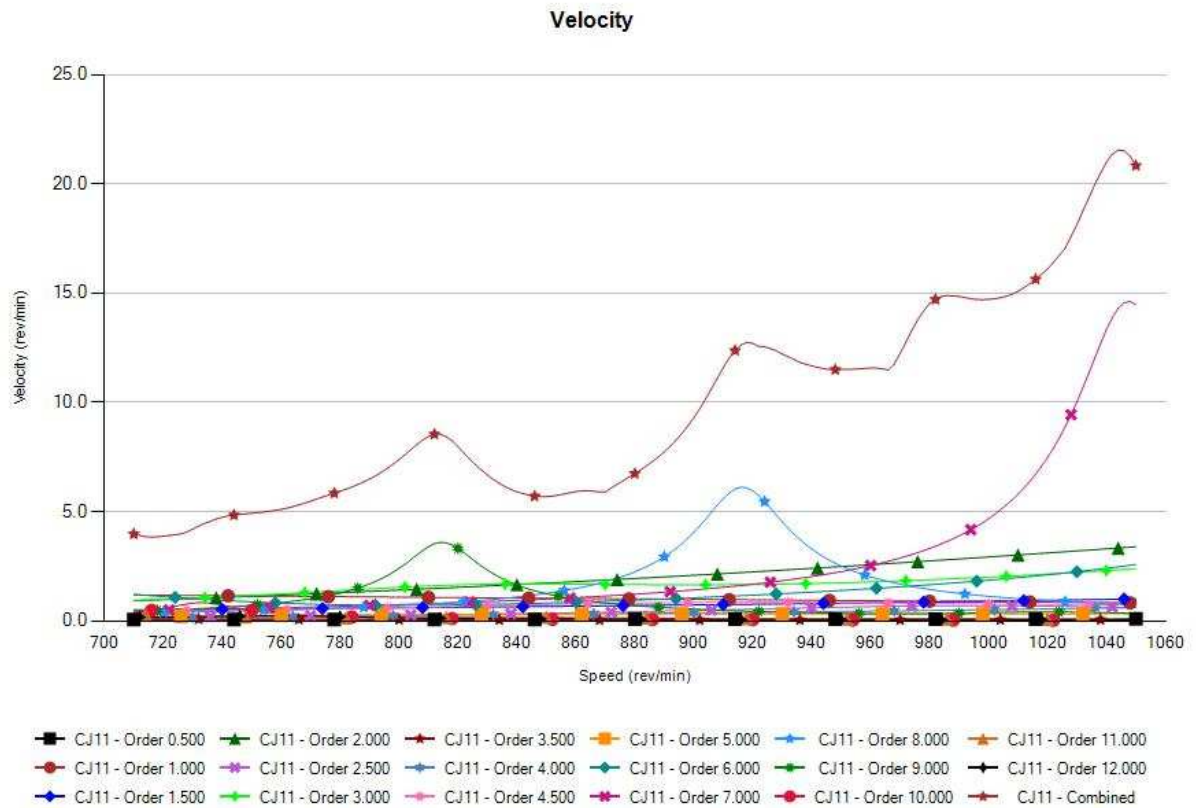
Component	Torque (Nm)
CPK Steady State	14165
CPK Min + SS	-22530
CPK Max + SS	46768

Compressor Shaft Combined Order Vibratory Torque



Component	Max Vibratory Torque (Nm)
CSK	35571
CK1	35524
CK2	35126
CK3	34069
CK4	43860
CK5	42765
CK6	42150
CK7	40791
CK8	22848
CK9	3517
CK10	1022

Compressor Aux End Velocity



Component	Max Velocity (rev/min)
CJ11 - Order 0.500	0.088
CJ11 - Order 1.000	1.190
CJ11 - Order 1.500	1.008
CJ11 - Order 2.000	3.393
CJ11 - Order 2.500	0.698
CJ11 - Order 3.000	2.394
CJ11 - Order 3.500	0.093
CJ11 - Order 4.000	0.613
CJ11 - Order 4.500	0.850
CJ11 - Order 5.000	0.327
CJ11 - Order 6.000	2.583
CJ11 - Order 7.000	14.619
CJ11 - Order 8.000	6.118
CJ11 - Order 9.000	3.594
CJ11 - Order 10.000	0.841
CJ11 - Order 11.000	0.352
CJ11 - Order 12.000	0.237
CJ11 - Combined	21.546

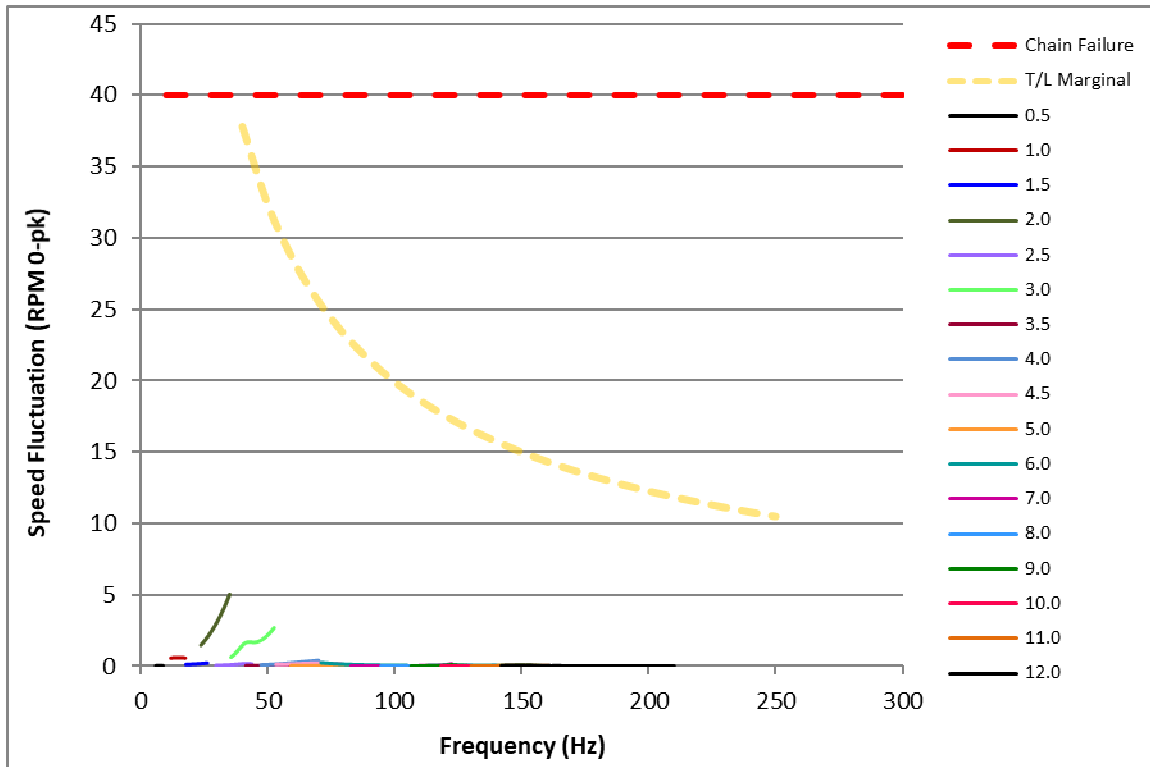
No-Load Analysis

Forced Response Highlights

Engine Firing Normal

Model Symbol	Component	Measured	Units	Order	Predicted Value	Limit	Comments
VDK	Damper	Power Absorbed	kW	Combined	0.267	10	Acceptable
HSNG	Damper Housing	Absolute Amplitude	deg	1.0	0.066	0.50	Acceptable
				3.0	0.062	0.20	Acceptable
EK2	Engine Crankshaft	Vibratory Stress	MPa	Combined	11.554	42.75	Acceptable
CPK	Coupling	Nominal Torque	Nm	Combined	0	158340	Acceptable
		Minimum Torque			-14669	-62318	Acceptable
		Maximum Torque			16074	124749	Acceptable
CSK	Compressor Crankshaft	Vibratory Torque	Nm	Combined	16543	59660	Acceptable
CK4					39132	59660	Acceptable
CJ11	Aux End	Absolute Velocity	RPM	2.0	5.041	40	Acceptable
				Combined	8.908	55	Acceptable

Compressor Aux End Velocity: Predictions vs. Limits



Forced Response Highlights

Speed Range

The torsional response has been analyzed from 710 RPM to 1050 RPM.

Engine Damper Thermal Loads

The predicted damper thermal loads are within the manufacturer's limits.

Engine Front End Amplitudes

The predicted front end amplitudes are within the manufacturer's limits.

Engine Crankshaft Stresses

The predicted engine crankshaft stresses are within the manufacturer's limits.

Coupling Torques

The predicted vibratory torque for the TB Woods FSH 92HT-28 coupling is within the manufacturer's limits.

Compressor Crankshaft Torques

The predicted vibratory torque for the Ariel KBZ/4 compressor is within the manufacturer's limits.

Compressor Auxiliary End Velocity

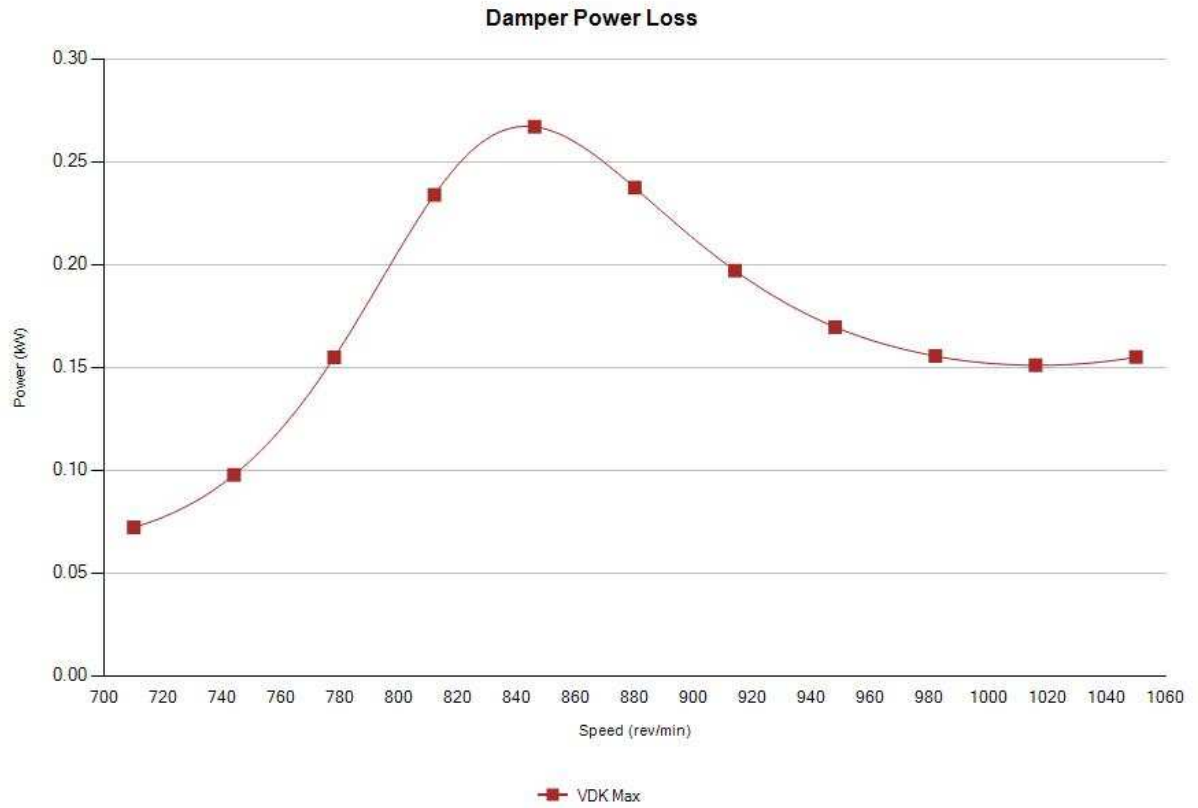
The predicted velocity at the auxiliary end of the Ariel KBZ/4 compressor crankshaft is within the manufacturer's limits.

Compressor Torsional-Lateral Awareness

The torsional-lateral (T/L) curve is intended to reduce high frequency lateral vibration levels by minimizing torsional oscillations. The T/L curve is only a recommendation, not a mechanical limit. Adherence to the T/L curve is not mandated. For more information on torsional-lateral awareness please see Ariel's Engineering Reference in the Appendix.

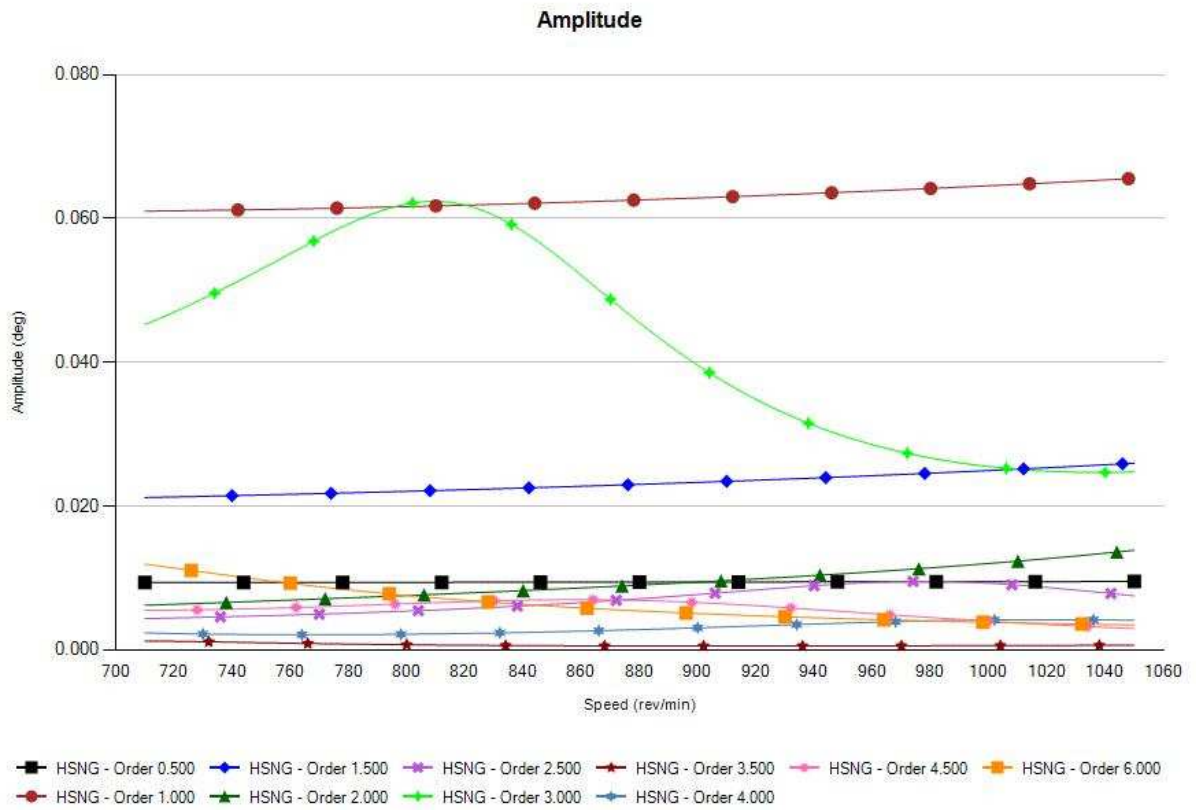
Forced Response Results

Damper Combined Order Thermal Loading



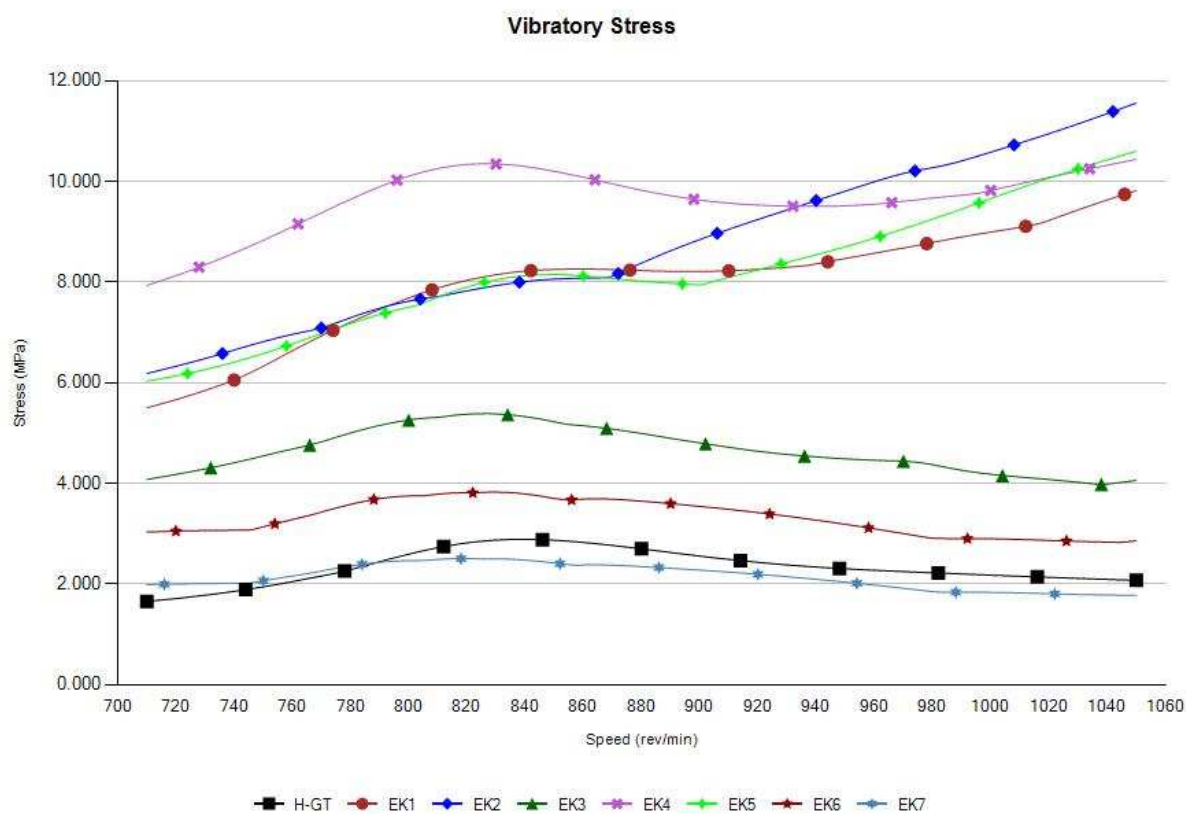
Component	Max Damper Power Loss (kW)
VDK Max	0.267

Front Crank Single Order Amplitude



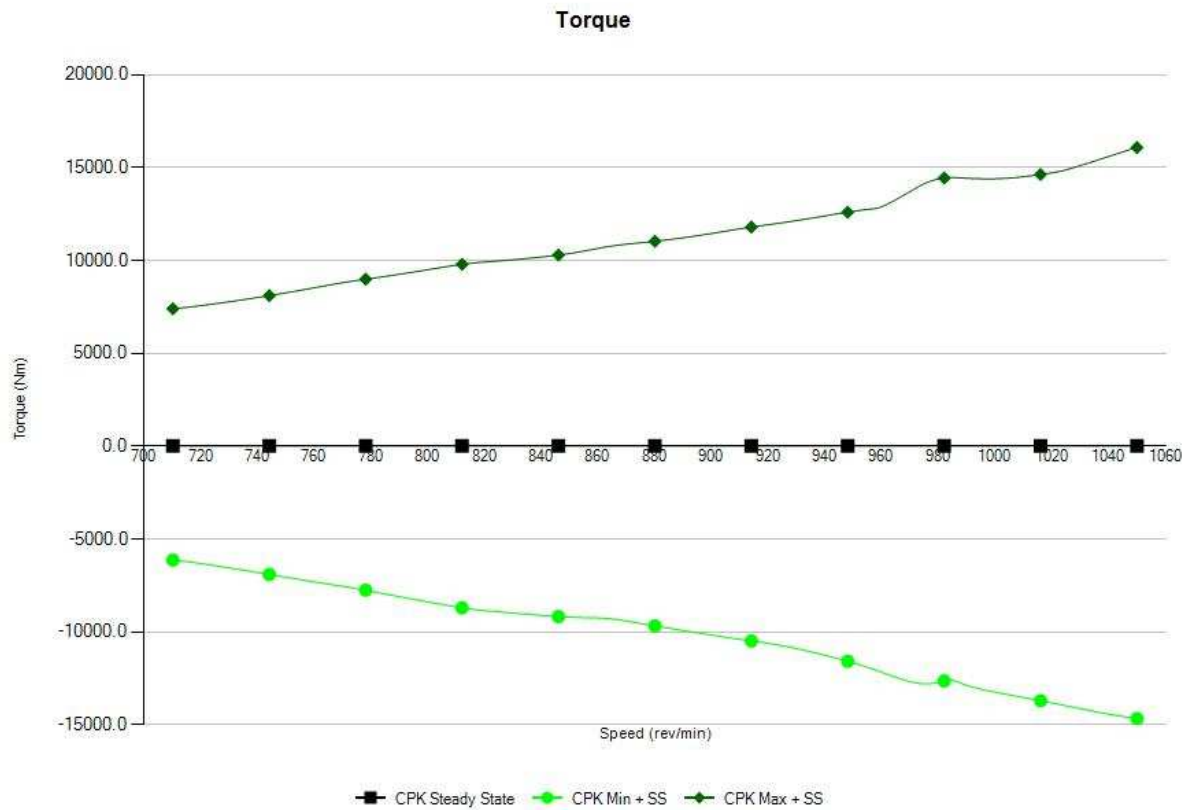
Component	Max Amplitude (deg)
HSNG - Order 0.500	0.009
HSNG - Order 1.000	0.066
HSNG - Order 1.500	0.026
HSNG - Order 2.000	0.014
HSNG - Order 2.500	0.010
HSNG - Order 3.000	0.062
HSNG - Order 3.500	0.001
HSNG - Order 4.000	0.004
HSNG - Order 4.500	0.007
HSNG - Order 6.000	0.012

Engine Crankshaft Combined Order Vibratory Stress



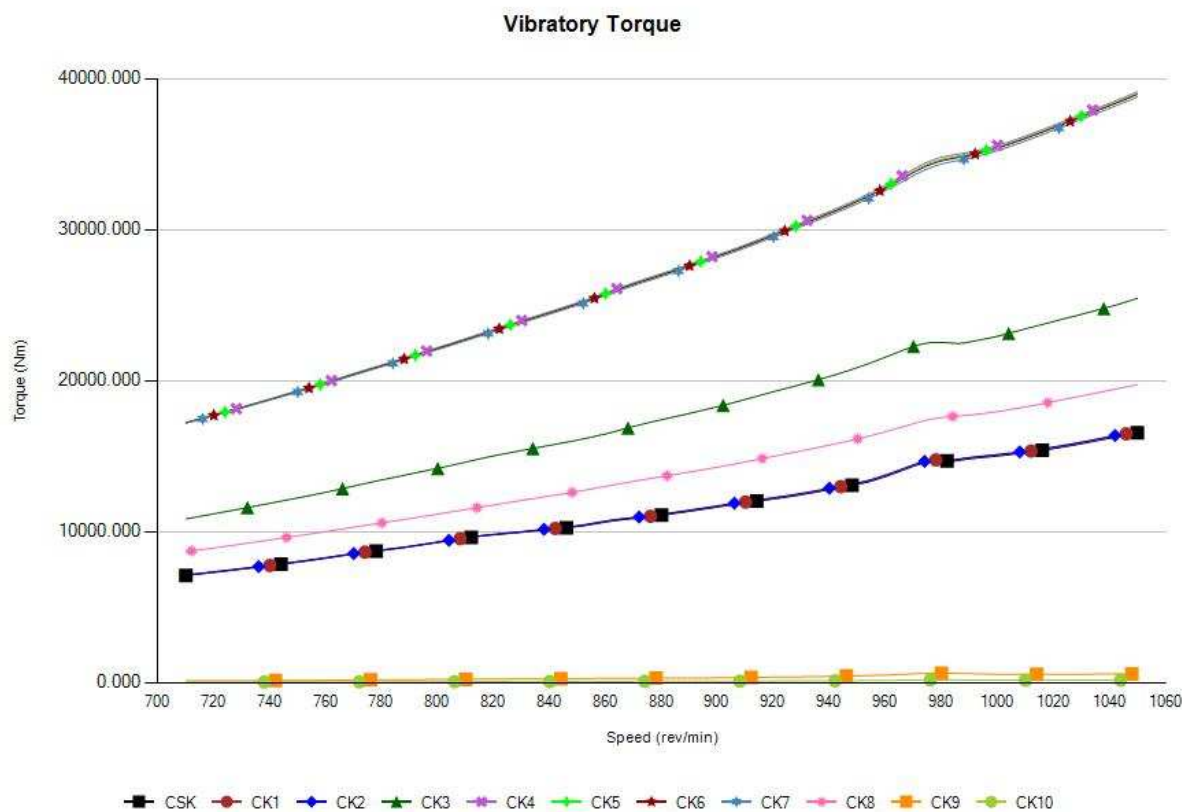
Component	Max Vibratory Stress (MPa)
H-GT	2.887
EK1	9.816
EK2	11.554
EK3	5.384
EK4	10.435
EK5	10.600
EK6	3.824
EK7	2.503

Coupling Combined Order Torque



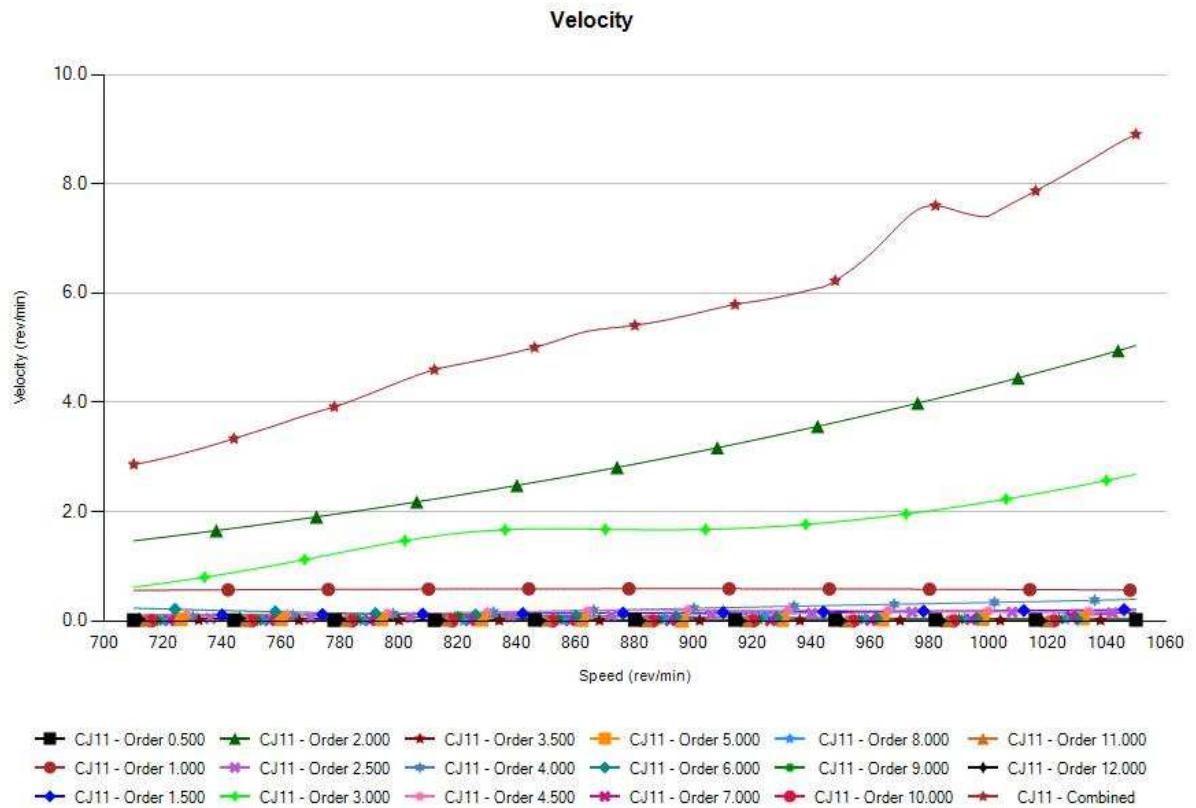
Component	Torque (Nm)
CPK Steady State	0
CPK Min + SS	-14669
CPK Max + SS	16074

Compressor Shaft Combined Order Vibratory Torque



Component	Max Vibratory Torque (Nm)
CSK	16543
CK1	16611
CK2	16651
CK3	25451
CK4	39132
CK5	39029
CK6	38961
CK7	38791
CK8	19741
CK9	622
CK10	179

Compressor Aux End Velocity




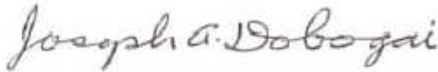

Component	Max Velocity (rev/min)
CJ11 - Order 0.500	0.021
CJ11 - Order 1.000	0.588
CJ11 - Order 1.500	0.208
CJ11 - Order 2.000	5.041
CJ11 - Order 2.500	0.162
CJ11 - Order 3.000	2.685
CJ11 - Order 3.500	0.021
CJ11 - Order 4.000	0.397
CJ11 - Order 4.500	0.196
CJ11 - Order 5.000	0.051
CJ11 - Order 6.000	0.234
CJ11 - Order 7.000	0.148
CJ11 - Order 8.000	0.083
CJ11 - Order 9.000	0.086
CJ11 - Order 10.000	0.005
CJ11 - Order 11.000	0.023
CJ11 - Order 12.000	0.048
CJ11 - Combined	8.908

Notes

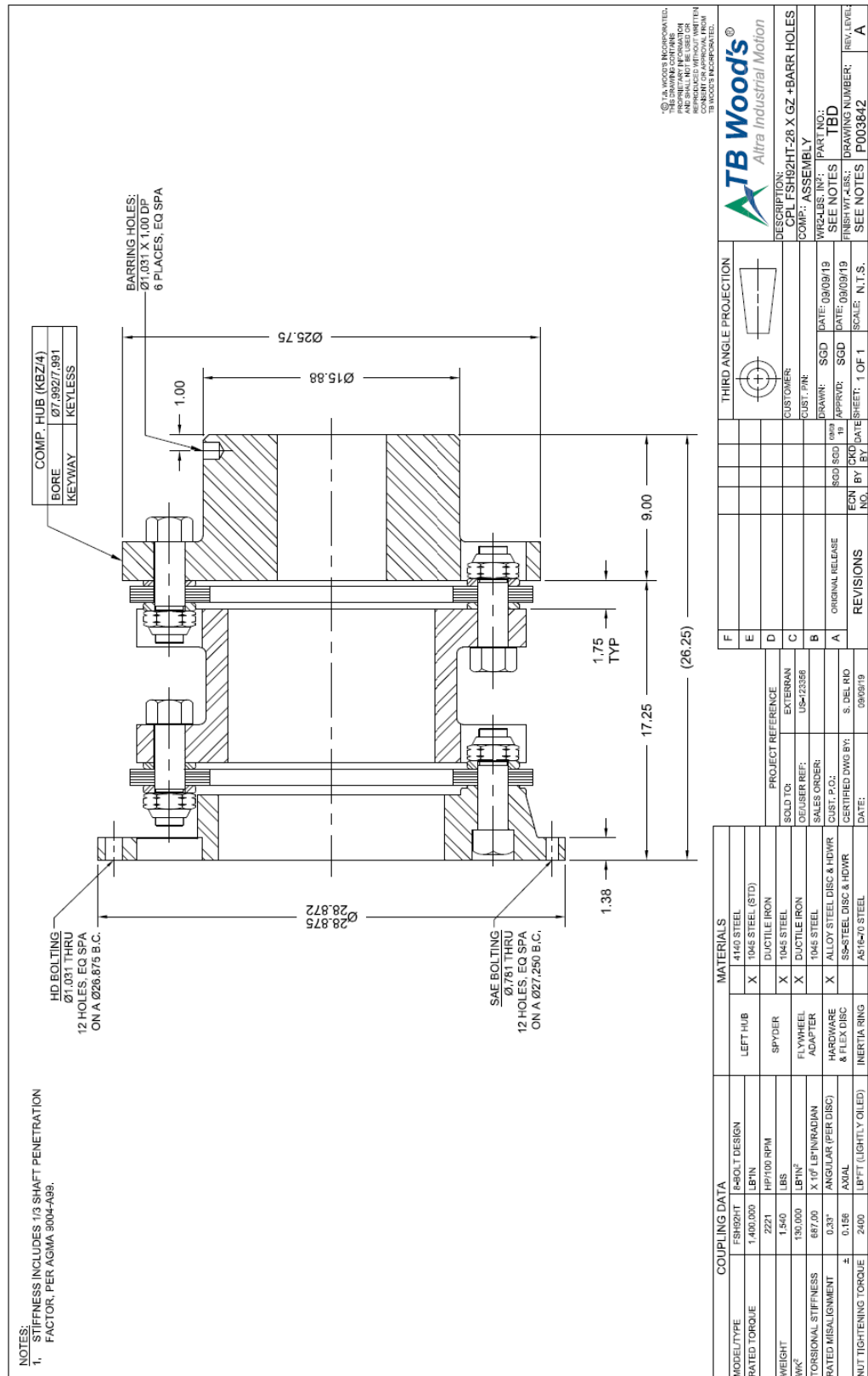
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2. Satisfactory system operation also depends on factors other than torsional vibration. This report should not be used as a guarantee of a successful system installation.
3. Combined order results include single orders 0 through 12. Vibratory amplitudes, stresses and torques are single amplitude, which means they are +/- from zero.
4. System mass-elastic data values are actual values. Mass-elastic values for components driven through a gearbox are not adjusted to engine speed. 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.
5. This report contains information from two different analysis methods that produce complementary results. The natural frequency tables and the resonant speed diagram contain no damping or excitation. The forced response results shown in the report include system damping and excitation.

Appendix

Waukesha Engine Mass Elastic Data

	Waukesha Gas Engines								
	AJR 6629-00								
Mass-Elastic System Data For Exterran Energy Solutions LP Waukesha Engine Model: 12V 275GL⁺ + Engine Order: ATO#: 12V275+-1442692 SO#: 3200005 August 21, 2019 Total Pages: 4									
Contents: <ul style="list-style-type: none"> Mass Elastic Diagram General Torsional Vibration Analysis Data Harmonic Coefficients of Tangential Pressure 									
Written By:	 Joseph A. Dobogai								
Approved By:	 Karl B. Schneider								
<small>Analysis results are based on data believed to be correct and complete as provided by the customer, hardware vendors, or otherwise obtained via INNIO Waukesha Gas Engines Inc. and its affiliates ("INNIO") in-house resources. INNIO is not responsible for verification of data. INNIO disclaims all warranties or guarantees, expressed or implied, by operation of law or otherwise, including but not limited to the warranty of merchantability and fitness for any purpose. INNIO assumes no obligation or liability for the advice given, or results obtained, all such advice being given is accepted by the customer or the recipient of the analysis its own risk.</small>									
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Coupling Drawing



Compressor Mass Elastic Data

Mass Elastic Data			
	Company: Exterran Energy	Customer: Kaego Energy & Technology Corp.	
Project #: AP035401 Rev:7	Inquiry:		
7.7.6.0 Case 7:	Project:		

Frame: KBZ/4 Stroke: 6.75 in Conrod Center Dist: 18.50 in Rotation: Clockwise

Throw #:	1	2	3	4
Cylinder Model:	20-1/8Z:10	11Z:10	20-1/8Z:10	15-7/8Z:10
Cylinder Bore, in	20.125	10.500	20.125	15.875
WEIGHTS, lbs:				
Conrod Large End:	156.67	156.67	156.67	156.67
Conrod Small End:	117.23	117.23	117.23	117.23
Piston & Rod Assembly:	295.18	246.00	295.18	318.90
X-Head:	230.60	287.00	230.60	230.60
X-Head Pin Assembly:	93.10	93.10	93.10	93.10
Balance Nut:	30.00	20.00	40.00	20.00
Recip Weight, lbs	766.11	763.33	776.11	779.83

THROW INERTIA:				
Crankpin, lb-in ² :	7294.450	7294.450	7294.450	7294.450
Conrod Large End, lb-in ² :	1784.578	1784.578	1784.578	1784.578
Recip Weight, lb-in ² :	4399.547	4383.570	4456.974	4478.325
Total, lb-in ² :	13478.575	13462.599	13536.002	13557.354

COUNTERWEIGHTS:			
Unbalanced Mass, lbs	183.87		183.87
Cg, in	1.86		1.86
Dist Crank Center, in	45.563		45.563
Leading Angle	225		45

MASS ELASTIC DATA

Location	Leading Angle	Station (in)	Symbol	Inertia (lb-in ²)	Internal Flywheel (lb-in ²)	Symbol	Stiffness (in-lbs/RAD x 10E6)
Shoulder Stop		0.000	I1	3550.250		K1	574.960
Main #1 CL		12.000	I2	6211.630		K2	487.740
Throw #1 CL	0	22.625	I3	13478.575		K3	488.790
Throw #2 CL	0	32.375	I4	13462.599		K4	487.740
Main #2 CL		43.000	I5	4382.140		K5	857.840
Spreader CL		51.500	I6	2191.890		K6	857.840
Main #3 CL		60.000	I7	4382.140		K7	487.740
Throw #3 CL	90	70.625	I8	13536.002		K8	488.790
Throw #4 CL	90	80.375	I9	13557.354		K9	487.740
Main #4 CL		91.000	I10	6211.630		K10	136.310
Aux Drive End		103.438	I11	2483.170			
Total:				83447.383	0.000		


Crankshaft Material:

Material: ASTM A668 Class DH/AISI 1045 (Forged Carbon Steel)
Yield, psi: 45000
Tensile, psi: 90000

NOTES:

1. Inertia and Stiffness of the drive stub forward of the stop shoulder are not included in this table.

Compressor Mass Elastic Data (Continued)

Mass Elastic Data			
 7.7.6.0	Company:	Exterran Energy	Customer: Kaego Energy & Technology Corp.
	Project #:	AP035401 Rev:7	Inquiry:
	Case 7:		Project:



NOTES:

- Throw Inertias include inertia for the crankshaft, as well as the connecting rod, crosshead, balance nut and piston and rod assembly for that throw.
- Drive stub stiffness must be calculated appropriately depending upon coupling or flanged hub connection.
- Mass elastic data listed does not include the added inertia from any optional flywheels or detuners.
- 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.
- 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).
- For inertia units of lb-in-sec², divide the value of lb-in² by 386.1 in/sec².

Compressor Crankshaft Torque Limit

	ENGINEERING REFERENCE		
	ER-83	ECN: 201801127	VER: 14 - 11-27-2018

Ariel Torsional Limitations and Guidelines

Vibratory Torque Limits

- Vibratory torque limits include appropriate factors for design safety, endurance limit, stress concentrations, and specific shaft diameters.
- Apply vibratory torque limits to combined order peak torque predictions (overall, not individual orders). Overall Peak Levels = (Max-Min)/2.
- Torque limits are for torsional (shear) loading only. Applications with significant bending or axial stresses require additional investigation.
- Contact Ariel before applying these limits to existing equipment. Existing equipment may have different materials or shaft end designs (i.e. keyed vs. non-keyed) than current production.
- These limits apply to units running up to the mean torque at rated horsepower and speed. For applications that exceed this mean torque, contact Ariel to determine acceptability.

TABLE 1 Vibratory Torque Limits [0-Peak], in x lbf (kN·m)

Frame	Throws	Material	Drive End Type	Drive Stub Limit Overall Peak (Max-Min)/2	Journal Limit Overall Peak (Max-Min)/2
STANDARD CRANKSHAFT MATERIAL					
JG, KB 100, JGM:P:N:Q:A	1, 2	1045	Stub	23,200 (2.62)	29,900 (3.38)
JG, JGA	4	1045	Stub	23,700 (2.68)	29,700 (3.38)
JGA	6	1045	Stub	29,400 (3.32)	29,400 (3.32)
JGR:J	2, 4	1045	Stub	62,700 (7.08)	78,900 (8.92)
	6	1045	Stub	78,300 (8.85)	78,300 (8.85)
JGH:E:K:T	2, 4	1045	Stub	150,900 (17.05)	191,500 (21.64)
JGE:K:T	6	4340	Flange	N/A	277,400 (31.34)
KBK:T	2	1045	Stub	150,900 (17.05)	277,400 (31.34)
	4	1045	Stub	254,000 (28.70)	277,400 (31.34)
	6	1045	Stub	277,400 (31.34)	277,400 (31.34)
JGC:D:F	2, 4	1045	Stub	318,100 (35.94)	396,800 (44.83)
	6	4340	Stub	575,000 (64.97)	575,000 (64.97)
KBZ:U, JGZ:U	2	1045	Stub	430,800 (48.67)	530,400 (59.93)
	4	1045	Stub	528,000 (59.66)	528,000 (59.66)
	6	4340	Stub	765,200 (86.46)	765,200 (86.46)
KBB:V, JGB:V	4, 6	4340	Flange	N/A	1,272,000 (143.72)

Compressor Crankshaft Auxiliary End Limits

Frame	Throws	Material	Drive End Type	Drive Stub Limit Overall Peak (Max-Min)/2	Journal Limit Overall Peak (Max-Min)/2
ALTERNATE CRANKSHAFT MATERIAL					
JGJ	4	4340	Stub	94,800 (10.71)	118,800 (13.42)
	6	4340	Stub	118,300 (13.37)	118,300 (13.37)
JGE:K:T	2, 4	4340	Stub	228,900 (25.86)	288,500 (32.60)
JGC:D	2, 4	4340	Stub	481,600 (54.41)	597,700 (67.53)
KBZ:U, JGZ:U	2	4340	Stub	647,600 (73.17)	796,300 (89.97)
	4	4340	Stub	794,700 (89.79)	794,800 (89.80)

Auxiliary End Mechanical Limits in Velocity (rpm 0-Peak)

Velocity limits apply to individual harmonics up to and including the 9th order. Large machines have different limits based on a single or dual chain design. Small, high speed machines are of single chain design, but utilize the higher limit.

Note: Harmonics over the 9th order are omitted because the applied velocity limit becomes overly conservative (for mechanical reliability) at high frequencies.

Combined overall velocity limits are provided to prevent high amplitudes when multiple resonances combine at common speeds.

Maximum angular acceleration limits (Rad /s², 0-Peak) are provided in [TABLE 6](#) for the available flywheels that can be installed on the auxiliary end of crankshafts. The angular acceleration limits apply to combined order peak predictions (overall, not individual orders). Overall Peak Levels = (Max-Min)/2.

Auxiliary End Torsional Amplitude Limits (RPM 0-PK)

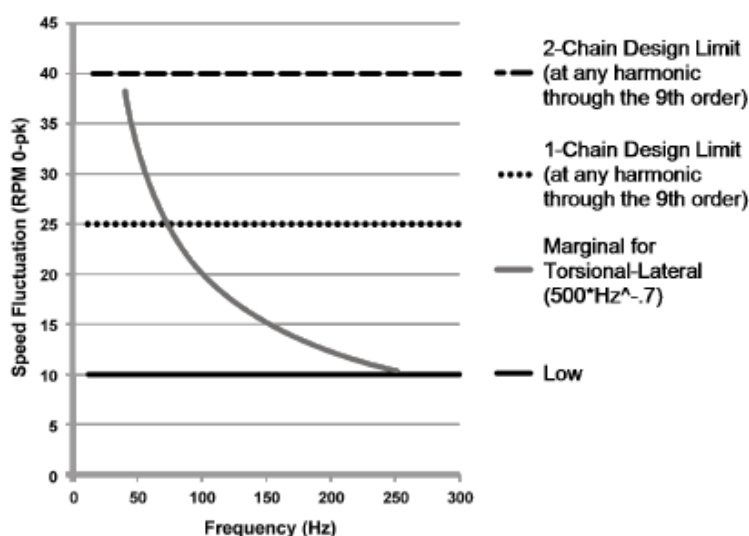


TABLE 2 Overall Auxiliary End Velocity Limits [0-Peak], RPM

Frame	Throws	Chain Config.	Order Summation Velocity Limit Overall Peak (Max-Min)/2	Individual Order Velocity Limit (Peak at any Harmonic through the 9 th Order)
JG, KB100, JGM:P:N:Q:A:R:J	All	Single	55	40
JGH:E:K:T	2, 4	Single	40	25
JGE:K:T	6	Dual	55	40
KBK:T	All	Dual	55	40
JGC:D:F	2, 4	Single	40	25
JGC:D:F	6	Dual ^a	55	40
KBZ:U:B:V, JGZ:U:B:V	All	Dual	55	40

a. JGC:D/6 frames shipped before 9/16/2002 (approximate frame serial number F18137) had single chain designs.

Compressor Torsional-Lateral Awareness

Torsional-Lateral Awareness

The torsional-lateral (T/L) curve is intended to reduce high frequency lateral vibration levels by minimizing torsional oscillations. See the 2012 GMRC paper "Torsional to Lateral Coupling in Reciprocating Compressors" for more information.

The T/L curve is only a recommendation, not a mechanical limit. Adherence to the T/L levels is not mandated. It may be difficult and costly to achieve the low levels dictated by the T/L curve, but doing so will minimize higher frequency shaking forces caused by torsional oscillations. There is a large population of machines that operate above the T/L curve with acceptable reliability as the machines can tolerate moderate vibration.

It is difficult to verify if T/L forces are acceptable. Kinematic algorithms, inclusive of the angular accelerations due to torsional oscillations, can be used to quantify the bearing and crosshead forces. The forces can then be analyzed in traditional mechanical studies; however, mechanical studies do not typically evaluate the high frequencies associated with T/L interactions.

Maximum Allowable Flywheel Weight

TABLE 3 shows the maximum weight F_{max} of flywheel and coupling if the combined center of gravity is located at the end of the crankshaft. To adjust maximum weight if the combined center of gravity of the coupling and flywheel is not located at the end of the crankshaft, use this equation:

$$F_{act} (A + X) \leq F_{max} (A)$$

F_{act} = weight of hubs, flywheel, and half the coupling

F_{max} = maximum weight at the end of the crankshaft (tabulated)

A = moment arm for (F_{max})

X = distance from the end of the crankshaft to the center of gravity of the hub, flywheel, and half the coupling (F_{act}) [positive if away from compressor, negative if towards compressor]

