VIRGINIA ELECTRIC AND POWER COMPANY
RICHMOND, VIRGINIA 23261

December 12, 2001

U.S. Nuclear Regulatory Commission
Attention: Document Control Desk
Washington, D.C. 20555

Serial No. 01-640A
NLOS/GDM R3
Docket Nos. 50-280
50-281
License Nos. DPR-32
DPR-37

Gentlemen:

VIRGINIA ELECTRIC AND POWER COMPANY
SURRY POWER STATION UNITS 1 AND 2
NRC SPECIAL INSPECTION REPORT NOS. 50-280/01-06 AND 50-281/01-06
TRANSMITTAL OF TECHNICAL REPORTS

On October 11, 2001, the NRC issued Special Inspection Report Nos. 50-280/01-06 and 50-281/01-06, which provided the NRC's preliminary significance determination finding associated with the inoperability of Emergency Diesel Generator (EDG) No. 3 and degraded components on EDG No. 1 at Surry Power Station. A Regulatory Conference was held on November 30, 2001 to discuss the finding. At the conclusion of the conference, the NRC requested copies of the independent technical assessments that were performed as part of Dominion's root cause analysis efforts to further evaluate the condition and operability of the EDGs based on observed and projected component wear.

Accordingly, attached hereto are copies of the following technical reports:

- Engine Systems, Inc. (ESI) Report No. 87360-FA dated May 25, 2001, "Failure Analysis for (1) One Power Assembly, Fork Rod EMD P/N 8470863, Revision 1"
- Engine Systems, Inc. (ESI) Report No. 90342-FA dated August 15, 2001, "Failure Analysis for (10) Ten Power Assembly, Fork Rod EMD P/N 8470863 & (10) Ten Power Assembly, Blade Rod EMD P/N 8470864, Revision 0"
- Trident Engineering Associates, Inc. Report dated October 3, 2001, prepared for Surry Power Station

IE01

- Ricardo, Inc. Report dated November 15, 2001, “Engine Life Predictions for EDG3 at Surry Nuclear Power Station for Dominion Virginia Power”

If you have any questions or require additional information, please contact us.

Very truly yours,

L. N. Hartz
Vice President – Nuclear Engineering

Attachments

Commitments made in this letter: None.

cc: U.S. Nuclear Regulatory Commission
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Mr. R. A. Musser
NRC Senior Resident Inspector
Surry Power Station

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Revision 1: 05/25/01

REPORT NUMBER 87360-FA

REVISION NO: 0

April 26, 2001

FAILURE ANALYSIS FOR (1) ONE POWER ASSEMBLY, FORK ROD EMD P/N 8470863

FOR

Dominion Virginia Power
Surry Power Station

Engine Systems Inc. Work Order 87360

Prepared By:	John H. Battigelli (signature on file)	5/25/01 Date
Reviewed By:	James B. Abernathy (signature on file)	25May01 Date
Approved By:	Kevin Broussard (signature on file)	5/25/01 Date

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REV	DATE	PAGE	PARA	DESCRIPTION
0	4/26/01	ALL		ORIGINAL ISSUE
1	5/25/01	App A		Added Appendix A

Overview

Surry Power Station has experienced increasing silver levels in the engine lubricating oil on one of their safety-related emergency diesel generators. In response to this, service technicians were called in to examine the potential sources of silver contamination: carrier insert bearings and the turbocharger bearings. Upon initial inspection of the power assemblies, three of twenty exhibited degraded insert bearings. One of the three degraded power assemblies (#16 cylinder) and one of the non-degraded power assemblies (#3 cylinder) were shipped to Engine Systems, Inc. for analysis. Both power assemblies were disassembled for inspection. The disassembly and inspection were witnessed by Chuck Silcox (Virginia Power), Kevin Broussard (ESI), Tommy Millwood (ESI), Scott Tharrington (ESI) and John Battigelli (ESI).

Receipt Inspection

Upon receipt inspection the exteriors of the assemblies were found to be in normal condition. Cylinder heads were removed from both power assemblies. The connecting rod/carrier/piston assemblies were removed from the bottom of the liners. The oil control rings were found missing from the piston, #16 cylinder. Otherwise, the exterior of the connecting rod/carrier/piston was entirely normal in appearance. The top surface of the piston did not exhibit a firing "star" pattern; i.e. the piston rotated as designed during service. The cylinder liner surface exhibited normal honing marks with no signs of scuffing or scoring.

Internal inspection

The snap rings were removed and the carrier/rod assemblies were separated from the pistons. The oil holes in the pilots of the carriers were free of obstruction. The following observations apply to the #16 power assembly condition: Two of the three bearing surfaces on the carrier were found to be scored. See Figure 1 and Figure 2. The corresponding lower bearing surface of the piston also showed evidence of scoring. See Figure 3. The thrust washer bearing surface of the carrier appeared to be "machined" by its interface with the thrust washer. See Figure 4.

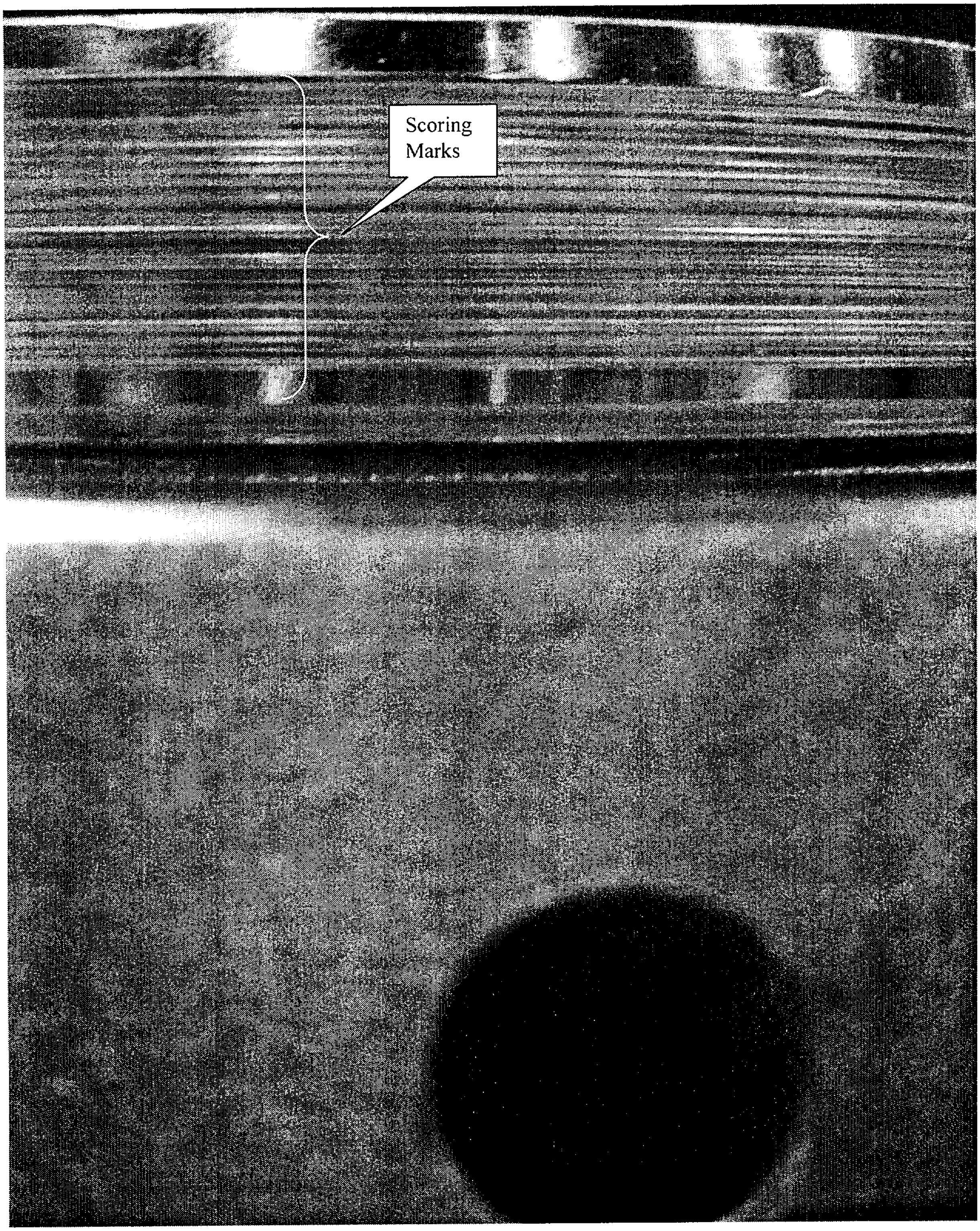


Figure 1
Carrier Pilot

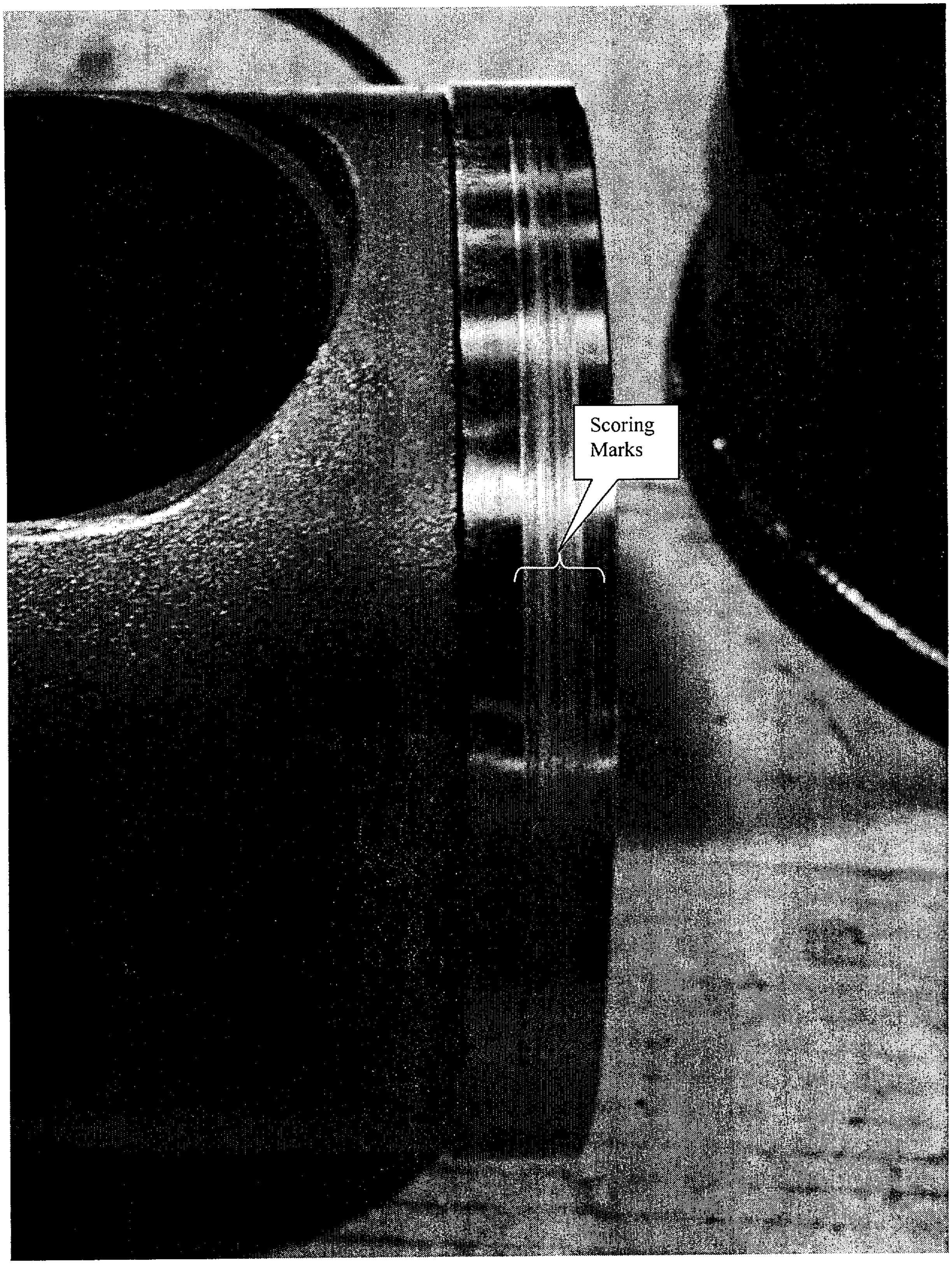


Figure 2
Carrier Skirt

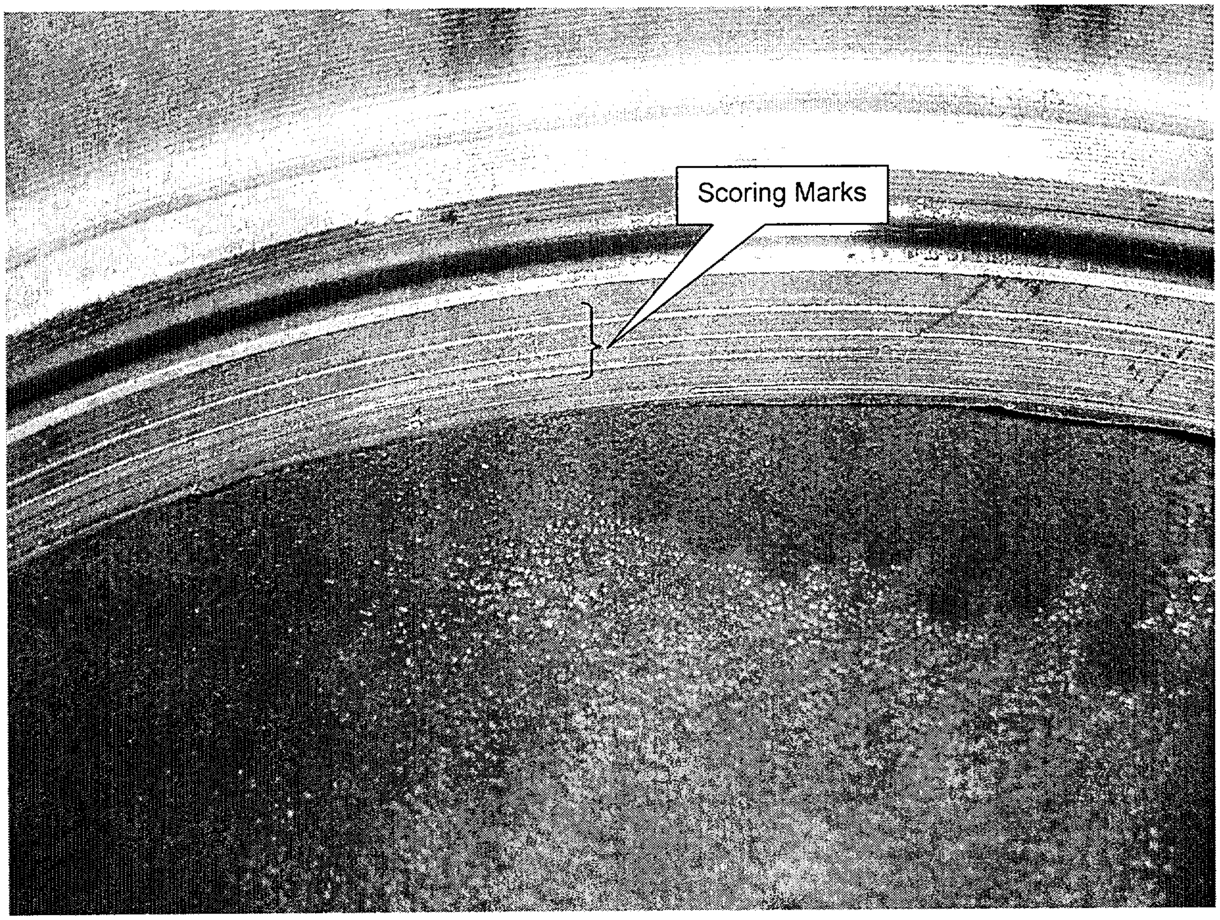


Figure 3
Piston Internal Surface, Region of Carrier Skirt Interface

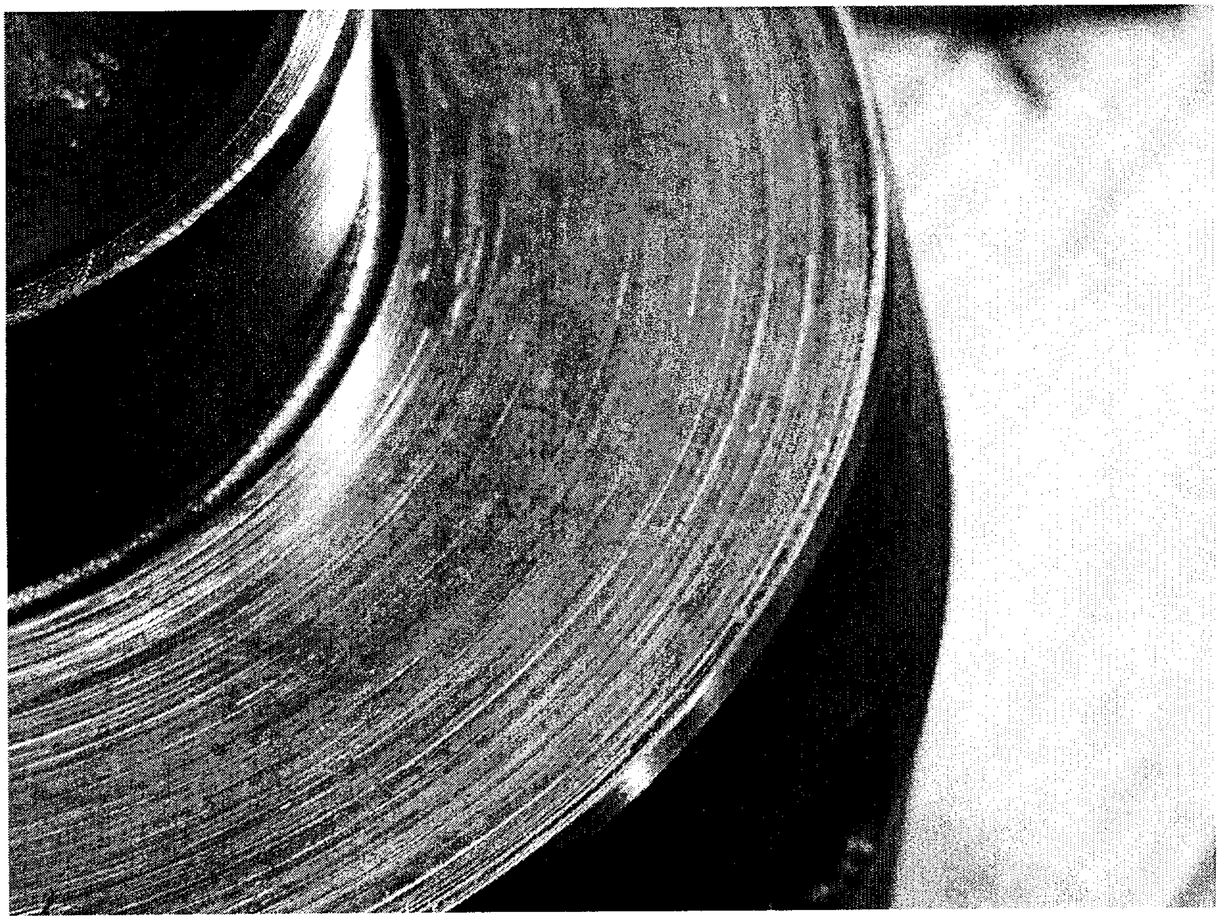


Figure 4
"Machined" Bearing Surface of Carrier,
Thrust Washer Interface

Both faces of the thrust washer exhibited evidence of either oil channeling or scratches from foreign material. These signatures are largely radial in their direction. The inner diameter of the thrust washer has a wear step at the edge of the loaded and unloaded region of the washer's bearing surface. See Figures 5 and 6.

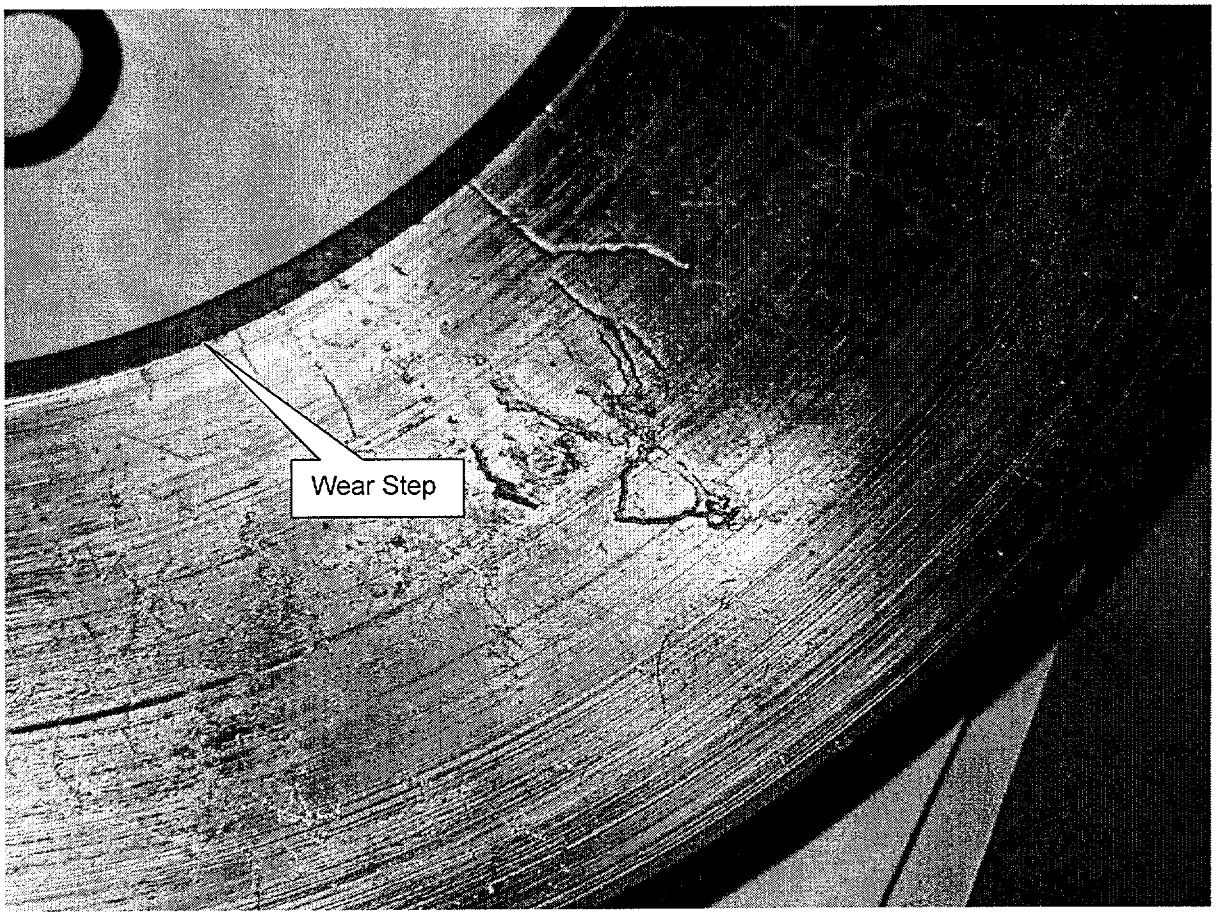


Figure 5
Bottom Face of Thrust Washer

Figure 6
Top Face of Thrust Washer

The two bolts clamping the rod trunnion to the piston pin were removed, and the connecting rod was separated from the piston pin. Bearing fragments were visible at the edge of the insert bearing. The lower portion of the piston pin had a normal appearance. The pin was rolled over, exposing the portion of the piston pin in contact with the insert bearing during operation. See Figure 7. This portion of the pin exhibits substantial distress from metal transfer between the insert bearing and the pin, resulting in a "seized" appearance. The insert bearing has a similar appearance. See Figure 8. The bearing did not actually seize to the pin – the retaining tabs were still intact and secure to the carrier. See Figure 9.

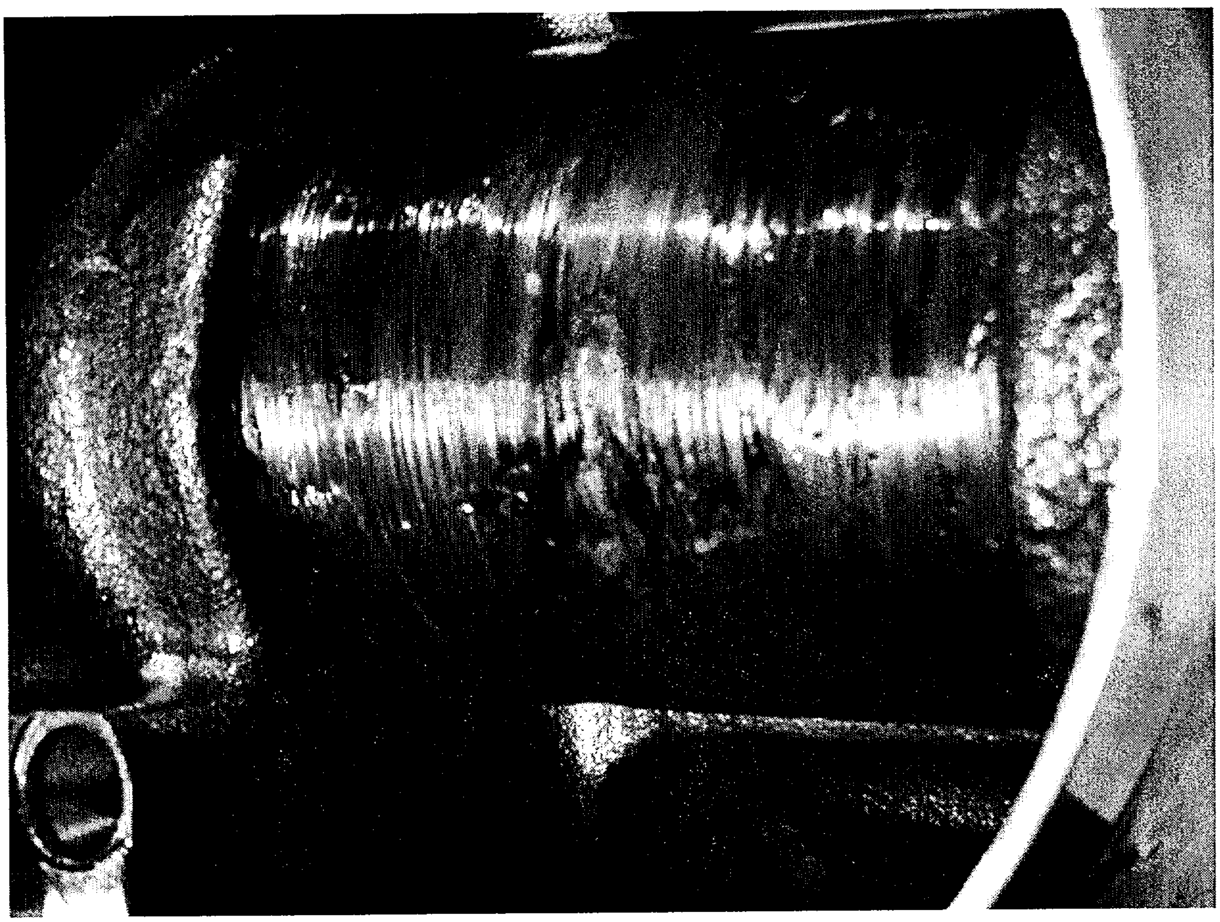


Figure 7

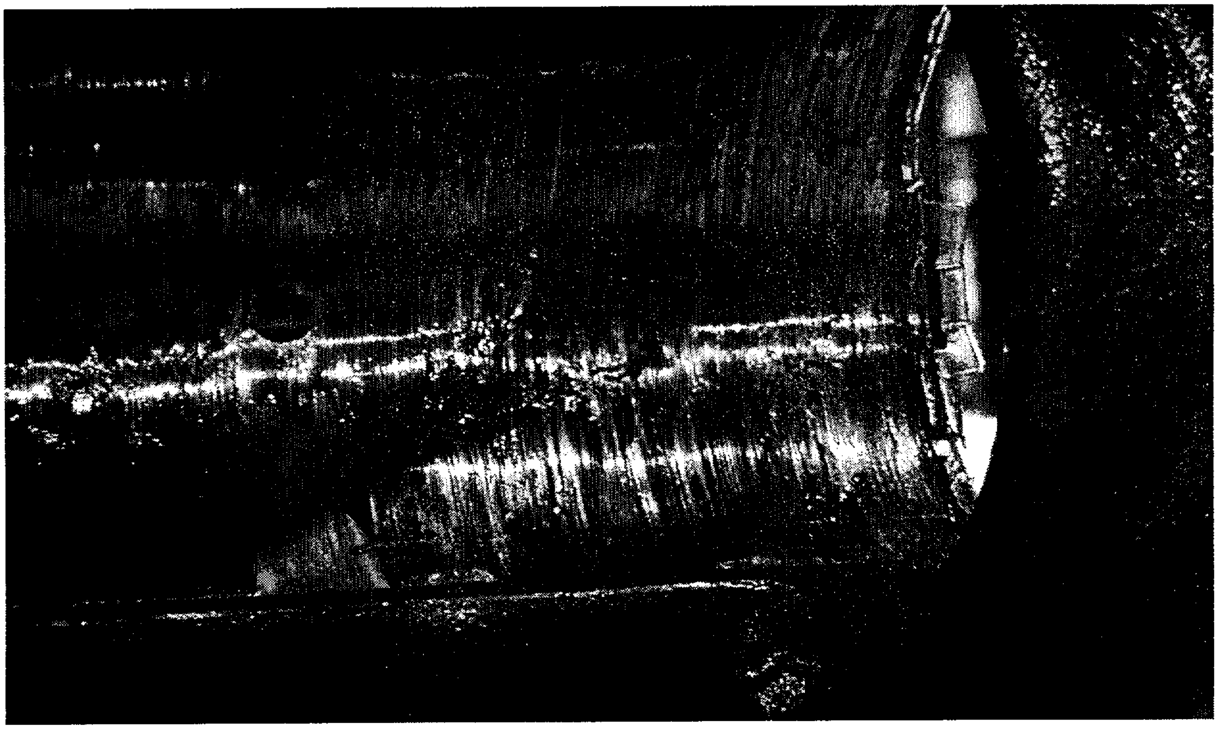


Figure 8
Carrier Insert Bearing

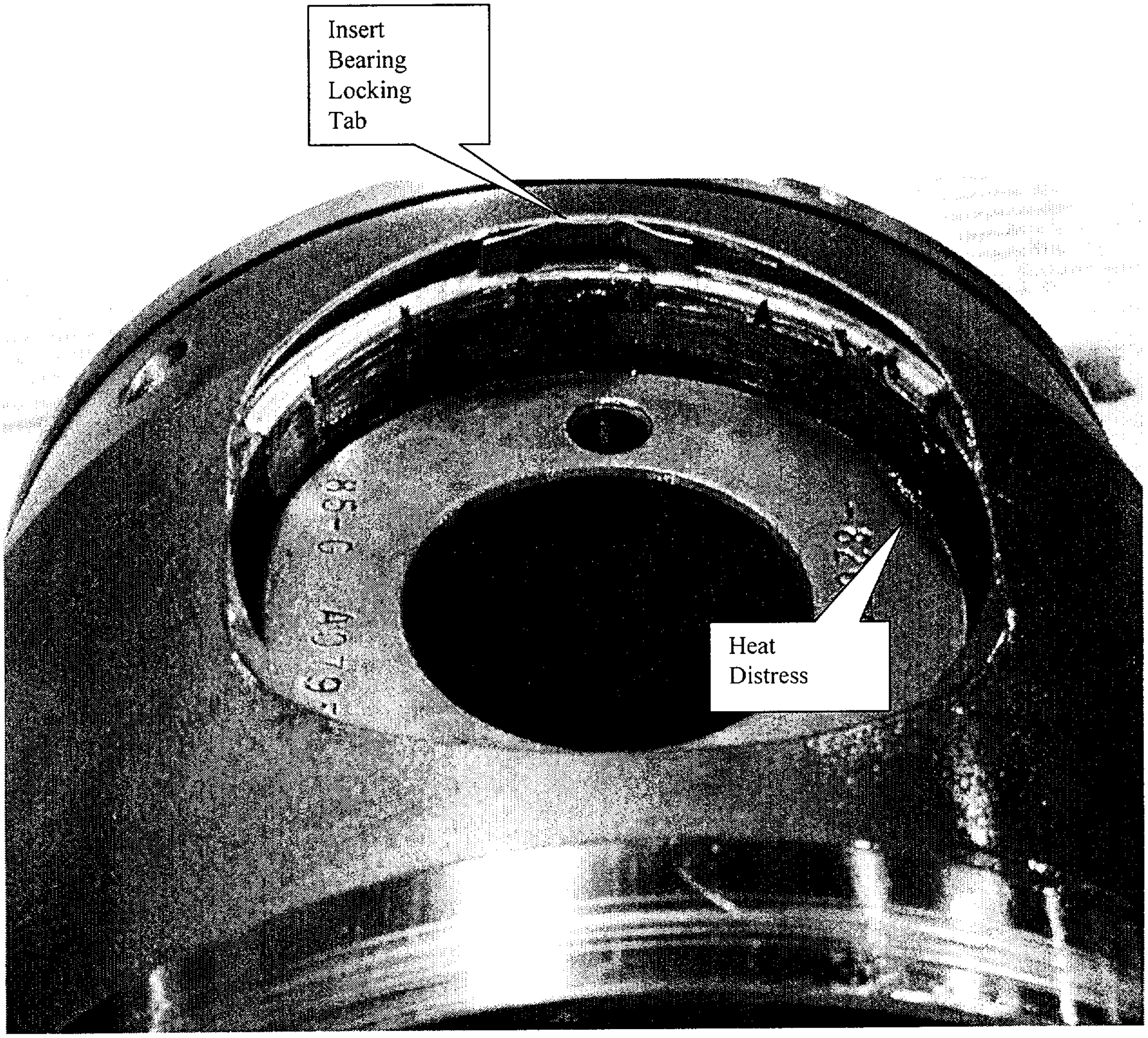


Figure 9
Piston Pin, Insert Bearing, Carrier Assembly

Conclusion

The damage identified in the #16 cylinder power assembly is consistent with failures resulting from lack of lubrication. The failed insert bearing, distressed piston pin, and machined thrust washer face of the carrier all appear to be directly caused by lube oil starvation. The scoring on the remaining bearing surfaces of the carrier and the distress in the thrust washer are probably secondary damage resulting from circulation of insert bearing material and piston pin material.

The increasing silver level in the engine lubricating oil as identified in plant analyses/trending indicates that the failure probably developed progressively over a period of several years. This would seem to rule out a single discrete failure mode such as an oil path obstruction, pump failure, etc. This belief is further supported by ESI technicians on site who witnessed the as-found condition of the diesel. No obstructions were identified in the piston cooling manifold and piston cooling tubes. None of the piston cooling tubes were found loose or obviously bent. The oil pump strainers were all inspected and found to be unobstructed. As this report is being written, the applications of the blanking flanges to the end of the piston cooling manifolds are being verified. Additionally, the piston cooling pump should be checked for excessive gear backlash and broken teeth.

Future preventive maintenance activity should include the following practices: continued trending of lube oil analysis, continued operation with approved zinc-free lubricating oil per EMD Maintenance Instruction 1760, and lead wire piston-to-cylinder head clearance checks at twenty-four month intervals.

Reducing the frequency of a temporary oil starvation condition, particularly in fast-start applications, will minimize the possibility of this type of damage. EMD encourages the installation of the Critical Start Lube Oil Modification described in detail by Maintenance Instruction 9644. ESI endorses the installation of this modification for all fast-start units.

APPENDIX A

INSPECTION OF TWENTY (20) EA CARRIER INSERT BEARINGS

Overview

As part of a continued inspection of engine components, eighteen (18) power assemblies were delivered to ESI, specifically to measure the thickness of the piston carrier insert bearings. The intent was to compare the actual bearing dimensions vs. OEM acceptance criteria. The eighteen (18) bearings were inspected, along with the two (2) bearings received with the previous power assemblies. See the inspection results below. Note that some bearings were missing, or could not be removed from the piston carriers, due to the extensive displacement of bearing overlay material onto the surrounding surfaces. All dimensions are in inches.

Specimen #	Type	Position on Bearing Shell							
		1	2	3	4	5	6	7	8
87360-1	Fork	0.153	0.152	0.151	0.152	0.151	0.152	0.151	0.151
87360-2	Fork	0.151	0.151	0.151	0.150	0.151	0.150	0.149	0.150
87360-3	Fork	0.151	0.162*	0.152	0.151	0.151	0.151	0.151	0.152
87360-4	Fork	0.152	0.150	0.150	0.151	0.150	0.151	0.151	0.150
87360-5	Blade	0.151	0.149	0.149	0.151	0.151	0.150	0.150	0.151
87360-6	Blade	0.152	0.151	0.150	0.151	0.151	0.151	0.150	0.150
87360-7	Blade	0.153	0.150	0.152	0.152	0.150	0.151	0.151	0.150
87360-8	Blade	0.150	0.149	0.151	0.151	0.152	0.150	0.151	0.150
87360-9	Blade	0.151	0.151	0.150	0.150	0.152	0.151	0.151	0.152
87360-10	Fork	0.151	0.151	0.151	0.151	0.152	0.152	0.152	0.151
87360-11	Blade	0.149	0.150	0.150	0.150	0.151	0.150	0.149	0.151
87360-12	Blade	0.153	0.150	0.150	0.151	0.150	0.154	0.153	0.153
87360-13	Fork	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
87360-14	Blade	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
87360-15	Fork	-	-	-	-	-	-	-	-
87360-16	Blade	0.152	0.152	0.150	0.151	0.152	0.152	0.151	0.151
87360-17	Fork	0.150	0.150	0.152	0.150	0.151	0.150	0.152	0.151
87360-18	Fork	0.149	0.150	0.149	0.150	0.150	0.152	0.149	0.151
87360-19	Fork	-	-	-	-	-	-	-	-
87360-20	Blade	0.151	0.149	0.150	0.150	0.151	0.150	0.151	0.152

Notes

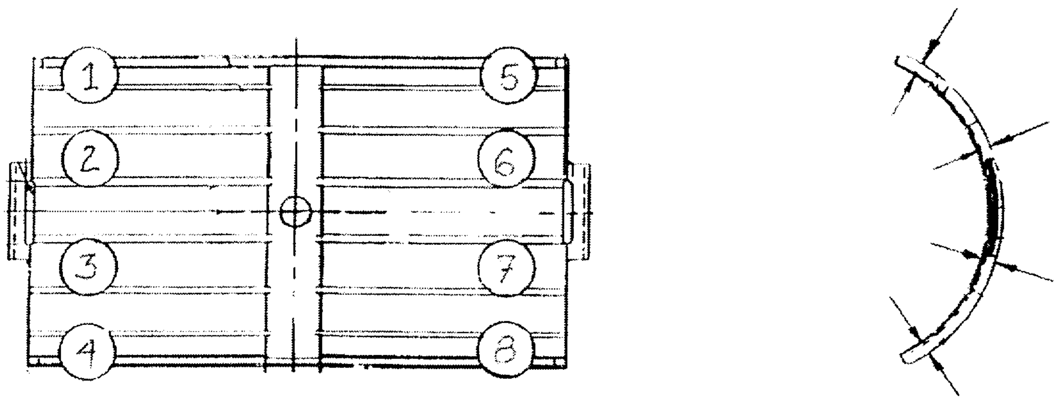
New carrier insert bearings have a thickness of 0.150-0.151"

0.162 reading at position 2 on 87360-3 was due to damage during bearing removal

No bearings were provided to ESI for 87360-13 and 87360-14.

Bearings could not be removed from carriers for 87360-15 and 87360-19.

See sketch below for location of measurements.



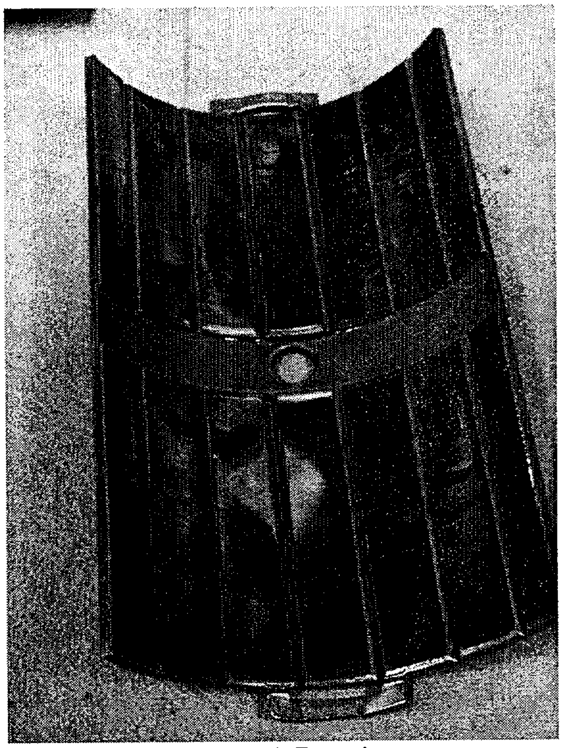
Position of Measurement on Bearing Shell

Observations

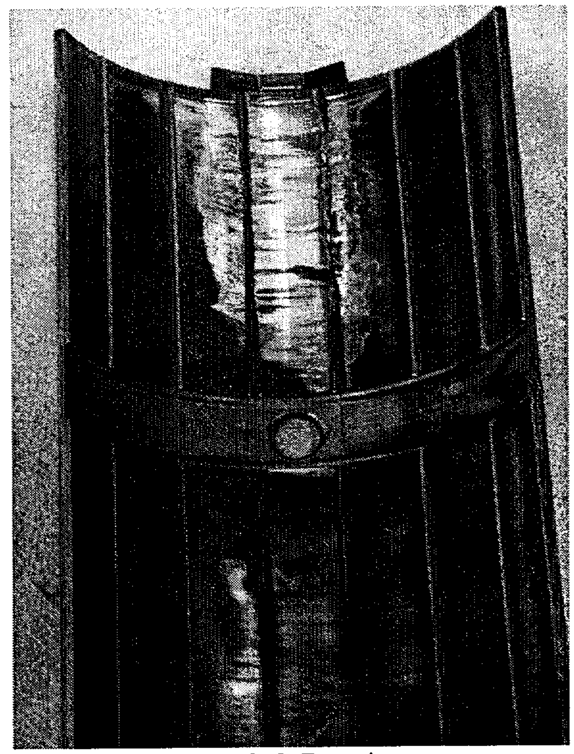
The following visual observations were made of each specimen's bearing and piston pin:

Specimen #	Description
87360-1	Bearing - discoloration, polishing, dirt scratches, distressed oil channel edges, pin – distressed oil channel edges
87360-2	Bearing – heavy distress, overlay displacement blocking oil channels, pin – slight distress
87360-3	Bearing – minor distress, pin – minor distress
87360-4	Bearing – distress visible at outboard edge, pin – distress visible at outboard edge
87360-5	Bearing – heavy distress, heat discoloration, overlay displacement blocking oil channels, pin – heavy distress
87360-6	Bearing - mild distress, dirt scratches, pin – OK
87360-7	Bearing – minor distress, pin – OK
87360-8	Bearing – minor distress, pin – OK
87360-9	Bearing – minor distress, pin – OK
87360-10	Bearing – minor distress, overlay appears mottled as if beginning to dissolve, pin – OK
87360-11	Bearing – heavy distress, pin – heavy distress, scratches, mirror finish damaged
87360-12	Bearing – minor distress, pin – OK
87360-13	Not available
87360-14	Not available
87360-15	Bearing – heavy distress, pin – major distress
87360-16	Bearing – minor distress, pin – OK
87360-17	Bearing – heavy distress, overlay displacement blocking oil channels, pin – heavy distress, mirror finish damage, heat discoloration
87360-18	Bearing – medium distress, pin – medium distress, mirror finish damage
87360-19	Bearing – heavy distress, overlay displacement blocking oil channels, pin – heavy distress
87360-20	Bearing – minor distress, pin – OK

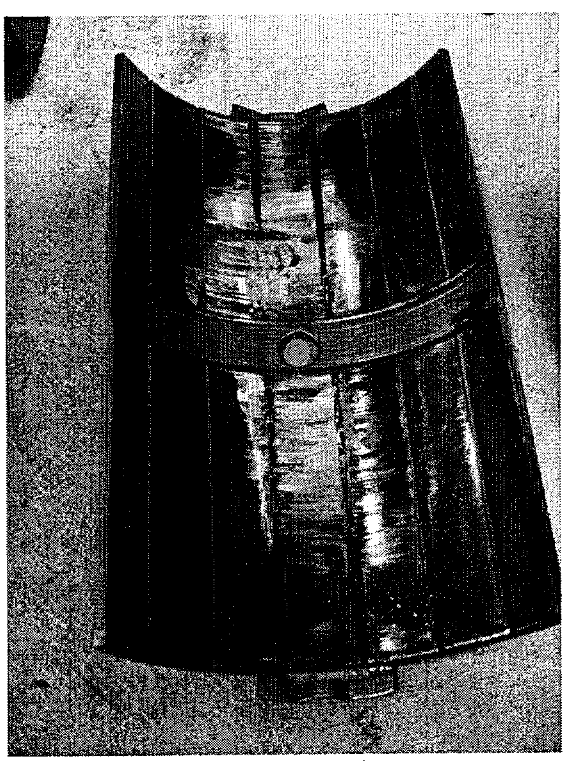
Photos of some of the specimens follow.



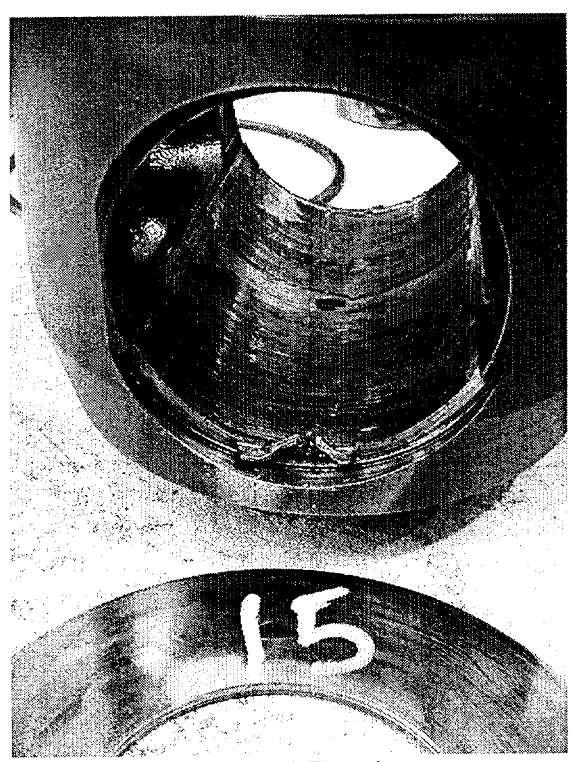
87360-1 Bearing



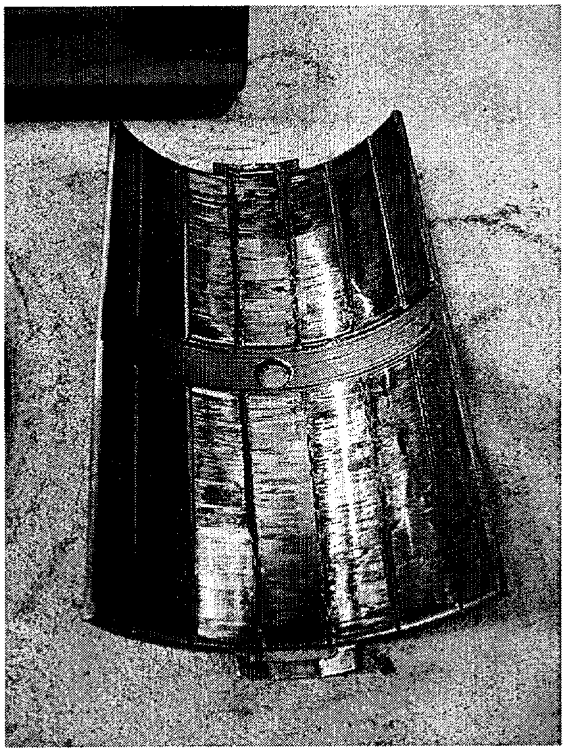
87360-2 Bearing



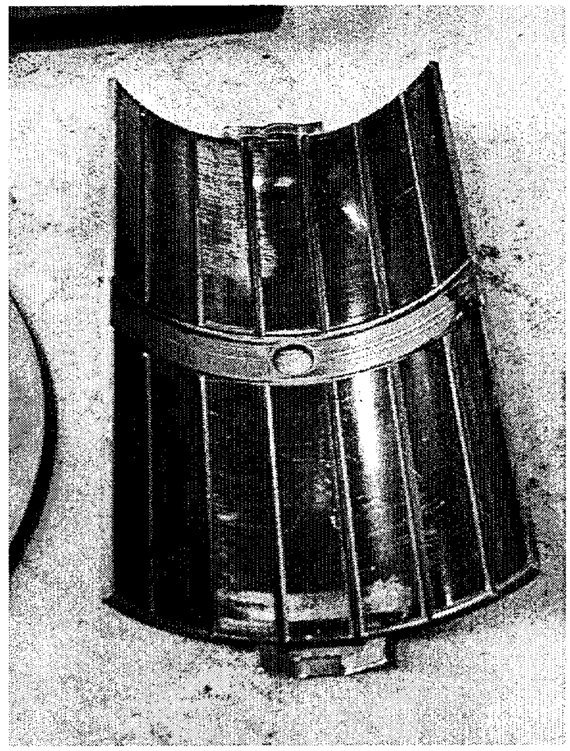
87360-5 Bearing



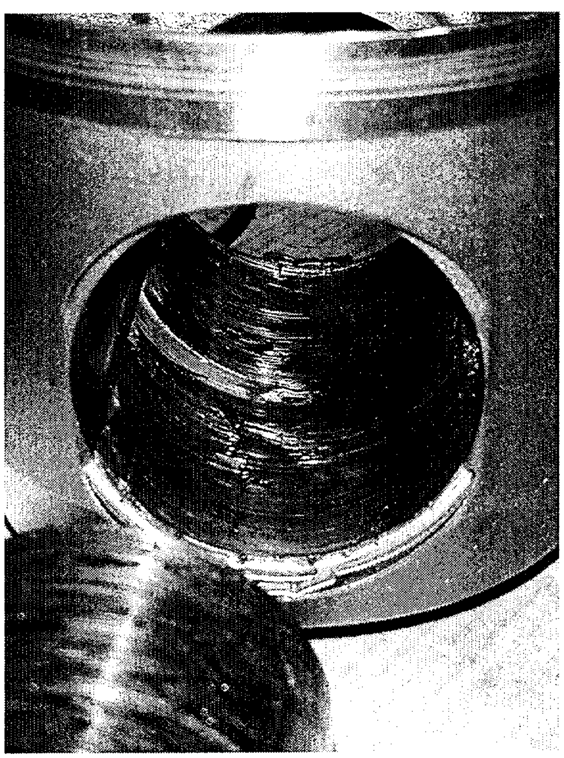
87360-15 Bearing



87360-17 Bearing



87360-18 Bearing



87360-19 Bearing

The overall condition of the inspected parts indicates some distress at every cylinder location. This further reinforces earlier conclusions that the damage was not due to components such as individual piston cooling tubes, but was rather an overall condition of the engine. All cylinder positions were found either in a failed condition or trending towards failure.

In addition to previous recommendations concerning preventive measures, ESI recommends a thorough review of past lube oil analyses be made by the site to ensure that no zinc enriched lubricating oils were utilized in this engine. ElectroMotive Division's acceptance criteria for zinc content in lubricating oils is no more than 10 ppm.

One possible explanation for the observed damage, is the past presence of a high zinc oil. The silver surfaces of the carrier insert bearings would have been sacrificial elements in the presence of zinc. This may have led to the premature failure of the silver surface, which was evidenced in the increasing trends of silver found in subsequent lube oil analyses.

The displacement of the silver surface, would have then began to block the lubricating oil channels of the bearing surface, thereby preventing normal oil flow through the bearing/pin interface. Consequently, oil temperatures in this highly loaded area would have begun to increase, with more material being displaced over time. The addition of fast engine starts without the benefit of full oil pressure, would only exacerbate the problem under the above stated conditions.

Conclusion

While the root cause of failure of these power assemblies may not be fully explained, it is the opinion of ESI that the presence of failing and failed components throughout the engine indicates a lubricating oil issue. The presence of increasing silver levels over time in the lubricating oil analyses serve as evidence of a developing problem. If the cause was related to a zinc enriched oil, it is possible that the damage occurred with only 1 oil change, and that while subsequent oils may have met the EMD criteria, the damage was already done.

As stated previously, ESI recommends continuing trending of the lube oil via laboratory analysis, comprehensive engine airbox inspections per standard procedures including lead-wire readings, and installation and operation of a full lube oil mod per EMD M.I. 9644. In addition, all oils used in these engines must meet the requirements of EMD M.I. 1760 including zinc specifications and testing for silver lubricity.

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EMD Electro-Motive Authorized Distributor

ORIGINAL
When Stamped in Blue

REPORT NUMBER 90342-FA

REVISION NO: 0

August 15, 2001

FAILURE ANALYSIS
FOR (10) TEN
POWER ASSEMBLY, FORK ROD
EMD P/N 8470863
& (10) TEN
POWER ASSEMBLY, BLADE ROD
EMD P/N 8470864

FOR

Dominion Virginia Power, Surry Power Station
Emergency Diesel Generator No. 1

Engine Systems Inc. Work Order 90342

Prepared By:	[signature]	15AUG01 Date
Reviewed By:	[signature]	15 Aug 01 Date
Approved By:	[signature]	8/15/01 Date

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Quality Performance With Pride

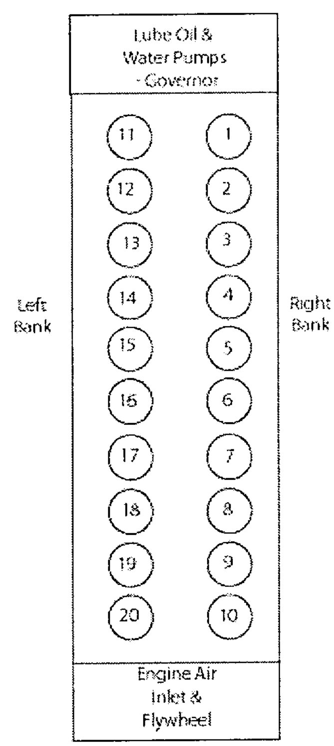
REV	DATE	PAGE	PARA	DESCRIPTION
0	8/15/01	ALL		ORIGINAL ISSUE

Overview

Surry Power Station has recorded increasing silver levels in the engine lubricating oil on their safety-related emergency diesel generators. The cylinder power assemblies include wrist pin bearings (insert bearings) containing a silver substrate beneath a lead-tin overlay. Increased silver levels in the lubricating oil may indicate a problem with bearing degradation. As part of an ongoing investigation, these twenty (20) power assemblies from Surry's No. 1 emergency diesel generator were delivered to ESI for disassembly, visual inspection, and a dimensional inspection of the insert bearings. John Rosenberger (Dominion Virginia Power) and Joe Swartz (Trident Engineering) witnessed the disassembly and visual inspections. Kevin Broussard (ESI) and Robin Weeks (ESI) performed the dimensional inspections. This work was performed in accordance with Dominion purchase order number 70012819.

Inspection

Each carrier insert bearing was given a specimen number. Later, Surry provided instructions as to the cylinder number where each specimen originated from in the engine. The connecting rods were inspected for the presence of an identifying cylinder number and recorded in the dimensional table below. The relative position of each power assembly can be determined from the following diagram. All left bank power assemblies are "fork rod" and all right bank power assemblies are "blade rod" in a left-hand rotation engine.

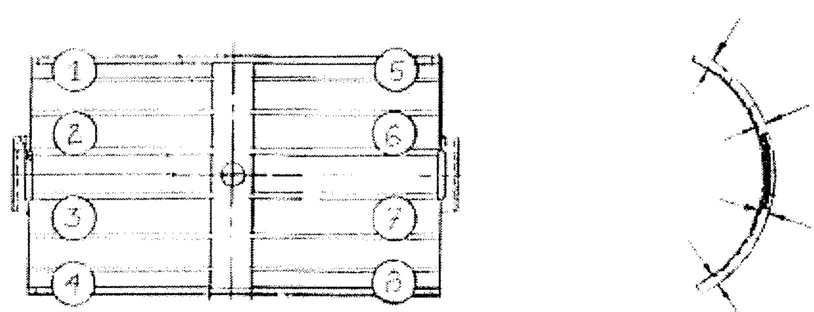


Cylinder Arrangement – EMD 20cyl engine

The (20) bearings were dimensionally inspected. See the inspection results below. Note that some bearings could not be removed from the piston carriers, due to the displacement of bearing overlay material onto the surrounding surfaces. All dimensions are in inches.

Specimen #	Type	Cylinder	Position on Bearing Shell							
		Position	1	2	3	4	5	6	7	8
90342-1	Blade	7	0.151	0.150	0.151	0.156	Bearing could not be fully removed from carrier			
90342-2	Blade	2	0.151	0.150	0.151	0.151	0.151	0.150	0.150	0.151
90342-3	Fork	12	0.150	0.150	0.150	0.150	0.150	0.151	0.150	0.151
90342-4	Fork	17	0.151	0.150	0.151	0.150	0.151	0.151	0.151	0.152
90342-5	Blade	10	0.151	0.151	0.151	0.151	0.150	0.150	0.150	0.151
90342-6	Fork	20	0.150	0.150	0.149	0.150	0.150	0.149	0.151	0.151
90342-7	Blade	3	0.151	0.151	0.150	0.151	0.150	0.150	0.151	0.151
90342-8	Fork	13	Bearing returned to Surry							
90342-9	Fork	18	0.152	0.151	0.149	0.151	0.150	0.151	0.150	0.151
90342-10	Blade	8	Bearing could not be removed from carrier							
90342-11	Fork	11	0.151	0.150	0.150	0.151	0.150	0.151	0.150	0.150
90342-12	Blade	1	0.151	0.151	0.150	0.150	0.151	0.151	0.150	0.150
90342-13	Blade	9	0.150	0.154	0.149	0.150	0.150	0.151	0.150	0.150
90342-14	Blade	5	0.150	0.170	0.162	0.150	0.152	0.151	0.151	0.151
90342-15	Fork	15	0.150	0.150	0.151	0.150	0.151	0.150	0.151	0.155
90342-16	Fork	19	0.150	0.151	0.151	0.151	0.151	0.151	0.151	0.150
90342-17	Fork	14	0.150	0.151	0.151	0.151	0.151	0.150	0.149	0.149
90342-18	Fork	16	0.152	0.150	0.151	0.151	0.150	0.150	0.150	0.149
90342-19	Blade	6	0.149	0.149	0.150	0.151	0.150	0.151	0.149	0.150
90342-20	Blade	4	0.150	0.151	0.150	0.151	0.151	0.151	0.151	0.152

Notes
New carrier insert bearings have a thickness of 0.150-0.151"
All initial measurements of these bearings were later discovered to be incorrect, and all available bearings were remeasured. 90342-8 could not be remeasured because it had been returned to Surry.
M&TE data: Mitutoyo 6" caliper, ESI s/n 2511, last calibration on 7/3/01, next calibration due on 12/30/01.
See sketch below for location of measurements on the bearing shell.



Position of Measurement on Bearing Shell

Comparison to Unit 3 Insert Bearings

The carrier insert bearings' average thickness over all of the measurements taken was 0.151". This is the same average thickness as from those removed from the unit 3 diesel generator.

The physical appearance of these bearings was better than from unit 3. As will be discussed below, there were eight (8) bearings in this engine that exhibited some blockage of lubricating oil channels, even if only slight. In the unit 3 engine, there were (5) bearings that exhibited blockage. However, the severity of the blockage in the unit 3 components was much greater than in the unit 1 components. While there was only (1) bearing in the unit 1 components that was condemned (specimen 90342-10), of the 18 sets of components that were inspected from unit 3 there were (5) bearings that showed catastrophic failure.

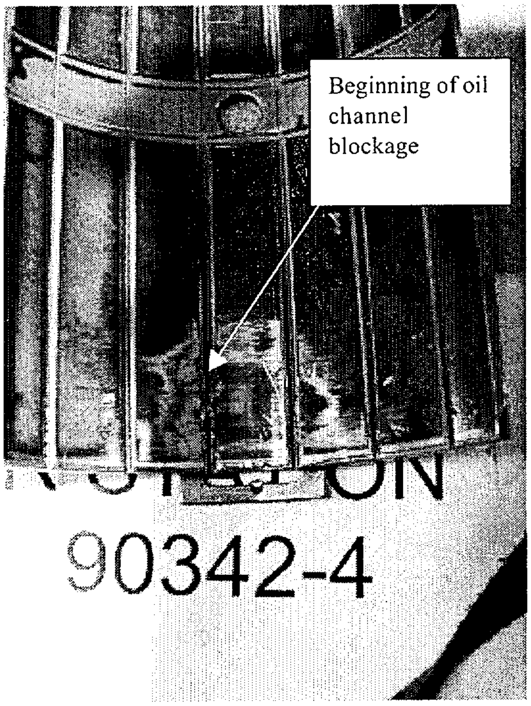
Visual Observations

The following visual observations were made of each specimen's piston carrier insert bearing, piston pin, thrust washer and piston carrier:

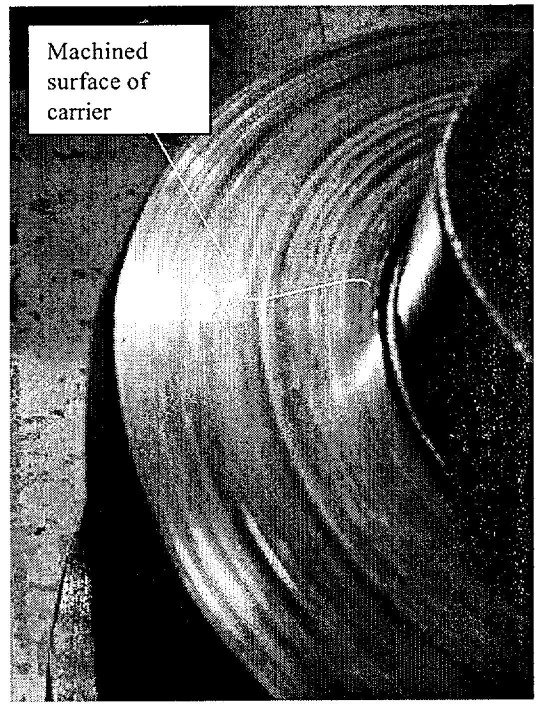
Specimen #	Description
90342-1	Bearing – minor distress, some polishing, all oil channels open, Pin – Sat, Thrust Washer has a significant wear step, Piston Carrier – Sat
90342-2	Bearing – some polishing, all oil channels open, Pin – Sat, Thrust Washer – wear step, Piston Carrier – Sat
90342-3	Bearing – some polishing, all oil channels open, Pin – Sat, Thrust Washer – wear step, Piston Carrier – Sat
90342-4	Bearing – distressed, 1 oil channel 80-90% blocked, another oil channel at beginning stages of being blocked, Pin – Sat, Thrust Washer – Sat, Piston Carrier – Sat
90342-5	Bearing – some polishing, minor distress, all oil channels open, Pin – Sat, Thrust Washer & Piston Carrier exhibit a significant number of circular grooves across the mating surface
90342-6	Bearing – distressed, 1 oil channel 50% blocked, another oil channel 30% blocked, Pin – Sat, Thrust Washer – slight wear step, Piston Carrier – some circular grooves present
90342-7	Bearing – some polishing, all oil channels open, Pin – Sat, Thrust Washer & Piston Carrier exhibit some circular grooves
90342-8	Bearing – some polishing, some material displacement beginning to enter an oil channel, Pin – Sat, Thrust Washer – wear step and circular grooves, Piston Carrier – some circular grooves
90342-9	All components – Sat
90342-10	Bearing – Catastrophic damage, all oil channels blocked, Pin – Catastrophic, Thrust Washer – wear step, debris scratches, Piston Carrier – Sat w/some debris scratches
90342-11	Bearing – some polishing, all oil channels open, Pin – Sat, Thrust Washer – some debris scratches, Piston Carrier – Sat
90342-12	Bearing – some distress, beginning of material displacement, all oil channels open, Pin/Thrust Washer/Piston Carrier – all Sat
90342-13	Bearing – polishing, 1 oil groove beginning to be blocked, some material displacement, Pin – Sat, Thrust Washer – wear step, Piston Carrier – Sat

90342-14	Bearing/Pin/Piston Carrier – Sat, Thrust Washer has a wear step
90342-15	Bearing – some polishing, all oil channels open, Pin – Sat, Thrust Washer & Piston Carrier exhibit a significant number of circular grooves across the mating surfaces
90342-16	Bearing – some polishing, 1 oil groove beginning to be blocked, Pin – Sat, Thrust Washer – wear step, Piston Carrier – Sat
90342-17	Bearing – polishing present, all oil channels open, Pin – Sat, Thrust Washer & Piston Carrier have 1 heavy groove apparently from a debris scratch
90342-18	Bearing/Pin/Piston Carrier – Sat, Thrust Washer has a wear step
90342-19	Bearing – distressed, heavy polishing, 1 oil channel 50% blocked, 1 oil channel 25% blocked, Pin – Sat, Thrust Washer – wear step, Piston Carrier – Sat
90342-20	Bearing – polishing, 1 oil channel beginning to exhibit blocking from displaced material, Pin – Sat, Thrust Washer – wear step, Piston Carrier – Sat

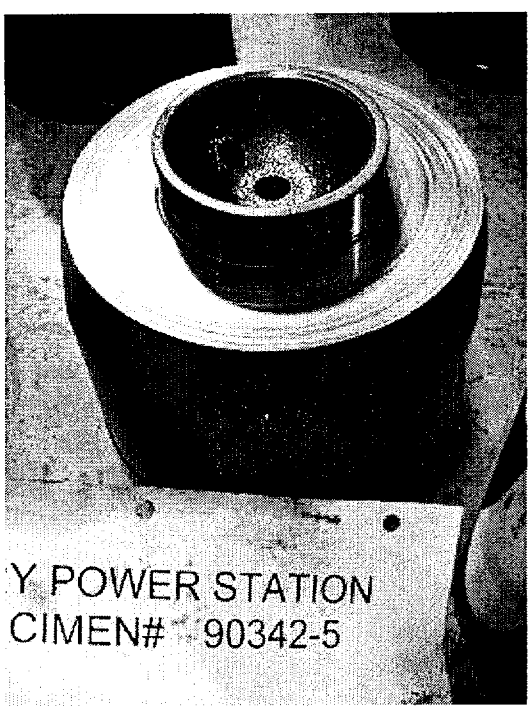
Photos of some of the specimens follow.



90342-4 Bearing

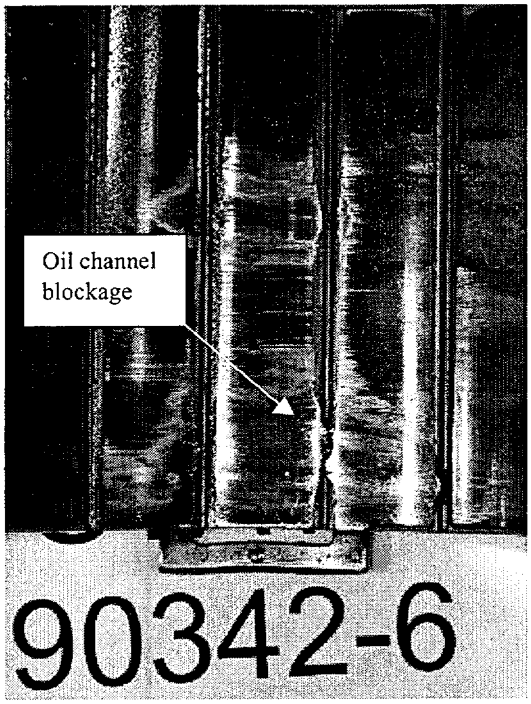


90342-5 Carrier detail

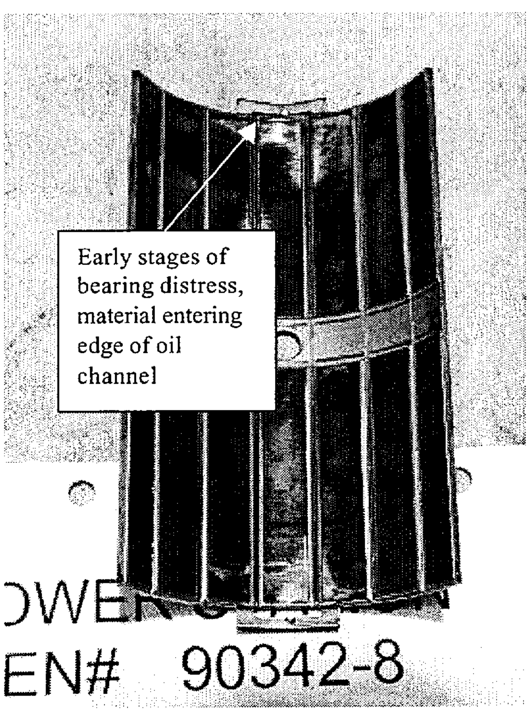


90342-5 Carrier

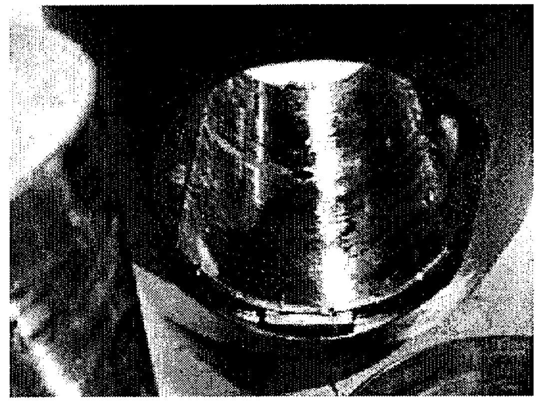
90342-6 Bearing



90342-6 Bearing detail

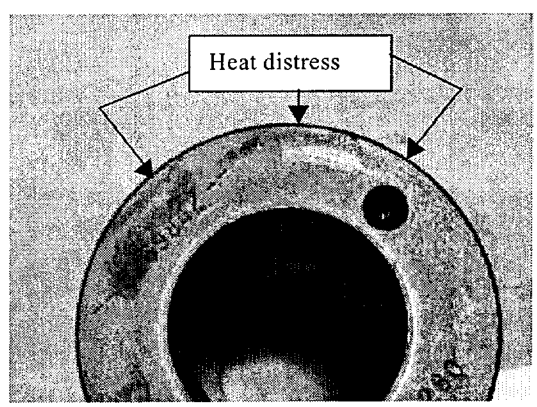


90342-8 Bearing



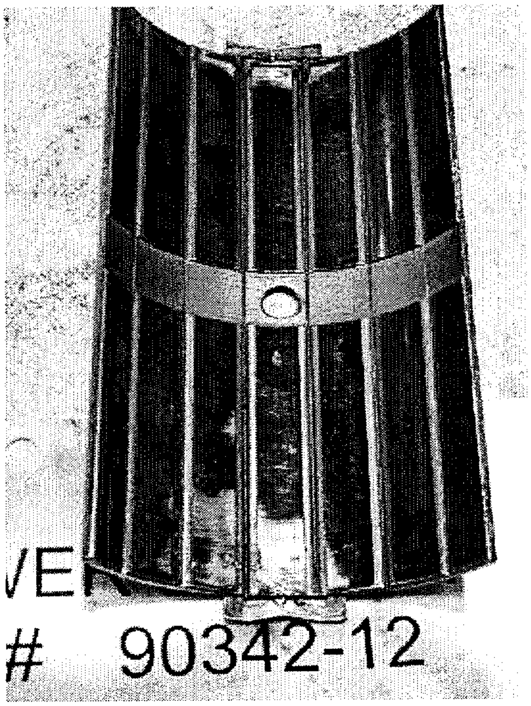
90342-10 Bearing in Carrier

90342-10 Bearing detail

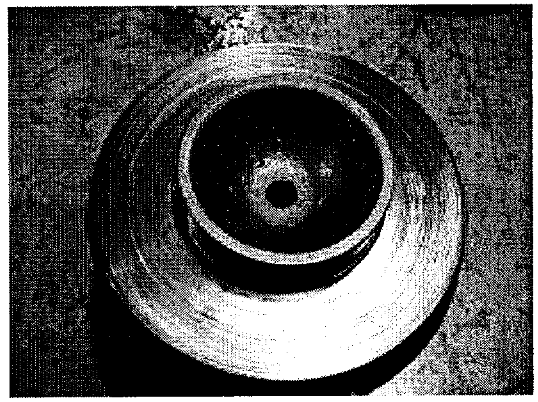


90342-10 Pin

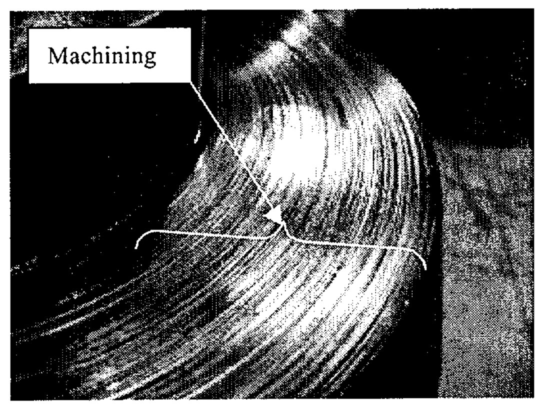
90342-10 Pin



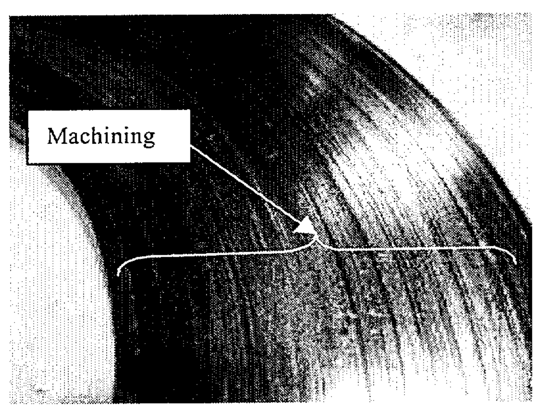
90342-12 Bearing



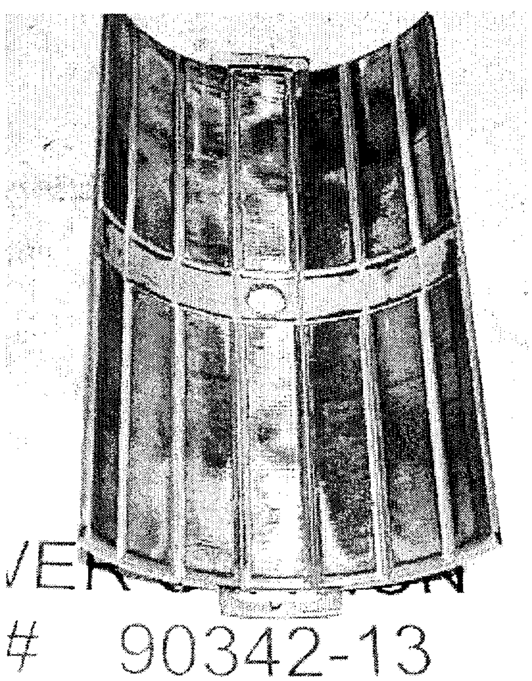
90342-15 Carrier



90342-15 Carrier detail

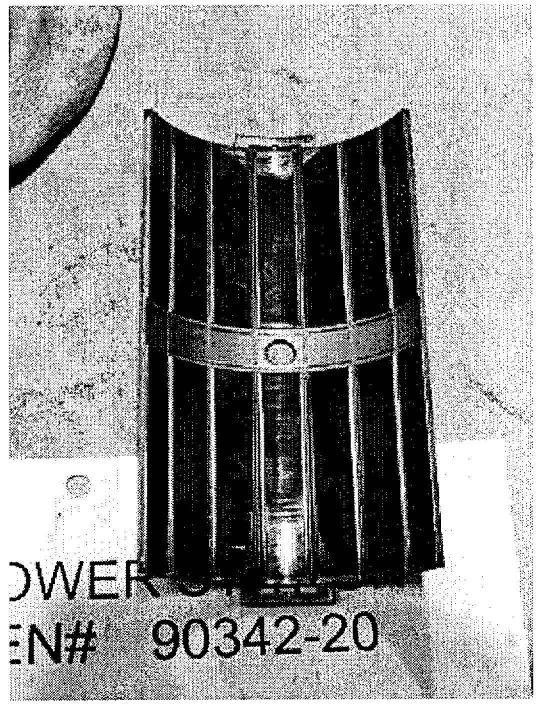


90342-15 Washer detail



90342-13 Bearing

90342-19 Bearing

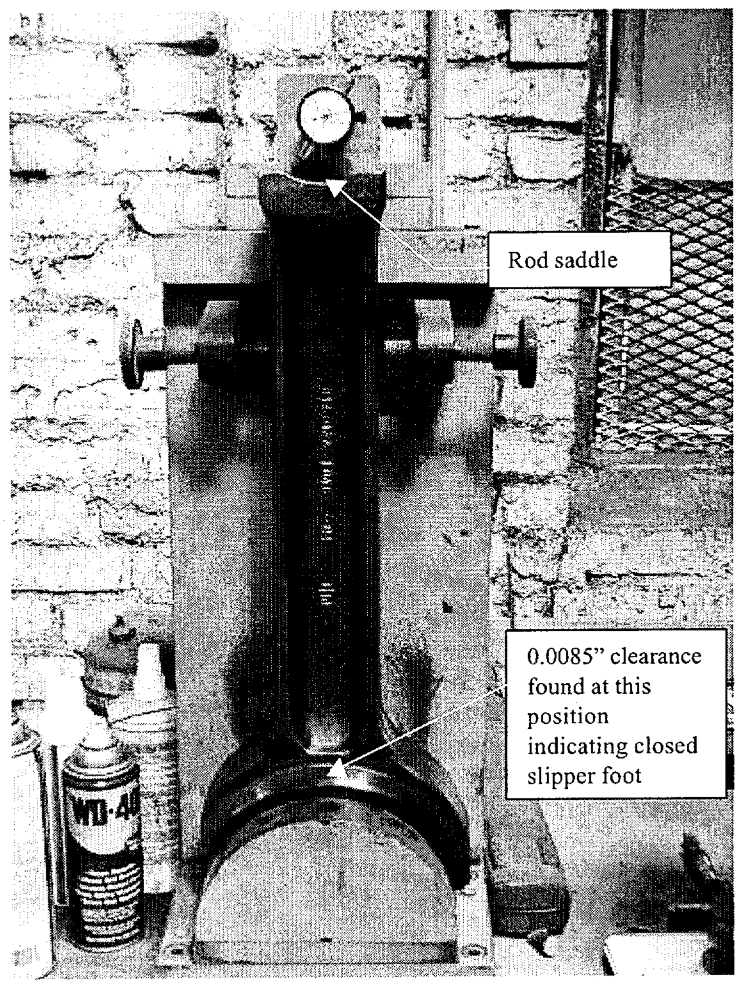


90342-20 Bearing

The connecting rod from specimen 90342-10 indicated some distress to the bearing surface. Surry personnel questioned the condition of the rod. This rod plus several others picked at random were inspected, with the results provided below:

Specimen #	Type	Acceptable	Notes
90342-4	Fork	Yes	
90342-6	Fork	Yes	
90342-10	Blade	No	The slipper foot (load bearing surface) was found out of tolerance, i.e. it was closed in which showed a 0.0085" clearance at the top of the radius. The acceptance criteria is 0.007" maximum. The slipper foot surface showed visible distress, as well as a wear step at the main oil channel.
90342-18	Fork	Yes	
90342-19	Blade	No	The rod saddle was found to be out of parallel by 0.0045". The maximum out of parallel dimension is 0.004"

M&TE data: Starrett dial indicator, ESI s/n 3440, last calibration on 7/5/01, next calibration due on 1/1/02.



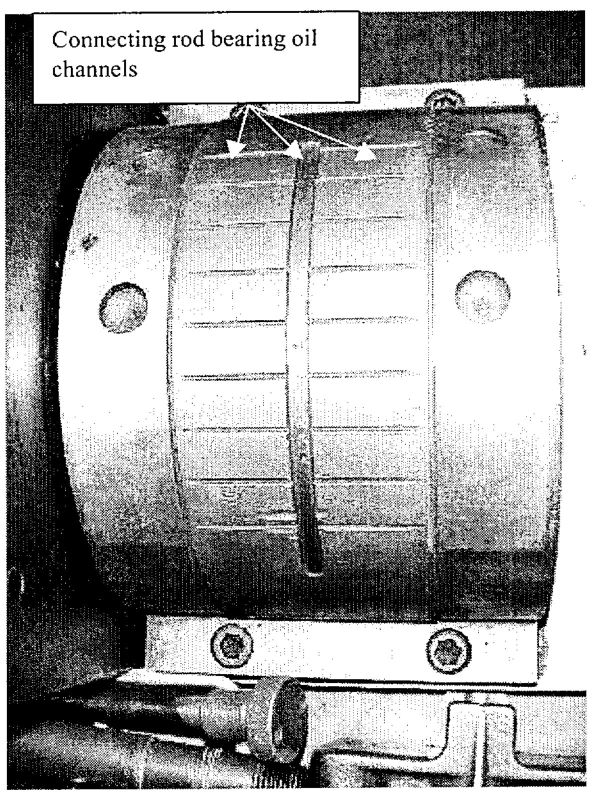
90342-10 Rod on Measurement Fixture

In addition to slipper foot dimensions, the rods were checked for twist and parallelism of the saddle as well as overall rod length. They met all criteria with the exception noted above for specimen number 19.

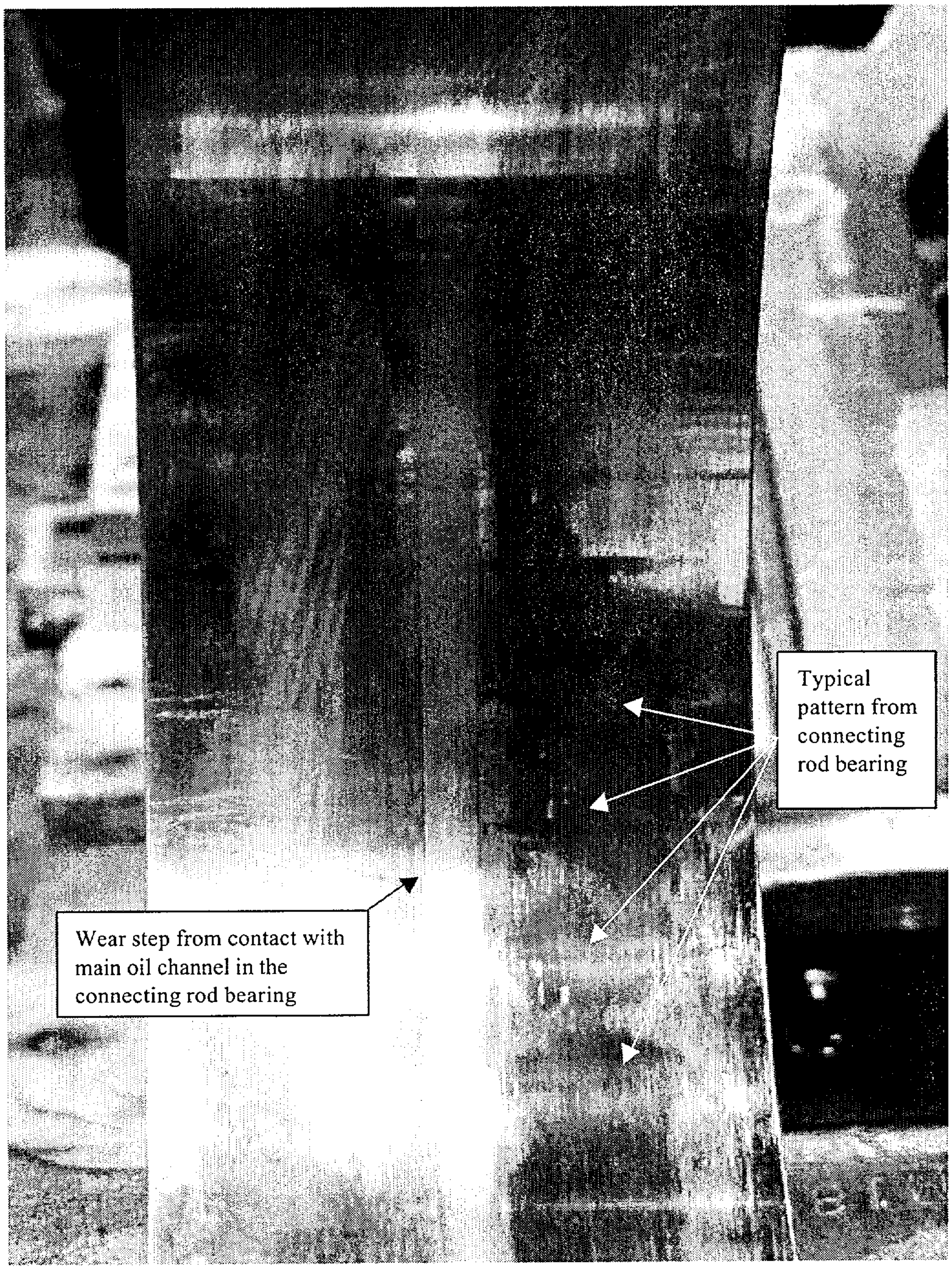
According to the EMD engine maintenance manual, "The glazed finish and the bearing pattern oil stain usually found on the blade rod slipper surface is considered normal..." As can be seen on the photograph that follows, the slipper surface of specimen 90342-10 includes a pattern matching the back side of a typical connecting rod upper bearing shell. However, considerable scuffing of the slipper surface is evident, as well as an abnormal wear step from contact with the main oil channel in the bearing.

It is ESI's opinion that the scuffing and wear are results from the previous damage to the piston carrier insert bearing found in this cylinder. As the bearing and piston pin wear increased to the catastrophic damage found in this cylinder, it is likely that heavy loading/unloading cycles occurred in this cylinder. The clearances in the piston pin to insert bearing were such that each combustion cycle pounded the piston carrier assembly down onto the pin. These forces were transferred through the rod to the slipper surface/connecting rod bearing interface. The normal oil film that is present between the slipper surface and the bearing was being pushed out of the space, with the result being higher impulse pressures and higher oil temperatures in that zone. This is evidenced by the wear step in the slipper surface and by the abnormal scuffing.

In contrast, all of the other (9) blade rod slipper surfaces from this engine were found to be normal, with a mirror-like finish. The normal pattern of connecting rod bearing channels could be seen on the surface of the slippers, but they could not be felt.



Typical Connecting Rod Bearing Upper Shell
(from ESI training center stock)



90342-10 Rod Slipper Foot

Conclusion

The damage identified in specimen 90342-10 is consistent with failures resulting from lack of lubrication. The failed insert bearing and distressed piston pin appear to be directly related to lube oil starvation. The connecting rod from this cylinder is also condemned as a result of the damage to the carrier insert bearing.

As seen in previous inspections, the condition of the insert bearings appears to be a degrading one. Some bearings exhibit fairly normal wear consisting of minor abrasions and/or light scuffing. Others exhibit more prominent scuffing marks, with some beginning to show lead-tin overlay migration into the oil channels. The more severely distressed bearings show oil channel blockage ranging from 30%-100%, with the worst case being the number 10 specimen which was completely destroyed from an oil cooling perspective.

As stated in the previous report, the displacement of the silver surface would have begun to block the lubricating oil channels of the bearing surface, thereby preventing normal oil flow through the bearing/pin interface. Consequently, oil temperatures in this highly loaded area would have begun to increase, with more material being displaced over time. The addition of fast engine starts without the benefit of full oil pressure would only exacerbate the problem under the above stated conditions.

With a bearing in the catastrophic state found in specimen 10, the concern would be that oil temperatures in that localized region would be rapidly increasing, with little or no lubricating oil present between the piston pin and the insert bearing. Resultant damage to the connecting rod/bearing interface would also trend towards failure. Metal temperatures would likewise increase as was indicated by the bluing marks found on the piston pin. Continued operation at the high temperatures present could lead to piston pin to bearing seizure, catastrophic failure of the power assembly, and a potential to ignite the crankcase vapors (crankcase explosion).

The attached report is hereby submitted, including results of the investigation complete with appropriate findings and professional opinions and conclusions found to bear upon the indicated subject.

Prepared by

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EMERGENCY DIESEL GENERATORS
SUPPORT SERVICES
SURRY POWER STATION
VIRGINIA ELECTRIC AND POWER
CONTRACT NO. PR-CU0012-000

Trident Contract No. 918-007

October 3, 2001

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INTRODUCTION

On May 30, 2001, Trident Engineering Associates, Inc., (Trident) was authorized to conduct a three-part assignment to (1) provide a fresh and independent look at the adequacy of the lube oil system for Surry Power Stations (SPS) Emergency Diesel Generators (2) determine why sometimes the lube oil temperature for the No. 2 engine is low enough to trigger the alarm and (3) determine if the limit for silver in the lube oil (2ppm) is reasonable. A fourth assignment was authorized on June 4, 2001 to assess the differences between Amoco Super Diesel 13 and Chevron DELO 6170 SAE 40 engine oils. An additional task (8/13/01) requested that Trident determine whether there would be a compatibility problem if small quantities (2 to 2-1/2%) of Chevron DELO 6170 were mixed with Mobilgard 450 NC. (This report is not presented in the above order, but rather so that the inter-relationships flow together.)

This study was assigned to William Henderson, Trident's President, Harry Halliwell, P.E., and Joseph I. Schwartz, P.E.

BACKGROUND

The three emergency diesel generators at (SPS) have performed satisfactorily for a number of years with no apparent wrist pin bearing problems. Recently on engines number 1 and 3 increased levels of silver have been detected in lube oil (L.O.) samples after test runs, especially in No. 3 (the only locations of silver are in the wrist pin bearings and turbocharger bearings). The only test possible in the unassembled condition were a "feel test" and a lead wire test. It was initially reported to Trident that these tests indicated a problem in the No. 3 engine wrist pin bearings for cylinders No. 12, 15 and 16. Upon overhaul and removal and inspection of all power packs, these bearings were found to be damaged in the extremis. In later examinations, the wrist pin bearings for all other cylinders were found to be distressed to some extent as noted later in this report.

The No. 2 EDG set has developed a history of low oil temperature alarms during standby. A minimum oil temperature is required to ensure adequate lubrication during emergency starts as required by Surry Technical Specifications. In addition, there appears to be a disparity in the operating conditions between the oil temperature controls among the three sets.

Concerns resulting from the above developments resulted in the decision to assign the investigation noted above to Trident.

INVESTIGATION AND ANALYSIS

Trident met with Mr. Joseph A. DeMarco and his staff at the SPS Nuclear site to discuss the nature of the problems and a history of the operation of the three EMD 645 Emergency Diesel Generators. This initially involved a tour of engine room spaces with Mr. Charles Silcox who explained the engine operating procedures and presented a general overview of engine standby requirements necessary to provide emergency service within 10 seconds for the SPS. The tour was followed with a detailed group discussion that involved all pertinent plant personnel who were cognizant in the problem area. A major review of the Category 2 Root Cause Evaluation dated May 23, 2001 was the main subject of discussion, particularly the oil analysis program in place to monitor and ensure proper engine operation based on monthly crankcase sampling. The sampling procedure as described appeared to be customary and proper and should produce accurate and consistent engine trend analysis results. However, this procedure measures only wear debris that is "in suspension" as particles that are small enough to "float" in the oil sump during or shortly after engine shut down. Larger particles sink to the bottom and are not accounted for in the oil analysis.

Based on this meeting and subsequent telephone conversations with Mr. Charles Silcox and other SPS people, Trident reviewed the Root Cause Evaluation, ESI Laboratory Report on No. 2 engine plus Oil Analysis, Vibration Data, and lube oil temperature history, on all three engines, and the Maintenance History Time Line.

Various other contacts were made with organizations such as EMD, Chevron, NRC and ESI personnel to establish a background for addressing the four subject assignment areas.

ADEQUACY OF LUBRICATION SYSTEM

In order to determine the adequacy of a lubrication system, two things need to be defined. First, the component parts of the system and second the ability of the lubricant to perform its intended function. For the purposes of this report, the component parts of the lube oil system shall include all of the components which heat, cool, pump, store, filter, and control or limit any of these items. The ability of the lubricant to perform its intended function, all other things being equal, shall be the ability to generate and maintain an oil film thickness which prevents metal to metal contact of the rotating, oscillating, and reciprocating parts within the engine and all other associated parts of the lube oil system. Use of this definition also permits the inclusion of the circulating oil system which maintains the engine at or above the minimum temperature required for fast starts.

If one considers the operating history of these engines using Amoco oils, then, in Trident's opinion, the engine lube oil system is adequate for its intended purpose. An analysis of the Emergency Diesel Generator Maintenance Timeline reveals that the last power pack change outs on these engines occurred in the 1986 to 1989 time frame. During this period of operation, Amoco oil was the engine lubricant of

choice. Review of a Surry graphic, Emergency Diesel Generator Lube Oil Results, reveals that from the period commencing in July 1998, and probably earlier, the suspended silver levels in the lube oil remained constant at about 0.15 parts per million. The lack of variation of silver concentration is an indicator, therefore, of normal engine wear and tear between oil changes. No evidence was provided regarding the presence of larger silver particles in the oil filters or the engine sumps. Hence, It is Trident's opinion that the use of Amoco oil in these engines resulted in adequate lubrication over a long time of use.

The data for these engines since the changeover to Chevron oil, as evidenced in the lube oil results graphic, shows that the suspended silver levels increased significantly in two of the three engines. While this result is based on questionable statistical samples (3 units) of the engine/oil combination, it is certainly significant to Surry. Other data obtained by Trident indicates that this model engine is very successfully used in the railroad and river boat towing industry using the same Chevron oil. (These applications involve engines without a fast-start requirement.) In these industries, the EMD 645 engine thrives on the use of Chevron.

The difference between these industries and the SPS engines is the fast start requirement for the SPS engines. Fast start procedures require these engines to start, come up to speed and begin to provide increasing amounts of electrical power within 10 seconds of startup. In addition, standby engines sit idle up to one month creating an oil retention problem.

We must consider in detail the conditions under which the oil must perform its intended function during a fast start. The engines as currently used in reactor plants sit idle for periods as long as a month with only sufficient oil circulating to keep the engine at or above 95 degrees F., generally in the amount of 6 gpm. Oil film adhesion to silver bearing surfaces is a concern for "fast-start" standby engine operations. The following is taken from the DOE Backup Power Working Group Handbook, titled Best Practices Handbook for Maintenance and Operation of Engine Generators, Vol. II: "With modern high technology oils, the concern for drying of oil films during period of standby are not what they once were. Qualitative field testing at one site has indicated that when cylinder liners were maintained in the range of 100-150°F, more than 60 days was required for the oil film to dissipate." A separate analysis of this oil system is available in another section of this report which states that Trident believes this system is not performing in a satisfactory way. In addition, that current warming system is unable to provide any lubrication to the engine wrist pins during standby. According to data provided to Trident, a period of 30 to 60 seconds after engine start is required to bring up the oil to the appropriate flow rate and pressure to the entire engine. Oil is supplied to the pistons, rings, and wrist pins through a "fountain" system. Each piston has a conically shaped cavity which, as each piston passes through bottom dead center of crank rotation covers a jet of oil flowing vertically up from a standpipe. Hence, each piston receives oil only during a very small part of the crank rotation cycle. Further, the oil pressure in the piston oil passages goes to zero as the piston starts its

journey to top dead center and ignition. This method of oil supply coupled to that lack of oil provided to the pistons during standby means that unless the oil is retained in areas such as around the wrist pins, they will be forced to operate under a boundary lubrication regime. Boundary lubrication implies metal to metal contact between rotating parts, high friction, high wear, and high temperatures perhaps in the range of the melting point of the bearing itself. If the oil does not adhere well to the mating surfaces, but is squeezed out during the periods of idleness, this will exacerbate the boundary lubrication problem. In order to ensure adequate lubrication to the wrist pin bearings during start-up, one of two actions must occur. Either copious amounts of oil at the proper temperature, pressure, and location must be supplied, or the oil itself must have the tenacity (adhesive/cohesive properties) and sufficient film strength and adhesion to offset the boundary lubrication problems present during startup. It is Trident's opinion that the piston/wrist pin lubrication system is not adequate to supply the required amount and pressure of oil needed to lubricate the pistons during start-up. Hence, this engine requires an oil with sufficient film strength and adhesion to be retained to provide start-up lubrication. The ability of an oil to remain in place during periods of standby depends upon the base stock used and the additive package in the oil. Certain oils have sufficient film strength and adhesion to remain in place during standby and reduce the severity of the startup transient boundary lubrication as noted above, and others do not. Since Amoco oils performed in a satisfactory manner for many years in a fast start application, it appears to have the requisite properties. Chevron oil has a history of

extremely satisfactory performance when used in applications of continuous operation under heavy loads. Based on an admittedly small sample size, it is Trident's opinion that Chevron oil does not have the required film strength and adhesion properties to work satisfactorily in a fast start application.

The items discussed above to aid a boundary lubrication problem are not the only consideration in determining the adequacy of a lube oil system. Consider the two ESI reports provided. Postmortem analysis of failed components especially if they are caught prior to total destruction can provide valuable insights to the operation of a mechanical system. They show evidence of boundary lubrication indicating inadequate oil supply or perhaps an unsatisfactory oil for the application. The evidence provided to Trident by these reports tends to reinforce the opinions expressed above.

An opportunity to examine the power packs removed from engine No. 1 at Surry was provided to Trident. Each piston was disassembled and visually examined. One wrist pin was scarred from metal pickup and blue from heat. Trident estimates, based on the wrist pin color, that it reached a temperature of 700 to 800 deg. F. That was sufficient to draw the temper from the wrist pin. It was scarred and gouged by metal-to-metal contact with the wrist pin bearing. The wrist pin bearing was totally destroyed. Continued engine operation would be detrimental to the engine. Pictures were taken by the Surry representative. Two other bearings showed incipient wipes and several had "swallowed" particulate matter.

The remaining 17 bearings all had minor damage and some scarring due to boundry operation. All of the bearings showed wear at the outboard ends. Their appearance was similar to the bearings removed from the No. 3 engine. Two representative wrist pins and bearings were measured and showed 0.015 to 0.020 inches diametral clearance. Several large pieces of unknown composition about 3/32 inch in diameter were found, but not identified.

Prior to this examination, Trident was of the opinion that the wrist pins were misaligned resulting in the peculiar wear patterns noted. Trident now believes that the wear pattern on the wrist pin bearing is directly connected to the flow pattern of oil through the wrist pins.

Oil is supplied to the bearing via a central hole in the bearing which is on top of the wrist pin. The oil flows circumferentially around and down the central bearing groove and thence into the several axial grooves. The reciprocating motion of the wrist pin spreads the oil radially and axailly to the sides and ends of the bearing. Hence the last part of the bearing to receive oil is the outboard end of each land. This is exactly the location of the typical wipes seen during this examination. When the engine is stopped, the oil drains out of the central and axial grooves to the crankcase.

During engine stand down, any oil remaining in the bearing will be contiguous to the oil supply hole at the center of the bearing. The driest part of the bearing is the outboard ends, resulting in boundary lubrication during startup.

Each cylinder liner was visually inspected inside and out with no visible signs of wear, misalignment or distress.

Based on the visual examination of the power packs, all present agreed that 2 ppm silver in the oil was not an adequate means of assessing wrist pin wear. If it continues to be used, the action level should be reduced to 1 ppm in the oil, and a maximum rate of increase limit below 1 ppm should be established.

NEW OIL COMPARISONS

An evaluation using EMD new oil physical and chemical properties limits and current SPS new oil data was conducted as referred to in assignment four. This comparison of the additive-type engine lubricants prescribed by EMD per Maintenance Instruction M.I. 1760 Rev. G for engines used in continuous operations is shown along with similar new oil properties of Amoco Super 13 and Chevron DELO 6170. (Note: Trident could find no evidence that EMD had tested or approved any oil for fast-start applications.)

Property	ASTM Test Designation	EMD New Oil Limits	New Amoco Super 13	New Chevron DELO 6170
Viscosity @ 100°C Centistokes	D445	(12.9 – 16.8)	14.1	14.8
Viscosity Index	D567	(60 – 100)	76	101
Flash Point (°F)	D92	420°F Min.	477°	505°
Fire Point (°F)	D92	475°F Min.	---	---
Pour Point (°F)	D97	40° Max	- 5°	- 18°
Zinc Content		10 ppm Max	1.22 to 1.97	<0.1, to 1,147
Total Base Number	D2896	(7 – 20)	13.9	17

These data show that both oils meet standards established by The Locomotive Maintenance Owners Association (LMOA) Fuels and Lubricants Committee. However, only Chevron fits the Generation 5 designation for the highest quality oil used in locomotive diesel engines. EMD people state that as many as 10,000 EMD 645 engines are produced each year. A major requirement today for these engines is that the oil must be zinc-free and chlorine free to satisfactorily lubricate the silver wrist pin bearings. This precludes the use of zinc dithiophosphate additives since the zinc additive attacks silver resulting in rapid bearing failure. EMD specifies the 10 ppm Zn limit shown above based on extensive service experience with the 645 engines. Both new oils (Amoco and Chevron) are well below this limit. LMOA guidelines based on field service in continuous operating engines in US and overseas indicate that high viscosity index (VI) lube oils are being used successfully. Amoco, a generation 3 oil, is marginal at 76 VI and contains 2000 ppm Cl whereas Chevron with 101 VI is definitely in the high VI range and is chlorine free.

The pedigree of these oils is best described in the CRC Handbook of Lubrication Volume 1, p.281-282 as follows: " . . . candidate formulations undergo an initial screening in bench tests, followed by laboratory small engine tests, and finally are run in a full scale engine. These are typified by the EMD "two-holer" test with special silver insert bearings and by the General Electric (GE) test in a full scale engine. Following such tests, the successful candidate oil is service tested in the field in a number of engines. At the end of the field test, which can be 2 years, the components of a number of power assemblies are examined, deposits evaluated, and wear measured. Selection of engines of the highest horsepower operated in the most severe service is indicated in order to obtain the clearest rating of oil performance. " (Note: This applies to continuously operating engines.)

This gives a capsule digest of the stringent requirements that each of the oils (Amoco and Chevron) must pass before it is considered by LMOA as acceptable for diesel engine service in locomotives. Both oils are high quality formulations that meet requirement limits for zinc content, viscosity and total base number (TBN). Difference shown in TBN (13.9 Amoco and 17 Chevron) above are consistent with the differences at SPS shown below. The differences in Molybdenum content (1.25 to 1.308 Amoco and 130 to 146.6 Chevron) are anti-oxidant additives added to improve wear resistance.

SPS New Oil – ppm

Chevron
DELO 6170
Generation 5

	10/20/97	6/18/98	2/16/99	1/6/00
Ca	6825/6450	5453	5801	5619
Ba	<0.1	<0.1	<0.01	<0.01
P	1.06/<0.1	<0.1	<0.01	<0.01
Zn	0.114/0.810	0.9	1.147	0.3
Mg	23.6/22.7	24.7	24.3	21.6
Si	6.0/5.3	5.6	6.2	4 spls.=12.16 2 spls.= 5.5
Na	7.62/7.8	7.7	8.3	6.0
B	0.44/0.52	0.3	<0.1	3 spls.=0.20 3 spls.=<0.01
Fe	3.8/3.4	5.65	3.9	2.7
Al	2.9/2.95	3.5	3.2	3.2
Mo	145.0/143.8	138	146.6	130
Pb	4.5/4.2	4.1	5.4	1.2

AMOCO SUPER D13 – Generation 3

	2/26/98	6/3/97
Ca	3791	3487
Ba	0.134	<0.01
P	<0.01	1 spl.= 3.223
Zn	1.97	1.22
Mg	17.4	18.2
Si	4.28	3.94
Na	4.43	4.56
B	0.85	0.88

Fe	3.4	3.45
Al	2.9	2.9
Mo	1.308	1.250
Pb	2.95	3.08

Chevron Oronite technical experts indicated that Amoco 13 uses an additive package (OLOA 2939) that was widely accepted for EMD and GE diesel engines in the early 1990's. This oil was an SAE 40 with a medium viscosity index (76 VI) and contained around 2000 ppm chlorine from a chlorinated hydrocarbon. The chlorine was added specifically to impart extra extreme pressure (EP) properties to the base oil. This extreme pressure property provides resistance to being squeezed out under static stationary contact. This was to provide extended life to the silver wrist pin bearing. Chlorine and its associated compounds have been determined to be carcinogenic. This necessitated that new chlorine-free EP additives be developed. This change resulted in the chlorine-free oils currently in use.

In 1997, after several years of product development and field tests in 6 locomotives for one year, Chevron Oronite introduced a chlorine-free additive package that was approved for use by the EMD engine people, in continuously operating engines. It should be noted that Trident could find no data indicating that EMD had approved the Chevron oil for fast-start applications. The reformulated oil, although called chlorine free, contains usually less than 10 ppm Cl due to residual Cl from other additive processes. The new additive package (OLOA 2000) as used in Chevron DELO 6170 has passed EMD Method Number L0 201 Silver Corrosion Test. This

test is used to detect whether additives in lubricating oil may be corrosive toward silver metal. More importantly, it has also passed the EMD Two (2) Holer silver bearing test in a two-cylinder Model 567 type engine. It has not been tested in fast-start applications.

LUBE OIL COMPATIBILITY

Discussions with Exxon/Mobil personnel who have more than 25 years experience with Exxon/Mobil lube oil used in EMD 645 engines (not fast-starts) informed the following:

a) Chevron DELO 6170 and Mobilgard 450 NC oils are both endorsed by EMD for use in their engines;

b) Basically the spectrographic analyses are similar for both oils; and

c) Although they couldn't discuss confidential information related to the additive packages, both oils have similar additive packages. The original Mobilgard 450 has been in service for more than 30 years and the Mobilgard 450NC has been in engine service since 1997.

Further discussions with Chevron Oronite revealed the following: Chevron continuouly buys samples of their competitors oils to analyze the additive packages and check for compatibility with its lube oil products. Compatibility studies of Chevron DELO 6170 and Mobilgard 450NC have been extensive and thorough – with no compatibility problems period. Chevron also ran spectro chemical studies on Mobilgard 450NC to determine elemental components used as additives and then

compared this data with its Chevron DELO 6170. The two additive packages are chemically similar and should provide similar lube oil performance characteristics. Therefore, no functional compatibility problem.

Based on this review of new oil data provided by SPS and coupled with information from EMD and Chevron reports and discussions with their technical experts, it appears that state-of-the-art high quality lubricating oils have been used in the EMD 645 diesel engines at SPS. The similarity in viscosity levels (14.1 and 14.8) indicate excellent base stock choices that have demonstrated successful usage in a wide range of diesel engines including EMD 645 engines, but not in fast-start applications. The limits for flash, fire and pour points are also similar and both oils exceed the EMD new oil limits. Zinc content limits are easily met by both oils. The differences shown for Viscosity Index (Amoco 76 and Chevron 101) are representative of industry requirement changes in the past 15 years. Total base number (13.9 Amoco and 17 Chevron) reflects an upgraded additive package in DELO 6170 designed to provide a premier zinc and chlorine-free product. Although the Chevron DELO 6170 has demonstrated successful operation in EMD 645 engines, Chevron technical experts have indicated concern with usage of a chlorine-free product, such as Chevron 6170, in ". . .the extremely severe operating conditions at Surry. . .". See Appendix A.

LIMITS FOR SILVER IN THE LUBE OIL

Zinc additives such as zinc dithiophosphate, when blended into lubricating oils can cause severe damage in engines with silver-coated bearings in highly loaded applications as typically seen in standby operation of the Emergency Diesel Generator engines used in SPS. Galvanic corrosion can occur between the zinc compound and the silver bearing surface resulting in heavy wear leading to "wiped" bearings. The low zinc limit (10 ppm) then is necessary since bearing degradation can progress while the engines are not running. Trident did not examine the bearings removed from Engine #3 negating any opportunity to visualize and assess whether corrosion is a factor in the failure of the silver wrist pin bearings. However, any zinc readings above 10 ppm should be treated as dangerous to the silver bearings. Engine shut-down is necessary to correct the condition.

Silver electroplated onto carbon steel backed bearings were found to greatly improve the reliability of bearings used in high performance aircraft engines in World War II. Similar type bearings are used in EMD 645 engines today because they provide very high load capacity and tend to have forgiving modes of failure. Laboratory tests have shown that after a momentary shutdown caused by high bearing temperatures these silver bearings can be restarted and perform satisfactorily. This self-healing characteristic probably has contributed heavily to the long-term operations (since 1987) of the SPS engines.

Silver is relatively soft and can easily shear to reduce friction. It is chemically inert and generally resists oxidation and it has high thermal conductivity. However, if the silver coating becomes oxidized due to high temperatures it leads to heat discoloration, polishing, dirt scratches and ultimately the coating overlay blocks oil channels as described in ESI document 87360-FA dated 05/25/01. Hard oxide particles also are formed in this highly distressed state resulting in visually observed damage to the hardened carbon steel pins in various cylinders of Engine No. 3.

Trident reviewed the SPS oil analysis data for all three engines dating from 7/8/96 to 5/14/00 and related this to ESI report that "recommends a thorough review of past oil analyses . . . to ensure that no zinc enriched lubricating oils were utilized." The following summarizes the results:

Time Interval	Ave. Zn Level	Oil Used	
8/12/96 – 1/13/97	~ 5.0 ppm	AMOCO 13	Engine #3
2/6/97 – 2/20/00	~ 2.0 ppm	AMOCO 13	
3/22/00 – 12/24/00	~ 1.0 ppm	CHEVRON	
9/02/96 – 1/13/97	~ 2.5 ppm	AMOCO 13	Engine #2
2/9/97 – 8/22/99	~ 3.0 ppm	AMOCO 13	
10/21/99 – 12/10/00	~ 1.5 ppm	CHEVRON	
9/2/96 – 1/13/97	~ 3.7 ppm	AMOCO 13	Engine #1
5/10/97 – 1/17/99	~ 2.0 ppm	AMOCO 13	
2/18/99 – 6/2000	~ 2.0 ppm	CHEVRON	

All of the above zinc levels are considerably less than EMD's acceptance criteria of no more than 10 ppm. The only instance of the past presence of a high zinc (5.0 ppm) content would have been in Engine No. 3 during the time interval 8/12/96 to

1/13/97, hardly high enough to lead to premature failure of the silver surfaces. Trident does not consider the Amoco or the Chevron oil to be a zinc enriched oil.

Oil analyses for Engine No. 3 show the last silver result using Amoco on 2/20/00 was 0.1187 ppm but the silver level continued to increase with the changeover to Chevron on 3/00, going steadily each month from 0.1635 ppm (3/22/00) to 1.1051 ppm (6/11/00); a level at which additive manufacturers recommend an investigation and taking extra oil samples to determine its cause. Silver readings continued upward to 2.0126 (10/31/00) until reaching a 2.549 ppm level by 12/21/00. An independent laboratory (ANALYSTS, INC.) reported silver levels of 2.3 ppm (3/4/01) and 2.6 ppm (3/14/01) that confirmed the high (2.549 ppm) levels reported 12/21/00 by the North Anna oil analysis laboratory.

Engine No. 1 shows the same silver trend beginning 4/12/99 approximately 3 months after changeover to Chevron with a silver level at 0.1849 ppm, increasing steadily each month to 0.9244 ppm (11/21/99) to 1.0252 ppm (3/12/00) and continued at approximately this same level for another year reaching 1.1489 ppm on 4/8/01.

Engine No. 2 had relatively no change (<0.1 ppm to 0.1244 ppm) from 9/2/96 to 1/2/01 which included an oil changeover from Amoco to Chevron in October 1999.

One suspect value was recorded on 2/18/01 with a 2.6623 ppm silver reading. The silver readings returned to 0.2216 and 0.2339 ppm silver for the next 2 months.

Trident discussion with EMD personnel cited EMD Maintenance Instruction MI 1760 which generally indicates the following for levels of silver in crankcase oils:

0.0 to 1.0 ppm Ag: Normal – No action required

1.0 to 2.0 ppm Ag: Borderline – Take extra oil samples

Above 2.0 ppm Ag: High – Correct condition.

This M.I. indicates when silver levels are above 2 ppm, it is time to shut down the engine, check for broken piston cooling tubes, inefficient oil cooler, or improper temperature control, feel sides of piston pins for signs of distress, measure piston to head clearances with lead wire readings, check strainer, oil filters and bottom of oil pan for heavy wear debris, also, check air box and turbo bearing condition.

Engine No. 3 reached the borderline condition around August 2000 with silver level at 1.6926 ppm. Ultimately, 18 power assemblies were delivered to ESI for inspection and to measure thickness of the piston wrist pin bearings. No significant thickness changes were noted considering the severe service operation.

ESI's visual observation description and photos tell another story regarding each specimen's silver wrist pin bearing and its piston pin. Cylinder Nos. 7, 8, 9, 12, 16,

and 20 indicated minor bearing distress and pins in O.K. condition, only 6 of the 18. Cylinder Nos. 3 and 6 were considered minor to mild distress in the bearings; minor distress (No. 3) to O.K. (No. 6) for pins.

Cylinder Nos. 1, 2, 5, 11, 15, 17, 19 exhibited heavy bearing distress, heat discoloration, overlay displacement blocking oil channels, scratches and piston pins experienced heavy distress and heat discoloration. Accompanying photos depicted classic examples of "wiped" bearings. Cylinder Nos. 4, 10 and 18 bearings showed minor to medium distress, pins were O.K. (No. 10) to medium distress (No. 18). Numbers 13 and 14 were not available. Seven of the above 16 available bearings and pins were rated "heavy distress".

Trident agrees with ESI's appraisal for Engine No. 3 that "all cylinder positions were found either in a failed condition or trending towards failure." Trident's summary of crankcase oil analyses for all three (3) engines for the time interval from 8/12/96 to 12/13/00 indicates that zinc was probably not a major factor in the failure of the silver bearings.

Trident's overall analysis of the lubrication oils (Amoco and Chevron) regarding increasing silver levels cannot place any single factor or event as cause for failures noted in ESI report. It does appear that due to fast start-ups, there is a strong probability that a lack of lubricant in the wrist pin bearing clearances coupled with

extremely severe operations conditions leads to metal-to-metal contacts resulting in damage seen in Engine No. 3.

Based on the ESI observations/description of extensive bearing/pin damage in Engine No. 3, where silver levels (2.549, 2.6, 2.3 ppm) were reported by North Anna and Analysts, Inc., it appears that change in the silver limit (2.0 ppm) needs to be considered, probably lowered to 1.5 ppm silver or use the 2 ppm silver as a not-to-exceed limit and that a maximum rate of increase of silver concentration be established as allowable above which corrective action should be taken.

In the mid 90's chlorinated hydrocarbons were determined to be carcinogenic necessitating removal of Amoco 13. New chlorine-free additive packages were formulated and are used in chlorine-free oils.

LOW NO. 2 STANDBY LUBE OIL TEMPERATURE

SPS provided Trident operating data and oil flow diagrams for the lube oil heating system for all three EDG sets. Figures 1 and 2 (Appendix B) are sketches of the water flow and the oil flow respectively. Trident's major concern for this task is with the water flow path shown in Figure 1. The water systems is, in reality, two water flow systems with a common set of piping. The major flow path provides a large volume of water flow through the engine and through the oil cooler to maintain proper engine and oil temperatures during operation. A secondary path using the

cooler and some additional associated piping, during the standby condition, provides hot water via free convection flow to the oil cooler being used as a heater in this configuration. The water heats the oil as it flows to and from the engine maintaining it (the engine) at the temperature required for emergency starts. This system is alarmed to notify the operators that the water and hence the oil temperature is less than the required minimum temperature (95°F).

The numbers shown in the circles on Figure 1 (Appendix B) represent the location of temperature measuring devices used to monitor the oil heating system operation as follows. Cool water, location 1, flows into an electric heater controlled by an off/on temperature controller at location 11. The hot water at location 2 flows via free convection against gravity to a tee where the flow splits. Part of the flow goes to the temperature controller, 11, and the remainder flows against gravity to location 5 where it enters the heater/cooler. The flow from the controller enters a separate heater connection at location 7. The heater is also connected to an expansion tank whose temperature is monitored at location 17. After heating the oil, the water exits at locations 6 and 8 respectively. The flow from location 8 splits and flows to the left bank water pump and to one of two return lines to the heater, location 16. The flow from location 6 flows to the right bank water pump and rejoins the flow from the left bank pump at location 14 which translates to location 15. The flows from 15 and 16 combine and flow back into the heater completing the flow circuit. It should also be noted that the flows from 13 and 14 combine and flow through the two radiators

and thence back to locations 5 and 7 at the oil heater inlet. A chart of the temperatures measured at the above locations is provide for three sets of data in Table 1 in Appendix B.

In an attempt to determine the differences between the heating systems of the three EDG sets, a number comparisons are provided below.

1. The temperature rise across the heaters should be the same.

	EDG 2 Data Set			EDG 3 Data Set			EDG 1 Data Set		
	1	2	3	1	2	3	1	2	3
T2	147	137	141	75	101	75	NA	NA	NA
T1	108	108	101	77	76	77	NA	NA	NA
Delta T	39	29	40	- 2	25	- 2	NA	NA	NA

(Certain data provided to Trident were unavailable due to computer file format problems.)

The first item of note is that the temperature rise proceeds in both directions in EDG3. The electric heater is not continuously on as previously noted. The negative heat flow translates to a negative (reverse) water flow since the flow is a free convection flow. The condition will be noted throughout the data presented herein. Where positive flows are shown in data set 3, the temperature rises across the heater are comparable, but not the same since the heater is on in a random manner.

2. T2, T5, T7, AND T11 should be about the same temperature with T2 the highest T5 and T7 the lowest, and T11 intermediate.

	EDG 2 Data Set			EDG 3 Data Set			EDG 1 Data Set		
	1	2	3	1	2	3	1	2	3
T2	147	137	141	75	101	75	NA	NA	NA
T5	139	135	132	120	73	122	NA	NA	NA
T7	129	125	122	75	76	119	146	138	131
T11	156	152	149	129	143	128	157	151	142

T5 and T7 are fairly consistent, but EDG1 data for T2 and T5 was unavailable. T11 is reasonably consistent across the DG sets and is usually greater than T5 and T7. This can probably be attributed to heat gained from inadequately insulated controllers.

3. T6 and T8 should be about the same temperature.

	EDG 2 Data Set			EDG 3 Data Set			EDG 1 Data Set		
	1	2	3	1	2	3	1	2	3
T6	114	112	112	75	75	109	123	118	118
T8	114	112	112	75	83	109	120	118	118

Some anomalous temperatures are seen, probably due to heater on/off, but data are consistent.

Items 2 and 3 above revealed the consistency of T6 and T8 and T5 and T7. Consequently, the heat loss across the oil heater should also be consistent.

	EDG 2 Data Set			EDG 3 Data Set			EDG 1 Data Set		
	1	2	3	1	2	3	1	2	3
T5	139	135	132	120	73	122	NA	NA	NA
T6	114	112	112	75	75	109	NA	NA	NA
Delta T	25	23	20	45	- 2	13	NA	NA	NA

	EDG 2 Data Set			EDG 3 Data Set			EDG 1 Data Set		
	1	2	3	1	2	3	1	2	3
T7	129	125	122	75	76	119	119	146	138
T8	114	112	112	75	83	109	120	118	118
Delta T	15	13	10	0	- 7	10	- 1	28	20

The delta temperatures are not consistent and even go negative in one case. Trident believes that is once again related to the heater cycling operation.

5. T16 should be about the same temperature as T6 and T8. T17 should be somewhat warmer but close to the same temperature.

	EDG 2 Data Set			EDG 3 Data Set			EDG 1 Data Set		
	1	2	3	1	2	3	1	2	3
T16	108	108	104	NA	NA	NA	NA	NA	NA
T17	112	112	112	NA	NA	NA	NA	NA	NA

T6	114	112	112	NA	NA	NA	NA	NA	NA
T8	114	112	112	NA	NA	NA	NA	NA	NA

The temperature values are consistent.

6. Assuming balanced flow between 13 and 14, T15 should be the average of T13 and T14 for equal flow rates.

	EDG 2 Data Set			EDG 3 Data Set			EDG 1 Data Set		
	1	2	3	1	2	3	1	2	3
T13	88	88	88	77	99	94	94	101	100
T14	87	87	88	75	97	90	90	98	98
T-15	86	86	87	74	90	85	85	90	90

The data are consistent within but not across DG Sets.

7. T15 and T16 should be consistent and T1 should be the average of T15 and T16 for equal flows for equal flow distribution.

	EDG 2 Data Set			EDG 3 Data Set			EDG 1 Data Set		
	1	2	3	1	2	3	1	2	3
T15	86	86	87	NA	NA	NA	NA	NA	NA
T16	108	108	104	NA	NA	NA	NA	NA	NA
T1	108	108	101	NA	NA	NA	NA	NA	NA

Based on the data available, T15 and T16 are somewhat consistent and T1 appears biased toward T16 indicating that the flows are unbalanced.

8. T4 and T3 should be consistent across the data set since this difference is proportional to the heat gained by the oil.

	EDG 2 Data Set 1	EDG 2 Data Set 2	EDG 2 Data Set 3	EDG 3 Data Set 1	EDG 3 Data Set 2	EDG 3 Data Set 3	EDG 1 Data Set 1	EDG 1 Data Set 2	EDG 1 Data Set 3
T3	95	95	96	75	96	97	NA	NA	NA
T4	116	116	116	75	140	114	NA	NA	NA
Delta T	21	21	20	0	44	17	NA	NA	NA

The data are less consistent for EDG2 than for EDG3. EDG1 data are not available. This variation may be the result of heater OFF/ON more may indicate a problem with EDG3.

Trident's analysis of the temperature data available reveals that the expected positive temperature differences between certain locations can be negative. These negative temperature differences can therefore result in reversed flows in a convection flow system. In addition, the amount of water flowing is very small compared to the volume of water stored in various locations throughout the system. The upward flows at locations 5 and 7 are bucking the large water volume in the radiators. Prediction of mixing and the resulting temperatures and flows and flow directions is very difficult. Without such analyses, it is impossible to determine these temperatures and flows. The same situation exists at

the juncture location 13 and 17 and at the juncture of locations 13, 14, and 15. These areas are all areas of inconsistent temperatures compared to expectations. The addition of the problem of off/on heating adds further complications. In short, Trident believes that given the complexities described above it is almost impossible to ensure that the convection flow is always in the desired direction. Lack of predictable flows and temperatures may result in the alarm tripping at odd intervals.

Trident had conversations with Kevin Broussard at ESI who feels that the temperature control itself may be at fault. His experience indicated that the temperature controller has a wide set point range and a difficult procedure for adjustment because of long lag times in the controller. This type of problem would further exacerbate the conditions related to reversing flows due to temperature fluctuations.

CONCLUSIONS

Based on its own investigation and analysis, discussions with others, and data collected by Trident and supplied by others, Trident concludes to a reasonable degree of engineering certainty,

1. That the combination of Chevron oil, fast starts, and the current design of the lube oil system, results in a lube oil system that is, at best, marginal for its intended purpose; Trident further concludes that the combination of Amoco oil, fast starts, and the current lube oil system design was adequate to prevent wrist pin bearing failures;

2. That an assessment of the Amoco Super Diesel 13 and the Chevron DELO 6170 oils shows that both are state of the art, high quality lubricating oils that have demonstrated successful service in continuously operating diesel engines. However, Trident has found no evidence that the Chevron oil has been qualified in fast start applications. Additionally, the low chlorine content of the Chevron oil probably results in a reduction of the extreme pressure properties which would be a negative factor in fast start applications;

3. That a reduction in the silver limit (2.0 ppm) is warranted as well as establishing a maximum rate of increase of silver in the lube oil;

4. That mixing small quantities of Chevron DELO 6170 with Mobilgard 450NC would not pose a compatibility problem; and

5. That the performance of the oil heating system and the resulting alarms are the result of the use of the free convection flow system in a large water volume system which can overpower the convection system.

Trident's investigation did not include any inspection of the components removed from the No. 3 engine.

RECOMMENDATIONS

1) Develop a procedure to evaluate large metallic particle distribution in the crankcase using ferrographic analysis as a starting point.

2) Install pre-lubrication module per existing EMD design, M.I. 9644 *Rev. A.

3) Revise allowable silver levels in crankcase oil to ensure timely detection of potential wear problems:

    0 – 0.5 ppm, no action

    0.5 – 1.0 ppm increasing trends, additional monitoring

    < 1.0 ppm perform feel test and sludge analysis

4) Evaluate additional vibration analysis techniques to determine applicability for silver bearing wear analysis.

5) Modify design of wrist pin bearing for better oil retention.

6) Compare "new" and "old" Mobilgard 450NC spectrographic data generated by other nuclear facilities to Chevron and Amoco spectrographic data with respect to fast start problems.

7) Update trend analysis techniques for oil and vibration data to ensure timely recognition of potential problems.

8) Develop a fast start lube oil qualification test using a two-holer silver bearing test engine.

9) Re-design existing lube oil temperature control system to provide higher temperature oil – minimum 150°F. The redesign should ensure positive

water flow in the desired direction and hot enough to satisfy the low lube oil temperature alarm system.

In preparing this report, we have attempted to be thorough and accurate, and to meet the standards generally expected from members of the engineering profession and in accordance with our General Provisions. By accepting delivery of this report, the recipient agrees that we shall not be liable for any special, indirect, incidental or consequential loss or damage whatsoever.

FINIS

TRIDENT ENGINEERING ASSOCIATES, INC.