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Technical Evaluation Report

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

March 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
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REVIEW OF
ENGINE BASE AND BEARING CAPS
FOR TRANSAMERICA DELAVAL DSR-48
DIESEL ENGINES

March 1985

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Reliability/Operability

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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.

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Date March 18, 1985

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This report was compiled by PNL project team members 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, P. J. Louzecky, and A. Sarsten.

ABSTRACT

This technical evaluation report documents Pacific Northwest Laboratory's (PNL) review of the engine base and bearing caps for Transamerica Delaval, Inc. (TDI) DSR-48 engines. Failure Analysis Associates (FaAA), a consultant to the TDI Diesel Generator Owners' Group, addressed the known problems associated with these engine components. The Owners' Group resolution of the problem is described in the FaAA report, Design Review of Engine Base and Bearing Caps for Transamerica Delaval Diesel Engines.

PNL and its consultants reviewed the FaAA report and other documentation relevant to the components. Based on the review, PNL concludes that both the engine base and bearing caps for the DSR-48 engines are acceptable for unlimited use in nuclear service.

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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 Owners' Group resolution of problems identified with the engine base and bearing caps for the TDI DSR-48 engines. The details of the Owners' Group efforts were described in the April 1984 report, Design Review of Engine Base and Bearing Caps for Transamerica Delaval Diesel Engines (FaAA-84-4-1), by Failure Analysis Associates, a consultant to the Owners' Group.

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 COMPONENT 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 improper stud removal and replacement procedures.

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 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.

Failure Analysis Associates (FaAA) reported a nut pocket failure in a DSRV-16 engine at the ANAMAX mine near Tucson, Arizona. This failure was attributed to nonferrous impurities in the base casting. Two through-bolt failures were also reported on a DSR-46 engine operated by Copper Valley Electric in Valdez, Alaska, and were attributed to insufficient bolt preloading. These preloads were 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 DSR-48 engine have sufficient strength for the intended service. These components include bearing saddles, bearing caps, bolting and nuts, and nut

pockets. An analysis was performed by Failure Analysis Associates, a consultant to the Owners' Group, and reported in FaAA-84-4-1, Design Review of Engine Base and Bearing Caps for Transamerica Delaval Diesel Engines (April 1984).

2.1 SCOPE OF EVALUATION

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, which was 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, both the static and dynamic loading for the system were found and assumed to act axially on the bolt to produce the axial stress. The fatigue factor for infinite life was calculated using the modified Goodman criterion. 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 interface between the cap and base to resist horizontal motion. 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 the factor of safety for the nut pocket area.

2.2 SUMMARY OF RESULTS

The finite element and fatigue analyses for the bearing saddles yielded a factor of safety (FS) of 1.75 against fatigue failures in the most highly stressed regions of the saddle. Further, FaAA concluded that cracks smaller than 0.040 inch by 0.259 inch would not grow if they had been introduced during fabrication or an accident. A conservative analysis of the cracks already present in the Shoreham EDG 103 engine base indicated FS = 1.1 or larger at full load for all cracks. Periodic inspections were recommended to ensure that crack growth has not occurred, because the calculated margin of safety was not large. The recommended inspection frequency was not specified.

Stress and fatigue analyses of the cast steel bearing caps showed an acceptable factor of safety of 2.43 in fatigue and a conservative factor of safety of 1.18 against yielding in compression. It was noted that, even though the latter safety factor appears small, if compressive yielding were to occur, it would be confined to a small area. An analysis was made of the lateral

friction force that keeps the cap from sliding relative to the saddle. Results indicated that a friction force of 62,800 lb would be available for the clamped cap, assuming the presence of a lubricant. This would be sufficient to withstand the expected maximum force of 58,500 lb.

Both through-bolts and nuts and the bearing cap studs and nuts had adequate safety margins in fatigue. The margin for the through-bolts was $FS = 1.67$; for the cap studs and nuts it was $FS = 1.88$.

Large margins of safety were found for both through-bolt and bearing saddle nut pockets. The factors of safety were 4.04 for the former and 4.30 for the latter.

2.3 CONCLUSIONS

The Owners' Group concluded that the engine base and bearing caps and associated bolting for the DSR-48 engine are adequate for their intended service, provided that the bolting is properly preloaded according to TDI specifications. They also concluded that the cracks found in the Shoreham EDG 103 base were caused by improper stud removal methods. Nevertheless, based on a crack growth analysis, the cracks are not expected to grow, even at full-load operation of the engine. A similar conclusion was reached about a crack in the No. 8 main bearing of Shoreham's EDG 102 that was formed when the crankshaft broke. The Owners' Group recommended that periodic inspections (frequency not specified) be performed to ensure that crack growth has not occurred.

3.0 PNL'S EVALUATION

The TDI DSR-48 engine base and bearing caps were evaluated by the following members of the PNL project team, staff, and consultants:

- 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.

PNL's evaluation of the DSR-48 engine base and bearing caps involved

- review of the methodology used by FaAA in their design review as documented in FaAA-84-4-1 (April 1984)
- review of the operating history of the DSR-48 engines as presented in FaAA-84-4-1
- meetings and written and other oral communications with FaAA representatives to obtain clarification of the contents of their report
- review of the Owners' Group design review/quality revalidation report for SNPS (TDI OG June 29, 1984) to provide a basis for evaluating any component-specific recommended maintenance and surveillance (M/S) actions provided in FaAA-84-4-1.

Based on its review of the FaAA report and associated clarifications, PNL found that the analytic stress, fatigue, and fracture analyses used by FaAA are consistent with good engineering practice and were properly applied. Furthermore, with two exceptions, PNL found the predicted factors of safety (FS) were adequate to ensure long component lifetimes. These factors of safety are consistent with the historic reliability of the engine base, bearing caps, and associated bolting since corrective actions (e.g., increased bolt torques) were instituted. The two lowest factors of safety are 1) for crack growth in the main bearing saddles ($FS = 1.1$) and 2) for side friction force of the bearing cap on the saddle ($FS = 62,800 \text{ lb} / 58,000 \text{ lb} = 1.07$). However, the Owners' Group analysis was conservative. Furthermore, the operating history to date supports the adequacy of these values. Therefore, PNL believes that the bases and bearing caps would be adequate for the intended service, provided that the bases of engines with existing cracks are periodically inspected to verify the predicted absence of crack growth and the bearing caps are installed with precautions as recommended by the Owners' Group.

Because of the low margin of safety for lateral motion of bearing caps, the Owners' Group recommended that the mating surfaces of the bearing cap and the saddle be dry (no lubricant) during installation. PNL concurs with this recommendation. In addition, PNL recommends that, during future installations,

special precautions be taken to ensure that the mating surfaces are flat and free from burrs or other surface imperfections that could prevent the tight bolt-up of the mating surfaces.

PNL notes that the maintenance and surveillance (M/S) recommendations for the engine base and bearing caps were not provided in detail in the report FaAA-84-4-1. However, they are reflected in the plant-specific DR/QR report for SNPS (TDI OG June 29, 1984). The OG recommendations contained therein were used as a basis for PNL's review of recommended actions presented in FaAA-84-4-1. The principal recommended M/S activity in this report is the magnetic particle inspection of bearing saddles with linear indications after 500 hours of operation.

4.0 CONCLUSIONS AND RECOMMENDATIONS

Based on review of the Owners' Group report and service history of the DSR-48 engine, PNL concurs that the engine base and bearing caps and associated bolting are acceptable for the intended service.

Due to the low factor of safety for friction forces resisting the lateral motion of the bearing caps, the Owners' Group recommended that any lubricant be removed from the mating surfaces of the bearing cap and base before installation. PNL concurs that this should be done any time a cap is removed. PNL further recommends that these mating surfaces be inspected whenever they are disassembled, to ensure the absence of surface imperfections that may prevent the tight bolt-up of the components and degrade the friction between them. Imperfections should be removed by stoning, machining, or replacement of parts, as needed.

With regard to maintenance and surveillance, PNL believes that once the bearing saddles are installed according to the Owners' Group recommendations and torqued according to TDI specifications, they will require no further routine attention until removed for other reasons. However, because of concern

for the factor of safety for crack growth in engines with indications in the area of the main bearing saddles, PNL concurs with the Owners' Group that the periodic inspection described in Section 3.0 should be performed on these engines.

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