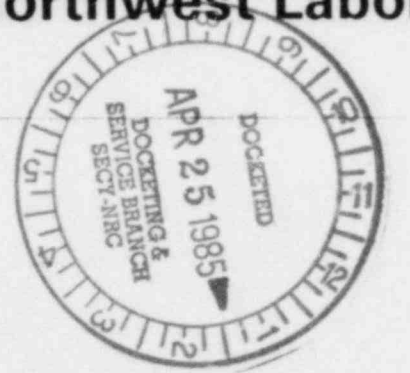
Summary of Conclusions and Recommendations on Resolution of Known Problems in TDI Diesel Generator Components (Phase I of Owners' Group Program)

Pacific Northwest Laboratory



Participants in Reviews

Consultants

- S.H. Bush
- A.J. Henriksen
- B.J. Kirkwood
- P.J. Louzecky
- Ricardo Consulting Engineers plc, West Sussex, England
- A. Sarsten

PNL Technical Coordinators

- F.R. Zaloudek, Task Leader
- J.M. Alzheimer
- J.F. Nesbitt

Information Considered by PNL in Reviews of Resolution of Known Problems

- Owners' Group reports on known problems
- Operating experience in nuclear and non-nuclear applications
- Plant-specific reviews
  - Grand Gulf (July)
  - Catawba (August)
  - Comanche Peak (September)
  - San Onofre (November)
  - Shoreham (December)

Air Start Valve Capscrew

Type Failures:

1) Loosened capscrew at Shoreham and Grand Gulf due to bottoming-out during torquing

2) No failures have occurred

Air Start Valve Capscrew

Conclusions:

Capscrew design is adequate, provided that
- sampling procedure is established to ensure capscrews are of specified length
- installation is made according to SWEC recommendations

M/S Recommendations:

Capscrews should be torqued to Owners' Group recommendations and retorqued following first period of engine operation whenever an air-start valve is removed/replaced

Auxiliary Module Wiring and Terminations

Concern:

Suitability of all class IE auxiliary module wiring and terminations

- Flame retardancy
- Qualification to industry standards
- Routing in conduit
- Compatibility with circuit requirements

Conclusions:

PNL concurs with OG that wiring and terminations are adequate with indicated modifications

- Shoreham
  - Replace crankcase ventilating fan wiring
  - Inspect sliding link terminal block
- Catawba
  - Replace wiring of questionable integrity
  - Inspect sliding link terminal blocks
- San Onofre
  - Replace wiring of questionable integrity

Connecting Rods (DSR-48 Engines)

Type Failures:

1) None reported in nuclear service

2) One failure in non-nuclear service after 8000 hours at 1975 psi peak firing pressure

Connecting Rods (DSR-48 Engines)

Conclusions:

PNL concurs with OG that

- Rods adequate for intended service
- Indications in rod eye bushing within ± 15° of bottom center are not acceptable
- Rod eye cracks more than 0.04 inch deep are not acceptable
- No detectable cracks allowed at root of rod bolt threads

Recommendation:

Connecting rod bolts should be torqued to OG/TDI recommendations at each major engine disassembly (approx. every 5 years)

Connecting Rods (DSRV-4 Engines)

Type Failures:

1) None in nuclear service

2) Fatigue cracking of connecting rod bolts, link rod box, and fretting of serrations (non-nuclear service)

Connecting Rods (DSRV-4 Engines)

Conclusions:

1) Analytical evidence alone does not provide a sufficient basis for concluding that connecting rods are adequate
2) Service history provides confidence that, with suitable M/S, continued use is justified

Recommendations:

1) Implement OG recommendations
   - Inspect and measure every 5 years
   - Measure clearance between link pin and link rod every 5 years
   - Visually inspect rack teeth; verify minimum specified contact surface
   - Inspect 1 7/8-inch bolts and bolt holes each 270 hours above 50% load
2) Bolt torque (both 1 1/2 and 1 7/8-inch bolt sizes) should be checked every 270 hours of operation above 50% load or every 5 years

Connecting Rod Bearing Shells

Type Failures:

1) Cracked bearing shells at Shoreham after only 600-800 hours of operation

2) No other reported failures in nuclear service

Connecting Rod Bearing Shells

Conclusion:

Bearing shells are suitable for continued use with enhanced M/S

M/S Recommendations of Owners' Group:

- Inspect and measure every 5 years
- Bump test at each refueling cycle
- X-ray new bearing shells per OG criteria

Crankshaft
(R-48, Shoreham)

Type Failures:

1) Fracture of Shoreham EDG 102
   11-inch crankshaft

2) Cracks in EDG 101 and 103

Crankshaft
(R-48, Shoreham)

Conclusions regarding replacement 12-inch crankshafts:

1) Test to 10^7 stress cycles proves adequacy of Shoreham crankshafts for "qualified" load (3300 kW)

2) Portion of test at higher loads provides basis for concluding loads to 3430 kW are acceptable for limited period in emergency

3) Momentary ($<$1 minute) loads to 3900 kW in emergency would not compromise operability

M/S Recommendation:

1) NDT fillets and oil holes of crankpin journals 5, 6, and 7 and main journals between them in EDG 101 and 102 engines at first refueling outage

2) NDT of fillets and oil holes of two most heavily

Crankshaft
(DSRV-16-4, Grand Gulf)

Type Failures:

None reported in nuclear service

Crankshaft
(DSRV-16-4, Grand Gulf)

Conclusions:

1) Comply with DEMA recommendations for torsional stresses at rated speed

2) System has 4th order critical at 432 rpm (within ± 5% DEMA range)
   - Engine should not be operated below 440 rpm
   - Cylinder load balance is important
   - Misfiring especially undesirable

M/S Recommendations:

1) Measure hot and cold deflections at 270 hours or each refueling (OG)

2) Inspect journals 4, 6, 8 (OG)

3) Determine adequacy of TDI cylinder balance/governer speed variations by torsiograph (OG)

4) Following major maintenance, balance cylinders carefully per TDI procedures (PNL)

5) Monitor for misfiring via exhaust temperatures (PNL)

Crankshaft
(DSRV-20-4, San Onofre)

Type Failures:

Linear crack discovered in both crankshafts

- Torsional vibration during rapid startup likely cause
- Cracks removed by remachining oil holes

Crankshaft
(DSRV-20-4, San Onofre)

Conclusions:

1) At rated load and speed, torsional stresses within DEMA limits

2) Engines conservatively rated
   - Vibratory stresses low at 450 rpm

3) Crankshafts are adequate for their intended function, provided that:
   - requirement for rapid start testing is removed
   - M/S is implemented to detect future cracking

M/S Recommendations:

1) Hot and cold deflection checks at 270 hours or each refueling (OG)

2) Inspection of oil hole regions of journals 9, 10 and 11 at refuelings (OG)

3) Following major maintenance, balance cylinders carefully per TDI procedures (PNL)

4) Monitor for misfiring via exhaust temperatures (PNL)

Cylinder Block

Type Failures:

1) Camshaft gallery cracks (8-cylinder engine)

2) Circumferential cracks in cylinder liner counterbore

3) Cracks in ligament between liner counterbore and stud

4) Stud-to-stud cracks

Cylinder Block

Conclusions:

1) Camshaft gallery cracks
   - Hot tears
   - Not expected to propagate

2) Circumferential cracks
   - Caused by liner proudness
   - Not detrimental to engine performance

3) Ligament cracks
   - Not detrimental to engine performance
   - Increase probability of stud-to-stud cracks

4) Stud-to-stud cracks
   - Potential threat to engine integrity
   - Must be evaluated on case-by-case basis

Recommendations:

1) Camshaft cracks should be monitored

2) Circumferential cracks need not be monitored

3) Where ligament cracks exist, check for stud-to-stud cracks after each operation at >50% load

4) Blocks with known stud-to-stud cracks should be analyzed for suitability for further service

Cylinder Heads

Type Failures:

Crack originating at stellite valve seal allowing entrance of water into cylinder

Failures have involved principally "Group I" heads (of the three groups in service)

Cylinder Heads

Conclusions:

Heads from all three groups are suitable for intended service, provided that:

- firedeck has no plug welds
- engine is rolled over 4 to 8 hours after shutdown, again at 24 hours, to detect water leaks. Engine is rolled again before planned starts

Recommendations:

- Liquid penetrant inspection of firedeck
- Record cold compression and maximum firing pressures at each refueling
- Roll over engine per PNL recommendations after shutdowns
- Visually inspect fuel injection ports during surveillance tests
- Return leaking heads to vendor for repair

2) Inspections prior to nuclear service

- Ultrasonic inspection of firedeck to verify thickness is at least 0.400 inch
- Surface inspection of firedeck and valve seats to verify absence of unacceptable defects. Any heads with plug welds in firedeck should be rejected

Cylinder Head Studs (Straight and Necked Designs)

Type Failure:

1) None in nuclear service

2) Isolated failures in non-nuclear service from insufficient preload

Cylinder Head Studs (Straight and Necked Designs)

Conclusion:

PNL concurs with OG that both designs are suitable for intended service

M/S Recommendation:

Torque per Owners' Group/TDI recommendations whenever a head is removed/replaced

Engine Base and Bearing Caps

Type Failures:

1) Cracks in main bearing saddles of DSR-48 engines (at Shoreham) from improper stud removal

2) Cracks in main bearing saddles from insufficient stud preload (marine service)

3) Nut pocket failure due to defective casting (non-nuclear)

Engine Base and Bearing Caps

Conclusions:

PNL concurs with OG that base and caps are adequate, provided that:

- LP examination of saddles is performed at alternate fuel cycles (DSR-48)
- main bearing saddle stud torque is checked at alternate cycles
- OG recommendations on removal of oil from mating surfaces before assembly are implemented

Recommendation:

Additional inspection of cap and base mating surfaces to ensure absence of imperfections preventing tight bolt-up

Jacket Water Pump

Type Failures:

Fatigue failure of pump shaft initiating at keyway (Saudi Arabia and Shoreham)

Jacket Water Pump

Conclusions:

1) Concur with latest Shoreham redesign and proposed River Bend and Rancho Seco redesign

2) Concur with OG that V-12, V-16 and V-20 designs are adequate with addition of torque values and limits to assembly procedures

M/S Recommendations:

None

Types AF and AE Piston Skirts

Type Failure:

Fatigue cracks in skirt-to crown attachment bosses

Types AF and AE Piston Skirts

Conclusions:

1) Type AF skirts suitable
   - Up to 130 BMEP with initial inspection only
   - Over 130 BMEP
     Initial inspection
     100% boss area inspection at each refueling

2) Type AE skirts suitable to normal TDI ratings

M/S Recommendations:

1) Inspection as above
2) Inspection, measurement of pin and skirt per TDI recommendations

Types AN and AH Piston Skirts

Type Failures:

1) AN - Numerous reports of cracks in nuclear and non-nuclear applications

2) AH - No reports

Type AN and AH Piston Skirts

Conclusions:

1) AN skirts not suitable

2) AH skirts suitable
   - Normal TDI ratings
   - Subject to 10^7 cycle test on lead engine

M/S Recommendation:

Inspect skirt and pin every 5 years per TDI recommendations

Push Rods (Ball-End, Forged-End and Friction-Welded Designs)

Type Failures:

Numerous failures of ball-end design in weld area

Push Rods (Ball-End, Forged-End and Friction-Welded Designs)

Conclusions:

1) Concur with OG that ball-end rods should be removed from service

2) Concur with OG that forged-end design and friction-welded design are acceptable

M/S Recommendations:

1) Inspect after 800 hours with LP; replace rods with detectable cracks

2) Implement OG recommendation for destructive examination of friction-welded design

Rocker Arm Capscrews (Original and Modified Designs)

Type Failures:

- **Isolated fatigue failures from insufficient preload**

Rocker Arm Capscrews (Original and Modified Designs)

Conclusions:

1) PNL predicts stress may be 3 times higher than SWEC prediction, but margin remains adequate

2) Both designs are adequate
   - based on conservative PNL stress estimate
   - based on service history

M/S Recommendations:

1) Torque per Owners' Group/TDI recommendations whenever capscrews are removed/replaced

Elliott Model 65G/90G Turbochargers

Type Failure:

Thrust bearing failure from inadequate lubrication during startup

Elliott Model 65G/90G Turbochargers

Conclusions:

1) Turbochargers are suitable, provided that FaAA recommendations on drip and full-flow prelube systems are followed
2) Flange and piping alignment and surge margin are possible plant-specific items

Recommendations:

Follow OG recommendations on M/S

- Inspect bearings after 40 fast/100 total starts
- Measure clearances, clean bearings, analyze oil at each refueling
- Inspect bearings, other items each 5 years

Consider operation of manual prelube system for brief period following engine shutdown, to cool down bearings

Inlet Nozzle Ring
Elliott Model 90G Turbocharger

Type Failures:

1) Vanes
   Missing vanes
   Fatigue cracks in roots (low operating hours)

2) Broken bolts

3) Cracked washers

4) Cracked hub

Inlet Nozzle Ring
Elliott Model 90G Turbocharger

Conclusions:

1) No evidence that missing vanes had, in fact, been installed

2) Fatigue cracks pose potential threat

   Turbocharger destruction

   Performance degradation

3) Other isolated failures (e.g., bolts and washers) pose a less serious threat to operability

Recommendations:

1) Inspect at every refueling outage

2) Replace missing or cracked components