EMERGENCY DIESEL GENERATOR

ENGINE DRIVEN JACKET WATER PUMP

DESIGN REVIEW

Prepared For

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By

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TABLE OF CONTENTS

SECTION 1

APPLICABILITY

This review is applicable to the engines at Shoreham (LILCO), River Bend (GSU) and Rancho Seco (SMUD). The River Bend and Rancho Seco engines have jacket water pumps somewhat larger in size, but of the same basic design as Shoreham.

SECTION 2

EXECUTIVE SUMMARY

This pump is included in the list of sixteen components with significant known problems because of the history of pump shaft failures and two redesigns by TDI. The review covers the redesigned pump now installed on the Shoreham engines and the pumps now installed on the River Bend and Rancho Seco engines.

The jacket water pumps have been reviewed from a mechanical design, material suitability and hydraulic performance standpoint, and were found to be acceptable with one exception: the impellers on the River Bend and Rancho Seco engines should be changed from cast iron to ductile iron and the keyways on the impeller eliminated.

SECTION 3

HISTORY

The original pumps furnished at Shoreham had the impeller and gear keyed to the shaft on a straight slide fit. Because of the shaft failures at the impeller end on similar pumps on R-48 engines in Saudi Arabia, the design was modified to utilize a Morse taper on each end. The impeller and gear were retained by an interfernce fit on the taper; however, the keys were retained. Shoreham experienced two shaft failures with this first redesign. Failure Analysis confirmed that fatigue initiating from the keyway was the cause of failure. TDI redesigned the pump a second time removing the keyway on the impeller end and changing the impeller material to ductile iron. The impeller is now driven entirely through the interference fit. This is the present configuration on the Shoreham engines.

The River Bend and Rancho Seco engines have pumps of somewhat larger size with a design similar to the first redesign at Shoreham except that the impeller is cast iron and the shaft is larger in the impeller area.

SECTION 4

OBJECTIVE

The design review was initiated to determine the suitability of these pumps to perform their required function and to look particularly at the design of both pumps in the impeller-shaft-gear area to determine if the design by TDI is acceptable.

The following areas were specifically addressed:

A. Pressure boundary integrity to prevent jacket water leakage.

B. Ability of pump to provide adequate jacket water flow for cooling.

C. Mechanical seal applicability and history of satisfactory life.

D. Material compatibility.

E. Adequate mechanical design particularly in the pump shaft.

SECTION 5

SUMMARY OF SERVICE CONDITIONS

The engine driven jacket water pumps are single stage centrifugal type that are driven through the crank to pump gear. At full load engine speed of 450 RPM, the pump speed is 1928 RPM. The pump is designed to deliver approximately 800 GPM of treated water to the cylinder jackets, turbo charger intercooler and lube oil cooler. The heat picked up in these components is transferred to the reactor building service water system through the jacket water cooler. The normal jacket water temperature leaving the engine is 170-180°F with an alarm and shutdown setting of 190° and 200°F respectively.

SECTION 6

METHODS OF ANALYSIS

The task description required that the pump be reviewed by stress analysis of the impeller, gear and shaft, review of materials, pressure ratings, mechanical seal design and application and pump hydraulic performance. Section 3 on "History" gives a brief description of the original pump design and the first and final redesigns.

Present Shoreham Design

The present pump rotor design consists of a ductile iron impeller shrunk on a #4 Morse taper on a 303 stainless steel shaft using a detailed TDI assembly procedure. This procedure was reviewed and found satisfactory. This interference together with the additional interference as a result of the increased operating temperature of the pump (approximately 180°F) provides sufficient interface pressure to transmit the torque requirements. There is no key or keyway on the shaft or impeller.

At the other end of the shaft, the water pump gear, a hardened carbon steel, is shrunk on a larger #5 Morse taper with a procedure the same as for the impeller. Again, the controlled interference fit and the temperature increase due to the crank case environment result in an interface pressure sufficient to transmit the torque requirements. The shaft and gear also have keyways.

At the impeller end, the impeller is additionally held with a conventional washer and nut with a prescribed torque for the nut. At the gear end, the gear is additionally held with a washer and a castle nut. The castle nut is restrained by a cotter pin through the castellated nut and a hole drilled in the shaft.

The analysis looked at the stresses in the 303 stainless steel shaft as a result of the following factors and compared them with the shaft material endurance limit. Appropriate stress concentration factors were used where required.

1. Hydraulic torque of the pump.
2. Torque fluctuations from the crankshaft through the gear train.
3. Hydraulic radial force on the impeller.
4. The shrink fit of the impeller and gear on the shaft.
5. The force on the gear due to torque transmission.
6. The installation torque of the impeller and gear nuts.

Present River Bend and Rancho Seco Design

The jacket water pumps at River Bend and Rancho Seco are of a slightly larger design and utilize a rotor design similar to the first redesign of the Shoreham pumps. The impeller is cast iron and is shrunk on a 303 stainless steel shaft with a procedure similar to Shoreham. It has a larger #5 Morse taper but also retains the keyway in the impeller and shaft. The gear-shaft design is identical to Shoreham. In both cases, the interference fits are adequate to transmit the torque and the keyways and keys are redundant.

The analysis methods are similar to Shoreham with similar loads and stresses in the shaft. In addition, the tensile stresses in the impeller hub were examined because of the cast iron impeller and the stress concentration due to the keyway.

SECTION 7

FINDINGS

A. Pressure Boundary Integrity - TDI purchases the pump casing, suction cover and impeller from Berkeley Pump Co., Berkeley, CA. The maximum working pressure of the casing and suction cover is 200 PSIG by design. Berkeley hydrotests these parts to 80 PSIG for TDI orders since the pump can only develop 56 PSI of head based on cold water. The pressure boundary integrity of these components is satisfactory.

B. Mechanical Seals - Each pump has one mechanical seal to prevent leadkage of the jacket water pumpage. These seals are subject to a maximum pressure of 56 PSIG of clean treated jacket water at a maximum temperature of 200°F. The rotational speed is 1928 RPM at full engine speed; the seal face speed is a very low 17 fps. This is a mild duty for a mechanical seal. There have been no reported failures of the mechanical seals to date and no reports of excessive leakage at Shoreham. The mechanical seal is adequate for its function.

C. Materials - A list of the major materials of construction of the pumps is shown in Table 1. These materials are routinely used on pumps in this and similar services involving water at the temperature specified. Note that the materials for both pumps are identical except for the impellers. The Shoreham impeller is ASTM A-536 ductile iron and the River Bend and Rancho Seco pumps have cast iron impellers. The ductile iron is stronger and more suitable than the red brass originally used especially since the coefficient of thermal expansion is lower than the 303 stainless steel shaft. This increases the interference fit of the impeller on the shaft as the pump heats up to the running temperature of the jacket water. The cast iron material is suitable for the temperature and treated water. However, the shrink fit on the pump shaft with a keyway introduces tensile stresses in the impeller bore that are considered to be unacceptable. (See Section 7E - "Pump Mechanical Design" for details.)

D. Pump Performance - The hydraulic performance of both pumps is shown in Appendix C. The pump on the Shoreham engine is slightly smaller than the River Bend and Rancho Seco pumps although they both deliver the same flow and head requirements for the cooling system. The hydraulic performance was used to develop the brake horsepower, torque, and radial thrust. The jacket water pumps at Shoreham have demonstrated their capability to properly cool the engines and maintain jacket water temperature below 190°F (the alarm temperature). The River Bend and Rancho Seco engines should perform adequately.

E. Pump Mechanical Design - The design of both jacket water pumps is typical for a centrifugal pump. Two areas are specifically addressed:

1. The bearing design on both pumps is identical and uses bronze backed babbitted journal bearings and a thrust collar running against a bronze backed babbitted faced bushing. Since the

pump bearings are force lubicated using the same filtered and cooled lubricating oil as the engine, they have an excellent environment. There have been no premature bearing failures to date and the analysis indicates the bearings are adequate for the intended service.

2. Appendix D is a summary of stresses calculated for the pump shaft impeller and gear for all three plants. The individual stress levels in the 303 stainless steel shaft are low so that even when they are combined, the resultant principal stresses are well below the endurance limit of 35,000 PSI for hot rolled and annealed 303 stainless steel.

The shrink fits of both impellers and the gear are adequate to transmit the steady state and fluctuating torque. The keys on the gears and the River Bend and Rancho Seco impellers are redundant and possibly detrimental since they are stress concentration areas.

The hoop tensile stresses in the bore of the River Bend and Rancho Seco cast iron impellers are calculated in excess of 35,000 PSI in the area of the keyway and cracks could initiate at the impeller keyway corners. It is recommended that the impeller material be changed to a ductile iron similar to the Shoreham impellers and that the keyway be eliminated on the impeller.

The stresses in the reduced section of the shaft at the shoulder of the impeller end on the Shoreham pump are adequately low. These low stresses are a result of torquing the impeller nuts to 40-48 ft-# as specified by TDI.

The stress calculated for the gear-end of the shaft on all three sites and the impeller end shaft on River Bend and Rancho Seco are conservatively high. No torque limits are given and the worst case of maximum nut rotation to line up the castellated nut groove and the hole in the shaft end for the cotter pin does not account for any looseness prior to shaft elongation. It is recommended that torque limits be specified.

The present design of the impeller and shaft had run in the Shoreham engines for about a year until the failure of the crankshaft in August, 1983. After this failure, the jacket water pump on this engine was disassembled and inspected. The impeller had rotated relative to the shaft and damage was evident as a result. The pumps on the remaining two engines were subsequently inspected and showed no damage or evidence of rotation. An analysis by FaAA concluded that the design was sound and that the damage was caused at the same time the crankshaft failed and was the result of the severe torsional loading associated with the crankshaft failure. After engine 102 was rebuilt with the new crankshaft and a rebuilt water pump, it has run for approximately 281 hours. In February, 1984, the pump was removed and the shaft, gear, and impeller were inspected. There was no fretting at the gear/impeller/shaft interfaces and L.P. examination revealed no cracks.

SECTION 8

CONCLUSIONS AND RECOMMENDATIONS

The jacket water pumps for Shoreham, River Bend and Rancho Seco are adequately designed in the following areas:

A. Pressure boundary and mechanical seal integrity.

B. Ability to keep jacket water temperatures within limits during engine operation.

C. Materials of construction.

Except for the following point the mechanical design, in particular the shaft redesign, is acceptable:

The impeller material for the River Bend and Rancho Seco pumps should be changed from cast iron to the same spec ductile iron as used on the Shoreham pump impellers (ASTM A-536 Grade 65-45-12). The keyway on the impeller should be eliminated to reduce the stress concentration.

With these modifications, the pumps are suitable for the service.

APPENDIX A

COMPONENT DESIGN REVIEW
TASK DESCRIPTION

JACKET WATER PUMP
PART NO. 03-425

Classification A
Completion 3/18/84

PRIMARY FUNCTION: This pump takes suction from the jacket water standpipe and delivers the required flow of treated jacket water at the required pressure to the engine jacket water header. The jacket water circulates through the engine cylinder jackets, exhaust manifold, the turbocharger intercooler, turbocharger lube oil and jacket water cooler. The Reactor Building Service Water System heat exchanger interfaces with the jacket water system for the ultimate heat removal.

FUNCTIONAL ATTRIBUTES:

1. The pressure boundary must maintain integrity to prevent unacceptable water leaks.
2. The jacket water pump must deliver required flow at normal operating pressure during engine operation.
3. The mechanical seal must be adequately designed for appropriate wear life.
4. The pump shaft must be able to deliver required torque to pump impeller with fluctuating torque input through gear train.
5. Pump drive gear must be adequate to transmit steady state and transient loads.

SPECIFIED STANDARDS: None

EVALUATION:

1. Evaluate design and hydrotest pressures for casing and impeller supplied by Berkeley Pump Co. for the R48 and Pacific Pump for the RV engines.
2. Verify that pumps have run to date with no unacceptable leaks in pressure boundary components.
3. Verify that jacket water pump has provided sufficient flow and pressure such that the cooling water temperature has not exceeded acceptable limits in the absence of other system problems, at rated load and speed.
4. Evaluate pump performance tests.
5. Verify that there have been no unacceptable mechanical seal conditions to date.
6. Analyze stresses in pump shaft due to bending, torque and nut tension on gear and impeller end (R-48 and RV engines).
7. Evaluate the effects of the fluctuating torque input from engine gear train.

REVIEW TDI ANALYSES:

1. Review any TDI analyses associated with changes in impeller attachment configurations.

INFORMATION REQUIRED:

1. Maintenance records associated with pump casing and mechanical seals
2. Start up and operational logs which identify cooling water system temperatures.
3. Design and hydrotest pressure for the casings provided by Berkeley & Pacific Pump Companies
4. Detailed drawings of pump rotors including fits and tolerances on impeller and gear and materials
5. Steady state and transient torque oscillations input to the jacket water pump from the drive gear assembly
6. Pump performance data including mechanical efficiency
7. Gear ratio on pump gear and crank gear
8. LP and visual inspection results of the SNPS jacket water pump assembly following 100 hours at full load and a LOOP/LOCA simulation
9. TDI specified procedures for installing gear and impeller on shaft including percent contact required, torque on gear and impeller nut

APPENDIX B

Engine Driven Jacket Water Pumps

Materials List

Part	Shoreham	River Bend and Rancho Seco
Casing	Cast iron	Cast iron
Suction cover	Cast iron	Cast iron
Bracket assembly	Ductile iron	Ductile iron
Impeller	Ductile iron	Cast Iron
Shaft	303 stainless steel	303 stainless steel
Gear	Carbon steel	Carbon steel
Bushings	Babbitted bronze	Babbitted bronze

APPENDIX C

Pump Hydraulic Performance

Parameter	Shoreham	River Bend & Rancho Seco
Pump model	4E (Berkeley Pump Co.)	B6JRBL (Berkeley Pump Co.)
Speed, RPM	1928	1928
Impeller, dia., in.	10	10-1/8
Design flow, GPM	800	800
Design head, TDH, ft	88	88
Efficiency	72	75
BHP	25.2	23.8
Torque lb.-in.	823	778
Radial thrust, lb.	119	105

APPENDIX D

Summary of Stresses - PSI

Typeload & Resultan Stress Shaft-Impeller End	Shoreham	River Bend	Rancho Seco
1. Steady State Hydraulic Torque - Shear Stress	2248	740	740
2. Fluctuating Torgue from Crankshaft - Shear Stress	1216	876	876
3. Radial Hydraulic Load Bending Stress	448	473	473
4. Shrink Fit - Axial Tensile Stress	6575	4770	4770
5. Shrink Fit - Tensile Hoop Stress	4383	3180	3180
6. Shrink Fit - Radial Shear Stress	4676	3392	3392
Impeller			
1. Shrink Fit - Tensile Hoop Stress	27000	35000*	35000*
Shaft - Gear End			
1. Steady State Hydraulic Torque - Shear Stress	783	740	740
2. Fluctuating Torque from Crankshaft - Shear Stress	423	876	876
3. Radial Gearload - Bending Stress	783	1049	1049
4. Shrink Fit - Axial Tensile Stress	7192	7192	7192
5. Shrink Fit - Tensile Hoop Stress	4795	4795	4795
6. Shrink Fit - Radial Shear Stress	5115	5115	5115
Gear			
1. Shrink Fit - Tensile Hoop Stress	22000	22000	22000

These values include stress concentration factor of 2. It may be 2 to 3. Recommendation is made in Section 8 "Conclusions & Recommendations" to eliminate keyway and use ductile iron instead of cast iron for impeller.