SUCCESSFUL TESTING OF AN EMERGENCY DIESEL GENERATOR ENGINE AT VERY LOW LOAD

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Abstract

For more than 30 years, the nuclear power industry has been concerned about the ability of emergency diesel generator sets (EDGs) to operate for extended periods of time at low loads (typically less than 33% of design rating) and still be capable of meeting their design safety requirement. Most diesel engine manufacturers today still caution owners and operators to avoid running their diesel engines for extended periods of time at low loads. At one nuclear power plant, the emergency electrical bus arrangement only required approximately 25% of the EDG's design rating, which necessitated that the plant operators monitor EDG operating hours and periodically increase electrical load. In order to eliminate the plant operations burden of periodically loading the EDGs, the nuclear power plant decided to conduct a low-load test of a "spare" diesel engine. A SACM Model UD45V16S5D diesel engine was returned to the factory in Mulhouse, France where the week long testing at rated speed and 3% of design rating was completed.

The test demonstrated that the engine was capable of operating for seven days (168 hours) at very low loads, with no loss of performance and no unusual internal wear or degradation. The planning and inspections associated with preparing the diesel engine for the test, the engine monitoring performed during the test, the final test results, and the results and material condition of the engine following the test are described. The successful diesel engine low-load test resulted in the elimination of unnecessary nuclear power plant operation restrictions that were based on old concerns about long-term, low-load operation of diesel engines. The paper describes the significance of this diesel engine test to the nuclear power plant and the entire nuclear power industry.

Purpose

Certain plant emergency conditions at the Calvert Cliffs Nuclear Power Plant (CCNPP) in Lusby, Maryland may result in the requirement to operate the SACM 1A EDG for an extended period of time at rated speed and low load. Presently the SACM engines are limited to operating for no more than eight hours at loads less than or equal to 30% of their design rating. This limitation requires plant operator action to monitor EDG load at times when the operators may be dealing with other important plant conditions. It was anticipated that the test would confirm the engine is capable of operating at low loads with no concern for long-term wear or damage that could prevent subsequent operation of the engine under required, fully loaded conditions.

Background

Earlier technical reviews and evaluations concluded that the SACM Model UD45V16S5D diesel engine was capable of supporting long-term, low-load operation (References 1 and 2). These reviews were based on the extensive experience of this model diesel engine in railroad and marine applications, as well as the experience of other four-stroke diesel engines in nuclear power plant standby applications. However, CCNPP concluded that the most direct method for confirming to the United States Nuclear Regulatory Commission (USNRC) the engine's capability was to conduct an actual low-load test. Thus, in October, 1999, CCNPP requested MPR Associates to evaluate various test options to complete the SACM diesel engine test of seven days (168 hours continuous) duration at no load or very low load, followed by operating the engine at or near its design continuous rating for several hours. The following are the several test options considered by MPR prior to developing, along with Wärtsilä France, the diesel engine test plan approved by CCNPP for the low-load test:

1. Testing a readily available locomotive diesel engine of similar design to the Model UD45,
2. Testing a "new" Model UD45 diesel engine at the Wärtsilä France factory,
3. Testing a "used" Model UD45 diesel engine at a test laboratory,
4. Testing of CCNPP's "spare" Model UD45 diesel engine at a test laboratory or at the factory, and
5. Testing one of the installed Station Blackout diesel engines at CCNPP.

Calvert Cliffs Nuclear Power Plant personnel concluded that the most realistic option for completing this technical effort was to utilize the test option involving the CCNPP "spare" engine in an off-site diesel engine test cell. It was decided that the test could be best performed at the Wärtsilä France factory in Mulhouse, France. Having the original equipment manufacturer (OEM) directly involved in the test provided added technical credence to the low-load test, as well as increased access to any needed technical information and spare parts or fittings that would be required to support the test. MPR Associates, acting as CCNPP's Project Manager, developed the 168-hour engine test requirements and had responsibility for air freighting the 24-ton diesel engine and 800 gallons of diesel engine lubricating oil from the Calvert Cliffs Nuclear Power Plant to the Wärtsilä factory in Mulhouse, France.

Diesel Engine Design Details

The SACM Model UD45V16S5D diesel engine is a very mature design, and several variants of its design have been in service since about 1959. More than 800 similar design SACM diesel engines have been in railroad service around the world. Another 600 similar design SACM diesel engines are in various marine and military uses. Finally, more than 275 SACM design engines are installed as standby power systems in over 80 nuclear power plants worldwide (Reference 3). Thus, this basic SACM diesel engine design has over 40 years experience in a wide variety of applications.

The SACM Model UD45V16S5D diesel engine design features are (Reference 4):

Engine Size	16 cylinder
Cylinder Arrangement	50 degree Vee
Engine Power	3744 bhp continuous rating (or 2792 kW)
Engine Cycle	Four-stroke
Engine Speed	1200 rpm
Piston Bore	9.45 inches/240 mm
Piston Stroke	9.11 inches/231 mm
BMEP	250 psi at 3744 bhp continuous

At the Calvert Cliffs Nuclear Power Plant, the SACM diesel generators are tandem units that are rated at 5400 kWe. In this arrangement, there are two diesel engines providing power to a single generator mounted between the engines. One engine rotates in a clockwise direction and the other engine rotates in a counter clockwise direction. The low-load test was accomplished on CCNPP's "spare" SACM Model UD45V16S5D diesel engine which is identical to the four other engines installed as the prime movers for the 1A emergency diesel generator (EDG) and the 0C Station Blackout (SBO) diesel generator at CCNPP.

Pre-Test Inspections and Test Conditions
After the "spare" diesel engine was air freighted back to the factory, it was visually and dimensionally inspected before the test. Four of the engine's 16 cylinders were completely disassembled and confirmed to be within the original design dimensions. No other pre-test grooming or conditioning was done to the engine. Prior to the test the engine was subjected to a 12-hour period of operation to confirm it was in good operating condition following its extended five-year storage period at CCNPP. Then the engine was operated for another 50 hours at varying loads to better simulate the actual conditions of the engines installed at CCNPP and to establish actual operating time on the engine. In addition, the 50-hour operation provided the time to collect operating data to confirm the engine met the as-built performance requirements when it was originally delivered to CCNPP.

The test was conducted in one of the manufacturer's test cells for a period of seven days (168 hours). The engine load of approximately 3% (84 kW) of the design continuous rating was maintained by a Zöllner Model ES 116, Type 12-N6-N65 hydraulic brake (water brake) coupled to the engine's flywheel. This is the same test arrangement as used during the original factory acceptance tests for the CCNPP diesel engines in 1994. The water brake provided reliable control of the engine load in that during the test, the load varied by less than ±0.25%. The test was performed with the diesel engine starting from its normal "keep-warm" standby conditions. The diesel engine was lubricated using the same lube oil as is used in the SACM diesel engines installed at CCNPP. The engine was operated on low sulfur, Number 2 diesel fuel oil similar to that used at CCNPP.

As noted above, the engine was tested in one of the manufacturer's test cells, and all the standard qualification test parameters were recorded using the installed calibrated instrumentation. In addition to the standard test equipment, engine ultrasonic and vibration parameters were monitored and trended during the 12-hour and 50-hour pre-test operating periods and during the low-load test. This additional monitoring effort helped confirm that the engine was in good condition. Further, if an off-design condition such as high vibration or excessive noise condition arose during the test, the monitoring and trending equipment would have been useful in identifying the cause. Further, the vibration and ultrasonic monitoring equipment would have also been useful, if necessary, in helping to decide to shut down the engine during the test. Figure 1 shows the engine installed in the test cell during the low-load test and Figure 2 shows the engine coupled to the water brake. Table 1 compares the engine test conditions with the installed engine conditions at CCNPP. To the maximum extent possible, the test conditions were designed to simulate the worst case condition for low-load operation of the diesel engine.

Low-Load Test Results

The "spare" diesel engine operated at its design speed of 1200 rpm with a load of between 83 and 91 kW for more than 168 hours. As reported in Reference 5, the test was completely successful and confirmed that the SACM Model UD45V16S5D diesel engines can be operated at low loads for periods as long as seven (7) days without damage to the engine and without impairing the engine's ability to accept rated load.

A two-minute pause at the 41-hour point in the test, due to the loss of electrical power in the manufacturer's test facility, was the only interruption during the low-load test. The engine was immediately restarted and operated at low load for the remaining 127 hours. One cylinder's fuel injection pump exhibited a slight sticking of its metering rod following the restart, and that cylinder's exhaust gas temperature ran slightly hotter for several minutes. However, applying an oil coating to the metering rod resolved that problem. Following that correction, the low-load test was completed without incident.

After seven days of low-load operation, the engine load was increased from 88 kW to 1528 kW (approximately 55% of design rating) in slightly less than 2 minutes. The engine operated at this load for one hour, at which time the load was increased to the engine's design continuous rating of 2792 kW. The engine then operated for two hours at design rated load and all the engine operating parameters (lube oil pressure and temperature, jacket water pressure and temperature, intake and exhaust temperatures, etc.) were recorded to be within the manufacturer's normal design values.

As the engine load was first applied, there was a brief, light brown/gray appearance to the combustion gases emitted from the exhaust stack. There was no measured loss of engine speed as the loads were applied to the engine. This indicated the engine, turbochargers, and governor were able to develop the required engine response during the transient conditions.

The test also demonstrated that while the diesel engine was operating, the various thermostats in the engine lube oil and jacket water cooling loops functioned properly and maintained the fluid temperatures within their appropriate limits. As expected, the fuel injection pumps were observed at a higher than normal temperature when operating at low loads. However, once rated load was applied, the fuel injection pump temperature decreased to normal. The test demonstrated that the fuel injection pumps did not experience degradation from the elevated operating temperatures. The engine fuel oil and lube oil consumption rates were monitored during the test, compared to the original factory test results from 1994, and confirmed to be within the engine's design specifications. Finally, the turbochargers suffered no ill effects from the low pressure differential across their labyrinth seal while operating at low loads.

Results of Post-Test Engine Inspections

As described above, selected engine internal components were dimensionally inspected before the 12-hour break-in run and the 50-hour variable load run. Those same parts from the four cylinders were inspected after the 168-hour, low-load test and 3 hours of loaded operation. As expected, there were no unusual wear conditions identified on any of the parts. All parts and measured clearances were found to be within the original design dimensions.

The pistons had very light carbon deposits on the piston crowns, however there was almost no indication of carbon deposits behind the piston rings. There was no evidence of combustion gas blowby on any of the pistons or cylinder liners. The piston crowns, piston skirts, and cylinder liners were free of any signs of wear, scoring or scuffing. One piston wrist pin bushing had a score mark in the babbitt overlay. The score mark did not impact engine operation and did not appear to be the result of operating the engine at low load. The score mark was likely the result of some hard dirt particle being trapped between the pin and the bushing. The connecting rod bearings had some very slight markings on the babbitted surfaces of the bearing shells however, the manufacturer stated they were suitable for reinstallation.

The intake valves had carbon deposits on the tulip region of the valve. The deposit accumulation was not excessive and did not interfere with the engine operation. The valve seat surfaces and valve guide surfaces were in excellent condition. Before returning the "spare" diesel engine to CCNPP, Wärtsilä France inspected the entire engine for any other signs of wear or degradation. No other major engine or turbocharger parts required repairing or replacing. The engine will be returned to the nuclear power plant ready for installation, if needed.

Conclusions

The test was completed successfully and confirmed that the SACM diesel engines can be operated with low-load for periods of as long as seven (7) days without damage to the engine or jeopardizing its safety function. Selected engine internal components were inspected before and after the 168-hour low-load test and 3 hours of loaded operation. As expected, there were no unusual wear conditions identified on any of the parts. All parts and measured clearances were found to be within the original design dimensions.

The test described in this technical paper provided the technical bases for CCNPP to operate its SACM emergency diesel generator set at low-to-moderate loads for extended periods of time, if required by other plant emergency conditions. Calvert Cliffs Nuclear Power Plant saved more than a million dollars by eliminating the need to purchase a safety-related load bank to support periodic operation of its SACM EDG. The perceived need for a load bank arose from a long-held belief that long-term, low-load operation is damaging to diesel engines and a load bank could eliminate this mode of operation. Finally, the plant was able to completely address the USNRC's technical concerns and reduce the operating burden on the nuclear plant operating personnel.

References

1. "Technical Evaluation of SACM Model UD45 Emergency Diesel Generator Long-Term Operation at No-Load and Low-Load Conditions", MPR-1950 Revision 0 dated July 1998.

2. "Technical Evaluation of Emergency Diesel Generator Long-Term Operation at No-Load and Low-Load Conditions", MPR-1817 Revision 1 dated August 6, 1997.

3. Attachment 1 to Northern States Power Company Letter to U.S. Nuclear Regulatory Commission dated September 29, 1989, Subject: Project for Addition of Two Emergency Diesel Generators.

4. Baltimore Gas & Electric Design Specification No. SP-616 "Emergency Diesel Generator 1A & 0C".

5. "SACM Model UD45 Diesel Engine Low-Load Test Report", MPR-2146 Revision 0 dated September 2000.

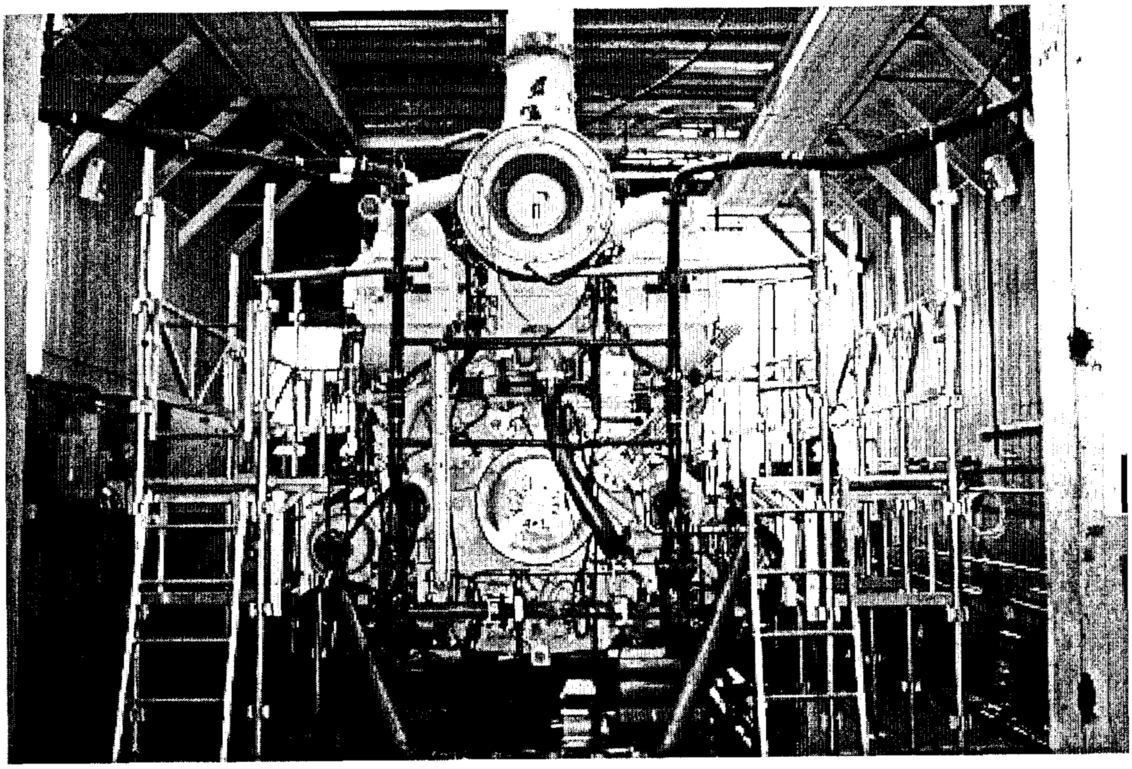

Figure 1
Engine in Test Cell

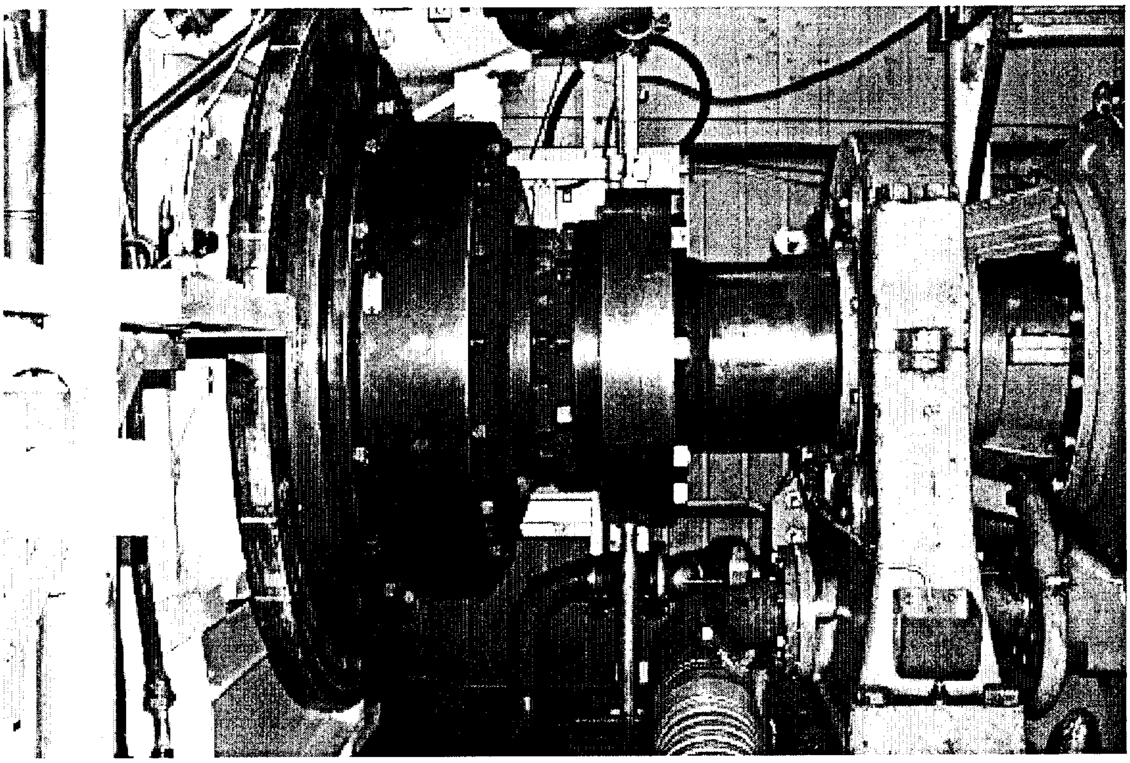

Figure 2
Engine Flywheel with Coupling to Water Brake

Table 1
Summary of Diesel Engine Low-Load Test Conditions vs. Installed Conditions at CCNPP

Parameter	Test Configuration	CCNPP Configuration (1A EDG)	Comment
Test Engine	One SACM UD45V16S5D	Two SACM UD45V16S5D	The low-load characteristics of the tandem engine installations at CCNPP are adequately demonstrated by testing a single engine running at half the load of the tandem set.
Engine Load	Zöllner Hydraulic Brake, Model ES 116, Type 12-N2-N65	Jeumont - Schneider Model SAT 100/100/6 Generator	Use of a hydraulic brake enables reliable control of engine load and is therefore, equivalent to the generator, for the purposes of this test.
	Applied load of approximately 83 to 91 kW	Nominal low-load per engine of 139 kW to support minimum load operation.	The load applied to the single engine during testing adequately replicates the low-load operation of the tandem set.
Intake Air System	Separate intake air filters installed on each turbocharger.	Piping connects a single filter to both turbochargers on each engine.	Low combustion air flow during low-load conditions results in small pressure losses in intake air piping. Therefore, intake air system configuration has no significant impact on low-load operation.
Exhaust System	Exhaust gases from the engine turbochargers are discharged through a silencer to the outside.	Exhaust gas from the engine's turbochargers are discharged through a silencer and then to the outside.	Silencer and piping configuration in the test cell is different from the plant configuration. Differences in exhaust back pressure due to the system differences is considered negligible due to the low exhaust flow during the test.
Diesel Fuel Oil	Shell Direct Low-Sulfur No. 2 Diesel Fuel (European fuel)	Amoco Low-Sulfur No. 2 Diesel Fuel	Pertinent properties of the European and U.S. fuels are similar, including carbon residue, ash content, kinematic viscosity, heat content, specific gravity, Cetane Index, and sulfur content.

Table 1 (continued)
Summary of Diesel Engine Low-Load Test Conditions vs. Installed Conditions at CCNPP

Parameter	Test Configuration	CCNPP Configuration (1A EDG)	Comment
Crankcase Lube Oil	Shell Rotella T 15W-40 Multigrade with Advanced Soot Control	Shell Rotella T 15W-40 Multigrade with Advanced Soot Control	The lube oil used during the low-load test is the same oil as that used by CCNPP. Laboratory tests of the lube oil have been performed to demonstrate that properties of the oil used in the low-load test are consistent with oil used by CCNPP.
Turbocharger Lube Oil	Mobil DTE oil, heavy medium grade	Regal Oil (Texaco) R&O 68	R&O 68 is the Texaco equivalent to Mobil DTE oil, heavy medium. The SACM engine technical manual lists both oils as applicable for the turbocharger.
Ambient Temperature	Ranged between 58 and 92 degrees F	Ambient air temperature of 0 to 95 degrees F, and up to max of 105 degrees F intake air temperature without loss of net generating capacity.	Ambient temperature during test reflects typical ambient temperature for CCNPP EDGs. The moderating effects of the HT and LT thermostatic control valves reduces the influence of ambient air temperature.
Cooling Water Systems	Water-to-water heat exchangers for HT and LT cooling water loops	Air-cooled radiators for HT and LT cooling water loops	Choice of system heat sink is not a factor. The HT and LT thermostatic control valves ensure the engine temperatures remain within design values.