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TORSIOGRAPH TEST OF EMERGENCY DIESEL GENERATOR 1DG2 AT COMANCHE PEAK STEAM ELECTRIC STATION

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TDI Diesel Generator Owners Group

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1.0 INTRODUCTION

The purpose of the torsiograph test of the emergency diesel generator was to measure the angular displacements of the forward end of the crankshaft. These displacements were then used in conjunction with a dynamic torsional analysis of the crankshaft to assess the maximum stresses in the crankshaft.

2.0 INSTRUMENTATION

The instrumentation generally consisted of an HBM Torsiograph, Signal Conditioner, Data Tape Recorder, Frequency Analyzer, Oscilloscope, Multimeter, and assorted interconnecting cables. The specific instrumentation used is shown in Table 2.1.

3.0 PROCEDURE

The torsiograph, which was attached to the front end of the crankshaft through an adapter plate supplied by the Catawba plant, was used to measure angular displacements of the crankshaft relative to its mean rotational speed. The angular displacement signal from the signal conditioner was recorded on magnetic tape for further analysis to determine angular displacement components for each order. The torsiograph data was recorded continuously from start-up through coastdown. Tests were conducted at several speeds under no-load conditions, and at several loads at operating speed. The spectrum analyzer was used to verify data integrity by determining harmonic components for each test condition.

The test was carried out in the following four stages:

1. Calibration and instrumentation run-in.
2. Variable speed tests at 0% load.
3. Variable load tests at rated speed.
4. Post test calibration.

3.1 Calibration and Instrumentation Run-in

The torsiograph was mounted on the front end of the crankshaft using a rigid adapter plate. The torsiograph was connected to the signal conditioner and the signal conditioner to the instrumentation recorder with the designated cables. The signal conditioner was also connected to the spectrum analyzer and oscilloscope to monitor the torsiograph signals.

The following steps were completed to calibrate the instrumentation before and after testing:

1. The recording equipment and cabling was calibrated by introducing a known signal into the signal conditioner connection and recording the signal.

2. The calibration signal was verified by playing back the calibration recording.

3. A field calibration of the torsiograph was completed following the manufacturer's instructions [1]. The field calibration signal was recorded.

4. The field calibration signal was played back for verification.

After the calibration procedure was completed, the diesel engine was operated at no load for approximately five to ten minutes while data was recorded. The engine was then shut down while the recorded data was examined to verify the instrumentation and recording system operation.

The test documentation information in Table 3.1 was logged.

3.2 Variable Speed, 0% Load Tests

The engine was operated for two to five minutes at rated speed and no load. The speed was then adjusted using the mechanical governor to operate at speeds between 410 and 470 rpm. The engine was operated at each speed for five to ten minutes while the torsiograph output was recorded. The output speeds and tape footage were recorded (Table 3.2).

3.3 Variable Load, Operating Speed Tests

The engine was brought to operating speed. The load was adjusted successively to operate at the following load conditions for five to ten minutes: 25%, 50%, 75%, 100%, and 110%. The load, current, speed, and tape footage were recorded (Table 3.3).

3.4 Post Test Data Verification and Calibration

Selected data records were played back to verify proper measurement and recording. The calibration procedure outlined above was repeated and the signals recorded.

4.0 RESULTS

4.1 Calibration Data

The pre and post test static calibration data are shown in Tables 4.1 and 4.2. The torsiograph sensitivity was calculated as follows:

$$\text{Torsiograph Sensitivity, } \frac{\text{mV/V}}{\text{degree}} = \frac{\left(\begin{array}{c}\text{Teac}\\ \text{Output, V}\end{array}\right)\left(\begin{array}{c}\text{Amp. Range}\\ \text{Setting,}\end{array} \frac{\text{mV/V}}{\text{10V}}\right)}{(\text{Input, degrees})\left(\begin{array}{c}\text{Tape Deck}\\ \text{Gain, } V_{out}/V_{in}\end{array}\right)}$$

Thus, from Table 4.1 for Channel 1,

$$\text{Torsiograph Sensitivity} = \frac{(1.426)\left(\frac{20}{10}\right)}{6\ (0.10)} = 4.75\ \frac{\text{mV/V}}{\text{degree}} \pm 1.1\%$$

and for Channel 2,

$$\text{Torsiograph Sensitivity} = \frac{(1.429)\left(\frac{20}{10}\right)}{6\ (0.10)} = 4.76\ \frac{\text{mV/V}}{\text{degree}} \pm 0.1\%$$

The sensitivities for the post test calibration were found to be 4.73 $\frac{\text{mV/V}}{\text{degree}}$ for channels 1 and 2.

The multiplication factors used in data reduction were calculated as follows:

$$\begin{array}{c}\text{Vibration}\\ \text{Amplitude}\\ \text{(degrees-pk)}\end{array} = \frac{\left(\begin{array}{c}\text{Tape Deck*}\\ \text{Output, Vpk}\end{array}\right)\left(\begin{array}{c}\text{Amp. Range}\\ \text{Setting,}\end{array}\ \frac{\text{mV/V}}{\text{10Vpk}}\right)}{\left(\begin{array}{c}\text{Torsiograph}\\ \text{Sensitivity,}\end{array}\ \frac{\text{mV/V}}{\text{degree}}\right)\left(\begin{array}{c}\text{Tape Deck}\\ \text{Gain, } V_{out}/V_{in}\end{array}\right)}$$

where Amp. Range Setting = $\frac{\text{20 mV/V}}{\text{10 Vpk}}$

Tape Deck Range Setting =	0.10 V_{out}/V_{in}	Ch. 1
	0.20 V_{out}/V_{in}	Ch. 2 (No Load Tests)
	0.50 V_{out}/V_{in}	Ch. 2 (Variable Load Tests)

Torsiograph Sensitivity

(From pre test static calibration) = 4.75 $\frac{\text{mV/V}}{\text{degree}}$

Thus, for time domain response:

Ch 1.

Input, degrees-pk = (Output, Vpk) $\left(4.21\ \frac{\text{degrees-pk}}{\text{Vpk}}\right)$

Ch 2.

Input, degrees-pk = (Output, Vpk) $\left(2.11\ \frac{\text{degrees-pk}}{\text{Vpk}}\right)$ For No Load Tests

* For output in V_{RMS} (as in spectral plots) multiply by $\sqrt{2}$.

$$\text{Input, degrees-pk} = (\text{Output, Vpk}) \left(0.84 \frac{\text{degrees-pk}}{\text{Vpk}}\right) \quad \text{For Variable Load Tests}$$

and for frequency domain response:

Ch 1.

$$\text{Input, degrees-pk} = (\text{Output, } V_{RMS}) \left(5.95 \frac{\text{degrees-pk}}{V_{RMS}}\right)$$

Ch 2.

$$\text{Input, degrees-pk} = (\text{Output, } V_{RMS}) \left(2.98 \frac{\text{degrees-pk}}{V_{RMS}}\right) \quad \text{For No Load Tests}$$

$$\text{Input, degrees-pk} = (\text{Output, } V_{RMS}) \left(1.19 \frac{\text{degrees-pk}}{V_{RMS}}\right) \quad \text{For Variable Load Tests}$$

4.2 Variable Speed, No-Load Data

The variable speed test was performed to determine the frequency of the first mode of the crankshaft torsional system. The results of this test are shown in Table 4.3. Figure 4.1 shows that the 4th order critical speed is reached at about 432 rpm. Thus, the first natural frequency is 28.8 Hz. This is in good agreement with the Holzer calculation of 28.9 Hz made by Delaval [2].

The amplitude of nominal shear stress may be estimated from the amplitude of free-end vibration by assuming that the shaft is vibrating in its first mode. Under these conditions, the nominal shear stress in the number 8 crankpin journal and the number 9 main journal is 8494 psi per degree of free-end vibration [2]. Thus, the maximum amplitude of nominal shear stress during the variable speed test was 3160 psi.

4.3 Variable Load Data

The variable load test at rated speed was performed to determine the amplitude of vibration and estimate the nominal shear stress as a function of load. The results of this test are shown in Table 4.4. Figure 4.2 shows the amplitude of vibration increases with load to a maximum of 0.59 degrees. The figure also shows the response of the other major orders.

The amplitude of nominal shear stress may be estimated from the amplitude of free-end vibration by assuming that the shaft is vibrating in its first mode. Under these conditions, the nominal shear stress in the number 8 crankpin journal and the number 9 main journal is 8494 psi per degree of free-end vibration [2]. Thus, the amplitude of nominal shear stress at full load and overload are as follows:

	Full Load 7000 kW	Overload 7700 kW	DEMA [3] allowable
Single order ($3\text{-}^1/_2$)	1971 psi	2064 psi	5000 psi
Combined response	4544 psi	5011 psi	7000 psi

4.4 Start-up and Coastdown Data

Transient data was recorded to determine the maximum peak-to-peak free-end response of the crankshaft during fast start and coastdown operation. Data was recorded during two fast starts and two coastdowns. The maximum peak-to-peak free-end response for the fast-starts was found to be 1.64 degrees. The maximum peak-to-peak free-end response for the coastdowns was found to be 0.77 degrees. The amplitude of nominal shear stress may be estimated from the amplitude of free-end vibration by assuming that the shaft is vibrating in its first mode as discussed previously. Thus, the maximum amplitude of nominal shear stress during a fast start was 6965 psi and during a coastdown was 3270 psi.

5.0 CONCLUSIONS

The following conclusions are made:

- the first natural frequency of the torsional system is approximately 28.6 Hz, and is in good agreement with Delaval Holzer calculations [2].
- the stresses are below DEMA's [3] allowables for both single order and combined response at full load and 110% load.

References

1. HBM Operating Manual for Rotary Vibration Transducer, 160.03-1.0-1.0e.

2. Yang, Roland, "Torsional and Lateral Critical Speed, Engine Numbers 76001/20 Delaval-Enterprise Engine Model DSRV-16-4, 7000 kW/9737 BHP at 450 RPM for Texas Utilities Services Inc.," Delaval Engine & Compressor Division, Oakland, California, Revision 1, 10/5/76.

3. Standard Practices for Low and Medium Speed Stationary Diesel and Gas Engines, Diesel Engine Manufacturers Association, 6th ed., 1972.

Table 2.1: EQUIPMENT LIST

Equipment Manufacturer	Equipment Description	Model No.	Serial No.	FaAA ID No.
HBM	Rotary Vibration Transducer	BD 5	701	n/a
HBM	5KHz Carrier Frequency Amp.	KWS 7073	72984	n/a
Teac	Cassette Data Recorder	MR-30	116404	00138
B&K Precision	Sweep/Function Generator	3020	89-11576	00119
B&K Precision	Dual Trace 40MHz Oscilloscope	1540P	11400731	00118
Hewlett Packard	Dual Channel FFT Analyzer	3582A	L039823	
HBM	cable (connect transducer to amplifier)	n/a	n/a	n/a
n/a	cable (connect amplifier to tape deck)	n/a	n/a	n/a
n/a	cable (connect tape deck monitor to Spectrum analyzer or oscilloscope)	n/a	n/a	n/a
Fluke	Digital Multimeter	8060A	8396137	00128
Hewlett Packard	Dual Channel FFT Analyzer	5423A	204CA00345	00124
Hewlett Packard	Plotter	7225B	1206A01534	00122

Table 3.1: TORSIOGRAPH TEST DOCUMENTATION

Job Name:	Comanche Peak Torsiograph Test	Date: 11/28/84
Job Number:	PAO 7596	
Location:	Comanche Peak Steam Electric Station Texas Utilities Generating Company	

Engine Description:

1 DG2
Transamerica Delaval Inc.
DSRV-16-4
Serial No. 76002-2850

Notes:

Test Personnel:

Steve Riess	FaAA
Selim Hammoud	FaAA
Carl Becker	TUGCO/IMPELL

Table 3.2: TORSIOGRAPH VARIABLE SPEED TEST

Test Personnel: Steve Riess, FaAA
Selim Hammoud, FaAA
Carl Becker, TUGCO/IMPELL

Date: 11/28/84

Test Speed (RPM)	Tape I.D.	Tape Footage
410	TUGCO/Comanche	251-277
420	Peak Torsiograph	285-305
425	Test	314-328
430		333-345
440		352-367
445		370-382
450		388-402

Table 3.3: TORSIOGRAPH VARIABLE LOAD TEST

Test Personnel: Steve Riess, FaAA
Selim Hammoud, FaAA
Carl Becker, TUGCO/IMPELL

Date: 11/28/84

Test Speed: 450 rpm

Load (Kw)	Current (Amp)	Tape I.D.	Tape Footage
1750 (25%)	170	TUGCO/Comanche Peak Torsiograph Test	484-501
3500 (50%)	300		509-522
5250 (75%)	425		529-540
7000 (100%)	560		550-566
7700 (110%)	610		576-586

Table 4.1: PRE TEST STATIC CALIBRATION

Static Input (degrees)	Voltage Output (Vdc) Ch. 1*	Voltage Output (Vdc) Ch. 2*	Teac Range Setting (V/V) Ch. 1	Teac Range Setting (V/V) Ch. 2	HBM Signal Cond. Setting (mV/V) / 10 V	HBM Signal Cond. Setting U_B (V)
0	-.002	.006	0.10	0.10	20	5
+3	.713	.722	0.10	0.10	20	5
0	-.001	.006	0.10	0.10	20	5
-3	-.713	-.707	0.10	0.10	20	5
0	-.004	.004	0.10	0.10	20	5
+3	.714	.722	0.10	0.10	20	5
0	-.002	.005	0.10	0.10	20	5
-3	-.712	-.707	0.10	0.10	20	5
0	-.004	.003	0.10	0.10	20	5

Table 4.2: POST TEST STATIC CALIBRATION

Static Input (degrees)	Voltage Output (Vdc) Ch. 1*	Voltage Output (Vdc) Ch. 2*	Teac Range Setting (V/V) Ch. 1	Teac Range Setting (V/V) Ch. 2	HBM Signal Cond. Setting (mV/V) / 10 V	HBM Signal Cond. Setting U_B (V)
0	-.003	.004	0.10	0.10	20	5
+3	.710	.717	0.10	0.10	20	5
0	.001	.005	0.10	0.10	20	5
-3	-.709	-.703	0.10	0.10	20	5
0	-.003	.002	0.10	0.10	20	5
+3	.711	.716	0.10	0.10	20	5
0	.000	.004	0.10	0.10	20	5
-3	-.708	-.703	0.10	0.10	20	5
0	-.004	-.002	0.10	0.10	20	5

* ± .002 Vdc

Table 4.3: VARIABLE SPEED RESPONSE OF 1DG2

	Amplitude of free-end vibration (millidegrees) for given speed (rpm)						
Order	410	419	421	429	439	445	450
0.5	5	5	5	5	5	5	5
1.0	1	1	1	1	1	1	1
1.5	38	38	38	38	39	39	39
2.0	7	9	8	9	12	13	13
2.5	56	57	58	58	60	62	62
3.0	3	3	3	3	3	3	4
3.5	41	46	48	51	60	65	73
4.0	58	105	160	261	139	104	81
4.5	44	31	27	24	20	5	16
5.0	1	1	1	1	2	2	1
5.5	8	7	7	7	5	5	5
6.0	5	6	7	9	4	4	3
Total	170	220	270	372	240	220	230

Table 4.4: VARIABLE LOAD RESPONSE OF 1DG2

	Amplitude of free-end vibration (millidegrees) for given load (kw)					
Order	0	1750	3500	5250	7000	7700
0.5	5	29	30	27	32	29
1.0	1	1	2	3	4	4
1.5	40	68	102	134	172	150
2.0	13	11	8	5	4	3
2.5	63	96	138	180	227	242
3.0	4	2	2	2	5	6
3.5	75	106	146	190	232	243
4.0	77	81	95	111	137	135
4.5	16	21	31	42	52	54
5.0	1	2	1	2	4	4
5.5	5	6	9	12	15	16
6.0	3	5	8	10	12	12
Total	220	265	325	415	535	590

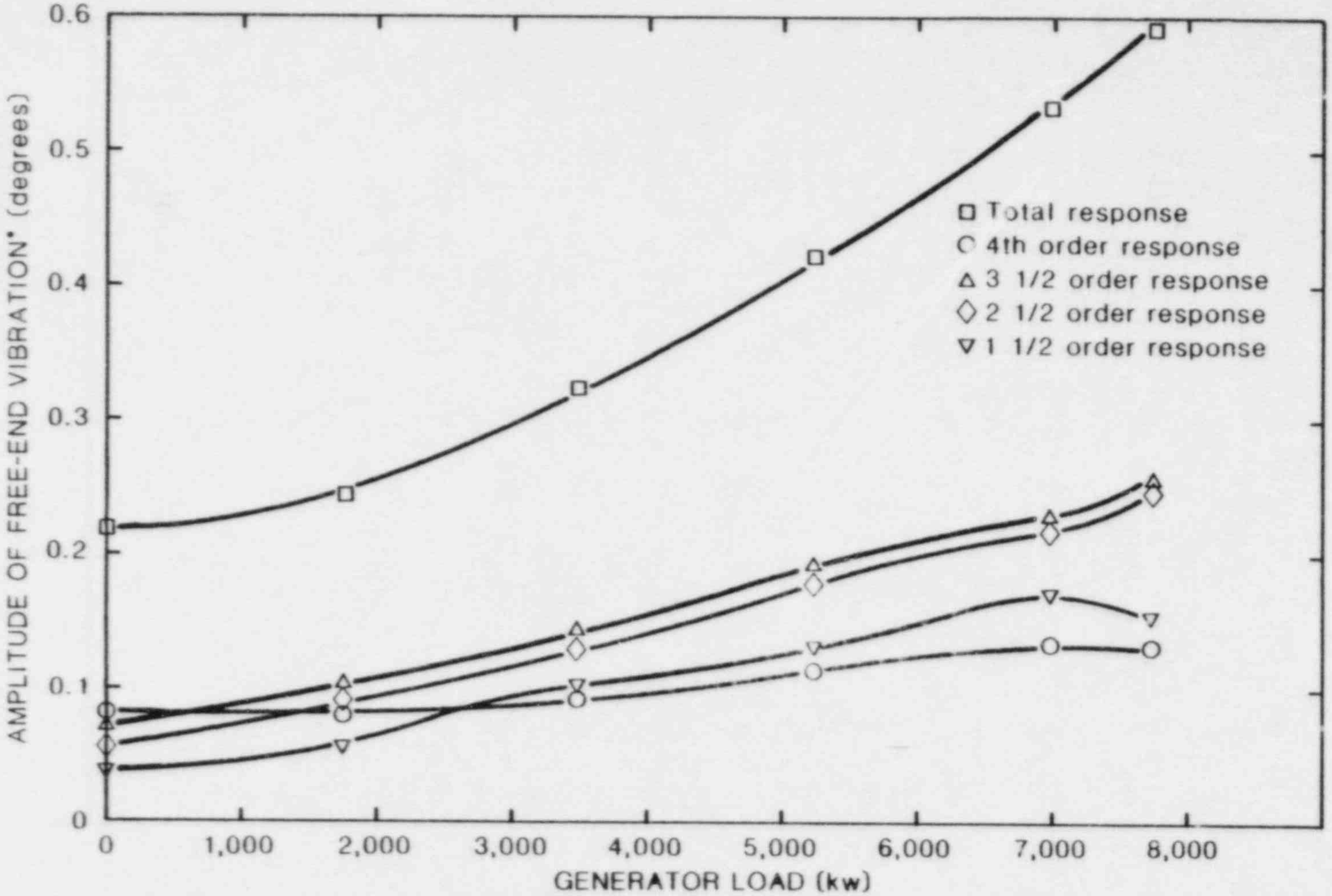

Figure 4-2. Variable load response of 1DG 2.

*Amplitude of nominal shear stress is 8494 psi/degree of free-end vibration, assuming the shaft is vibrating in its first mode.

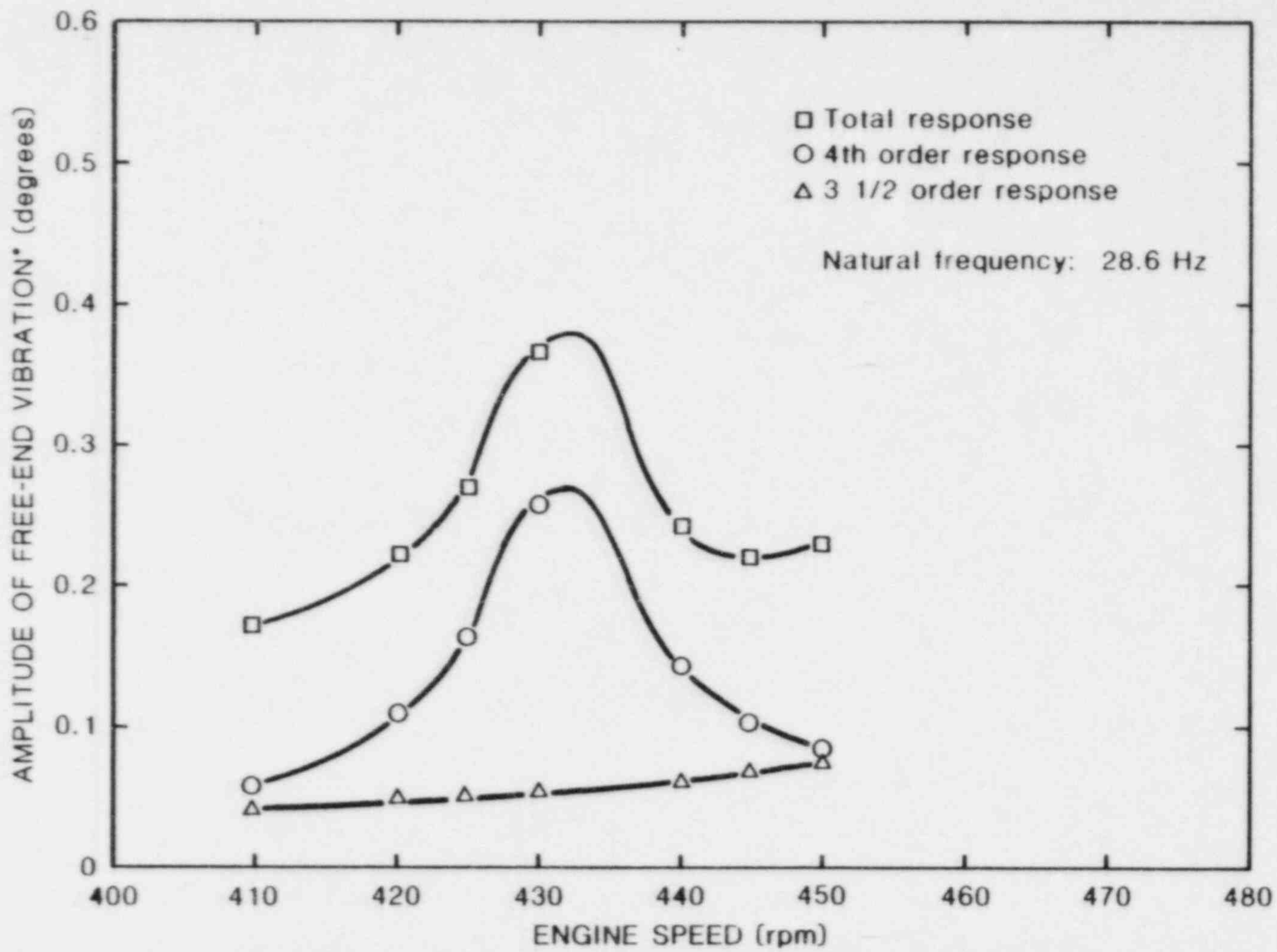

Figure 4-1. Variable speed response of 1DG 2.

*Amplitude of nominal shear stress is 8494 psi/degree of free-end vibration, assuming the shaft is vibrating in its first mode.

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