Maintenance concepts for Emergency Diesel Generator sets in nuclear power plants

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1 TECHNICAL PERSONNEL

Emergency Diesel Generator (EDG) sets do not acquire many operating hours, but their regimen of fast starts, rapid loading, short runs, and long periods of idleness creates numerous problems as a function of aging. The success of a maintenance program in preventing failures and in ensuring the reliability of the sets is dependent on developing an adequate maintenance philosophy. This philosophy must have at its core the recognition by management that a certain minimum of knowledgable engineering and technical support, of a continuing nature, is necessary to keep the units ready for emergency service. Without this continuity of effort, they can become severe maintenance problems.

The severe time constraints and importance of ensuring that a Diesel generator set will respond reliably to any call for emergency operation makes it incumbent on key personnel to be thoroughly familiar with the engines, to understand practical mechanics and failure analysis, and to be on site throughout critical inspections or repairs. These key personnel (for example, a mechanical engineer and a shop supervisor) also would review engine operating data sheets and lubricating oil analysis reports, would trend significant data, and generally would remain knowledgable about the current status of the engines and generators. These, then, should be the principal personnel on site when an inspection is being made, when components are removed, or when problems require investigation, so that there is a continuity of technical evaluation and effort. This is essential in developing the technical abilities and personal confidence necessary to:

- evaluate overall readiness of the EDGs
- detect the onset of potential problems
- make reasonably accurate assessments of problems
- make rapid decisions and take timely actions to avoid unnecessary down time.

It would not be expected that this would rule out the need for occasional assistance from the manufacturers' technicians or other sources, but it is important that key personnel be aware of everything recommended by or done by outsiders and that they take an active part in all examinations, diagnoses and decisions relating to EDG problems.

For example, visual inspections and observations are of immense importance in evaluating conditions in an engine or generator, in detecting the onset of a problem and in judging the performance of various components. However, it is not uncommon that the only engine records and the only information which gets to the attention of the responsible engineering personnel are numerical data, such as pressures, temperatures, and dimensions. The information which may be most important in making evaluations and decisions, information such as wear patterns, incipient erosion, fretting or fatigue patterns, or evidence of incorrect assembly methods, may go unnoticed. Without this information, a thorough diagnosis of problems cannot be made, and repair actions may be limited to a futile replacement of components rather than a correction of basic problems.

2 EDG OPERATION AND LOAD REGULATION

Two aspects of EDG operation which have an adverse impact on engine conditions are the numerous fast starts to which all of the engines are subjected, and the brief periods of operation. Simulated emergency starts in American practice did not allow operation of the pre-lube pump before starting, and this resulted in unusual wear and scuffing in such components as turbocharger bearings, piston pin and rocker arm bushings, aluminum bearings, push rod ends and rocker arm cups. Modifications are being made in some technical specifications to permit prelubrication prior to most engine starts, and this will serve to extend the life of these components. Brief periods of operation, with long periods of no operation, also create serious problems in engines; principally corrosion, carbon and varnish accumulation, and oil sludging. They stem from two factors: operation predominantly at very low power output, and operation at below normal temperatures. Results are compression rings which do not seat properly, stuck compression rings, varnish on pistons and cylinder liners, carbon fouling of turbochargers, and corrosion on various surfaces such as cams and gear teeth.

Break-in runs on a new engine, or on one which has been overhauled, do not provide time enough for piston rings and other components to seat properly. With the typical EDG operating schedule, an engine is in the process of wearing-in over a very long calendar period spanning one year or more. It is advantageous during this period to operate as much as possible at high engine outputs. Following this mechanical seating of the engine components, it remains advantageous for every run to include at least one hour at high output to reach full running temperatures and to ensure that any moisture from leaks or condensation has been evaporated.

The governing and load regulating systems are designed for two types of operation; one is test operation at constant load while paralleled with the electrical distribution grid, and the other, under emergency conditions, is to supply a dedicated bus independent of the grid. During constant load operation, at some fixed percentage of the full power rating, an engine is not intended to be in any sort of governing mode and should not be influenced by changes in either in-plant or outside loads. In effect, when an EDG is paralleled on the grid it faces an infinite load and is intended to deliver a specific amount of power into this grid, just the same as do numerous other Diesel generator sets in conventional power plant service. However, cases are reported from various EDG installations in nuclear power plants in which "steady load" operation is anything but steady, and that frequent load adjustments are required. Evidently the electronic load controls respond to some local influences and permit the EDG load to shift up or down. This carries the threat of unintended overloading and possible damage to engine components. Addressing this potential problem requires close consultation with the makers of the governing/control systems and the engine builder to sort out any discrepancies between the design intentions, actual operation, and the EDG technical specifications.

In most Diesel engines it is possible to mechanically limit the maximum injection pump rack position, and thereby limit the maximum load which the EDG will deliver, regardless of what derangement may strike the governing/control systems. Establishing a mechanical load limit, so that the EDG can deliver the maximum power required by the specifications, plus a small margin, accomplishes two desirable objectives:

- It positively prevents dangerous overloading.
- It limits the amount of excess fuel being delivered to the cylinders during start-up.

As an example of the above, in the Fairbanks-Morse opposed piston engines which are used in numerous nuclear power plants, it has been demonstrated that a momentary loss of load control while the EDG is running on the grid can bring the engine up to maximum fuel delivery and maximum power output. If there is no mechanical limit on the injection pump rack travel, the engine immediately goes up to power levels high enough to begin damaging some engine components. This only happens while running on the grid; if the engine was pulling an isolated emergency load the hydraulic governor would take over control as soon as it sensed a speed change. However, since all test operation is done at constant speed, while paralleled on the grid, protection by means of adjusting the mechanical limit on rack travel is an important precaution.

3 ENGINE CONDITION MONITORING

There are two basic approaches to engine condition monitoring. One is to use manual recording of temperatures, pressures and other data, with emphasis of keeping personnel as closely involved with the engines as is practical. This approach has merit provided that all of the personnel recording the data are sufficiently involved with the EDGs, that they are meticulous in their accuracy of observation and alert to the significance of variations in the data or to other factors which may impact on engine operation. One major limitation is that all data must be taken from time-averaging meters or gages, ignoring all peaks and valleys and patterns of modulations. A second limitation is that trending the manually recorded data may be excessively time consuming.

A second approach, computer recording of data, can utilize information from real-time sensors which can show either average values, peak values, or detailed cyclical patterns. Pickups are now available which can monitor cylinder pressures continuously and from which one can record accurate cylinder pressure diagrams. Much detailed information concerning cylinder scavenging, compression and combustion can be immediately available for analysis and for trending. Computerized recording can be used to study responses of temperatures and pressures during transient as well as steady state conditions, and can relate data to such parameters as fuel delivery, turbocharger speed and generator load.

Whichever methods are used for data recording, there are several basic requirements which must be fulfilled if monitoring is to have any significant usefulness:

- Data recording, analysis, and trending must be accomplished by the same personnel, repeatedly, so that there is continuity to the effort.
- Generator loading must be indicated with an accuracy within one percent.
- For steady-state data, engine conditions must be held constant for a minimum of one-half hour.

A diagnostic tool which is getting much attention is vibration analysis. Although the firing noise of an internal combustion engine successfully masks most of the internal signals, such as pump drive gears or connecting road bearings, vibration signals at extremities, such as turbochargers, blowers and generator bearings, as well as injection pumps and nozzles, can be informative. With the high background noise, one of the most interesting ways to use the vibration signature is to time-study selected frequencies. For example, on a turbocharger one can search out dominant signals, watch their patterns of modulation and gain information about rotor instabilities, gas flow instabilities, and mechanical resonances. While it may be impossible to interpret a spectrum of vibration, it is informative to record and trend various patterns of signal modulation on turbos, blowers and other auxiliaries. Somewhat the same approach is applicable to the fuel system and possibly to the cylinders themselves. Vibration sensors on main bearings can provide early warning after a failure has begun.

4 LUBRICATING OIL

The use of highly compounded lubricating oils in the EDG sets in nuclear power plants is an absolute necessity because the Diesel engines are generally rated somewhere close to the high end of their capabilities. High horsepower ratings, the necessity for numerous fast starts plus the high percentage of time in which the engines stand idle put severe burdens on the lubricant. In all of the science of compounding lubricating oils, it is impossible to predict how well an oil will perform in a specific model of engine and under a specific type of service. An oil may appear to perform very well in an engine, yet over a long period of time certain deficiencies may become evident through incipient damage to numerous components. The only way to qualify an oil for a particular model of engine is to get extensive operating experience with it. The engine itself is the final judge, and testing an engine oil may become a long, expensive ordeal. Therefore, the best route for the nuclear power plant is to select a lubricating oil with which the engine manufacturer and other operators of similar engines have had long and satisfactory experience. This selection should be very specific, in that a "new, improved formulation" of a tried and true oil may produce disappointing results.

Once a satisfactory lubricating oil is in service in an engine, its service life depends on how long it can retain the necessary physical and chemical properties. These properties change with the addition of carbon, water, jacket water chemicals and fuel dilution, dirt and wear metals. Most of the solids can be filtered out, but as the finely divided carbon builds up, it tends to form sludge behind the piston rings and in small oil passages. The presence of water may affect the chemical additives, possibly resulting in corrosive products or a tendency toward foaming. Chemical properties are affected by temperatures and contaminants, particularly products of combustion. Most of the changes in physical and chemical properties are irreversable, and an oil eventually reaches a point at which it must be replaced. However, present day engine oils are compounded to provide good service for long periods of time, provided the rates of contamination are not excessive.

It is reasonable to expect long life for a charge of oil, but it is essential that oil samples be taken periodically and that they be analyzed to detect either deterioration of the oil or deterioration of the engine. For the optimum benefits, an oil analysis program must meet the following requirements:

- periodic sampling, with the engine at full operating temperature for at least one-half hour before taking a sample;
- the samples are drawn from the lubricating oil pump discharge line, before the first filter or heat exchanger;
- the sampling procedure meets all requirements for cleanliness and preflushing;
- the laboratory analysis meets the needs of the program;
- the results are trended to show rates of change;
- inspections of engine components are conducted in sufficient detail to establish correlation between lubricant properties and hardware conditions.

The first three items, concerning how the oil samples are to be taken, are essential to sufficient mixing and to protection from contamination of the sample. They must be taken from a point having high velocity. Samples from the engine sump or from filter cases or heat exchangers will not show consistency suitable for trending.

Oil laboratories have wide variations in engine experience, accuracy, and methods of reporting. The laboratory must conduct the analyses with sufficient precision to make the results significant.

As an example of a precision requirement, many oil analyses will show a water content of a sample to be "less than 0.4%". This is about the limit of accuracy of checking for water by centrifuging. However, water contents down to 0.04% are of interest, so it must be specified that the water content be measured by a more accurate means, such as by distillation or by the Karl Fischer Method.

New oil must be free of harmful contaminants. Where oil is received in steel drums, it is very common to find a thick layer of water and rusty sludge in the bottom of these barrels. Similar contamination can occur to oil delivered in bulk. It is sufficiently common to make it well worthwhile to take steps to avoid contamination. One step is to ensure that all lubricating oil is pumped through coalescing filters before it enters the engine. This can be done by the use of portable equipment. Further, samples should be taken from the bottom of tanks or drums, and unsatisfactory products be kept out of engine service.

An oil analysis program for Diesel engines in emergency stand-by service can have a number of beneficial effects for the engines and for the personnel responsible for their maintenance and reliability, making it well worth the effort and expense. It can aid in the continuing assurance of the engine's operable condition, and can help to reduce the amount of "open and inspect" work. A significant contribution is that it serves as a focal point for engineering attention to the engine, and helps to ensure continuity of this attention.

5 COMPONENTS INSPECTIONS AND FAILURE DIAGNOSES

Detailed inspection of engine components during overhaul or repairs is essential to ensure a high level of confidence in an engine's continuing reliability, and can aid greatly in detecting and tracking the onset of problems. Similarly, knowledgable in-depth failure diagnosis is necessary to ensure that the basic causes of a failure are discovered, analyzed and corrected. Without adequate diagnosis, repair becomes an exercise in repeated parts replacement without eliminating the problems.

Visual inspections are by far the most important of all inspection methods, and permit a person to get a rapid subjective and objective evaluation of the conditions in an engine or generator. They usually provide the most significant information on which failure diagnoses can be made, or on which the performance of a component can be judged. However, there are few guidelines to their interpretation. They involve subjective evaluation, which requires a firm understanding plus a bit of experience in making these observations. Visual inspections require a hands-on introduction under the guidance of experienced personnel, plus a continuity of ongoing inspections to develop a recognition of patterns and deviations from these patterns. This serves to emphasize the importance of having key personnel whose primary assignment is to the EDG sets.

Dimensional measurements are less problematical than are visual inspections since most of the parameters are well-defined. However, there are two aspects which deserve consideration. One is <u>what</u> measurements are required. A data sheet may require six diameters to be made on a crankpin, oriented in a specific pattern, but these measurements may miss a flat spot which is developing, or the onset of an hourglass shape. In many cases the data should include maximum and minimum dimensions and their locations.

A second aspect is that of <u>how</u> dimensions are taken. Much can be gained in speed and accuracy in going from hand-held micrometers to dial-indicating comparative gages, where the gages and standards are used together in the shop or at the engine. One advantage is that the gage can be rechecked frequently on the standard, and thermal drift corrected. A second advantage is that dial-indicating gages can "sweep" a surface, registering high points and low points rapidly. Finally, they can be used accurately by relatively inexperienced personnel.

Good component inspections and failure examinations require availability of a bench magnifier with magnification power to at least 50X. Use of this magnifier in various cases of failures will help to familiarize personnel with the vast division which exists between a failure diagnoses based on casual observation or rule of thumb conclusions and a detailed observation of what actually occured. This can completely change many diagnoses, and can have a considerable impact on the professional quality of EDG support.

When evidence of a possible problem appears, or an outright failure occurs, there are three important steps which should be taken to ensure that repair decisions will be based on sound engineering judgement and will be fully adequate to ensure maximum reliability of the EDG:

- investigate the failure;
- diagnose the root cause and all contributing factors;
- evaluate the significance and potential impact on this and on other similar EDGs.

These steps should be recorded in detail, and retained in some format where they can be readily referred to at a later date when a similar problem may occur.

It is not adequate to simply call in the manufacturer's representatives and let them take charge of restoring a unit to operation. There can be very large gaps between getting a Diesel generator running and actually correcting a basic defect. There must be firm direction of the job on the part of the utility supervisors so that there will be a record of everything that was found and everything that was done, and so that there will be in-house knowledge of what, how, and why a repair or correction was made.