The Role of Testing in Requalifying TDI Engines for Nuclear Service

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Abstract

This paper discusses the role of testing in requalifying Transamerica Delaval, Inc. (TDI) diesel generators for use as emergency standby power sources at nuclear power plants. "Lead" engine tests (to confirm the design adequacy of key engine components under conditions that could induce high-cycle fatigue) and "following" engine tests (for engines of the same model and equipped with the same components as the "lead" engine) have been conducted at several nuclear power plants. The tests conducted by Duke Power Company (Catawba Nuclear Station Unit 1) and Long Island Lighting Company (Shoreham Nuclear Power Station Unit 1) are discussed.

1. Introduction

Following a crankshaft failure at a nuclear power plant in one diesel generator manufactured by Transamerica Delaval, Inc. (TDI) and less serious problems with TDI diesels at other nuclear plants, 13 nuclear utilities formed a TDI Diesel Generator Owners' Group to address engine reliability and quality issues. In March 1984, the Owners' Group submitted a plan to the U.S. Nuclear Regulatory Commission (NRC) describing a comprehensive program for requalifying the TDI engines as emergency power sources for nuclear systems. A principal element of the plan was engine testing and inspection.

NRC authorized the Pacific Northwest Laboratory (PNL), which is operated for the U.S. Department of Energy by the Battelle Memorial Institute, to manage a technical assessment of information submitted by the Owners' Group and by individual NRC licensees regarding TDI engines. In providing this technical support, PNL has relied heavily on the experience and expertise of consultants with well-established reputations in diesel engine technology.

As discussed in PNL's evaluation [1] of the Owners' Group Program Plan, the PNL project team and consultants concluded that engine tests and inspections are of primary importance for verifying design adequacy of key engine components and for confirming the adequacy of corrective actions. In the absence of such tests, available information did not provide an adequate basis for the PNL team to draw unequivocal conclusions about the overall adequacy of the engines for nuclear service.

Included in the PNL report referenced above are recommendations for tests of "lead" engines and "following" engines. These recommendations were adopted by the NRC staff [2].

PNL views "lead" engine testing as a means of verifying that key engine components will meet load and service requirements without evidence of abnormal behavior under conditions that could induce high-cycle fatigue. Tests completed successfully on a "lead" engine of a given "model" (where "model" refers to the manufacturer's designation for a particular engine design) are considered applicable to "following" engines equipped with the same components and operated at loads no higher than the load at which the "lead" engine was tested. The "following" engines need to be tested only as necessary to verify proper engine assembly and operation.

This paper summarizes PNL's recommendations for "lead" engine tests, and discusses the tests that have been performed at two nuclear power plants: Duke Power Company's Catawba Nuclear Station Unit 1 and Long Island Lighting Company's Shoreham Nuclear Power Station Unit 1.

2. "Lead" Engine Tests

The approach recommended by PNL [1] for verifying the adequacy of key engine components is to operate a "lead" engine for enough time (approximately 750 hours at the rated speed of 450 rpm for TDI R4-series engines) to accumulate 10^7 stress cycles at the load at which the engine is to be qualified. The engine should then be disassembled to the extent necessary for inspection of all key engine components. Results of these inspections, including nondestructive examinations of certain high-stress areas (e.g., fillets of crankshaft journals), should be compared with corresponding information from pretest inspections to identify any evidence of abnormal behavior of the components under the conditions imposed during the test.

PNL noted in Reference [1] that individual engine owners are best qualified to prepare the detailed plans for engine tests and inspections, because of the plant-specific nature of engine installations at nuclear power stations. PNL's recommendations concerning the test plans included the following. Key engine data (e.g., temperatures and pressures) should be defined, together with requirements for how these data are to be logged. Acceptance criteria should also be included. The plans should reflect recommendations of the engine manufacturer and the TDI Diesel Generator Owners' Group, and should also reflect any additional recommendations and requirements stemming from NRC's review of the Owners' Group Program.

At the time this paper was written, lead-engine tests had been performed at two nuclear power plants: Duke Power Company's Catawba Nuclear Station Unit 1 in South Carolina (equipped with TDI V-16 engines), and Long Island Lighting Company's Shoreham Nuclear Power Station Unit 1 in New York State (equipped with TDI inline 8-cylinder engines). The test plans prepared by the utilities generally reflected the recommendations summarized above.

2.1 Catawba Nuclear Station Unit 1

Duke Power Company (Duke) has conducted extensive tests on two TDI diesel generators, designated as 1A and 1B, that are installed at Catawba Nuclear Station Unit 1. Each engine is a TDI model DSRV-16-4, with 16 cylinders arranged in two banks in a V-type engine block. The manufacturer's rating for continuous operation of each engine is 7000 kW at

450 rpm, with a brake mean effective cylinder pressure of 225 psig. Duke predicts that the maximum loads for either engine are 5256 kW for a loss of coolant accident and 5714 kW for loss of offsite power.

In a test program completed in March 1984, the 1A diesel generator was operated for more than 800 hours. For approximately half of those hours, the engine load was equal to or greater than 5800 kW. The 1B engine was operated for more than 750 hours in a test program completed in July 1984, at loads that exceeded those required under emergency conditions for nearly all of the accumulated hours. During these tests neither engine experienced any problems that adversely affected continued operation or prevented meeting emergency load requirements.

The engines were subsequently disassembled, inspected, and reassembled in accordance with Duke's quality assurance program, primarily by Duke personnel. Representatives of the TDI Diesel Generator Owners' Group participated in selected inspections. The inspections encompassed all components of the 16 previously identified by the Owners' Group as having a history of known problems in TDI engines. Important engine components for which there was no history of problems received sampling inspections. PNL representatives visited Catawba in April and July 1984 to audit ongoing activities with the TDI engines and to review related documentation.

Significant findings of the post-test inspections of the 1A and 1B engines involved several components of the same type that had experienced problems in other TDI engines. Action taken on these findings reflected recommendations of the Owners' Group, which was in the process of evaluating and resolving generic problems as Phase 1 of the Owners' Group Program Plan. The findings, and the action taken on each, included the following:

- Six of the type AN piston skirts used in the engines were found to have one or more cracks in the region where an internal circumferential reinforcing rib intersects the piston pin boss. All of the AN piston skirts were replaced with type AE piston skirts, which have been proven in other engines to operate without cracking at loads at or above the emergency loads predicted for the Catawba engines.
- The turbocharger thrust bearings were found to be severely worn, although they had continued to function satisfactorily during the tests. Similar wear had been found in turbocharger thrust bearings of other TDI engines in nuclear service. To alleviate this problem, the Owners' Group developed modifications that provide additional bearing lubrication during engine starts.
- Four cylinder heads were found to have small jacket water leaks into the fuel injector nozzle cavity (external to the cylinder). A metallurgical examination of one of these heads by a consultant to the Owners' Group revealed that cracks had propagated from a plug weld performed during manufacture in the fuel injector nozzle seating area. These cracks were not a pathway for water to enter the cylinders, and were of no significance for diesel operation. Similar welds in the firedeck, however, could compromise the integrity of a cylinder head, in that weld cracking could lead to entry of water into the cylinder. Accordingly, PNL recommended that any cylinder head with a through-wall weld repair of the firedeck, performed from one side only (as is customary for a plug weld), should not be placed in service at a nuclear power plant.

PNL concluded that the extended operational tests conducted on the TDI engines at Catawba adequately demonstrated the capability of the engines to be placed in service. PNL also concluded that the tests provided substantial evidence applicable to other TDI engines in nuclear service of the adequacy of the components that operated successfully under the conditions imposed during the tests.

2.2 Shoreham Nuclear Power Station Unit 1

Three diesel generators manufactured by TDI are installed at the Shoreham Nuclear Power Station (SNPS) to carry emergency service electrical loads. Each engine is an inline 8-cylinder, TDI model DSR-48, with a nameplate rating of 3500 kW at 450 rpm. The brake mean effective cylinder pressure is 225 psig at rated load. The Long Island Lighting Company (LILCO) has designated these engines as EDG 101, 102, and 103.

In November 1984, LILCO completed a 740-hour confirmatory test of the EDG 103 engine at a "qualified" load of 3300 kW. The primary purpose of this test was to demonstrate that the high-cycle fatigue endurance limit of the crankshaft is at or above 3300 kW. No problems were experienced that affected engine operation at any time during the test.

PNL staff and consultants independently audited the condition of key engine components during the post-test inspections. These key components included the piston skirts and crowns, piston rings, cylinder liners, crankshaft, main and connecting rod bearing shells, and engine block.

The components audited by the PNL reviewers exhibited no evidence of deficiencies resulting from their exposure during the confirmatory test, and LILCO's nondestructive examinations of the crankshaft revealed no rejectable indications on critical surfaces. Rather, the good condition of the components provided convincing evidence that they had operated normally throughout the test.

3. Conclusions

The lead-engine tests and inspections described in this paper, together with numerous other tests performed on TDI engines in nuclear and nonnuclear installations and in TDI's manufacturing facilities, confirm that certain key engine components will meet load and service requirements without evidence of distress under the conditions imposed during the tests. Results of these tests have been a primary consideration in PNL's recommendations to the NRC staff concerning TDI diesel generators at nuclear power plants that are candidates for near-term operating licenses. At the time this paper was written, PNL had concluded that TDI emergency diesel generators at the following nuclear power plants are requalified for service: Catawba Nuclear Station Unit 1, Comanche Peak Steam Electric Station Unit 1, Grand Gulf Nuclear Station Unit 1, San Onofre Nuclear Generating Station Unit 1, and Shoreham Nuclear Power Station Unit 1. PNL's conclusions were subject to certain actions, including implementation of all relevant recommendations and requirements identified in the ongoing review by NRC and PNL of the Owners' Group Program.

References

[1] Pacific Northwest Laboratory. June 1984. Review and Evaluation of TDI Diesel Generator Owners' Group Program Plan. PNL-5161, Richland, Washington.

[2] U.S. Nuclear Regulatory Commission. August 1984. Safety Evaluation Report, Transamerica Delaval, Inc., Diesel Generator Owners' Group Program Plan. Washington, D.C.