Technical Evaluation Report

Review of Engine Base and Bearing Caps for Transamerica Delaval DSR-48 Diesel Engines

July 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

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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

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Pacific Northwest Laboratory

WD Richmond Date 6-25-85

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

ACKNOWLEDGMENTS

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

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 caps for the TDI 8-cylinder, inline, DSR4-series engines installed at several nuclear power plants. PNL's review of the engine base assemblies for the V-type DSRV-4 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 DSR4 engine base and bearing caps under the loads imposed by the crankshaft and by the engine block-to-base through-bolts. FaAA's conclusions and recommendations are presented in Design Review of Engine Base and Bearing Caps for Transamerica Delaval Diesel Engines (FaAA-84-4-1 Rev. 1, July 1984).

FaAA performed stress and fatigue analyses of the following components of the engine base assembly:

- main bearing saddles
- engine block-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 8-cylinder DSR4-series engines have sufficient strength to operate indefinitely 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.
- Problems encountered with TDI engine bases in non-nuclear service are not generic in the engines supplied for nuclear standby 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 for resisting 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.
- Cracks found in 13 bearing cap stud holes of the EDG 103 engine base at the Shoreham Nuclear Power Station were most likely caused by an inappropriate method of stud removal that introduced excessive side loads in the stud holes. These cracks were monitored for approximately 300 hours of engine operation, including 100 hours at full load (3500 kW). Furthermore, stress intensity factors computed by FaAA for these cracks are all below the threshold value for crack growth in fatigue at full engine load. These observations and calculations indicate that the cracks will not propagate. However, FaAA recommends periodic inspections to verify that crack growth does not occur.
- Damage found at the No. 8 main bearing position of the EDG 102 engine base at the Shoreham Nuclear Power Station was caused by failure of the original crankshaft in that engine. The bearing bore was displaced radially, and cracks were found in several of the bearing cap stud holes. Small cracks remained in the stud holes after machining operations to repair the base.

Included in the design review/quality revalidation (DR/QR) report prepared by the Owners' Group for the Shoreham Nuclear Power Station is a recommendation that the EDG 102 and EDG 103 bearing saddles with known cracks be inspected periodically in accordance with the maintenance procedures outlined in Engineering & Design Coordination Report (E&DCR) F-46505. The latter report calls for fluorescent dye, liquid penetrant examinations of these saddles at alternate shutdowns for power plant refueling. Any crack growth is unacceptable, according to the DR/QR report.

TDI 8-cylinder DSR4-series diesel generators are installed also at the River Bend Nuclear Power Station. The Owners' Group recommends in the DR/QR report for River Bend that, at each power plant refueling outage, a visual inspection be performed of the area adjacent to the main bearing stud nut pockets of each bearing saddle. Similar inspections are recommended by the Owners' Group in the DR/QR reports for TDI 16-cylinder DSRV-4 diesel generators at Comanche Peak and Perry. The purpose of this visual 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 engine at the Anamax mine.

PNL concurs with the Owners' Group that the engine base and bearing cap assembly for TDI 8-cylinder DSR4-series diesel generators is adequate for its intended service at nuclear power plants, subject to implementation of the maintenance and surveillance recommendations of FaAA and the Owners' Group and to the following PNL recommendations:

- The engine bases of all TDI DSR4-series engines at nuclear power plants should receive the visual inspection recommended by the Owners' Group in the DR/QR report for River Bend. 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 outages.
- 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 DSR-48 DIESEL ENGINES

1.0 INTRODUCTION

The Pacific Northwest Laboratory (PNL) is supporting the U.S. Nuclear Regulatory Commission (NRC) staff in addressing questions of 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 encountered 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 assembly for the TDI 8-cylinder, inline, DSR4-series engines installed at several nuclear power plants. It supercedes PNL-5200-11 issued in March 1985. PNL's review of the engine base assemblies for the V-type DSRV-4 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 engine block-to-base through-bolts and nuts. FaAA's conclusions and recommendations for the 8-cylinder DSR4-series engines are presented in Design Review of Engine Base and Bearing Caps for Transamerica Delaval Diesel Engines (FaAA-84-4-1 Rev. 1, July 1984). Operating experience with TDI engine base assemblies in both nuclear and non-nuclear applications is discussed in FaAA-84-4-1 and in FaAA-84-6-53, Design Review of Engine Base and Bearing Caps for Transamerica Delaval DSRV-16 Diesel Engines (August 1984). Information contained in both FaAA reports is reflected in the summary of engine base problems presented in Section 1.2 of this report.

Included in the design review/quality revalidation (DR/QR) reports prepared by the Owners' Group are plant-specific recommendations for surveillance and maintenance of the engine base and bearing caps. PNL's review discussed in this report reflects the recommendations of the Owners' Group in the DR/QR reports for Comanche Peak (September 1984), Perry (December 1984), River Bend (December 1984), and Shoreham (June 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 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 emergency diesel generators (EDGs) 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 stud removal and replacement procedures that introduced excessive side loads in the stud holes.

In addition, damage was discovered in the SNPS EDG 102 engine base following 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. This damage was attributed to the fatigue failure of the crankshaft and not to normal operating conditions. Repair 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. TDI concluded 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 8-cylinder DSR4-series engine have sufficient strength for the intended service. FaAA addressed this issue for the Owners' Group by performing stress and fatigue analyses of the main bearing saddles; the main bearing caps, studs, and nuts; the engine block-to-base through-bolts and nuts; and the nut pockets.

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 is the most critical due to the presence of the main bearing stud holes. It is also the area where linear indications were observed in the EDG 102 and 103 engines at SNPS.

The area was modeled as a horizontal plate of finite thickness, extending in one direction from the saddle/bearing interface to the centerline of the bearing stud holes and in the other direction from the outside corner of the saddle to the centerline of the saddle web. A two-dimensional finite element analysis was performed. Two loads were considered: the main bearing loads

calculated 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 will be partially supported by other parts of the base and cap not included in the area modeled, this load "diffusion" was also factored into the analysis.

FaAA assessed the fatigue strength of the base using the maximum normal stress multiaxial fatigue failure theory based on a modified Goodman method. A fracture analysis of the base was also performed. In the latter analysis, the stress intensity factor range was computed using the BIGIF fracture mechanics code. As a part of this analysis, the cracks present in the bearing saddle areas of the SNPS EDG 103 base were investigated.

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 finite element model was used to determine the stresses. At the point of maximum tensile stress, the fatigue strength was analyzed using a modified Goodman criterion.

Additional analyses were performed to determine if the through-bolting is adequate to transmit the firing forces from the upper engine to the base, and if the main bearing bolting is adequate to carry the crankshaft inertial loads and provide sufficient clamping to resist lateral loads. In both these cases, the static forces due to bolt preloading and the dynamic forces that act on these components were considered. Factors of safety against fatigue failure were calculated using the modified Goodman criterion. To evaluate the adequacy of the main bearing clamping forces, the horizontal loads found from the Clevite journal orbit computer code were compared with the friction forces acting at the interface between the cap and base. For conservatism, it was assumed that the contact surfaces were lubricated.

The adequacy of the nut pockets associated with the through-bolts and bearing studs was evaluated using conservative analytical models of casting sections judged to be the most critical. The maximum stresses computed from

these models and fatigue strengths evaluated by the modified Goodman criterion were used to determine factors of safety against fatigue failure of the nut pockets.

2.2 SUMMARY OF RESULTS

FaAA's design review of the engine base assembly for the 8-cylinder DSR4 engine yielded the following results:

- Main bearing saddles

  The factor of safety against fatigue failure in the most highly stressed region of the bearing saddles is 1.75. Further, the stress intensity factors for the cracks already present in the bearing saddle areas of the Shoreham EDG 103 engine are all below the threshold value for crack growth in fatigue at full engine load (3500 kW), with a factor of safety of 1.1 or larger for these cracks. Cracks as large as 0.040 inch by 0.259 inch at the area of maximum stress should not grow, according to the FaAA analysis. However, FaAA recommends periodic inspections to verify that crack growth does not occur.

- Main bearing caps

  The factor of safety against fatigue failure is 2.42 or greater throughout the bearing cap, and the factor of safety against local yielding in the area of maximum compressive stress is 1.18. FaAA noted that if local yielding were to occur, it would be confined to a small area at bearing No. 6 only, and would not cause a bearing failure.

  With the conservative assumption that the contacting surfaces are lubricated, the friction force to resist lateral movement of the bearing cap is 62,800 pounds. The maximum lateral load found from the Clevite journal orbit computer program is 58,500 pounds, acting on the bearing cap at the No. 6 bearing. Thus, the friction force is sufficient to react the maximum lateral load with a factor of safety of 1.07.

- Bolting and nuts

  The through-bolting, bearing studs, and associated nuts have sufficient strength for unlimited operation at full load, with a factor of safety of 1.67 for the through-bolting and higher factors of safety for the studs and nuts.

- Nut pockets

  Provided that the base casting material has strength equivalent to that of Class 40 grey cast iron, the factors of safety for the through-bolt and the bearing stud nut pockets are 3.51 and 1.87, respectively.

2.3 CONCLUSIONS AND RECOMMENDATIONS

2.3.1 FaAA Investigation

FaAA presented the following conclusions regarding the base assembly for the 8-cylinder DSR4-series engines:

- All components of the base assembly have sufficient strength to operate indefinitely 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.
- Problems encountered with TDI engine bases in non-nuclear service are not generic in the engines supplied for nuclear standby 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 for resisting 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.
- Cracks found in 13 bearing cap stud holes of the EDG 103 engine base at the Shoreham Nuclear Power Station were most likely caused by an

inappropriate method of stud removal that introduced excessive side loads in the stud holes. These cracks were monitored for approximately 300 hours of engine operation, including 100 hours at full load (3500 kW). Furthermore, stress intensity factors computed by FaAA for these cracks are all below the threshold value for crack growth in fatigue at full engine load. These observations and calculations indicate that the cracks will not propagate. However, FaAA recommends periodic inspections to verify that crack growth does not occur.

- Damage found at the No. 8 main bearing position of the EDG 102 engine base at the Shoreham Nuclear Power Station was caused by failure of the original crankshaft in that engine. The bearing bore was displaced radially, and cracks were found in several of the bearing cap stud holes. Small cracks remained in the stud holes after machining operations to repair the base.

2.3.2 Design Review/Quality Revalidation Reports

Included in the DR/QR report prepared by the Owners' Group for the Shoreham Nuclear Power Station is a recommendation that the EDG 102 and EDG 103 bearing saddles with known cracks be inspected periodically in accordance with the maintenance procedures outlined in Engineering & Design Coordination Report (E&DCR) F-46505. The latter report calls for fluorescent dye, liquid penetrant examinations of these saddles at alternate shutdowns for power plant refueling. Any crack growth is unacceptable, according to the DR/QR report.

TDI 8-cylinder DSR4-series diesel generators are installed also at the River Bend Nuclear Power Station. The Owners' Group recommends in the DR/QR report for River Bend (December 1984) that, at each power plant refueling outage, a visual inspection be performed of the area adjacent to the main bearing stud nut pockets of each bearing saddle. Similar inspections are recommended by the Owners' Group in the DR/QR reports for TDI 16-cylinder DSRV-4 diesel generators at Comanche Peak (September 1984) and Perry (December 1984). The purpose of this visual 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 engine at the Anamax mine.

3.0 PNL'S EVALUATION

PNL reviewed the action taken by the Owners' Group to evaluate the engine base and bearing cap assembly for the TDI 8-cylinder DSR4-series engines. PNL's evaluation encompassed the FaAA and Owners' Group reports referenced in Section 1.0 of this report.

3.1 PARTICIPANTS IN REVIEW

The PNL evaluation was conducted by

- S. D. Dahlgren, PNL project team
- S. H. Bush, consultant, Review and Synthesis Associates
- P. J. Louzecky, consultant, Engineered Applications Corporation
- A. Sarsten, consultant, Norwegian Institute of Technology
- S. G. Pitman, PNL staff.

3.2 CONCLUSIONS AND RECOMMENDATIONS

PNL concurs with the Owners' Group that the engine base and bearing cap assembly for TDI 8-cylinder DSR4-series diesel generators is adequate for its intended service at nuclear power plants, subject to implementation of the maintenance and surveillance recommendations of FaAA and the Owners' Group and to the additional PNL recommendations discussed later in this section. The stress, fatigue, and fracture analyses documented in FaAA-84-4-1 substantiate the adequacy of the components of this assembly, and the results of these analyses are supported by the operating history summarized in FaAA-84-4-1 and in FaAA-84-6-53. Relatively few problems with engine base assemblies have been reported; the reasons for the problems are well understood, and corrective action (principally maintaining bolt preloads at specified values) has been effective.

One of the recommendations of the Owners' Group is to inspect certain bearing saddles of the EDG 102 and EDG 103 engines at the Shoreham Nuclear Power Station at alternate power plant refueling outages, to verify that existing cracks do not grow. The DR/QR report for Shoreham (June 1984) recommends a magnetic particle inspection, and references E&DCR F-46505 for details of the

procedure. However, the latter report calls for a fluorescent dye, liquid penetrant inspection. PNL considers either type of inspection to be satisfactory for monitoring the known surface-connected cracks.

In PNL's opinion, the visual inspection of the engine base recommended by the Owners' Group in several DR/QR reports is 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 and bearing caps, in addition to those recommended by the Owners' Group:

- The engine base visual inspection (Section 2.3.2 of this report) recommended by the Owners' Group in the DR/QR report for River Bend should be performed on all TDI DSR4-series 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.

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Failure Analysis Associates (FaAA). July 1984. Design Review of Engine Base and Bearing Caps for Transamerica Delaval Diesel Engines. FaAA-84-4-1 Rev. 1, Palo Alto, California.

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