Cooper-Bessemer Reciprocating Products Division
Cooper Industries, Inc.

Applied Mechanics Report
AM-3423

Torsional Vibration Analysis
KSV-20-T SN-7183-88
SO-0391

Bechtel Power Corporation
for
Arizona Public Service Company
Palo Verde

Prepared by
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Scope

This report covers the results of a torsional vibration analysis of the subject engines which was originally performed in 1978. Attachment 1 to this report covers the results of a torsiograph test which was performed on one of the subject engines in August of 1978.

Attachment 2 covers additional analysis work done in February 1987 to address the reduction in diameter of the #9 crankpin in SN-7187.

Procedure

Resonant Holzer tables were developed using computer program FORTV installed on our Hewlett-Packard 1000 digital computer. Resonant stresses in the engine crankshaft and generator shaft were calculated for all significant multiples of the firing frequency within the operating envelope of the engine. Stimulation torques for the 1/2 through 10th orders of operating speed were calculated from actual indicator cards taken from similar engines. Normal energy balance methods were used to calculate the resonant stresses. The resonant Holzer tables are shown in figures 1 through 3 of this report.

Results

The results of this analysis are:

Mode I - 1459 cpm

Order	RPM	Resonant Stress ± ksi. Crankshaft	Generator Shaft
2	730	2.03	0.55
2-1/2	584	2.55	0.69
3	486	0.41	0.11
3-1/2	417	4.41	1.19
4	365	0	0
4-1/2	324	4.69	1.26
5	292	5.13	1.38
5-1/2	265	2.54	0.68
6	243	0.08	---
6-1/2	222	0.66	0.18
7	208	0.28	---
7-1/2	195	0.07	---
8	182	0.20	---
8-1/2	172	0.10	---
9	162	0.03	---
9-1/2	154	0.34	---
10	146	1.27	0.34

[illegible]

Mode II - 4097 cpm

5-1/2	745	3.16	1.41
6	683	0.18	0.08
6-1/2	630	0.56	0.25
7	585	0.91	0.40
7-1/2	546	0.06	---
8	512	0.64	0.29
8-1/2	482	0.09	---
9	455	0.07	---
9-1/2	431	0.43	0.19
10	410	0.33	0.15

Mode III - 5969 cpm

10	597	0.06	0.09

The stresses in the crankshaft are shown graphically in figure 4 of this report.

Discussion

These resonant stress values are based on steady state operation at 231 BMEP at the corresponding resonant speed. During startup of the engine the full rated torque is not developed until the engine reaches rated speed, and the individual resonant speeds are passed through very quickly, so that full resonant buildup does not occur. Thus the torsional stress values during startup will be well below the values shown above, and the full calculated values will develop only at speeds close to 600 rpm. These stresses are well below the DEMA limit of ±5.0 ksi within ±10 percent of rated speed.

Conclusion

All torsional vibration stresses in these engines will be well below the acceptable limits for all modes of engine operation.

John M. Horne

458.7 CPM 1ST MODE

NO.	WRSQ	INERTIA	AMPL.	TORQUE	STIFFNESS	TWIST
1	251.190	15.184	1.0000	15.18	-12.45	-1.2196
2	133.960	8.098	2.2196	33.16	959.24	.0346
3	254.078	15.359	2.1850	66.72	772.00	.0864
4	253.350	15.315	2.0986	98.86	772.00	.1281
5	254.880	15.407	1.9706	129.22	772.00	.1674
6	254.880	15.407	1.8032	157.00	772.00	.2034
7	255.230	15.428	1.5998	181.68	730.26	.2488
8	255.230	15.428	1.3510	202.53	772.00	.2623
9	254.880	15.407	1.0887	219.30	772.00	.2841
10	254.880	15.407	.8046	231.70	772.00	.3001
11	253.350	15.315	.5045	239.42	772.00	.3101
12	264.870	16.011	.1944	242.53	580.60	.4177
13	2342.000	141.571	-.2234	210.91	1914.00	.1102
14	10460.000	632.293	-.3336	.00		

Figure 1
AM-3423

097.4 CPM 2ND MODE

IO.	WRSQ	INERTIA	AMPL.	TORQUE	STIFFNESS	TWIST
1	251.190	119.807	1.0000	119.81	-12.45	-9.6230
2	133.960	63.893	10.6230	798.54	959.24	.8325
3	254.078	121.184	9.7905	1985.00	772.00	2.5712
4	253.350	120.837	7.2193	2857.36	772.00	3.7012
5	254.880	121.567	3.5181	3285.04	772.00	4.2552
6	254.880	121.567	-.7372	3195.42	772.00	4.1391
7	255.230	121.734	-4.8763	2601.81	730.26	3.5629
8	255.230	121.734	-8.4392	1574.48	772.00	2.0395
9	254.880	121.567	-10.4787	300.62	772.00	.3894
0	254.880	121.567	-10.8681	-1020.57	772.00	-1.3220
1	253.350	120.837	-9.5461	-2174.09	772.00	-2.8162
2	264.870	126.331	-6.7299	-3024.29	580.60	-5.2089
3	2342.000	1117.032	-1.5210	-4723.30	1914.00	-2.4678
4	10460.000	4988.964	.9468	.06		

Figure 2
AM-3423

68.7 CPM 3RD MODE

O.	WRSQ	INERTIA	AMPL.	TORQUE	STIFFNESS	TWIST
1	251.190	254.230	1.0000	254.23	-12.45	-20.4201
2	133.960	135.581	21.4201	3158.39	959.24	3.2926
3	254.078	257.153	18.1275	7819.93	772.00	10.1294
4	253.350	256.416	7.9980	9870.76	772.00	12.7860
5	254.880	257.965	-4.7879	8635.65	772.00	11.1861
6	254.880	257.965	-15.9740	4514.92	772.00	5.8483
7	255.230	258.319	-21.8223	-1122.20	730.26	-1.5367
8	255.230	258.319	-20.2856	-6362.36	772.00	-8.2414
9	254.880	257.965	-12.0442	-9469.35	772.00	-12.2660
0	254.880	257.965	.2218	-9412.13	772.00	-12.1919
1	253.350	256.416	12.4137	-6229.07	772.00	-8.0687
2	264.870	268.076	20.4824	-738.23	580.60	-1.2715
3	2342.000	2370.345	21.7539	50826.03	1914.00	26.5549
4	10460.000	10586.596	-4.8010	.12		

Figure 3

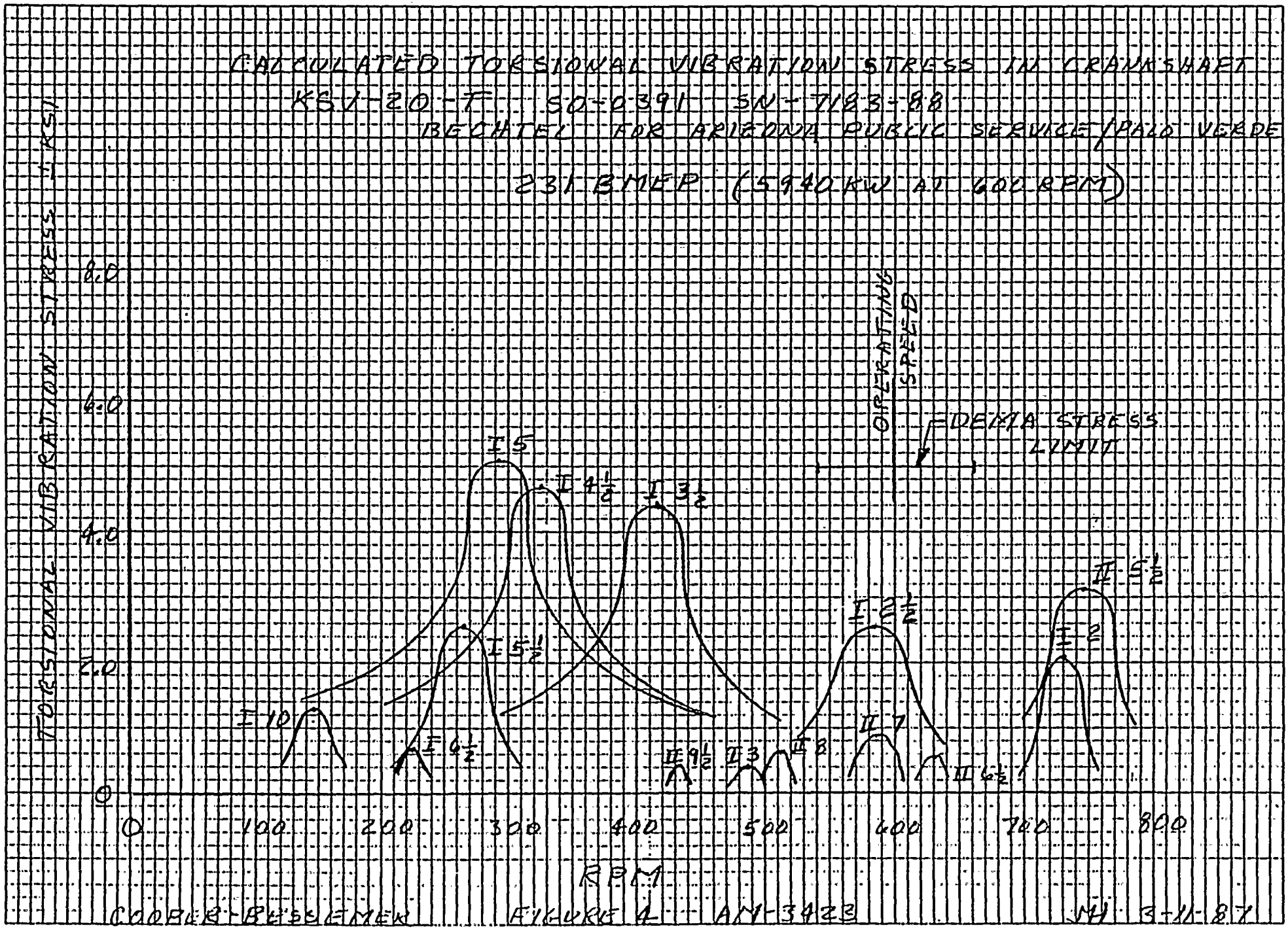
AM-3423

CALCULATED TORSIONAL VIBRATION STRESS IN CRANKSHAFT

KSV-20-T SO-0-391 SN-7183-88

BECHTEL FOR ARIZONA PUBLIC SERVICE-PALO VERDE

231 BMEP (5940 KW AT 600 RPM)



COUPLER-BESSEMER FIGURE 4 AM-3423 JH 3-11-87

ENCLOSURE 3

KSV-20 VECTOR DIAGRAM

KSU-20 Vector Σ

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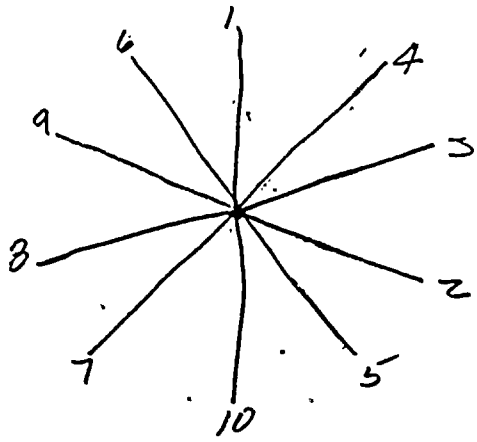

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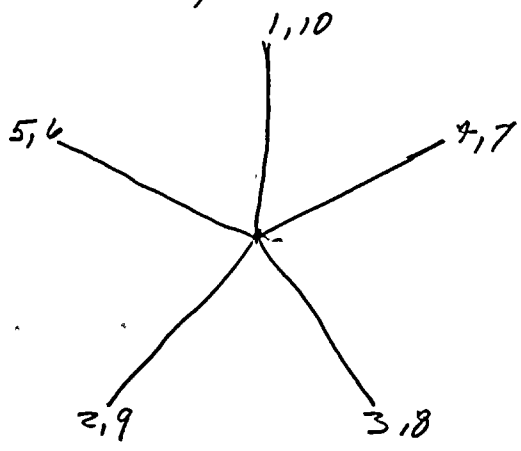

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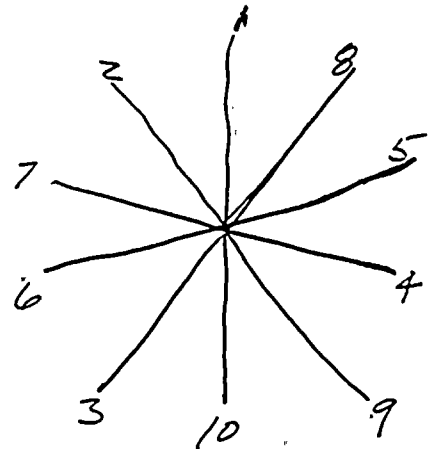

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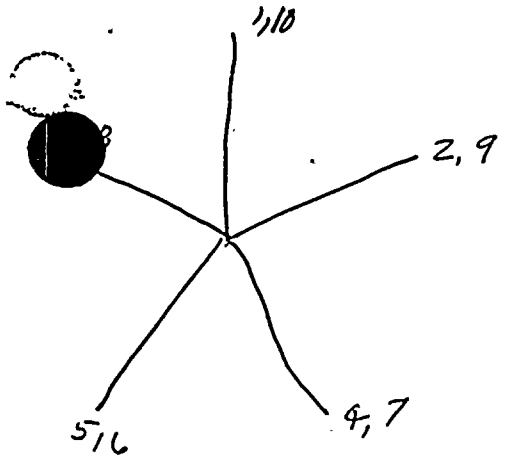

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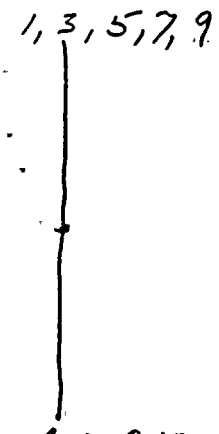

5, 10

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ENCLOSURE 4

UNIT 3
DIESEL GENERATOR "B"
TESTS AND INSPECTIONS
MARCH 13, 1987