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March 6, 1985
NE-85-0345

Director of Nuclear Reactor Regulation
Attention: Mr. B. J. Youngblood, Chief
Licensing Branch No. 1
Division of Licensing
U. S. Nuclear Regulatory Commission
Washington, D. C. 20555

Dear Mr. Youngblood:

Reference: (1) Fermi 2
NRC Docket No. 50-341

(2) Detroit Edison to NRC Region III
Letter "Final Report of 10CFR50.55(e)
Item 146, Failure of Emergency Diesel
Generator Nos. 11 and 12", EF2-70382,
February 12, 1985

Subject: Additional Information on Diesel Generators

At a meeting at the Fermi 2 site on March 1, 1985 with Mr. Carl Berlinger of NRC staff, it was requested that Detroit Edison supplement the information contained in reference (2). Accordingly, attached please find a copy of a report and attachments which we believe is responsive to Mr. Berlinger's request.

If you should have any additional questions, please contact Mr. O. Keener Earle, at (313) 586-4211.

Sincerely,

Wayne H. Jens

cc: Mr. P. M. Byron
Mr. C. H. Berlinger
Mr. M. D. Lynch
Mr. F. A. Maura
Mr. E. Tomlinson
Mr. A. R. Ungaro
USNRC, Document Control Desk
Washington, D. C. 20555

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EMERGENCY DIESEL GENERATORS

BEARING FAILURE

SUPPLEMENTAL REPORT

MARCH 7, 1985

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D. Failure Analysis Associates, "Investigation of Engine Bearing Distress in Fairbanks-Morse Emergency Diesel Generators at Enrico Fermi II Power Plant-Phase I: Inspection and Preliminary Conclusions" (DRAFT), February 1985

E. Letter, W. H. Jens to J. G. Keppler, February 12, 1985, Final Report of 10CFR50.55(e) Item 146 "Failure of Emergency Diesel Generators Nos. 11 and 12"

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J. Letter, T. J. Skinner (Fairbanks-Morse) to W. H. Jens, January 22, 1985, "Lube Oil System Modification Design Concept and Test Results"

K. Letter, T. J. Skinner to J. A. Nyquist, January 31, 1985, "Evaluation of EDG Nos. 13 and 14 Bearings

L. Letter, E. D. Green to W. Kirchoff, July 20, 1985, "F.M. Diesel Generators Prelubrication"

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I. Introduction

This report supplements the Final Report of 10CFR50.55 (e) Item 146, "Failure of Emergency Diesel Generator Nos. 11 and 12" (Attachment E). The 10CFR50.55(e) Report identified the cause of the bearing failures and the actions that are being taken to ensure the diesels are reliable and will be available during an emergency. This report provides details regarding the scope and methods used in the investigation; the basis for Detroit Edison's conclusion as to the cause of the bearing failures; and the basis for the conclusion that the corrective actions taken are appropriate and sufficient.

II. Description of the Event

Approximately 14 minutes after being started for a 24 hour surveillance test, EDG No. 11 tripped automatically as a result of low lubricating oil pressure. The engine had been operating at full rated load, 2850 kilowatts. The preliminary investigation revealed metal flakes and filings in the lube oil filter and strainer; therefore, a complete inspection of the machine was made with the assistance of the vendor, The Fairbanks-Morse Engine Division of Colt Industries.

Although operating properly, EDG Nos. 12, 13 and 14 were also inspected for damage. The EDG No. 12 lube oil filter contained easily visible bearing material. A check of the main bearing-to-bearing cap clearances revealed that some of the upper crankshaft bearings had abnormal clearances.

Subsequent internal inspections revealed extensive damage to bearings in the upper crankline of EDG No. 11 and excessive clearances on the upper crankline bearings of EDG No. 12. In both cases, the damage was generally restricted to the most remote bearings of the upper crankline (i.e., the last bearings to receive lubricating oil flow during the starting cycle).

EDG Nos. 13 and 14, which have run less time and have fewer starts than the other 2 engines, showed no signs of damage; although, several bearing surfaces in EDG No. 14 had small pieces of foreign material embedded in the surface. Instead of the polished surface expected with normal wear, these bearings had a frosted appearance which is not unusual for bearings with very little wear. However, all of the bearings in EDG Nos. 13 and 14 were judged to be satisfactory for continued service based upon an inspection by Detroit Edison, Fairbanks-Morse, Failure Analysis Associates, and the NRC.

III. Analysis of the Cause of the Failure

Numerous mechanisms were considered and eliminated as the potential cause of the bearing failure after of an investigation which included:

- Visual and laboratory inspections of the failed bearings (Attachments D, E, N);

- Internal inspections of the engine and components in the engine lubricating oil system (Attachments C and D);

- Analysis of the operating and maintenance history of all four (4) engines (Attachments A, B, F, G, H, I and M);

- Investigation of differences between the Fermi 2 engines and similar engines at other utilities (Attachments A, B, E, F, G, H, J, L and M);

- Engineering analysis of the adequacy of the bearing and lube oil system and design (Attachment D and J);

- A journal orbit analysis to determine the influence of oil inlet pressure on the properties of the oil film in the main bearings.

Possible causes of the failure of EDG No. 11 that were evaluated and eliminated, and a brief description of the technical justification for their elimination, are as follows:

- Contaminated lube oil - Bearing deterioration was not engine wide but was isolated to the remote upper bearings. One of the two most highly loaded bearings in the engine (bearing 10) was not damaged. Additionally, no evidence exists that the oil in these engines was ever contaminated based on the results of the oil analyses.

- Engine overload - The most load sensitive components, the piston rings and wrist pin bushings, were not damaged. The engine had been overloaded to approximately 125% of rated load for about 30 seconds on September 16, 1984; however, the manufacturer indicated that an overload of this magnitude and this duration is easily tolerated by the engine.

- Misalignment - The damage observed during the inspection of EDG No. 11 was not characteristic of damage resulting from misalignment, i.e. damage in the center or at both ends of the crankshaft.

- Installation Errors - The damage observed on EDG No. 11 was not characteristic of installation errors.

- Obstructions in the lube oil system - Lube oil piping was inspected and no blockages were identified. The engine was also inspected for missing or loose parts and none were found.

- Lube Oil - Immediately following the trip, the lube oil system valve lineup was verified to be correct. Also, the type and amount of lube oil in the engine was verified to be correct.

- Lube oil pump failure or cavitation - The lube oil pump was inspected and no abnormalities were observed. Engines of this design have not been identified as having pump cavitation problems.

- Lube oil system component failures - All lube oil system components were inspected and found satisfactory.

- Inadequate bearing design - Engineering analysis indicated that the bearing design is conservative.

- Bearing material - Metallurgical examination confirms that the bearing alloy present was that specified by the design, alloy SAE 770.

- Electrical discharge through the bearing - Neither the bearing damage in EDG Nos. 11 and 12 nor the frosted bearing appearance in the EDG No. 14 bearings is characteristic of the damage associated with electrical discharge through the bearings.

Physical examination of the EDG bearings indicated that the proximate cause of the failure was inadequate lubrication. An extensive investigation concluded that, without adequate prelubrication, the remote bearings of the upper crankline receive marginal or insufficient lubrication during the initial stages of a fast start. Although these engines have demonstrated the ability to tolerate a substantial number of fast starts without prelubrication, this type of start promotes deterioration and eventual failure of the bearings. This conclusion is supported by the following evidence:

- Without prelubrication, voids estimated between 5 and 10 gallons exist in the lube oil system at the initiation of the start sequence. The air-oil boost system (described in Attachment E) supplies approximately 1.1 gallons of oil directly to the bearings of the upper crankline during the starting cycle. However, to assure an adequate and continuous supply of lube oil to the bearings, the system voids must be filled. Therefore, Detroit Edison has concluded, that without prelubrication, there is a very high probability that lubrication during the starting cycle may be marginal or insufficient.

- Increasing the time that the bearings and lube oil system are allowed to drain before the EDG is restarted without prelubrication decreases the amount of oil in the bearings during the subsequent start. By a detailed comparison of the EDG operating histories (Attachment M), it was determined that the period of time that the bearings were allowed to drain before the EDG was restarted without prelubrication was typically longer for EDG Nos. 11 and 12 than for Nos. 13 and 14 with EDG No. 11 having the longest typical delay. Although all 4 EDGs have approximately the same number of fast starts without prelubrication, this analysis of operating history supports the fact that EDG Nos. 11 and 12 have experienced damage while Nos. 13 and 14 have not.

- After the installation of the air-oil boost system, Detroit Edison discontinued prelubricating before planned starts. Although this change in procedure was based on the recommendation of the vendor, Fermi 2 was the only owner of Fairbanks-Morse engines that discontinued prelubrication before planned starts.* This was the major difference identified between operating and maintenance practices at Fermi 2 and other plants with engines of this design.

Detroit Edison's conclusion that the bearing deterioration is progressive and, therefore, can be identified and corrected before failure is also supported by experience. Examination of the surface of the distressed bearings showed indications typical of intermittent seizure to the crankshaft which resulted in the removal of material from the bearing surface. Although distressed, the bearings in EDG No. 12 and most of the bearings in EDG No. 11 continued to provide adequate service. This distress was detectable, however, by the visible accumulation of bearing material in the oil filter and increased bearing to bearing cap clearance. This is consistent with experience at other nuclear plants where bearings are replaced because of high bearing to cap clearances but before there is any indication that the bearing is no longer functional.

Detroit Edison believes that more frequent oil filter inspection may have identified the deterioration before the bearings failed. Prior to the discovery of bearing problems in EDG Nos. 11 and 12, the lube oil filter for EDG No. 11 had not been inspected since July 15, 1983. The EDG No. 12 oil filter had not been inspected since the engine was put in service. Scheduled filter replacements were cancelled because filters were not available. The pressure drop across the filter - the key parameter for gauging filter condition - was within an acceptable range for both machines at all times.

Additionally, Detroit Edison believes that more frequent bearing-clearance checks also may have detected bearing deterioration prior to their failure. Prior to the discovery of bearing damage in EDG No. 11, the bearing-to-bearing cap clearances had not been inspected since January 15, 1983, and January 18, 1983 for EDG No. 12. However, on January 15, 1983, the bearing inspection revealed an out-of-specification clearance on the No. 1 upper main bearing of EDG No. 11. This condition was evaluated by the vendor and it was concluded this was a false indication because the high clearance did not extend the full width of the bearing. EDG No. 11 continued to operate with this same bearing until its bearing failed on January 10, 1985.

IV. Analysis of Corrective Actions

To maximize the reliability of the Emergency Diesel Generators, Detroit Edison has initiated action which will both:

- Minimize the stress on the bearings during the starting sequence in order to reduce the potential for bearing deterioration; and,

*The standard BWR 4 Technical Specifications on which the then Fermi 2 Technical Specifications were based required starts to be from "ambient" conditions which Edison interpreted to be without prelubrication.

- o Identify and correct deterioration before the deterioration results in the bearing failure.

The most significant actions being taken and the basis for each are as follows:

Action: Operating procedures have been modified to require a minimum of two minutes of prelubrication prior to planned starts of the EDG's. Following prelubrication, the prelube pump will not be secured until the EDG reaches full speed (900 RPM). After the EDG's are modified to permit slow idle speeds, securing the prelube pump will be allowed when the engine reaches idle speed.*

Basis: This action will limit the number of starts without prelubrication to the relatively few unplanned starts that may occur. Voids in the lube oil system will be filled and oil flow established at each bearing prior to any planned start of the engine. The relatively few starts without prelubrication are justified based on the demonstrated ability of the engines to tolerate a substantial number of starts without prelubrication and the more frequent inspections for the lube oil filter and bearing clearance which is described below.

Action: After 20 starts have been conducted without prelubrication, but not longer than 18 months, the gap between the bearing and bearing cap for the crankshaft and connecting rod bearings will be verified to be within the manufacturer's tolerance.

Basis: This inspection technique provides positive and reliable indication of bearing condition. Analysis of the bearing failure mode and extensive experience at Fermi 2 and elsewhere indicate that bearing deterioration is progressive and bearing failure is preceded by an increasing gap between the bearing liner and cap at the bearing mating surface. The inspection interval is conservative and is based upon the demonstrated ability of these engines to tolerate significantly more than 100 starts without prelubrication and without bearing failure.

Action: EDG lube oil filters will be inspected and replaced quarterly. The discovery of a visible accumulation of bearing material will trigger a verification of bearing clearances. An isolated deposit will not be considered an accumulation of bearing material, but will be evaluated on a case-by-case basis.

* Detroit Edison has requested the NRC to make changes to its draft Technical Specifications for Fermi 2 to accomplish these actions (see Detroit Edison to NRC Letter, "Request to Revise Draft Fermi 2 Technical Specifications"), NE-85-0329, February 14, 1985. Edison considered requesting in this letter reducing the required diesel power level from the maximum but still greater than that required by the FSAR. However, Edison deferred this request based on discussions with NRC staff.

Basis: Very few starts without prelubrications will occur in any calendar quarter. Experience indicates that bearing deterioration will result in the accumulation of large amounts of easily visible bearing material in the lube oil system's 5 micron filter; therefore, a quarterly inspection will provide early identification of rapid bearing failure.

Action: Monthly oil samples will be drawn from the sump (dipstick tube) while the engine is operating and will be analyzed to determine metal concentrations. The results of these analyses will be trended for 18 months. At that time, if the evidence confirms that trending metal concentrations will predict or detect bearing failures, a permanent program will be established.

Basis: The aluminum bearing material has a low solubility in lube oil. Therefore, samples will be taken while the engine is operating to ensure suspended aluminum is collected with the sample.

Action: Detroit Edison will perform a spectographic analysis of lube oil filter media and any deposits that are found during the quarterly replacement. The results will be evaluated as a method of predicting bearing failures. If this evaluation indicates that a spectographic analysis program is justified, a program will be established.

Basis: Detroit Edison's preliminary analysis indicates that a visible inspection of the oil filter media for the accumulation of bearing material may be a sufficient and reliable indicator of bearing condition. Spectographic analysis of selected areas of the filter media may be dependent upon factors other than bearing condition such as runtime, number of starts, diesel loading, etc. Analysis of deposits on the filter media would only confirm that the visible deposit is, in fact, bearing material.

Action: Operating procedures have been revised to require, whenever possible, gradual loading and unloading of the diesels. Also, a design modification to permit slow starts of the EDG's during some test procedures is being developed.

Basis: Allowing the EDG to idle at low speed for several minutes will ensure that the bearings are adequately lubricated before the bearings are subjected to the stress associated with high speed and large loads.

V. Conclusion

Detroit Edison has concluded that the actions being taken are sufficient to ensure that all 4 Emergency Diesel Generators are reliable and will perform as designed during an emergency.

ATTACHMENT A

SUMMARY OF OPERATIONAL DATA

ATTACHMENT A

SUMMARY OF OPERATIONAL DATA

EDG	11	12	13	14
Starts				
Prelube (PL) Used	127	52	25	30
Bearings Wet	112	89	78	72
Booster-No PL	63	63	56	68
No Prelube				02
Total Starts	302	204	159	172
Draintime Prior To No Prelube Starts				
# Starts $\geq$ 8 hr Drain Before Start	43	39	30	32
# Starts $\geq$ 24 hr Drain Before Start	25	23	20	22
# Starts $\geq$ 5 Day Drain Before Start	17	13	11	13
Fast Engine Loading (Fast loading from synchronous speed to > 2000 kw)				
# Fast Load To $\geq$ 2000 kw (Prelube)	45	0	0	0
# Fast Load To $\geq$ 2000 kw (wet)	18	3	13	11
# Fast Load To $\geq$ 2000 kw (Booster No Prelube)	37	46	45	45
Total	100	49	58	36
Run Hours				
Total Clock Hrs.	346	292	214	270
Unit Trips				
Total	60	62	27	13

Engine Loaded Hrs. (log)	#11	12	13	14
0-499 kw	0	.1	.2	.3
500-999 kw	2.1	2.1	2.1	1.6
1000-1499 kw	3.2	5.3	5.8	6.2
1500-1999 kw	19.8	6.8	3.6	3.3
2000-2499 kw	69.0	45.4	38.3	31.6
2500-2999 kw	147.2	76.5	109.3	174.4
Greater than 3000 kw*	9.7	8.4	10.2	9.0
Total Load Hrs	251.0	144.6	169.5	226.4

EDG BEARING INSPECTION DATES (BEARING GAP)

EDG	11	12	13	14
	1-14-83	1-18-83	8-15-83	4-14-83
			8-18-83	4-15-83

* Surveillance Testing requires operation above the 2850 kw rated load.

ATTACHMENT B

REVIEW OF OPERATING AND MAINTENANCE HISTORY

ATTACHMENT B

Review of Operating and Maintenance History

Detroit Edison has conducted a detailed analysis of the operating and maintenance history of each of the 4 EDG's. The following abnormal occurrences were identified:

EDG No. 11:

- 35% more starts than EDG No. 12 and twice as many starts as EDG Nos. 13 and 14. This was caused by repeated testing of this machine in conjunction with circuit modifications. Problems during initial testing were resolved with EDG No. 11 before the other engines were tested.

- Operated at approximately 125% of rated load for approximately 30 seconds on September 16, 1984. This event was evaluated and determined to be within the tolerance of this machine.

- Low lube oil trip indications (two) were the result of problems in the trip circuitry and not actual low lube oil pressure conditions.

- Experienced 60 trips during testing. This is more than twice the number of trips experienced by either EDG No. 13 or 14.

EDG No. 12:

- Experienced 62 trips during testing. This is about the same as EDG No. 11 and is more than twice the number experienced by EDG Nos. 13 or 14. The high number of trips resulted from difficulty calibrating the overspeed trip device.

- A plastic dust cap was found in the oil inlet for the #14 upper crankshaft bearing during the most recent inspection. It is suspected that this cap was left in the system after the lube oil modification was completed in December 1982. The #14 bearing was in excellent condition.

EDG No. 13:

- No known abnormal occurrence.

EDG No. 14:

- Experienced high vibration due to Brinelling of roller bearings in the generator. This event is not considered a contributing factor to any engine upper crankline journal bearing problems.

Miscellaneous

A vendor recommendation required that operation of the keepwarm system be verified monthly by looking for oil draining from the lower crankline. Although Detroit Edison verified keepwarm pump operation by monitoring engine oil temperatures, the required inspection was not performed on any of the EDG's.

ATTACHMENT C

SUMMARY OF INSPECTIONS AND SPECIAL TESTS

ATTACHMENT C

Summary of Inspections and Special Tests

In addition to the detailed inspections of all upper crankline bearings and components and selected lower crankline bearings, the following special tests or inspections were conducted to identify possible causes of the EDG bearing failure:

EDG No. 11:

- Lube oil headers, valves and pipes were inspected for blockage. None was found. Additionally, component vent lines were verified to be clear.
- Lube oil pumps were inspected and found to be satisfactory.
- Proper operation of the main lube oil pump relief valve was verified.

EDG Nos. 11 and 12:

- Lube oil cooler bypass control valves were verified to be operating properly.
- Functional test of the air-oil boost system accumulators were performed.
- Lube oil filter bypass relief valves were inspected for cleanliness. The results are discussed later in this attachment.
- The following instruments were verified to be working properly:
  - Low lube oil trip pressure switches.
  - Lube oil pressure gauges.
  - High oil temperature switches.
  - Low oil temperature switches.
  - Lube oil filter and strainer DP indication.
  - Crankcase high pressure switches.
- The air-oil boost system air pressure regulators were re-adjusted from approximately 120 psig to 150 psig.

EDG Nos. 11, 12, 13 and 14:

- Internal components were inspected for loose or missing parts. None were found.

- Proper operation and setpoint of the filter bypass relief valves was verified. This item is also discussed later in this attachment and the data sheets are in Attachment I.

- The time delay between start of the prelube pump and oil flow indication at the remote end of the upper oil header was measured. The minimum prelube times were measured at 39, 37, 23 and 38 seconds for EDG's Nos. 11, 12, 13 and 14 respectively. It should be noted that the time duration for EDG No. 13 (23 seconds) was measured from initiation of the pump until oil started to flow at the remote bearing. The time duration for the other EDG's was from pump initiation until steady flow was observed.

- The "Y" strainer in the keepwarm system and prelube system was inspected and found satisfactory.

Special Tests

- By design, the oil level in the engine lube oil system is maintained below the level of the upper crankline. With the keepwarm system operating, the keepwarm pump discharge pressure and, therefore, the elevation to which the oil level rises in the engine varies with the temperature of the lube oil. It was determined that oil temperatures below 105°F would result in oil levels above the upper oil header (crankline).

- The impact of the oil system modifications described in Attachment E were reviewed. These modifications include internal lube oil piping changes, rerouting standby heater discharge piping and increasing the size of the standby lube oil heater. These changes were considered beneficial.

- A special test was conducted on EDG No. 12 to determine the time-pressure response in the lube oil system during the starting sequence. These tests indicated that when the engine is prelubricated, a delay of 3 seconds occurs between the start of the engine and a 10 psi pressure at the remote end of the upper header. Preliminary analysis by Failure Analysis Associates indicates that a 10 psi header pressure is required to support an adequate oil film on the bearings during the starting cycle. The data sheets for these tests are in Attachment I.

Filter Bypass Relief Valves

The lube oil filter assembly contains 7 separate filter cartridges. These cartridges are in parallel flow paths, i.e., the oil may pass through the filter via any 1 of the 7 cartridges. Each cartridge assembly is equipped with a separate bypass relief valve which is factory set to open at the maximum recommended differential pressure for the cartridge, approximately 20 psid. The relief valves are intended to allow continued oil flow to the bearings should accumulations on the cartridges block lube oil flow through the filter. The setpoints at which the valves open were verified and found to be between 22 and 29 psi differential which is acceptable.

During inspection of these filters, very small amounts of debris was found under the seats of some bypass relief valves. Most of this debris is believed to be carbon combustion products, although some small metal flakes were detected in EDG No. 12. Similar metal flakes found in the EDG No. 11 strainer was analyzed and determined to be bearing material.

Tests were conducted to determine if the filter bypass valves would open during a starting transient. The results of this test were inconclusive. Detroit Edison does not consider momentary lifting of these bypass valves during a starting transient to be an unacceptable occurrence.

EDG Nos. 13 and 14 Bearing Condition:

No damage, except for minor surface scratches, was identified in any of the bearings in EDG Nos. 13 and 14. Detroit Edison, Fairbanks-Morse, the NRC and Failure Analysis Associates concurred that all of the bearings were acceptable for continued use. The NRC has expressed concern that EDG No. 14 bearings had a frosted appearance instead of the highly polished appearance associated with normal wear. These bearings were inspected by the vendor, Fairbanks-Morse, and an expert consultant Failure Analysis Associates. Both parties evaluated the bearings to be in good condition and satisfactory for re-installation.

To protect the journal from scratching, bearings are designed to have a characteristic called embedability. The black embedments (determined to be steel), surface scratches and scoring on the EDG No. 14 bearings were judged to be within the tolerance of the conservatively designed bearings. Additional analysis is in progress to determine the source of the small black metal particles embedded in the bearing surface.

ATTACHMENT D

Failure Analysis Associates, "Investigation of Engine Bearing Distress in Fairbanks-Morse Emergency Diesel Generators at Enrico Fermi II Power Plant-Phase I: Inspection and Preliminary Conclusions" (DRAFT), February 1985