Technical Evaluation Report

Review of Engine Base and Bearing Caps for Transamerica Delaval DSRV-12, DSRV-16, and DSRV-20 Diesel Engines

June 1985

Prepared for
the U.S. Nuclear Regulatory Commission
Division of Licensing
Office of Nuclear Reactor Regulation
under Contract DE-AC06-76RLO 1830
NRC FIN B2952

Pacific Northwest Laboratory
Operated for the U.S. Department of Energy
by Battelle Memorial Institute

Battelle

PNL-5200-12 Rev. 1

8507100223 850627
PDR ADOCK 05000206
S PDR

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

PACIFIC NORTHWEST LABORATORY
operated by
BATTELLE
for the
UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC06-76RLO 1830

Technical Evaluation Report

REVIEW OF ENGINE BASE AND BEARING CAPS FOR TRANSAMERICA DELAVAL DSRV-12, DSRV-16, AND DSRV-20 DIESEL ENGINES

June 1985

Prepared for
the U.S. Nuclear Regulatory Commission
Division of Licensing
Office of Nuclear Reactor Regulation
under Contract DE-AC06-76RLO 1830
NRC FIN B2952

Project Title: Assessment of Diesel Engine Reliability/Operability

NRC Lead Engineer: C. H. Berlinger

Pacific Northwest Laboratory
Richland, Washington 99352

FOREWORD

This report is supplied as part of the Technical Assistance Project, Assessment of Diesel Engine Reliability/Operability, being conducted for the U.S. Nuclear Regulatory Commission, Office of Nuclear Reactor Regulation, Division of Licensing, by the Pacific Northwest Laboratory. The U.S. Nuclear Regulatory Commission funded this work under authorization B&R 20-19-40-42-1 FIN No. B2952.

PACIFIC NORTHWEST LABORATORY

PROJECT APPROVALS

W. W. Laity Date May 31, 1985

W. W. Laity, Project Manager
Pacific Northwest Laboratory

W D Richmond Date 5-31-85

W. D. Richmond, Chairman
Senior Review Panel
Pacific Northwest Laboratory

ACKNOWLEDGMENTS

This report was compiled by PNL project team members W. W. Laity, F. R. Zaloudek, and S. D. Dahlgren based on technical contributions provided by PNL staff member S. G. Pitman and PNL consultants S. H. Bush and B. J. Kirkwood.

ABSTRACT

This report documents the review performed by the Pacific Northwest Laboratory (PNL) of action taken by the Transamerica Delaval, Inc. (TDI) Diesel Generator Owners' Group to evaluate the engine base and bearing cap assemblies for the TDI 12-, 16-, and 20-cylinder, V-type, DSRV-4 series engines installed at several nuclear power plants. PNL's review of the engine base assembly for the 8-cylinder, inline, DSR4 series engines purchased by some members of the Owners' Group is documented in a separate report.

Failure Analysis Associates (FaAA), a consultant to the Owners' Group, evaluated the structural adequacy of the engine base and bearing caps under the loads imposed by the crankshaft and by the crankcase-to-base through-bolts. FaAA's conclusions and recommendations are presented in a report titled Design Review of Engine Base and Bearing Caps for Transamerica Delaval DSRV-16 Diesel Engines (FaAA-84-6-53, August 1984).

FaAA performed stress and fatigue analyses of the following components of the engine base assembly for the 16-cylinder DSRV-4 engine:

- main bearing saddles
- crankcase-to-base through-bolts and nuts
- nut pockets
- main bearing caps, studs, and nuts.

FaAA's conclusions are as follows:

- All components of the base assembly for the 16-cylinder engine have adequate margins of safety for ultimate strength and fatigue loading. This conclusion also applies to the 12- and 20-cylinder engines, because the base assemblies of all DSRV-4 engines are similar and because the bearing loads in the latter two engines are lower than those in the 16-cylinder engine.
- Problems encountered with engine bases are not generic in the engines supplied for nuclear service. TDI found that these problems resulted

from inadequate bolt preloads and, in the case of one engine base at the Anamax mine in Arizona, from marginal strength due to inferior quality of a casting.

- To ensure that the friction force at the bearing cap/saddle interface is adequate to prevent movement of the bearing cap under lateral crankshaft loads, the mating surfaces should be thoroughly cleaned prior to assembly or reassembly.

Among the nuclear power plants that utilize 16-cylinder DSRV-4 diesel generators are Comanche Peak and Perry. The Owners' Group recommends in the design review/quality revalidation (DR/QR) reports for these plants that a visual inspection of the engine base be performed at each power plant refueling outage. As discussed in the two reports, this inspection should include the area adjacent to the main bearing stud nut pockets of each bearing saddle. The purpose of this inspection, as stated in the DR/QR report for Comanche Peak, is to verify the continued absence of cracking of the type that was observed in the base of one 16-cylinder engine at the Anamax mine.

PNL concurs that the engine base and bearing cap assemblies for the TDI 12-, 16-, and 20-cylinder DSRV-4 series engines are adequate for their intended service at nuclear power plants. PNL also concurs with the conclusions and recommendations of FaAA and the Owners' Group for maintenance and surveillance of these components. In addition, PNL recommends the following:

- All TDI DSRV-4 engines at nuclear power plants should receive the engine base inspection recommended by the Owners' Group in the DR/QR reports for both Comanche Peak and Perry. According to the Owners' Group, the inspection should be performed at each power plant refueling outage. The frequency of the inspection could be reconsidered if warranted by the inspection results over several refueling cycles.
- The mating surfaces at the bearing cap/saddle interface should be inspected whenever they are disassembled, to ensure the absence of surface imperfections that might prevent tight bolt-up. Imperfections should be removed by stoning, machining, or replacement of parts, as needed.

CONTENTS

REVIEW OF

ENGINE BASE AND BEARING CAPS FOR TRANSAMERICA

DELAVAL DSRV-12, DSRV-16, AND DSRV-20 DIESEL ENGINES

1.0 INTRODUCTION

The Pacific Northwest Laboratory (PNL) is supporting the U.S. Nuclear Regulatory Commission (NRC) staff in addressing questions related to the reliability, operability, and quality assurance of Transamerica Delaval, Inc. (TDI) diesel engines used to provide standby power in some nuclear power plants. These questions were raised because of a major failure in one TDI diesel at the Shoreham Nuclear Power Station in August 1983 and other problems experienced with TDI diesels. One of the principal tasks in PNL's effort is to evaluate the resolution by the TDI Owners' Group of known problems with potential generic applicability.

This report documents PNL's review of the engine base and bearing cap assemblies for the TDI 12-, 16-, and 20-cylinder, V-type, DSRV-4 series engines installed at several nuclear power plants. It supercedes PNL-5200-12 issued in March 1985. PNL's review of the engine base assembly for the 8-cylinder, inline, DSR4 series engines purchased by some members of the Owners' Group is documented in a separate report.

Failure Analysis Associates (FaAA), a consultant to the Owners' Group, evaluated the structural adequacy of the engine base and bearing cap assemblies to carry the loads imposed by the crankshaft and by the crankcase-to-base through-bolts. FaAA's conclusions and recommendations for the DSRV-4 series engines are presented in a report titled Design Review of Engine Base and Bearing Caps for Transamerica Delaval DSRV-16 Diesel Engines (FaAA-84-6-53, August 1984).

1.1 COMPONENT DESCRIPTION

The base assembly supports the crankshaft on bearing saddles and is fastened to both the upper engine assembly at the top and the engine foundation at the bottom. Functionally, the base assembly must support the upper engine, react loads from the crankshaft, and react firing loads transmitted via through-bolts from the upper engine to the base. The bearing caps secure the crankshaft to the engine base at each of the main bearing saddles.

1.2 FAILURE HISTORY

Relatively few problems have been reported in TDI engine bases and bearing caps.

A number of cracks were found in the main bearing saddles of two DSR-48 engines (EDG 102 and 103) at the Shoreham Nuclear Power Station (SNPS) during engine disassembly in 1983. These cracks emanated radially from the bearing cap stud holes toward the bearing saddle and, at the narrowest point, extended across the full width. Such cracks were found in 13 bearing cap bolt holes and were attributed to improper stud removal and replacement procedures.

Also, the SNPS EDG 102 engine base was damaged as a result of the crankshaft failure in August 1983. The bearing bore was displaced in an outward radial direction at three of the four bearing bolt holes of the No. 8 main bearing. Repair of the base consisted of milling the top of the base, reboring the main bearings, and fitting oversized bearings. No subsequent problems with the EDG 102 base have been reported.

Cracks were also reported in the bearing saddles of DSR-46 engines in the U.S. Coast Guard icebreakers West Wind and North Wind. The bearing cap stud preload was increased in these engines; no base assembly problems have been subsequently reported.

A through-bolt nut pocket failed in the engine base of one of the nine DSRV-16 engines at the Anamax mine near Tucson, Arizona. FaAA concurred with the TDI conclusion that this failure was due to reduced strength caused by nonferrous impurities in the engine base casting.

Two through-bolt failures were reported on a DSR-46 engine operated by Copper Valley Electric in Valdez, Alaska, and were attributed to insufficient bolt preloading. The preload was increased, and no subsequent problems have been reported.

2.0 RESOLUTION BY OWNERS' GROUP

The Owners' Group sought to determine if all base assembly components of the DSRV-4 series engines have sufficient strength to withstand the intended service. FaAA addressed this issue for the Owners' Group by performing stress and fatigue analyses of the base assembly for the 16-cylinder DSRV-4 engine and by evaluating the bearing loads for the 12- and 20-cylinder engines.

2.1 SCOPE OF ANALYSIS

FaAA analyzed the structural adequacy of the bearing saddle area for carrying the main bearing loads. The analysis focused on the area on the top of the saddles where the bearing caps rest, because this area was judged most critical due to the proximity of the main bearing stud holes. The area modeled consisted of a horizontal section at the top corner of the bearing saddle, spanning the ligament between the bolt hole and the saddle/bearing interface and encompassing the bolt hole itself. The width of this section was taken as one-half the thickness of the bearing saddle web. This section was analyzed as a hole in a flat plate of finite thickness under uniform compression. Two loads were considered: the main bearing loads, which were calculated from a journal orbit analysis using the computer code JORBIT developed by Imperial Clevite Inc., and loads introduced by the interference fit between the saddle and the main bearing. Recognizing that bearing loads are actually transferred to other parts of the base and cap not included in the area modeled, this load "diffusion" was also factored into the analysis.

This analysis indicated that the highest stresses act on the bolt hole edge nearest the saddle. The mean and alternating stresses calculated at this point are 6070 psi and 4300 psi, respectively. To determine the fatigue

strength at this point of maximum stress, FaAA used a modified Goodman method and took into account finish, size, temperature, and related fatigue parameters.

FaAA also analyzed the main bearing caps to determine their ability to carry the bearing loads. The analysis focused on the area where the main bearing stud hole is closest to the bearing saddle, the area judged to be subjected to the highest stresses. A two-dimensional analysis was performed using a hole-in-flat-plate model similar to that used in the bearing saddle analysis. The maximum positive normal stress was found to act on the bolt hole surface at the thinnest section between the hole and the bearing bore; the mean and alternating stresses at this point were 5900 psi and 4130 psi, respectively. The fatigue life of the cap at the point of maximum stress was determined by means of a modified Goodman analysis, and considered factors such as finish, size, and temperature of the area.

In addition, FaAA analyzed the DSRV-16 bolting and nuts to determine whether 1) through-bolting is adequate to carry the firing forces from the upper engine to the base and 2) the main bearing bolting is adequate to carry crankshaft inertial loads and provide sufficient clamping to resist lateral loads. In both cases both the static forces due to bolt preloading and dynamic forces were considered. The factor of safety for infinite life was calculated using a modified Goodman analysis. The horizontal loads on the bearing cap were found from the Clevite journal orbit computer code. The load imposed by the bearing shell was compared with the friction forces acting at the joint to resist horizontal motion. For conservatism, it was assumed that the contacting surfaces between the bearing shell and the base were lubricated.

2.2 SUMMARY OF RESULTS

The FaAA design review covered stress and fatigue analyses of the bearing saddles, bearing caps, bolting and nuts for both the bearing saddles and the through-bolts, and of the nut pockets for both the bearing saddles and through-bolts. Adequate safety factors were found for all components evaluated. The factor of safety in fatigue for each of the components was as follows:

Component	Factor of Safety
Bearing saddle	1.31
Bearing cap	3.35
Bearing cap stud	1.30
Through-bolt	1.45
Bearing stud nut pocket	1.32
Through-bolt nut pocket	2.50

Friction forces preventing lateral movement of both the bearing cap and the crankcase also were evaluated. The coefficient of friction used to compute the lateral forces on the cap was for steel on cast iron in the presence of a lubricant. Factors of safety were as follows:

Component	Factor of Safety
Cap lateral movement	1.19
Crankcase lateral movement	1.48

2.3 CONCLUSIONS AND RECOMMENDATIONS

2.3.1 FaAA Investigation

FaAA reached the following conclusions from the design review discussed above:

- All components of the base assembly for the 16-cylinder DSRV-4 series engine have sufficient strength to operate for indefinite periods at full load, provided that the base casting and bolting components meet their nominal material and dimensional specifications, that the components have not been damaged, and that bolt torque specifications are maintained. This conclusion also applies to the 12- and 20-cylinder DSRV-4 engines, because the base assemblies of all DSRV-4 engines are similar and because the bearing loads in the latter two engines are lower than those in the 16-cylinder engine.
- Problems encountered with engine bases are not generic in the engines supplied for nuclear service. TDI found that these problems resulted

from inadequate bolt preloads and, in the case of one engine base at the Anamax mine in Arizona, from marginal strength due to inferior quality of a casting.

- To ensure that the friction at the bearing cap/saddle interface is adequate to prevent movement of the bearing cap under lateral crankshaft loads, the mating surfaces should be thoroughly cleaned with solvent prior to first assembly and any reassembly.

2.3.2 Design Review/Quality Revalidation Reports

Among the nuclear power plants that utilize 16-cylinder DSRV-4 series engines are the Comanche Peak Steam Electric Station and the Perry Nuclear Power Plant. To verify the continued absence of cracking of the type that was observed in the base of one 16-cylinder engine at the Anamax mine (see Section 1.2 of this report), the Owners' Group recommends in the design review/quality revalidation (DR/QR) report for Comanche Peak (September 1984) that a visual inspection of the engine base be performed at each power plant refueling outage. This inspection, according to the DR/QR report, should include the area adjacent to the main bearing stud nut pockets of each bearing saddle, and should be performed under good lighting several minutes after a thorough wipe-down of the surfaces.

As discussed in the DR/QR report, the Owners' Group assumes that a crack in the base will cause a crack in the white coating covering the base and will, therefore, be detectable by a visual inspection. The Owners' Group recommends that any crack detected in this manner be investigated further before the engine is returned to service.

The Owners' Group also recommends the visual inspection described above in the DR/QR report for Perry (December 1984). This inspection is in addition to the maintenance and surveillance recommendations described in FaAA-84-6-53.

3.0 PNL'S EVALUATION

The TDI DSRV-4 engine base and bearing caps were reviewed by the following members of the PNL project team, staff, and consultants:

- S. D. Dahlgren, PNL project team
- S. G. Pitman, PNL staff
- S. H. Bush, consultant, Review and Synthesis Associates
- B. J. Kirkwood, consultant, Covenant Engineering.

PNL's evaluation of the engine base and bearing caps issue encompassed

- review of the FaAA report titled Design Review of Engine Base and Bearing Caps for Transamerica Delaval DSRV-16 Diesel Engines (FaAA-84-6-53, August 1984)
- review of the plant-specific recommendations for maintenance and surveillance of the engine base and bearing cap assemblies presented by the Owners' Group in the DR/QR reports for Comanche Peak (September 1984) and Perry (December 1984).

PNL reviewed the methods used by FaAA in their analyses of stress, fatigue, and fracture of the DSRV-16 engine main bearing saddles, bearing caps, through-bolting, and main bearing cap bolting. PNL found that these methods are consistent with good engineering practice and were properly applied. The factor of safety determined for each component is generally sufficiently large to ensure an adequate lifetime for nuclear service. However, the factor of safety for the friction force available to react the maximum lateral load of the bearing caps is low (1.19). In calculating this factor of safety, FaAA conservatively assumed that the contacting surfaces were lubricated.

PNL also reviewed the operating history of the DSRV-16 engines as provided in the FaAA report. This history substantiates that the factors of safety in the parts under consideration are adequate for long-term service. The number of failures for these components was small; the reasons for failure were well understood, and corrective action (principally maintaining bolt preloads) has been effective.

4.0 CONCLUSIONS AND RECOMMENDATIONS

On the basis of the review by PNL staff and consultants of the reports referenced in Section 3.0, PNL concurs with the Owners' Group that the engine base and bearing cap assemblies for the TDI 12-, 16-, and 20-cylinder DSRV-4 series engines are adequate for their intended service at nuclear power plants. PNL also concurs with the recommendations included by the Owners' Group in DR/QR reports for maintenance and surveillance of these assemblies.

The FaAA report notes that the conclusions regarding the adequacy of these components for the DSRV-16 engine can be applied as well to the DSRV-12 and DSRV-20 engines. The engine base, crankshaft, connecting rods, and pistons are similar for all models of the DSRV-4 series engines. Furthermore, the bearing loads calculated by FaAA for the DSRV-12 and DSRV-20 engines are lower than those for the DSRV-16. Under these conditions, PNL concurs that FaAA's conclusions regarding the engine base assembly for the latter engine also apply to the former two engines.

With respect to maintenance and surveillance for the engine base and bearing caps, PNL notes that, once the caps are installed according to the Owners' Group recommendations and torqued to TDI specifications, they should require no further attention until removed for other reasons. FaAA's analysis of the friction force resisting lateral motion of the bearing caps (which was calculated using the conservative assumption that the contacting surfaces are lubricated) led the Owners' Group to recommend that all lubricant be removed from the mating surfaces when the bearing caps are installed. PNL concurs that this should be done whenever a cap is removed.

The visual inspection of the engine base recommended by the Owners' Group in several DR/QR reports is viewed by PNL as a conservative precaution to verify the continued absence of cracking in the vicinity of the stud nut pockets of the bearing saddles. PNL notes that camshaft gallery cracks in the original block for the EDG 103 engine at the Shoreham Nuclear Power Station

could be seen by the naked eye as cracks in the white coating applied to the surface. This suggests that a crack in the engine base will also cause a crack in the white coating applied to the base, as assumed by the Owners' Group. Therefore, PNL concurs that it is not necessary to remove the coating to perform the inspection.

PNL recommends that the following provisions be included in maintenance and surveillance plans for the engine base assemblies, in addition to those recommended by the Owners' Group:

- The engine base inspection (Section 2.3.2 of this report) recommended by the Owners' Group in the DR/QR reports for both Comanche Peak and Perry should be performed on all TDI DSRV-4 engines at nuclear power plants. Because only one engine base (at the Anamax mine) has been reported to have the type of cracking that this inspection is intended to detect, the inspection will serve to verify the continued absence of an atypical problem rather than a problem representative of a design deficiency. Each engine that may be subject to this problem needs to be inspected to ensure that the problem does not exist. According to the Owners' Group, the inspection should be performed at each refueling outage of the power plant in which the engine is installed. The frequency of the inspection could be reconsidered if warranted by the inspection results over several refueling cycles.
- The mating surfaces at the bearing cap/saddle interface should be inspected whenever they are disassembled, to ensure the absence of surface imperfections that might prevent tight bolt-up. Imperfections should be removed by stoning, machining, or replacement of parts, as needed.

REFERENCES

Failure Analysis Associates (FaAA). August 1984. Design Review of Engine Base and Bearing Caps for Transamerica Delaval DSRV-16 Diesel Engines. FaAA-84-6-53, Palo Alto, California.

TDI Diesel Generator Owners' Group. September 7, 1984. TDI Diesel Generator Design Review and Quality Revalidation Report - Comanche Peak Steam Electric Station.

TDI Diesel Generator Owners' Group. December 1984. TDI Diesel Generator Design Review and Quality Revalidation Report - Perry Nuclear Power Plant.

DISTRIBUTION

No. of Copies

OFFSITE

16 Division of Licensing
Office of Nuclear Reactor Regulation
U.S. Nuclear Regulatory Commission
Washington, DC 20555
ATTN: C. Berlinger (10)
M. Carrington (2)
D. Corley
F. Miraglia
H. Thompson
M. Williams

12 NRC Plant Project Managers
Division of Licensing
U.S. Nuclear Regulatory Commission
Washington, DC 20555
ATTN: B. Buckley
S. Burwell
D. Hood
D. Houston
K. Jabbour
T. Kenyon
E. McKenna
M. Miller
S. Miner
C. Stahle
J. Stefano
E. Weinkam

2 U.S. Nuclear Regulatory Commission
Public Document Room
Division of Technical Information and Document Control
Washington, DC 20555

No. of Copies

P. Lang, NE-14
U.S. Department of Energy
Office of Nuclear Energy
Washington, DC 20555

ONSITE

DOE Richland Operations Office

H. Ransom/M. Plahuta

Pacific Northwest Laboratory

Consultant

B. Kirkwood

5 Senior Review Panel

F. Albaugh
S. Bush
C. Hill
W. Richmond
L. Williams

27 Project Team

J. Alzheimer
A. Currie
D. Dingee
R. Dodge
W. Gintner
W. Laity (20)
J. Nesbitt
F. Zaloudek

Technical Information (5)
Publishing Coordination (2)