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ACQUISITION AND REVIEW OF DIESEL GENERATOR TESTING DATA

Prepared by Thomas A. Hogan
Tennessee Valley Authority
400 West Summit Hill Drive, W7C165
Knoxville, Tennessee 37902

Abstract

Historically, diesel generator qualification and periodic testing has been primarily concerned with demonstrating equipment operability and providing a data base for which numerical values for reliability are calculated. Although these factors are required for plant licensing and operation, a properly planned and implemented testing program can provide useful information regarding maintenance and testing procedures and intervals, component deterioration, setpoint drift, or impending failures. To provide meaningful results in these areas, a testing program must rely on accurate data acquisition as well as a thorough review by qualified personnel to point out discernable trends and determine their significance. This paper is intended to be neither a comprehensive checklist of test data to be recorded and analyzed nor a reference book of problems associated with certain data trends. Rather, it is presented to illustrate examples of useful information obtained through test data review.

Introduction

Recently the NRC has expressed concern regarding the effectiveness of current diesel generator testing. In response to these concerns, TVA began an evaluation of the procedures in use at its nuclear power plants.

Investigation of Testing Programs

This investigation revealed that not only were the testing procedures different among the plants but that the apparent intent of the testing programs also varied. Most of these differences can in one way or another be attributed to changes in the guidance and regulations between licensing dates for the plants.

The formal testing programs at the earlier plants (Browns Ferry Nuclear Plant and Sequoyah Nuclear Plant which began commercial operation in 1974 and 1981, respectively) were primarily concerned with simply demonstrating unit operability. The tests were more or less limited to preparing the diesel generators to start, starting the unit, running for a short period, and returning it to standby conditions. These procedures require that certain parameters be verified within acceptable limits, but for the most part do not require that the actual value for the parameters be recorded. While this testing has provided a data base from which numerical values for starting reliability are calculated, it provides very little hard data (pressures, temperatures, etc.) to be analyzed. A contributing cause of this form of testing is the earlier plant technical specifications which require demonstration of diesel generator operability whenever the emergency core cooling subsystems become inoperable. As a result of the NRC's Generic Letter 84-15, many of these technical specifications are being revised. These revisions should reduce not only the number of periodic fast starts but also the number of starts required solely to demonstrate diesel generator operability.

In contrast, the procedures to be implemented at the plants still under construction (Watts Bar Nuclear Plant and Bellefonte Nuclear Plant scheduled to load fuel in early 1985 and mid-1987, respectively) require progressively more hard data acquisition. Finite values for temperatures, pressures, flow rates, etc., are required to be noted on the data sheets in addition to initials verifying that the parameters are within acceptance criteria.

Consistent with the varying testing procedures, there was no uniform practice among the plants for analyzing the resulting data.

Research for the purpose of designing uniform testing procedures and coincident analysis methods has yielded much information regarding various approaches.

The vendor instruction and maintenance manuals currently furnished along with diesel generators contain many more diagnostic testing and data retention and analysis recommendations than did those furnished in the 1960s and 70s. Although an adequate testing program can be patterned after such recent manuals, it would involve many man-hours to read and record the various data points, maintain the data sheets, and analyze the data either numerically or graphically.

Some of the older and many of the more recent nuclear standby diesel generators have been equipped with graphic recorders which provide a hard copy record of certain parameters. These recorders do save time in reading, recording, and graphically presenting data. They will point out drastic changes in a particular parameter, but in most cases lack the sensitivity to show small changes in a parameter.

Due to the small amount of time that nuclear standby diesel generators actually spend running and the fast starting and severe step loading to which they would be subjected in an emergency, these small changes in the values of parameters during testing may be the only clues available to point out a problem or an impending failure.

Potential Applications of Microprocessors

In the past few years several microprocessor-based systems have been marketed for data recording and/or diagnostic testing of diesel engines. The increase in accuracy and decrease in manpower requirements while using such systems have made them standard equipment for many manufacturers and maintenance organizations.

In a nuclear plant, technical specifications regarding plant operation with an inoperable diesel generator add a considerable commercial impact to a catastrophic diesel generator failure. Based on this reasoning, a microprocessor based system of automatic data acquisition/analysis would seem to have many advantages in this application. The cost of regularly having personnel read and record as well as graphically present data could be drastically reduced, while increasing the accuracy of the analysis by allowing trend analysis of smaller differences in a parameter value. In addition, plant permanent records of testing data could be kept in computer files with hard copies in various formats being available as required. The cost-effectiveness of implementing such a system would, of course, depend upon several factors. The amount and type of monitoring and protective instrumentation and the required interfaces with a microprocessor-based system would have to be evaluated with respect to separation, operability, seismic, and class 1E qualification requirements.

Even with a microprocessor-based system,, the individual parameters to be monitored and the methods of analyzing the data must be determined. Most diesel engines are equipped with instrumentation to monitor the temperatures and pressures of the engine jacket water, lubricating oil, combustion air, and exhaust. In addition, fuel oil and crankcase pressures and main bearing temperatures are usually either monitored or alarmed. Most generators in nuclear standby service are designed for parallel and isochronous operation and are equipped with instrumentation to monitor or alarm rotor temperature, bearing temperature, voltage and current. Some of the parameters that are alarmed only, yield no data for predictive analysis and offer very little time for action prior to serious damage once it is annunciated.

General conclusions to be drawn from rapid trends in these parameters have been derived from years of actual engine experience. For example, low lubricating oil pressure may be due to loose or worn bearings, pump problems, or leaks; whereas high jacket water temperature may indicate a dirty heat exchanger, air in the system, or even a clogged water passage. Troubleshooting procedures for these conditions are generally covered adequately in the instruction manuals. Some conclusions particularly applicable to diesel generators in nuclear standby service have been generated more recently as experience is gained. Additional test data accuracy could enable these conclusions to be reached earlier for smaller incremental changes in the values of the parameters. This would facilitate scheduling of periodic maintenance as well as decreasing the chances of a sudden failure and/or an unscheduled diesel generator outage.

One benefit of such a system would be that once the data base is established, each test run would add another set of results. With some programming and graphics hardware, detailed and accurate hard copies and graphs could be generated. It would also enable comparison with any previous test results for changes that may have been too gradual for the graphs to show. In addition, once all diesel generators at a plant or all diesel generators within a utility are placed on the same system, comparisons among all diesel generators would be possible.

Review of Previous Failures

As a step toward predicting impending failures, test results just prior to some major diesel generator problems and/or failures were reviewed to determine if additional or different analysis of the test data could have predicted them.

During preoperational testing of the WBN diesel generators in 1980, vibration readings showed shaft displacements in excess of 10 mils. After a detailed analysis of the problem, modifications to the generator supports were made to move a critical speed away from the operating speed. After the modifications, all displacements were less than the 3 mils acceptance criteria. A fully instrumented test however showed that even though the displacements had been reduced, the phase angle of the vibration on one diesel generator was shifting during operation. When the generator was uncoupled from the engines and "motored" the cause of the phase angle shifting was narrowed to a bad bearing or an imbalance within the generator. Inspection of the generator revealed one bearing was cocked at an angle on the shaft.

A review of test data from the generator manufacturer's shop showed that vibration of the generator when mounted in their test fixture was within NEMA standards. The addition of I-beam supports by the diesel generator packager and the very rigid foundation at WBN caused the vibrations to exceed acceptance criteria. A fully instrumented (including phase angle measurement) vibration test of diesel generators at installation may reveal potential future operating problems.

In June 1983, one of the diesel generators at Watts Bar Nuclear Plant had to be shutdown due to shaft insulation failure. Generator disassembly revealed that because the shaft was machined out of tolerance, the inner and outer races of the cylindrical roller bearing were misaligned. In fact, the misalignment was so great that the outer bearing race had come into contact with the retaining ring which held the inner bearing race on the shaft. This contact caused the inner race to rotate on the shaft and eventually caused the insulation under the inner race to wear and fail.

This failure was of particular interest because its occurrence could have been predicted either by noting a decrease in the shaft insulation resistance or by wear particle analysis of the metallic particles in the bearing lubricating oil resulting from the outer bearing race contact with the retaining ring.

Test records from the manufacturer's facility showed that the shaft insulation resistance had been measured as greater than 1 meg ohm prior to shipment to the diesel generator packager. There were no records of any shaft insulation resistance measurements being taken once the diesel generators were onsite. In addition, since such measurements would require that the generator be uncoupled from both engines which drive it, no such measurements were planned as a part of periodic testing or maintenance.

The site records were then reviewed for any bearing test results. In February 1981, the lubricating oil for the bearings was removed and sent to the laboratory for analysis. This analysis revealed a relatively high concentration of metallic particles of copper, iron, and silicon in the oil. At that time the particles were attributed to the previous vibration problems and a pinched outer bearing race. Shims were added to the bearing caps to allow the bearing more freedom of axial movement and monthly sampling and lab analysis of the bearing lubricating oil were instituted. Although some metallic particles continued to show up in the oil, the level was reduced to a point not considered abnormal. Any significant increase in the level of metallic particles in a sample was to be the trigger to initiate additional action.

After the insulation failed, the oil sampling procedure was reviewed. This procedure required that a one quart sample be removed from each bearing oil reservoir each month. Since the reservoir holds only five quarts, this resulted in a complete change of the oil every few months and kept the metallic particle levels below what would be considered abnormal. Thus, both the oil sample size and inadequate wear particle analysis of the oil contributed to the failure to identify or predict this problem.

Due to the test procedures in use, very little data was available for predictive analysis prior to the failures at the operating plants which were investigated. In early 1980, speed control was lost on one of the diesel generators at BFN. The cause was found to be a broken coupling between the speed pickup shaft and the signal generator. It appeared that the heat and oil in the environment around the engine had caused the elastomeric spider in the coupling to fail. Without this elastomeric spider, the metal-to-metal contact eventually caused the coupling to break. Although the confirming test data does not exist, small speed fluctuations or sluggish speed changes could have pointed to this impending coupling failure.

One of the diesel generators at SQN recently had a failure of a connecting rod and piston assembly. When the test prior to this failure was reviewed, no particular parameter changes could be determined. In talking to the test personnel, however, it was indicated that abnormal noise, similar to piston-slap, was heard in the area of the failed piston/rod assembly, prior to its failure. This noise was not however considered serious enough to stop the test until the assembly failed. Inspection revealed that the assembly probably failed due to insufficient bolt preload. While this example may not directly show the value of test data analysis, it does point out the importance of adequately following up on any abnormal conditions as soon as they are noticed.

This investigation also revealed information regarding changes made to preclude recurrence of specific problems. Most of these changes involved periodic inspections or examinations of the components or parts that had failed. Product improvements and/or system modifications were also instituted in some cases. Revision to test procedure methods and/or acceptance criteria were part of the effort to prevent recurrence in a high percentage of the failures reviewed. In all but a few isolated cases, changes to test procedures were on a per plant basis and not necessarily incorporated into the testing programs for all plants.

Conclusion

Based on the above, when setting up a nuclear standby diesel generator testing program or evaluating an existing program, the following points should be considered:

1. Which parameters are instrumented.

2. Instrumentation changes based upon experience or other information.

3. Conclusions to be drawn from the data for each parameter.

4. The feasibility of a microprocessor-based system for data recording, retention, and compiling.

5. Using analysis of available test data as action to prevent recurrence of problems or failures.

6. Ensuring that changes to test methods, acceptance criteria, or data analysis are extended to all affected diesel generators.