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TORSIOGRAPH TEST OF EMERGENCY DIESEL GENERATOR 1A AT CATAWBA NUCLEAR POWER STATION

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Prepared for
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. 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 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 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: 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:

$$\text{Torsiograph Sensitivity, } \frac{\text{mV/V}}{\text{degree}} = \frac{\left(\begin{matrix}\text{Teac}\\ \text{Output, V}\end{matrix}\right)\left(\begin{matrix}\text{Amp. Range}\\ \text{Setting } \frac{\text{mV/V}}{\text{10V}}\end{matrix}\right)\left(\begin{matrix}\text{Teac Range}\\ \text{Setting V/V}\end{matrix}\right)}{\text{Input, degrees}}$$

Thus, from Table 4.1 for Channel 1,

$$\text{Torsiograph Sensitivity} = \frac{(1.180)\left(\frac{50}{10}\right)(5)}{6} = 4.917\ \frac{\text{mV/V}}{\text{degree}} \pm .2\%$$

and for Channel 2,

$$\text{Torsiograph Sensitivity} = \frac{(1.179)\left(\frac{50}{10}\right)(5)}{6} = 4.913\ \frac{\text{mV/V}}{\text{degree}} \pm .2\%$$

The sensitivities for the post test calibration were found to be 4.921 and

4.904 $\frac{\text{mV/V}}{\text{degree}}$ for channels 1 and 2, respectively.

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

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

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

Tape Deck Range Setting = 2 V/V

Thus, for time domain response

$$\text{Input, degrees-pk} = (\text{Output, Vpk}) \left(0.407 \frac{\text{degrees-pk}}{\text{Vpk}}\right)$$

and for frequency domain response

$$\text{Input, degrees-pk} = (\text{Output, } V_{RMS}) \left(0.575 \frac{\text{degrees-pk}}{V_{RMS}}\right)$$

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. The speeds shown in this table are those calculated from the frequency of the 4th order and differ slightly from those shown in Table 3.2. Figure 4.1 shows that the 4th order critical speed is reached at about 429 rpm. Thus, the first natural frequency is 28.6 Hz. This is in good agreement with the Holzer calculation of 28.8 Hz made by Delaval [2]. The damping was established to be approximately 1.3%.

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

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 8452 psi per degree of free-end vibration [2]. Thus, the maximum amplitude of nominal shear stress during the variable speed test was 4649 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 0.60 degrees. The figure also shows the response of the other major orders. While the 1 $^1/_2$, 2 $^1/_2$, and 3 $^1/_2$ order responses increase with increasing load, the 4th order response has an increase followed by a decrease, so that the response of this order is approximately the same at full load as it is at no load.

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 8452 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 7800 kW	DEMA [3] allowable
Single order (3 $^1/_2$)	2079 psi	2172 psi	5000 psi
Combined response	4987 psi	5071 psi	7000 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 75017/20 Delaval-Enterprise Engine Model DSRV-16-4, 7000 kW/9770 BHP at 450 RPM," Delaval Engine & Compressor Division, Oakland, California, October 22, 1975.

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	597	n/a
HBM	5KHz Carrier Frequency Amp.	KWS 73.D8	79372	n/a
Teac	Cassette Data Recorder	MR-30	116404	01459
B&K Precision	Sweep/Function Generator	3020	89-11576	01441
B&K Precision	Dual Trace 40MHz Oscilloscope	1540P	11400731	01440
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	8396136	n/a

Table 3.1: TORSIOGRAPH TEST DOCUMENTATION

Date: 4/3/84

Job Name: Duke Power
Job Number: PAO 7702
Location: Catawba Power Station
Duke Power Co.

Engine Description:
EDG 1A
Transamerica Delaval Inc.
DSRV-16-4
Serial No. 2762.75018

Generator Description:
Synchronous EP Generator, Portec. Inc.
7000 kW
Serial No. 17503519-200

Notes: Tape ID No. 001

Test Personnel:

Steve Riess	FaAA
Paul Johnston	FaAA
Rae McElwee	Duke Power
Dennis Ivey	QA-Duke Power

Table 3.2: TORSIOGRAPH VARIABLE SPEED TEST

Test Personnel: Steve Riess, FaAA
Paul Johnston, FaAA
Dennis Ivey, QA-Duke Power
Rae McElwee, Duke Power

Date: 4/3/84

Test Speed (RPM)*	Tape I.D.	Tape Footage
450 (test-system check)	Duke Power #001	132-159
450-451	#001	159-184
440	#001	184-209
435	#001	209-236
430	#001	236-259
425	#001	259-282
420	#001	282-304
407	#001	304-326
460	#001	326-348
470	#001	348-371

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* All speeds determined by stroboscope synchronized with mark on EDG flywheel.

Table 3.3: TORSIOGRAPH VARIABLE LOAD TEST

Test Personnel: Steve Riess, FaAA
Paul Johnston, FaAA
Rae McElwee, Duke Power
Dennis Ivey, QA-Duke Power

Date: 4/3/84

Test Speed: 450 rpm

Load (Kw)	Current (Amp)	Tape I.D.	Tape Footage
3400 (50%)	490	Duke Power #001	371-395
5200 (75%)	760	#001	395-419
7000 (100%)	1010	#001	419-441
7800 (110%)	1110	#001	441-464

Table 4.1: PRE TEST STATIC CALIBRATION

Static Input (degrees)	Voltage Output (Vdc)		Teac Range Setting (V/V)		HBM Signal Cond. Setting	
	Ch. 1*	Ch. 2*	Ch. 1	Ch. 2	(mV/V) 10 Vp	U_B (V)
+3	.585	.587	5	5	50	5
-3	-.596	-.592	5	5	50	5
+3	.584	.587	5	5	50	5
0	.004	.009	5	5	50	5

Table 4.2: POST TEST STATIC CALIBRATION

Static Input (degrees)	Voltage Output (Vdc)		Teac Range Setting (V/V)		HBM Signal Cond. Setting	
	Ch. 1*	Ch. 2*	Ch. 1	Ch. 2	(mV/V) 10 Vp	U_B (V)
+3	.587	.589	5	5	50	5
-3	-.594	-.588	5	5	50	5
+3	.586	.589	5	5	50	5
0	-.007	-.003	5	5	50	5

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* ± .002 Vdc

Table 4.3: VARIABLE SPEED RESPONSE OF EDG 1A

	Amplitude of free-end vibration (millidegrees) for given speed (rpm)								
Order	**406**	**418**	**422**	**429**	**432**	**440**	**452**	**460**	**471**
0.5	28	22	14	27	25	14	16	16	24
1.0	7	9	7	6	7	6	7	6	8
1.5	41	41	40	40	40	41	41	42	43
2.0	5	6	6	8	9	10	12	12	14
2.5	57	58	58	60	60	61	64	66	68
3.0	1	1	1	1	1	1	2	3	4
3.5	40	44	47	51	54	61	77	95	141
4.0	76	140	236	410	375	171	90	66	51
4.5	48	32	26	24	22	19	15	13	11
5.0	2	1	2	2	3	2	2	1	1
5.5	9	8	7	7	6	5	5	5	5
6.0	5	6	8	11	10	4	3	3	3
Total	210	260	400	550	470	310	250	270	280

Table 4.4: VARIABLE LOAD RESPONSE OF EDG 1A

	Amplitude of free-end vibration (millidegrees) for given load (kw)				
Order	0	3400	5200	7000	7800
0.5	16	49	67	49	55
1.0	7	7	6	6	4
1.5	41	102	140	178	195
2.0	12	8	5	4	3
2.5	64	134	183	231	246
3.0	2	3	3	3	4
3.5	77	146	201	246	257
4.0	90	141	143	89	95
4.5	15	29	43	55	56
5.0	2	2	2	2	3
5.5	5	9	13	15	16
6.0	3	7	10	11	12
Total	250	410	520	590	600

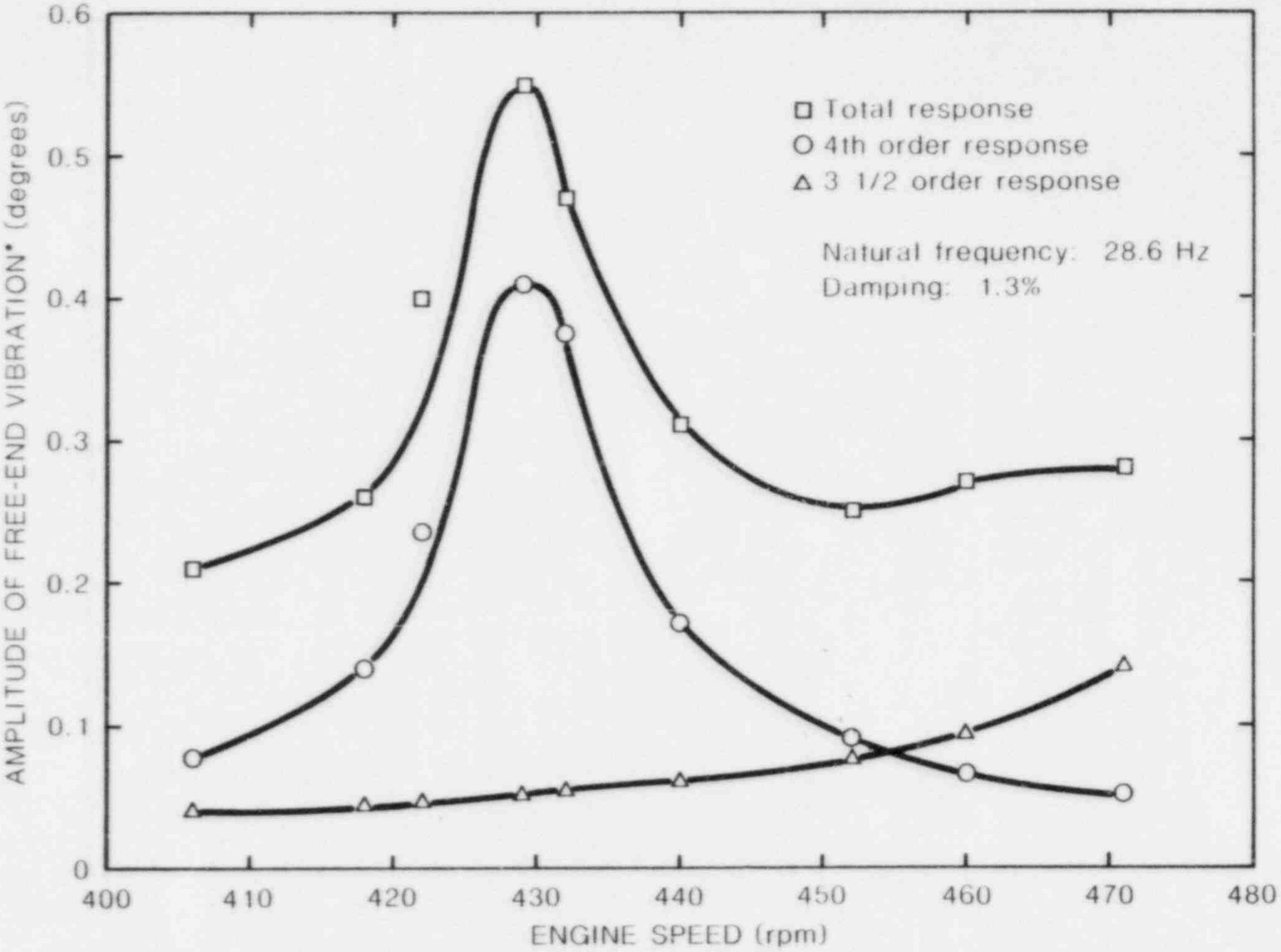

Figure 4-1. Variable speed response of EDG 1A.
*Amplitude of nominal shear stress is 8452 psi/degree of free-end vibration, assuming the shaft is vibrating in its first mode.

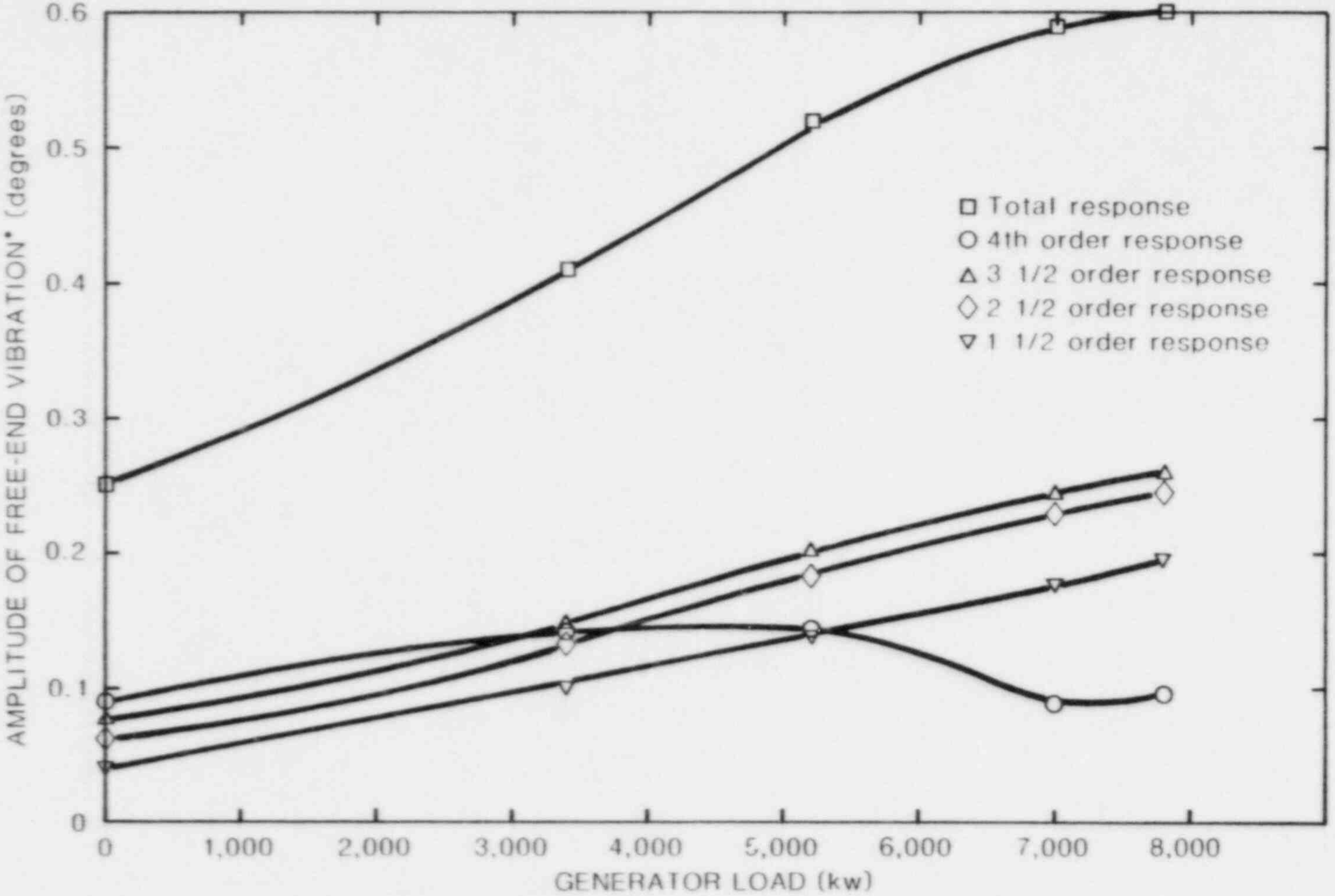

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Figure 4-2. Variable load response of EDG 1A.
*Amplitude of nominal shear stress is 8452 psi/degree of free-end vibration, assuming the shaft is vibrating in its first mode.