Failure Analysis Associates

NONDESTRUCTIVE EXAMINATION PROCEDURE

Title: EDDY-CURRENT INSPECTION PROCEDURE
MAIN-JOURNAL AND CRANK-PIN OIL HOLE

NDE: 11.3
Page 1 of 5
Revision: 2
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Approved by NDE Manager: Duane P. Johnson Date: 8-16-84
Reviewed - NDE Level III: Duane P. Johnson Date: 8-16-84

1.0 PURPOSE AND SCOPE

1.1 To establish calibration, scanning, and evaluation techniques for eddy current examination of the main-journal and crank-pin oil holes of TDI diesels for crack detection.

2.0 REFERENCES

2.1 ASME Section V - Nondestructive Examination

2.2 NDE 2 - Certification and Qualification of NDE Personnel

2.3 NDE 5 - Calibration of NDE Equipment

2.4 NDE 11.1 - Eddy-Current Inspection Procedure - General

3.0 PERSONNEL CERTIFICATION

3.1 Personnel performing eddy current examinations shall be at least Level I ET inspectors. Personnel interpreting data shall be at least Level II ET inspectors. All inspectors shall be certified in accordance with Reference 2.2.

4.2 EQUIPMENT

4.1 The eddy current instruments (ECI) used with this procedure shall be an impedance-plane display instrument such as the MIZ-17 and an impedance-component/time base instrument designed for use with rotating probes such as the FORSTER-DEFECTOSCOP D 2.831. The ECI shall be certified in accordance with Reference 2.3.

4.2 The eddy current probes (ECP) used shall be a FaAA ECP-100R for the oil hole fillet and FaAA ECP SP90-C for the remains of the hole. The inductance of the reference probe used with the MIZ-17 shall be similar to that of the FaAA ECP-100R.

4.3 The ECP fixture for the oil hole fillet will be of a hand held indexing type holding the ECP perpendicular to a tangent to the radius.

5.0 REFERENCE STANDARD

5.1 The reference standard shall be of similar material and geometry to the item being tested. The standard shall contain two (2) Electrical Discharge Machining (EDM) notches 0.020 inches deep, and 0.040 inches long. One notch shall be located on the oil hole fillet and one in the oil hole.

6.0 PROCEDURE QUALIFICATION

6.1 This procedure shall be qualified by its demonstrated ability to detect the reference notch and the calibration curve shown in Exhibit 11.3.1.

7.0 CALIBRATION PROCEDURE OIL HOLE FILLET

7.1 Set impedance plane display ECI frequency to 2.0 ± 0.2 MHz.

7.2 Set the ECI vertical volts per division to 0.5.

7.3 Adjust the horizontal and vertical positioning controls so that the balance point is at (0.0V, 1.0V).

7.4 Balance with test probe on a sound area in the radius of the reference standard.

7.5 Adjust ECI phase until initial lift-off signal is horizontal and to the right.

7.6 Adjust horizontal attenuator so that horizontal saturation is greater that 2.0V and less than -2.0V.

7.7 Adjust ECI gain so that the reference notch gives a negative signal of 2.0V ± 0.2V at the horizontal center of the CRT. Rebalancing will be necessary with each gain adjustment.

7.8 Calibration shall be completed prior to beginning the inspection, following a 10 minute warm-up of the ECI. Calibration checks shall be performed at least once per hour and at the conclusion of the inspection.

7.9 Should the reference notch or crack signal drop to below 80% of the previous calibration level, the system shall be recalibrated and all scans since the previous calibration shall be repeated.

8.0 CALIBRATION PROCEDURE OIL HOLE

8.1 With the rotating probe inserted in a sound area of the reference standard and the impedance-component/time base ECI in the impedance-plane display mode, adjust the phase so that lift-off is in the horizontal direction.

8.2 Switch the ECI to the time-base mode and adjust the Yo control so that the base line is at 0.0. Insert the rotating probe in the area of the reference standard containing the EDM notch and adjust the sensitivity and filter so that the notch signal-to-noise ratio is at least five (5) to one (1) and the peak of the reference notch signal on the cathode ray tube (CRT) is at 100% for level 1,2 or 3 inspections and 50% for level 4 or 5 inspections.

8.3 For level 1 inspections, set alarm threshold at 20%
For level 2 inspections, set alarm threshold at 60%
For level 3 inspections, set alarm threshold at 80%
For level 4 inspections, set alarm threshold at 60%
For level 5 inspections, set alarm threshold at 80%

8.4 Turn on audio and visual alarms.

8.5 Calibrate prior to beginning the inspection, following a 10 minute warm-up of the ECI. Calibration checks shall be performed at least once per hour and at the conclusion of the inspection.

8.6 Should the reference notch signal drop to below 80% of the previous calibration level, the system shall be recalibrated and all scans since the previous calibration shall be repeated.

9.0 EXAMINATION PROCEDURE

9.1 The full extent of the oil hole fillet shall be inspected using an impedance-plane display instrument. One 360 degree circumferential scan shall be made every 6 degrees.

9.2 The oil hole is inspected using the impedance-component/time ECI. There are five (5) possible inspection levels depending upon the engine, oil hole and distance down the oil hole from the journal surface. The level of inspection is specified by the Crankshaft Design Review Task Leader.

Level 1 Inspection - 0.010 x 0.020 inch notch
Level 2 Inspection - 0.015 x 0.030 inch notch
Level 3 Inspection - 0.020 x 0.040 inch notch

Level 4 Inspection - 0.030 x 0.060 inch notch
Level 5 Inspection - 0.040 x 0.080 inch notch

9.3 The forward motion of the rotating oil hole probe and the scan speed of the fillet probe shall not exceed $^1/_2$ inch per second.

9.4 All eddy current indications which exceed the alarm threshold shall be re-examined. The nature of the indication and its maximum amplitude shall be determined.

10.0 RECORDING CRITERIA

10.1 All eddy current crack indications with magnitude greater than the designated percent of full screen height shall be recorded.

Level 1 - 35%
Level 2 - 70%
Level 3 - 100%
Level 4 - 70%
Level 5 - 90%

10.2 In the oil hole fillet region, all crack indications exceeding level 1 shall be recorded unless otherwise specified by the Crankshaft Design Review Task Engineer.

10.3 The length of all recordable indications shall be traced to where the crack indication becomes indistinguishable from the noise. This information shall be noted on Form 11.1.11.

11.0 RECORDS

11.1 Set-up and calibration shall be recorded on Eddy Current Calibration Report (Form 11.1.10).

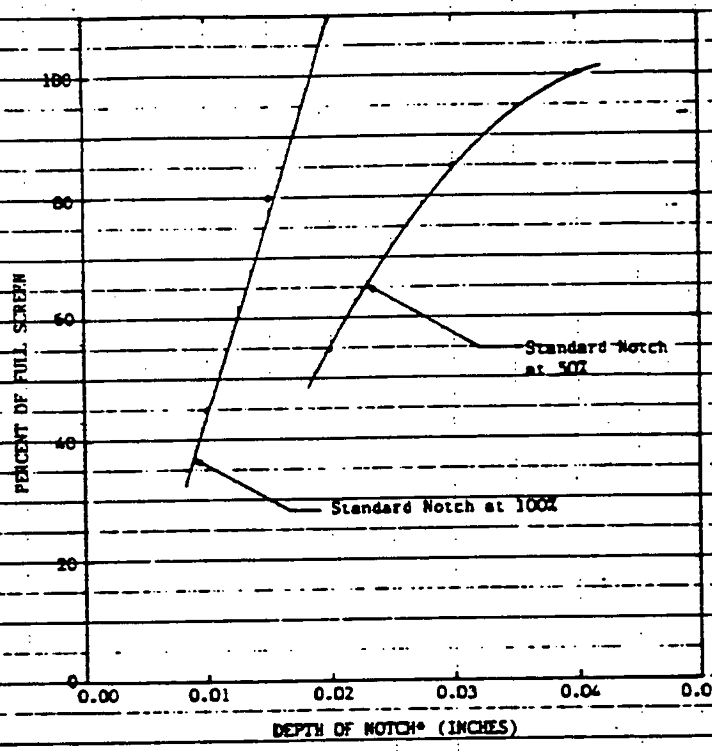
11.2 All relevant indications shall be recorded on Form 11.1.11.

11.3 All records shall be filed according to job number.

12.0 EXHIBITS

12.1 Magnitude of ET signal from diffent size EDM notches.

EXHIBIT 11.3.1
Magnitude of ET signal from different size EDM notches



* Length of Notch is Twice Depth

ATTACHMENT B: 200 RPM IDLE SPEED ANALYSIS

Introduction / Background

After maintenance and rework of the diesel, it is sometimes necessary to perform a 200 rpm idle speed test in which an engine start to 200 rpm is required. During a startup to 200 rpm, the engine passes through the first mode, 10th order critical speed of 119 rpm and approaches the first mode, 5.5 order resonant speed of 217 rpm. To evaluate the stress levels during this test, FaAA's computer programs SHAMS (Shaft Harmonic Analysis by Modal Superposition) and STAMS (Shaft Transient Analysis by Modal Superposition) were utilized. SHAMS was used to perform steady-state analyses to ascertain the effect of dwelling at an engine speed, and STAMS was used to perform transient startup analyses. The computed stress levels were compared to the stresses in the crankshaft during full-load, normal operation to verify that they remain below the full-load steady-state values.

Programs SHAMS and STAMS calculate the torsional natural modes of vibration of an axial system of springs and masses and have been used in previous steady-state and transient analyses of the SONGS Unit 1 crankshafts [1, 2, 3]. The response of the system to gas pressure and reciprocating inertia loads is calculated using modal superposition. The solution sums the response of specified harmonic orders for each mode of vibration, taking into account the correct phase angles for all cylinders. This summation is performed for each inertia and stiffness in the model. Time histories and maximum and minimum values of angular vibration for each inertia and shaft torques for each shaft section are provided. The thirteen degree-of-freedom lumped inertia and torsional spring model used for previous steady-state and transient analyses of the SONGS Unit 1 crankshafts was used for the current work. The inertias and stiffnesses used in the model were computed by TDI [4] and have been verified by FaAA using torsiograph testing [5].

Based upon conversations with SCE plant personnel [1], for a 200 rpm idle speed test, the diesel is started and the engine speed is manually increased by the operator until the engine speed reaches between 150 and 200 rpm. The engine is run at no load between 150 and 200 rpm for approximately 20 minutes. The engine is then shut down. The engine speed is not to exceed 200 rpm for the duration of the test [7]. The duration of the startup is between 20 and 30 seconds. The engine speed versus time data for the startup vary and are not

[1]Howard Schutter, Senior Engineer, SCE; Jorge Valdivia, Engineer, SCE; Joe Blanco, Engineer, SCE.

necessarily repeatable since the speed of the engine is controlled by the operator. The engine speed is not controlled during coastdown.

Steady-State Analyses

Steady-state harmonic analyses at engine speeds between 120 and 200 rpm (in 10 rpm increments) were performed utilizing SHAMS to determine the effect of dwelling at a particular speed. This can occur either during a startup or during constant speed operation at no load. No-load pressure harmonics calculated from a theoretical cold compression curve with a peak pressure of 450 psi (developed previously for the coastdown analysis [2]) were used to simulate no-load operation at a specified speed. The analyses were performed utilizing a damping value of 2.5% of critical damping for each mode. The amplitude of nominal shear stress versus engine speed is plotted for the 11 main journals in Figures B1 and B1A. The results indicate that the stresses are highest near the 119 rpm, 10th order critical speed and at 200 rpm where we are approaching the 217 rpm, 5.5 order critical speed. The maximum nominal torsional stress amplitude for all of the analyses is below the maximum full load steady-state response of 3185 psi at 6000 kW load [2].

The previous analyses were performed using a damping value of 2.5% of critical damping for each mode. This was the value used for previous analyses of the engine at the normal operating speed of 450 rpm [1]. At the normal operating speed, there are no major orders near resonance, so the value of damping used has little effect on the response amplitudes. For the current study, the first mode 5.5 and 10th order resonant speeds are in or near the analysis range. The literature suggests damping values for carbon steels on the order of 1% to 2.5% of critical damping [6]. To determine the effect of the lower damping value on the response of the crankshaft while operating near a resonance, analyses at engine speeds of 120 and 200 rpm were performed utilizing a damping ratio of 1% of critical damping. At an engine speed of 120 rpm, the maximum nominal stress amplitude was 2744 psi, approximately a 60% increase above the previous maximum of 1708 psi. At 200 rpm, the maximum nominal stress amplitude was 2149, approximately a 16% increase above the previous maximum of 1846 psi. At both speeds, the maximum stress amplitudes are below the full load steady-state value of 3185 psi at 6000 kW load.

Startup Analyses

Transient startup analyses were performed using STAMS to evaluate the stress levels during the startup portion of the 200 rpm idle speed test. Since the engine speed is manually increased by the operator until the engine speed reaches between 150 and 200 rpm, and the duration of the startup is between

20 and 30 seconds, the engine speed versus time data for the startup vary and are not necessarily repeatable. Due to the possible variation in the startup duration and final engine speed, the stress levels during the following startup conditions were evaluated: 1) startup to 150 rpm in 20 seconds, 2) startup to 150 rpm in 30 seconds, 3) startup to 200 rpm in 20 seconds, and 4) startup to 200 rpm in 30 seconds. For all start conditions a linear increase in speed was assumed.

The cylinder pressure loading on the crankshaft during the startup conditions was estimated using the same technique used for a previous study of the impact of slow starts on the SONGS Unit 1 crankshafts [3]. The average peak cylinder pressure for the events is estimated based upon the amount of energy required to bring the engine inertia up to speed in the specified duration. A theoretical indicator diagram representing the average cylinder pressure per cycle during the startup event is calculated based upon the average peak pressure and the power per cylinder. For the four startup conditions evaluated, the maximum average peak cylinder pressure was 472 psia. The theoretical indicator diagram with this peak pressure was used to evaluate all startup conditions. This pressure versus crank angle curve for a given cylinder is assumed to be repeated every two crankshaft revolutions. The modal damping value was estimated based upon previous transient analyses and test data for the SONGS Unit 1 crankshafts. A value of 0.6% of critical damping was estimated for the coastdown event where the damping is expected to be the lowest [2]. This value is appropriate for a coastdown and considered slightly conservative for a startup event. For the current study, a value of 0.6% critical damping was used. An initial crankshaft start angle of 0 degrees was used for all startup conditions. This corresponds to cylinder 1 LB at TDC firing.

The results of the four analyses are presented in Figures B2 through B5, and the peak free-end vibration and maximum stress amplitudes are summarized in Table B1 (all occur between cylinders 8 and 9). The results indicate that the linear startup to 150 rpm in 20 seconds produced the highest stress amplitudes. The maximum stress amplitude for this startup event is 2579 psi, which is below the 3185 psi peak stress amplitude during 6000kW normal operation.

Previous studies on parameters that affect the crankshaft vibration amplitudes during a startup indicated that the initial starting position of the crankshaft has an effect on the vibration amplitudes. To quantify the effect of initial starting angle on the crankshaft vibration amplitudes, the stresses in the crankshaft with initial startup angles of 45, 90, 135, 180, 360, and 540 degrees were performed for the startup condition producing the highest stress levels. The results of this study are presented in Table B2 and indicate that the maximum stress amplitude occurs when the initial crankshaft position is between 0 and 180 degrees. The maximum stress amplitude was 2634 psi; and the minimum stress amplitude was 2144 psi, indicating approximately a 22% variation in response as the initial crankshaft position is changed. The maximum stress amplitude is below the 6000kW load steady-state stress levels.

During recent torsiograph testing at SONGS Unit 1, data were collected during a 200 rpm startup. Preliminary data reduction indicates the duration of the startup was approximately 18 to 20 seconds and the average peak pressure for the initial four firing cycles was 460 psig (approximate engine speed at the end of the fourth cycle was 120 rpm). The preliminary test data are consistent with the input used for the analytical model.

Coastdown Review

To evaluate the stress levels in the crankshaft during the 200 rpm idle speed test coastdown, test data and analytical results from coastdown analyses on the SONGS Unit 1 crankshafts were reviewed [2]. Test data were available for coastdowns from no load, 450 rpm engine operation. Corresponding analytical results showed good agreement with the test measurements. For the current study, the maximum stress amplitude when the engine passed through the 10th order critical at 119 rpm was estimated to be 2400 psi [2]. This is well below the 6000 kW load steady-state maximum stress of 3185 psi.

Table B1. Summary of Startup Event Response

Startup Event dur/speed (sec/rpm)	Response Amplitudes Free End Displacement (deg)	Nominal Shear Stress (psi)
20/200	0.315	2550
30/200	0.311	2540
20/150	0.320	2579
30/150	0.307	2548

Table B2. Summary of 20/150 Initial Start Study

Initial Start Angle (deg)	Response Amplitudes Free End Displacement (deg)	Nominal Shear Stress (psi)
0	0.320	2579
45	0.313	2634
90	0.317	2623
135	0.311	2622
180	0.301	2523
360	0.254	2144
540	0.273	2267

SUMMARY OF STEADY STATE NOLOAD ANALYSIS RESULTS

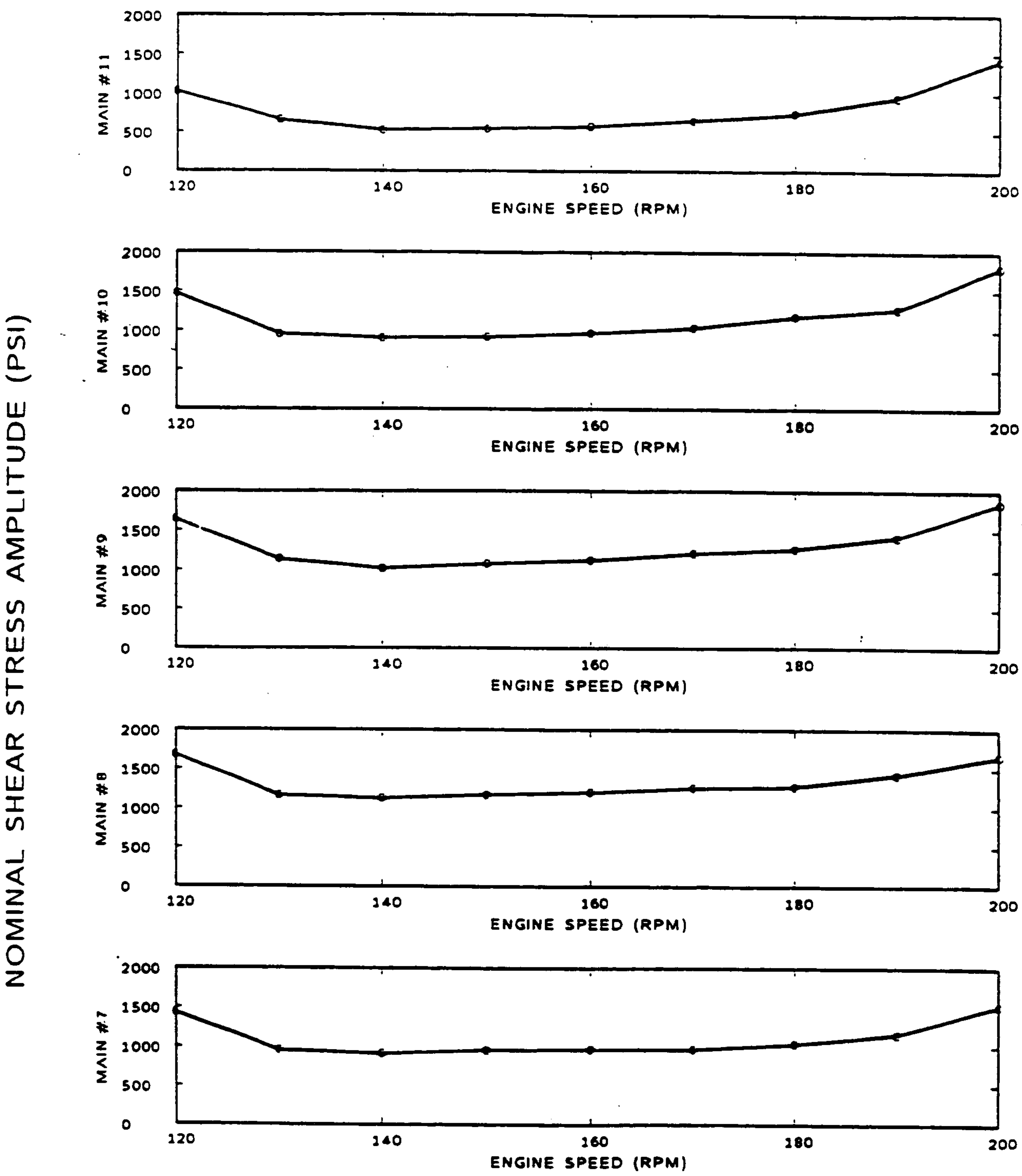


Figure B1. Summary of nominal shear stress versus engine speed for main journals 7 through 11.

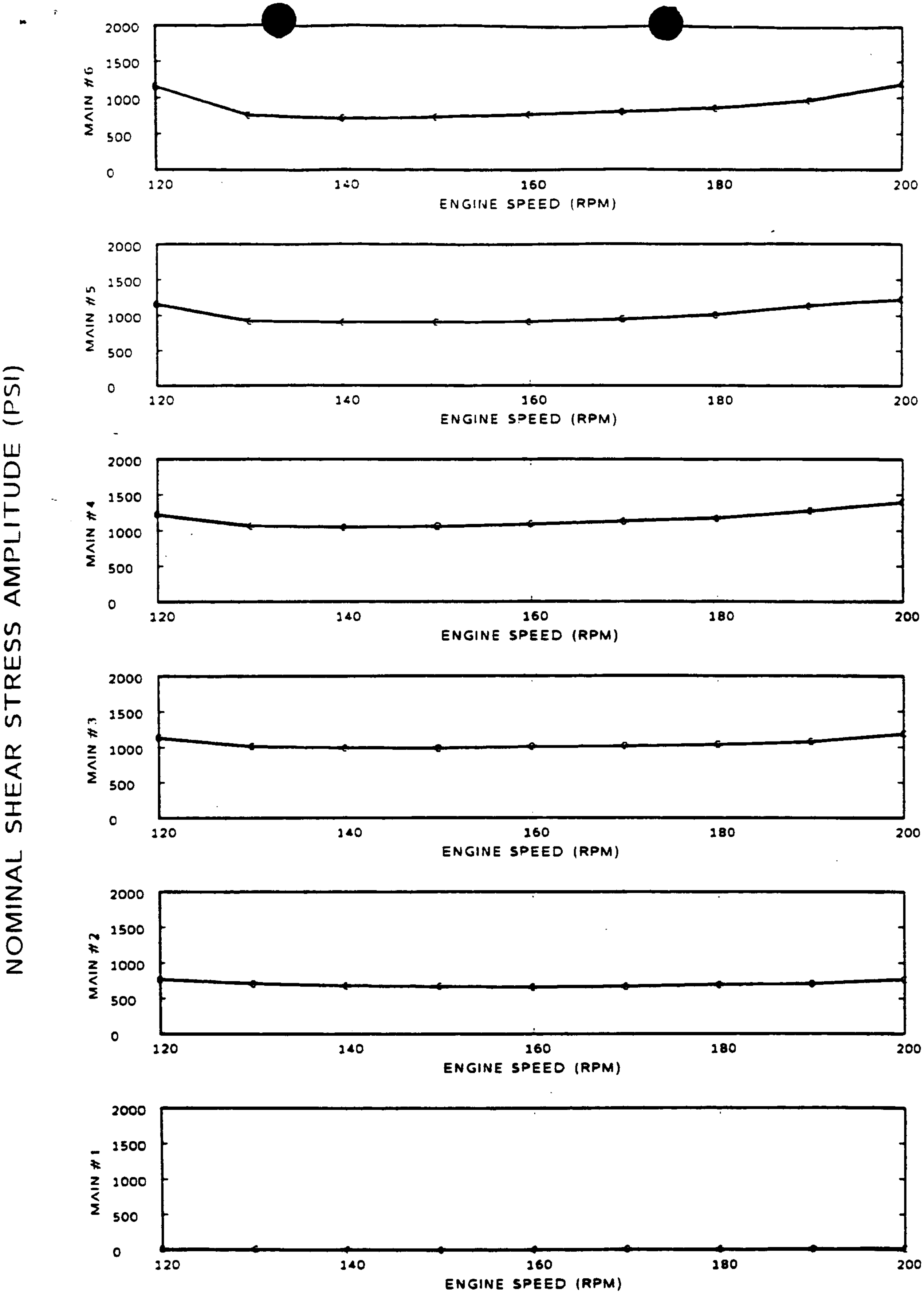
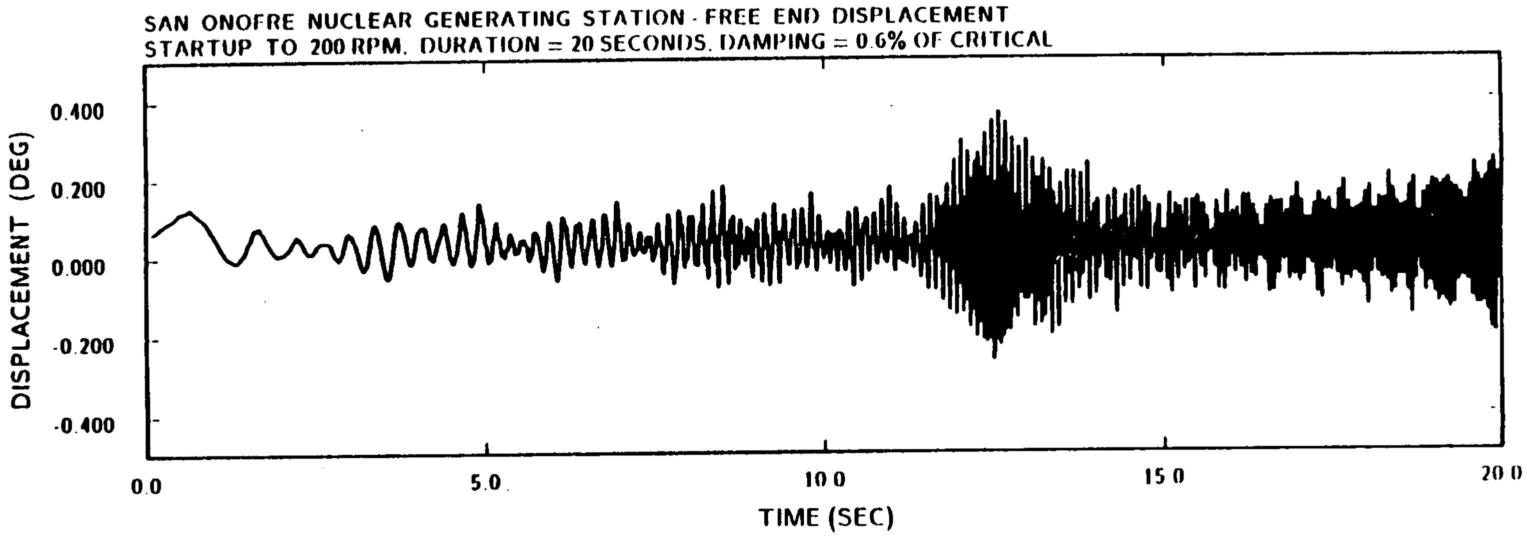


Figure B1A. summary of nominal shear stress versus engine speed for main journals 1 through 6.



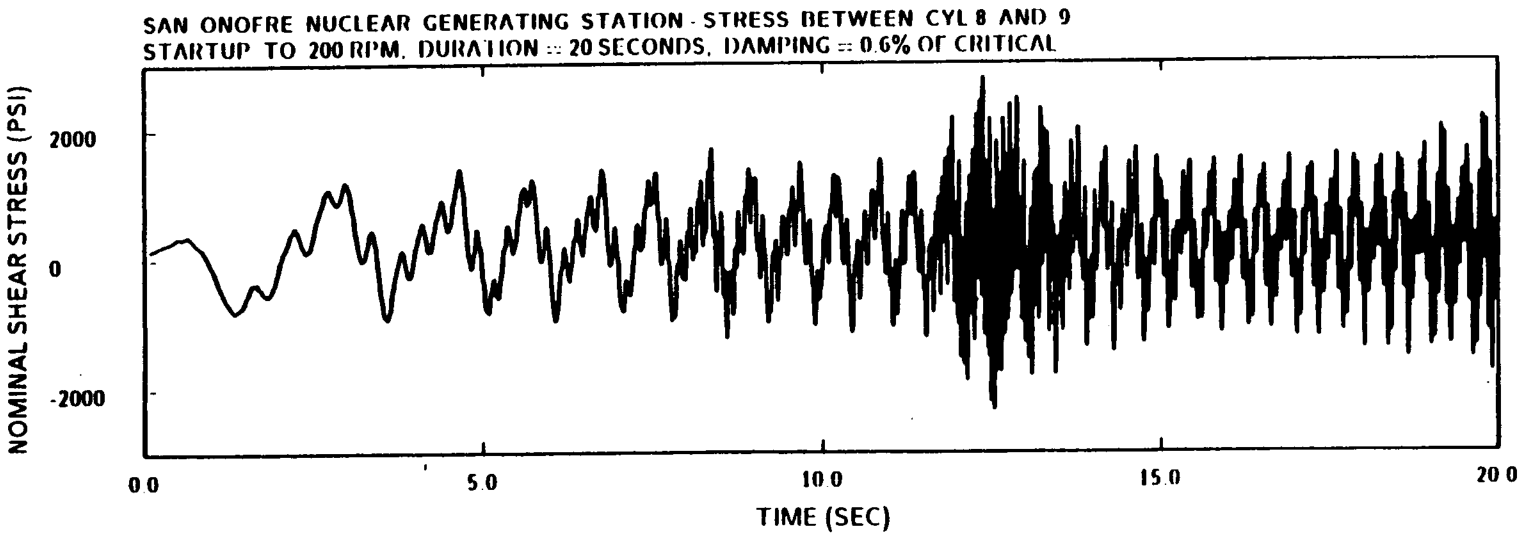


Figure B2. Transient response of crankshaft for 20 second startup to 200 rpm.

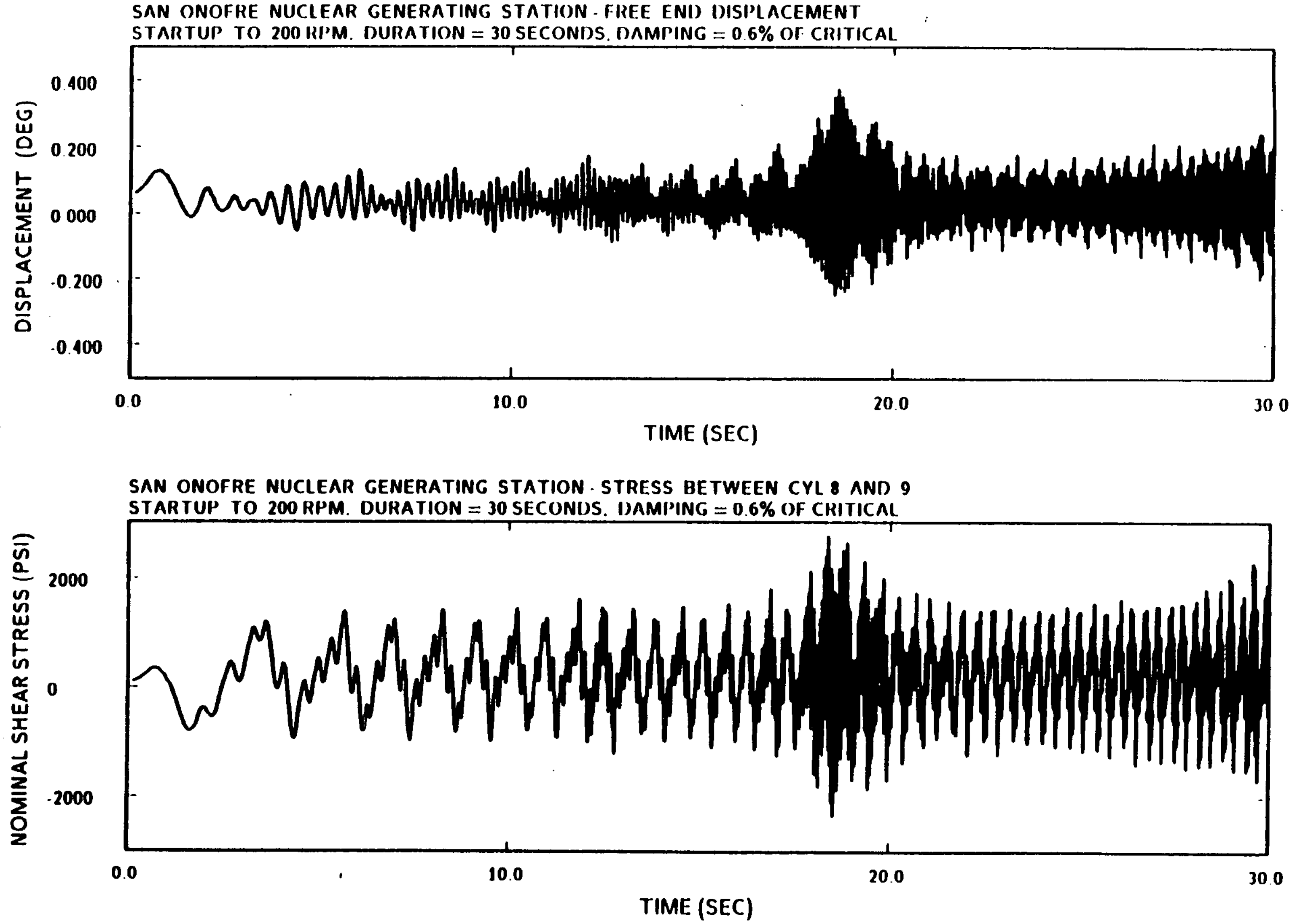


Figure B3. Transient response of crankshaft for 30 second startup to 200 rpm.

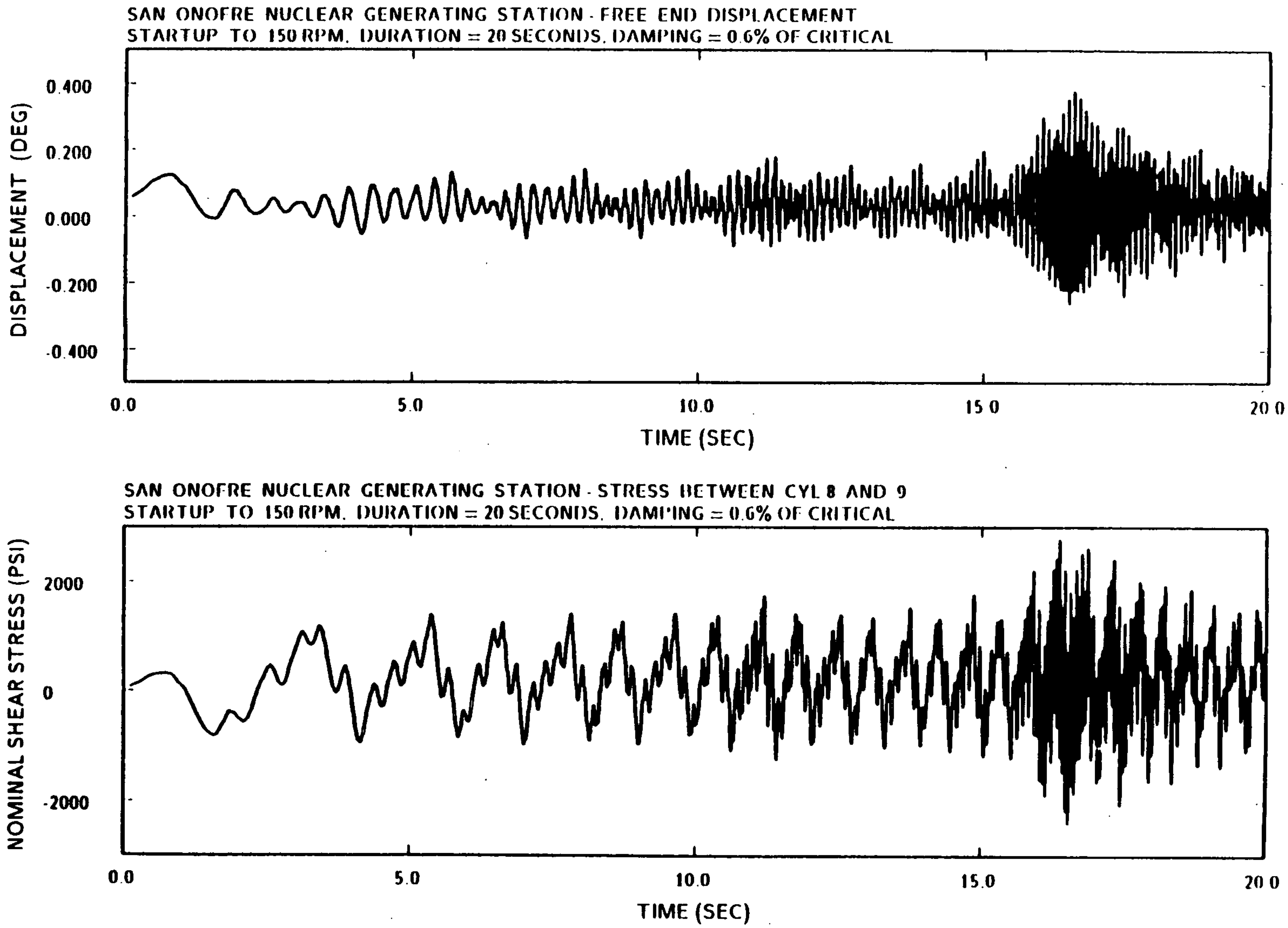


Figure B4. Transient response of crankshaft for 20 second startup to 150 rpm.

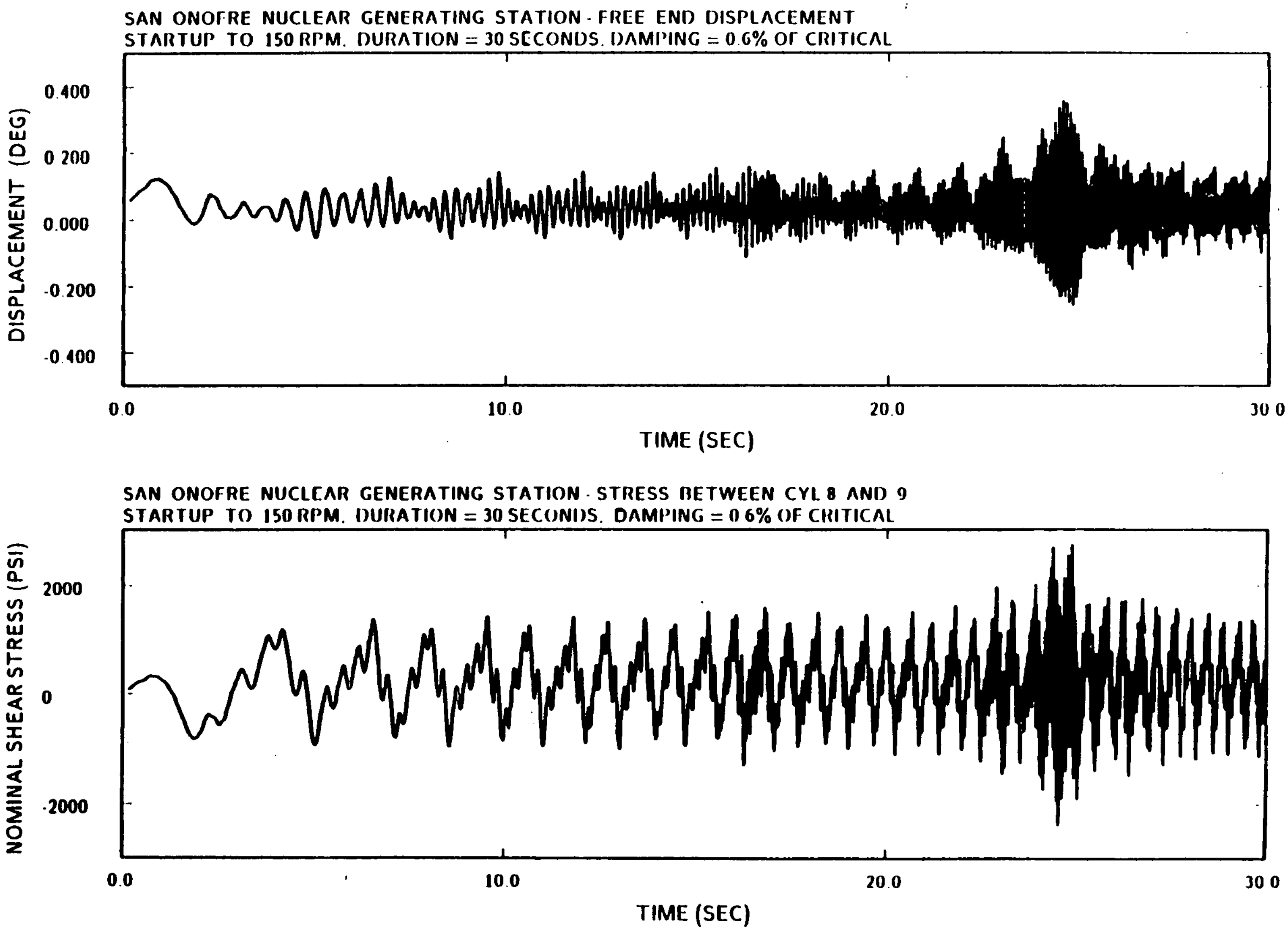


Figure B5. Transient response of crankshaft for 30 second startup to 150 rpm.

References:

1) "Evaluation of Emergency Diesel Generator Crankshafts at Midland and San Onofre Nuclear Generating Stations," Failure Analysis Associates, Report No. FaAA-84-6-54, June 1984.

2) "Evaluation of Transient Conditions on Emergency Diesel Generator Crankshafts at San Onofre Nuclear Generating Station, Unit 1," Failure Analysis Associates, Report No. FaAA-84-12-14, Rev. 1, April 1985, and corresponding support package.

3) "Impact of Slow Starts on the Fatigue Life of Emergency Diesel Generator DSRV-20 Crankshafts at San Onofre Nuclear Generating Station Unit 1," Failure Analysis Associates, Report No. FaAA-PA-86-07-21, July 1986.

4) "Yang, R., "Torsional and Lateral Critical Speed Analysis, Engine Numbers 75040/41 Delaval Enterprise Engine Model DSRV-20-4, 6000KW/8303 BHP at 450 RPM," for Southern California Edison Company, Delaval Engine and Compressor Division, Oakland, California, October 22, 1975.

5) "Steady-State Torsiograph Test of Emergency Diesel Generator #1 at San Onofre Nuclear Generating Station," Failure Analysis Associates, Report No. FaAA-84-10-9, October 1984.

6) Lilly, L. R. C., Diesel Engine Reference Book, Robert Hartnoll Ltd, Great Britain, 1985.

7) San Onofre Nuclear Generating Station, Unit 1, Special Engineering Procedure SO1-SPE-712, January 26, 1990.