APPENDIX

U.S. NUCLEAR REGULATORY COMMISSION
REGION IV

NRC Inspection Report: 50-498/89-46 Operating Licenses: NFP-76
50-499/89-46 NFP-80

Dockets: 50-498
50-499

Licensee: Houston Lighting and Power Company (HL&P)
P.O. Box 1700
Houston, Texas 77251

Facility Name: South Texas Project (STP)

Inspection At: STP, Matagorda County, Texas

Inspection Conducted: November 29 through December 22, 1989

Inspector: D. L. Garrison 1-25-90
D. L. Garrison, Reactor Inspector Date
Materials and Quality Programs Section
Division of Reactor Safety

Accompanied by: I. Barnes, Chief, Materials and Quality Programs Section
Division of Reactor Safety (December 19-20, 1989)

Approved: I. Barnes 1-26-90
I. Barnes, Chief, Materials and Quality Date
Programs Section, Division of Reactor Safety

Inspection Summary

Inspection Conducted November 29 through December 22, 1989 (Report 50-498/89-46)

No inspection was performed with respect to Unit 1 activities.

Inspection Conducted November 29 through December 22, 1989 (Report 50-499/89-46)

Areas Inspected: Nonroutine, announced inspection of licensee actions taken in response to the November 28, 1989, failure of the Standby Diesel No. 22.

Results: The licensee has performed a thorough evaluation of the root cause of the Standby Diesel Engine No. 22 failure and has implemented appropriate inspections and repair and recovery activities. The root cause has been established to be the propagation of a high-cycle fatigue crack from a stress riser created by the presence of an overdrilled lubricating oil passage hole in the No. 4 connecting rod assembly. The generic effects of overdrilling this particular oil passage will be determined upon completion of a three dimensional finite stress analysis of the connecting rod assembly. No violations or deviations were identified during this inspection.

The effectiveness of licensee management in meeting the challenges presented by the Standby Diesel Engine No. 22 failure was excellent. It was evident that the search for the root cause was thorough, and the recovery operations were focused on assuring that the engine would be rebuilt to meet its design function. The licensee's investigation of the occurrence also considered the potential for a similar failure on the other engines of like design.

DETAILS

1. PERSONS CONTACTED

HL&P

A. Harrison, Supervising Engineer
W. Kinsey, Plant Manager
S. Rosen, Vice President, Engineering
C. McIntyre, Manager, Site Engineering
D. Musick, Project Engineer
T. Fryar, Consultant, Engineering
R. Tarr, Site Engineer
S. Timmaraju, Site Engineer
A. Khosla, Licensing Engineer
T. Jordan, Manager, Plant Engineering

Cooper Industries

J. Horn, Engineering Manager

In addition to the above, the NRC inspectors also held discussions with various licensee, contractor, test lab, and consulting personnel.

2. OBJECTIVE

The purpose of the inspection was to assess the effectiveness of licensee actions with respect to the establishment of the root cause and recovery from the November 28, 1989, failure of the Unit 2 Standby Diesel Engine No. 22.

2.1 Background

In each unit of STP, the emergency safeguard features (ESF) for emergency power generation consist of three individual and separate diesel generator sets. Each set is composed of a Cooper Industries 20 cylinder, turbocharged, V-type engine of 7850 horsepower; an electric power (EP) continuous generator rated at 5500 kilowatts; two air compressor sets; remote control panel; and other support equipment. All equipment is housed in individual bays in the diesel building.

Technical Specifications require that each standby diesel generator (SDG) set be run at the rated load for 24 hours each month. During the test for November 1989, the No. 22 SDG was running in the 10th hour of the test when a loud knocking noise developed in the engine. Two maintenance technicians, who were in the engine bay performing work on nonrelated equipment, heard the noise and retreated to the control room where they reported that the engine was knocking and smoking. It was not evident from observation of the control boards what had caused the engine to stop. However, on reentry to the engine bay it was confirmed that the engine had stopped, and a large amount of engine debris was strewn, mainly on the floor to the right side of the machine.

Initial examination of the engine revealed that the No. 4 left and right (articulated) connecting rods and associated components had experienced to a massive failure of unknown origin. Approximately one-third of the rotating components at this location had been ejected from the engine. The parts had been thrown out of the engine through the right centerframe inspection port, the cover for which was knocked off of the engine.

The engine parts were gathered and reassembled in the maintenance shop where they were photographed and a more detailed inspection could be performed. Certain parts were selected for metallurgical evaluation, which was performed in the utility laboratories. The results of the metallurgical evaluation are documented in paragraph 2.3.1 below.

2.2 Damage Assessment

The crankshaft deflection was found to be .001" out of factory specification requirements; also the crankshaft journal had sustained several blows, the most severe of which required use of a .200" oversized bearing after repair and reassembly. The shoulders at the journal ends were beaten and worn and required machining.

The cylinder liners skirts were broken. The intake valves in each head were bent and the rocker arm assemblies were fractured. Fractures had also occurred in the counter weights, the connecting rod assembly, and the connecting rod assembly bolting.

The engine centerframe, which is a casting, sustained six minor fractures on the internal webs of the casting; the lower engine housing (welded plate) fractured in two places, one on each side of the engine at a centerframe to lower housing connection.

The NRC inspectors performed three separate inspections at the site. The first involved a damage inspection of the engine and engine bay and examination and photographing of damaged parts. Further inspections included review and evaluation of licensee actions, metallurgical reports, vendor data, and inspection of repair and recovery activities.

2.3 Licensee Actions

The licensee actions after the failure included securing the equipment, performing an initial examination of the failure, and organizing a response team to oversee analysis and recovery operations and made appropriate industry notifications. The recovery included assignment of tasks, generation of reports to the NRC, requiring support from the engine manufacturer and other engine consultants, transporting parts for analysis, generation of a critical path schedule, and issue of a final report on the failure mechanism.

2.3.1 Metallurgical Evaluation

Visual examination of the connecting rod assembly parts showed fractures had occurred through the section of material located between the articulated rod pin bore and crankshaft bore surfaces and also in the two connecting rod bails. Fractures had also occurred in the articulated rod pin bolts and the bolts which connect the master connecting rod to the bearing cap.

Macroscopic examination of the fracture located between the two bore surfaces revealed the presence of conchoidal or beach markings on a portion of the fracture surface (i.e., the portion located between a lateral mid-thickness oil passage hole and the articulated rod pin bore surface). These markings, which are characteristic of high-cycle fatigue failure, indicated that failure had originated at the articulated rod pin bore surface from both sides of a central longitudinal (i.e., through section) hole. This hole, which was required by drawing to be drilled to connect an oil passage machined in the crankshaft bore surface with the lateral mid-thickness oil passage hole, was actually drilled through the connecting rod section with the drill tip having broken through the articulated rod pin bore surface. This machining error had been repaired by tapping the hole and inserting a plug in the overdrilled portion of the hole. The breakthrough of the drill tip resulted in a sharp-edged hole configuration at the articulated rod pin bore surface, which acted as a severe stress riser.

The licensee performed scanning electron microscope (SEM) examinations of the fracture surface exhibiting the beach markings. These examinations revealed the presence of fine striations on the fracture surface, which are characteristic of high-cycle fatigue failure and represent crack advancement per stress cycle. High-cycle fatigue was thus confirmed to be the failure mechanism. Similar SEM examinations were performed on the fracture surface of one of the failed connecting rod bails, which revealed that failure in this location also occurred by a fatigue mechanism. The striations present were found to be much coarser than those present on the fracture located in the section between the articulated rod pin bore and crankshaft bore surfaces, indicating a much lower number of cycles to failure and significantly higher imposed stresses. Licensee personnel concluded that the connecting rod bail failures were secondary to the other failure and occurred as a result of the elevation of stresses resulting from the propagation of the primary fatigue crack. The inspectors concurred with this conclusion.

Mechanical properties and chemical composition of the failed connecting rod were also determined by licensee personnel. The results met Cooper specification requirements for the connecting rod forgings and showed good correlation with the data furnished by the forging supplier. Metallographic examination of the material found a fine grained microstructure consisting of partially spheroidized pearlite and grain boundary ferrite. This microstructure was initially questioned by the inspectors in that it potentially indicated a failure to perform the specification required quenching and tempering heat treatments. From review of a time-temperature-transformation diagram for the forging material (i.e., AISI 1050), the inspectors ascertained that to produce the initially expected martensitic structure would require the quench cycle to cool the material from the austenitizing temperature to below 1000° F in approximately 0.7 seconds. Considering the mass of the forging, the inspectors concluded that the pearlite/ferrite microstructure was consistent with a quench and temper heat treatment process for this grade of material.

Macroscopic and SEM examination of the failed bolts (i.e., articulated rod pin bolts and bolts connecting the master connecting rod to the bearing cap) showed evidence of plastic deformation, necking, and a dimple type of fracture. Licensee personnel concluded from these features that the bolting failures were the final fractures, and were indicative of tensile overload. The inspectors concurred with this evaluation.

The results of the licensee metallurgical evaluation indicate that the root cause of the engine failure was the presence of an improperly drilled and repaired oil passage hole in the connecting rod assembly, which acted as a stress riser and initiation site for high cycle fatigue crack propagation.

2.3.2 Inspection of Spare Connecting Rods and Other Connecting Rods in Standby Diesel Engine No. 22

The licensee undertook an inspection program to measure the extent of overdrilling present in the lubricating oil passage (which acted as the fatigue crack initiation site in Standby Diesel Engine No. 22) of spare connecting rods in their possession and of the nine remaining connecting rod assemblies in Standby Diesel Engine No. 22. Similar measurements of spare connecting rods were made by two other licensees at STP request.

A total of 15 connecting rods were examined in this inspection program, with 4 being found to be in conformance with drawing requirements regarding drilling of this oil passage hole. One STP spare connecting rod was found to have a through drilled hole. The hole had been chamfered, however, at the articulated rod bore surface, which would reduce the level of stress concentration at this location compared with the hole that initiated the fatigue failure. Ten of the connecting rods showed overdrilling from 0.03" to 0.60", which represents a range of 0.69" to 0.13" of remaining section present at the articulated rod bore surface. Consideration of these findings will be covered in the generic aspects of this event; responsibility for the generic has been assumed by the Office of Nuclear Reactor Regulation.

2.3.3 Other Inspection and Tests

The licensee conducted the following additional inspections and tests:

- Visual and boroscope inspection of the balance of the engine and cylinders

- Visual inspection of all pins and joints in the No. 22 engine rods for any signs of heat tint or loss of lubrication

- Magnetic particle examination of the center frame and lower housing at the No. 4 cylinder (The fracture areas were mapped where fractures were observed.)
- Mechanical inspection of the balance of the internals in the engine crankcase (No damage was found outside of the No. 4 cylinder area.)
- Electrical and mechanical inspection outside of the engine (Some auxiliary mechanical equipment was damaged as well as some electrical circuits faulted.)
- Vendor inspection at the factory to ascertain the effectiveness of the quality function concerning manufacturing defects
- Manufacturer and consultant inspection and evaluation
- Ferrographic analysis of the lubricating oil
- Inspection and analysis of nonsuspect rotating parts to determine if other items may have influenced the failure

The inspectors reviewed the completed reports and test results and concluded that the data was complete and sufficient to support the conclusions drawn regarding root cause of failure and extent of damage that occurred.

2.3.4 Stress Analysis

The licensee has contracted to a consultant for a three dimensional finite element stress analysis of the connecting rod. Cooper Industries is also performing a like analysis. The results of this analysis will be utilized in the assessment of generic effects of overdrilling on connecting rod reliability. The responsibility for followup on generic aspects has been assumed by the Office of Nuclear Reactor Regulation, Division of Engineering Technology.

2.4 Repair and Recovery Activities

The engine manufacturer contracted the repair of the engine to Reynolds/French, an engine repair firm that specializes in the type of repair and rework that was required for Standby Diesel Engine No. 22.

The repair consisted of mechanically repairing the fractures in the center frame and lower housing; straightening of the crankshaft; remachining the No. 4 crankshaft journal and thrust wall; replacement of the connecting rod assembly and other moving components with new parts, and replacement of the cylinder liner, bent valves, and rocker arms.

The NRC inspector observed the cleanup, machining of the rod journal, and reassembly of the engine.

No violations or deviations were identified in this area of inspection.

2.5 Summary

From observations and review of licensee activities, the inspectors concluded that the licensee has performed a thorough evaluation of the root cause of the Standby Diesel Engine No. 22 failure and has implemented appropriate inspections and repair and recovery activities. The root cause of the engine failure has been established to be the propagation of a high-cycle fatigue crack from a stress riser created by the presence of an overdrilled lubricating oil passage hole in the No. 4 connecting rod assembly. The effects of overdrilling of this particular passage will be determined by the licensee upon completion of a three dimensional finite stress analysis of the connecting rod assembly.

3. EXIT INTERVIEW

The inspectors met with Mr. C. McIntyre and other members of the licensee staff on December 20, 1989, for the purpose of finalizing the inspection effort. A formal exit interview was not held regarding the findings of the inspection.