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PROACTIVE MAINTENANCE INITIATIVES AT ARGONNE NATIONAL LABORATORY-WEST

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by

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ABSTRACT

In the late 1980's, ANL-W Management foresaw a need to provide dedicated technical support for maintenance supervisors. This need was driven by several factors. Maintenance supervisors were facing increased challenges to ensure all environmental, safety, and waste management regulations were followed in daily maintenance activities. This increased burden was diverting supervisory time away from on-the-job supervision. Supervisors were finding less time for their "mentor" roles to ensure maintenance focused on finding and correcting root causes. In this environment maintenance can quickly become a repetitive reactionary function. Additionally the traditional maintenance organization could not keep up with the explosion in predictive maintenance technologies.

As a result, engineers were tasked to provide direct technical support to the maintenance organization. Today the maintenance technical support group consists of two mechanical engineers, two electrical engineers and an I&C engineer. The group provides a readily available, quick response resource for crafts people and their supervisors. They can and frequently do ask the support group for help to determine the root cause and to effect permanent fixes. Crafts and engineers work together informally to make an effective maintenance team.

In addition to day-to-day problem solving, the technical support group has established several maintenance improvement programs for the site. This includes vibration analysis of rotating machinery, testing of fuel for emergency diesel generators, improving techniques for testing of high efficiency particulate air (HEPA) filters, and capacity testing of UPS and emergency diesel starting batteries. These programs have increased equipment reliability, reduced conventional routine maintenance, reduced unexpected maintenance, and improved testing accuracy.

This paper will discuss the interaction of the technical support group within the maintenance department. Additionally the maintenance improvement programs will be presented along with actual cases encountered, the resolutions and lessons learned.

I. INTRODUCTION

Over the last decade the complexity of maintenance supervisors' jobs has increased several fold. Equipment has increased in complexity. Just keeping the equipment running is no longer good enough. Budget strife and our own economic survival require equipment reliability and efficiency. In addition the work place has been inundated in reams of new environmental, safety, personnel, and waste management requirements. Even where these requirements have little impact on the way the maintenance work is performed, they add substantial efforts in training, documentation and record keeping. This creates a potential dichotomy. The "additional duties" can easily become the major job for the supervisor with little or no time to investigate maintenance problems. Without proper attention to maintenance problems, equipment reliability and efficiency will suffer. This jeopardizes our economic survival.

Obviously this is an untenable situation that demands management action. Departments have been created or expanded to provide expertise in safety, environmental, personnel, training, and waste management. Although these resources have been effective in decreasing the burden on maintenance supervisors, much still remains. Maintenance supervisors must still be very familiar with the requirements and screen each job to ensure these aspects are properly met. They can consult with the experts when needed, but they must be knowledgeable enough to know when to ask questions. The net effect is they regain some of the ground they lost, but still most are not able to devote sufficient time to evaluate recurring maintenance problems. Systems engineering groups may be available to handle these question; however, other programmatic efforts often take priority. The net effect is that often the problem gets the routine fix, and the equipment is put back on-line knowing the problem will recur.

Several year ago, management at ANL-W took a new approach to solve this dilemma. Engineers were assigned directly to the maintenance organization to provide direct support. This "Technical Support Group" is able to quickly respond to the needs of maintenance supervisors and crafts. This arrangement supports the concept of worker empowerment. Additionally technical support engineers can aid in evaluating and introducing new technology into the maintenance work place.

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II. THE ROLE OF A MAINTENANCE TECHNICAL SUPPORT GROUP

A. Validate Need for Maintenance Actions

Maintenance guidelines repetitively stress the need to review and validate the need for recurring maintenance actions. Frequently changes in equipment, operation modes or available technology make past maintenance unnecessary or improper. Unfortunately competing priorities often relegate periodic reviews to low priority and the unnecessary or improper actions continue to be performed. This is counterproductive and wastes maintenance assets. A technical support group, dedicated to support maintenance needs, is one way to reverse this trend. Even if reviews don't get done on a prescribed periodic basis, work control and crafts personnel have a ready resource to request immediate review of questionable tasks. With this support, the "common sense" of these personnel can go a long way to identifying and eliminating unneeded traditional preventive maintenance tasks.

This process works well at ANL-W. Many periodic maintenance tasks such as bearing replacements, shaft alignment verification and oil changes have been replaced with condition based maintenance. While some of these changes were made systematically with the introduction of new machine condition monitoring programs, many resulted from crafts or crafts' supervisors questioning the need for other related preventive maintenance tasks when they showed up on scheduling plans. Changes could be quickly made and documented resulting in saved labor hours and more effective maintenance.

B. Facilitate Improvements in Worker Productivity

Crafts and their supervisors are a great source of ideas and information that can lead to productivity improvements. This information can be hidden in complaints about monotonous, repetitive tasks or clearly communicated in suggestions for better equipment, design, etc. Suggestion boxes and awards programs can be effective in searching out these opportunities; however, a responsive ear often gives quicker feedback and an outlet for those who wouldn't otherwise take the time to go through the formal system. The technical support personnel can be used as a resource to quickly respond to the idea. They can complete necessary evaluations, prepare specifications and work orders, initiative design changes, or complete other technical tasks which are often required to implement the suggestion.

At ANL-W many of the ideas occur on the floor in discussions and informal brainstorming sessions between crafts, supervisors and technical support personnel. These sessions have led to actions as significant as being able to shut down an auxiliary cooling tower that is no longer needed during winter operation, making design changes that simplify the fabrication of evaporators, procuring computerized engraving equipment, and eliminating the need to daily attend to a purge manifold for a main coolant pump storage container.

C. Perform Root Cause Analysis and Facilitate Permanent Fixes

Effective crafts people are engaged in informal root cause analysis on a daily basis. When working a repair work request for non-critical equipment, the worker or supervisor is often the individual who makes an initial evaluation as to whether the found condition is "normal" or does it warrant a more detailed evaluation. If the process for getting help for a more formal evaluation is encumbered by organizational and physical barriers, human nature will be to only seek the additional help when the need is very serious. Unfortunately this leaves many problems that are "repaired" but not corrected for long term reliability. This is costly and counterproductive over the long term.

The direct support role of the technical support organization is one way to minimize the encumbrance of organizational and physical barriers. By being located within the maintenance facilities, the technical support personnel are readily accessible to maintenance personnel. Crafts and technical support engineers interact on a daily basis thus keeping the lines of communication open. Crafts and their supervisors do not hesitate to stop a job and call for a technical support engineer to help evaluate the root cause of a problem or to review the appropriate corrective action. Often this leads to identifying needed design improvements which can then be pursued by the technical support group.

This arrangement is working well at ANL-W. Recently technical support personnel were called to examine unusual wear in an auxiliary boiler feed pump. The pump had been disassembled to replace a bearing. The pump had been in service for about seven years, but it only had about 1.5 years of run time. The unusual wear prompted a more detailed evaluation. The evaluation determined that the pump was grossly oversized for the present use. Repair of the pump internals would likely be a temporary repair that would have to be repeated every 1.5 years of run time. A properly sized pump can be installed at about the same price as rebuilding the oversized pump. In addition to increased reliability and avoided high maintenance costs, the design change will generate energy savings by using a properly sized 5 horsepower motor where presently an oversized 40 horsepower motor is being used.

The preceding paragraph discussed one example. Many more exist. Investigation of abnormal bearing wear identified missing shaft slingers. Investigation of heating coils prone to freezing identified inappropriate coil designs being used where the coils are exposed to outside air temperatures. Investigation of questionable fuel tank sonic level indicator readings identified incorrect tank geometry data input to the computer. Investigation of "abnormal" pressure build up in two cryogenic storage tanks identified insufficient demand to keep up with normal cryogen evaporation. Investigation of recurring corrective maintenance on vehicle gate drive systems led to design improvements and reduced maintenance.

III. MAINTENANCE INITIATIVES

In addition to their day-to-day maintenance support roles, a technical support group can be used by management as a source to launch major maintenance initiatives. These initiatives can be new predictive maintenance programs or upgrades of existing maintenance practices. Several programs are being implemented by maintenance technical support personnel at ANL-W. The following sections discuss four of the programs: 1) rotating machinery vibration analysis, 2) testing and treatment to improve the reliability of fuel for standby, backup and emergency diesel generators, 3) improved techniques for in-place testing of high efficiency particulate air (HEPA) filters, and 4) capacity testing of batteries for uninterruptible power supplies (UPS) and starting batteries for diesel generators.

A. Rotating Machinery Vibration Analysis

In the late 1980's, ANL-W procured a swept filter analyzer specifically to balance critical turbine compressors. The analyzer worked well for this application. Gradually it was used for some selective vibration analysis; however, it was not suitable for this use on a large scale. Data output consisted of strip chart plots and meter readings. The data could not be easily stored, recalled and trended. In 1990 a maintenance support engineer initiated trending by setting up routes and having the printed strip charts posted to machine files. This was an effective technique to detect machine faults; however, it was very time intensive. In 1992 a portable data collector/single channel analyzer and computer software were procured. The equipment significantly increased the data collection and evaluation capabilities and expedited the data collection process.

The vibration analysis program has been very effective. The program monitors 60 machines and approximately 500 data collection points. Most, if not all, vibration analysis programs can be economically justified solely on cost savings from avoided, unplanned outages. However, many other savings and benefits have been realized.

Vibration analysis encourages root cause investigation of problems. Inquisitive vibration analysts and crafts naturally want to verify the accuracy of diagnosis. In the process, failed parts are closely inspected rather than merely replaced. The inspections often lead to more thorough and accurate identification of causes. In one instance monitoring of a pump revealed a spectral pattern indicative of a bearing cage fault. Inspection of the bearing cage revealed excessive axial play. The cage was contacting the bearing shield. Further investigation revealed that the shaft had developed excessive axial play due to a worn snap ring and groove. Replacement of the shaft was necessary to eliminate the problem. Although the bearing was also replaced, it was merely the weak point in the assembly and not the cause of the failure. In another instance, vibration analysis determined a bearing on an electrically driven feed pump had a race defect. Upon inspection of the bearing, it was evident the bearing had arc strikes on the bearing races and balls. In an electrical inspection a few months prior, it was noted that the machine had wiring termination problems resulting in no electrical wiring ground and a short on one of the hot leads. It is likely the stray electrical currents caused the arc strike damage to the bearing.

Post repair vibration analysis provides crafts with an objective performance evaluation. It has moved to the point where the crafts want to see the before and after spectrum for feedback on the effectiveness of the repairs. It is a motivator that supports their sense of pride and ownership of their work. The post repair reports provide positive feedback and often draws management attention to "mundane" maintenance repairs that are easily taken for granted. The positive reinforcement builds morale and further encourages quality work.

Vibration analysis trend data provides a valuable supplement to machinery history and configuration documentation. All effective vibration analysis programs require equipment configuration information. Information such as specific bearing numbers, coupling types, number of pump vanes, fan blades et cetera is collected to establish the fault frequencies for each piece of equipment. In the process of gathering this data, configuration information is improved. Additionally trend data provides a history of most rotating equipment repairs.

Figure 1 shows one example of trend data. It shows spectrum before and after bearing replacements on a cooling water pump. The trend data provided immediate information regarding the time between failures and the need for a thorough evaluation of the cause. The time between bearing failures was inconsistent with the expected average bearing life for this machine. The investigation ultimately determined that a shaft slinger was missing. Water was migrating down the shaft and washing out the bearing grease.

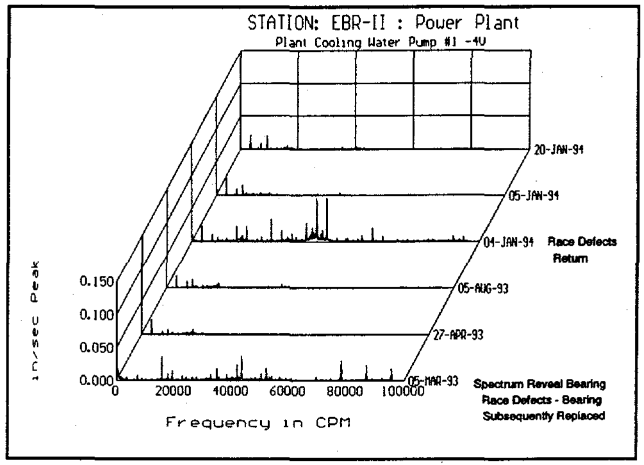

Figure 1

Substituting condition based maintenance for time based maintenance also provides cost savings for vibration monitoring programs. ANL-W has replaced numerous time based maintenance tasks with condition based maintenance. Bearing replacements and shaft alignments are prime examples. Traditional maintenance practices of routinely replacing bearings based on L_{10} life means that 90% of the replaced bearings are still good. Furthermore birth defects and assembly errors can result in replacing a good bearing with a bad one. The stages of bearing failure and resulting vibration patterns have been well documented.[1,2] Vibration analysis is a very effective tool for trending bearing condition and determining when bearings need to be replaced. Similarly vibration analysis and trending can be used to determine if a machine's shaft alignment needs to be checked. A machine that is properly aligned upon installation and periodically monitored will show a definite change in the spectrum if the alignment has shifted.

Another often overlooked benefit of vibration analysis is that it provides an objective tool to use to resolve differences in opinion between operators and maintenance personnel. Most operators become very familiar with the sound emissions in their machinery spaces. Very slight changes often trigger work requests to perform corrective maintenance. This frequently leads to differences in opinion on the need for maintenance. With vibration analysis, an objective evaluation can usually be made efficiently and quickly. Experience at ANL-W has been that this process is well accepted by both operation and maintenance personnel. The process improves the teamwork between the organizations.

Vibration analysis is also an excellent tool for evaluation and acceptance of new equipment. With the recent renovation of the ANL-W Fuel Conditioning Facility, several systems were refurbished and new system were added. Vibration analysis was used as the basis of acceptance for some of the new systems. This not only ensures that the equipment was operating smoothly prior to acceptance, it also provides a baseline for future monitoring.

B. Testing and Treatment of Fuel for Diesel Generators

In 1993 a program was initiated to test new and stored fuel for standby, backup and emergency diesel generators. Since these diesel generators are only normally operated during their required periodic run tests (1/2 hour to 2 hours per month depending on the generator), the diesel fuel oil in the storage tanks may be several years old. Therefore, it is necessary to perform surveillance testing on this stored fuel in order to verify and maintain fuel quality for this emergency equipment. The program is based on NRC[3], ANSI[4], DOE[5], EPRI[6] and ASTM[7] Standards and also benefitted from advice obtained from cognizant personnel at the Savannah River and Rocky Flats sites. The program consists of three essential parts: 1) Periodic testing of all on-site diesel generator day and storage tanks to verify the quality of existing supplies is maintained, 2) testing of all new deliveries of diesel fuel to verify quality of new supplies, and 3) the addition of a biocide additive and a long-term storage additive to all new fuel oil deliveries to reduce the possibility of microbiological organism growth and to improve the long-term stability of the fuel.

Periodic testing consists of three different surveillance tests: 1) A monthly check of each tank for water, 2) a quarterly all-level sample that is drawn from each tank to test for suspended particulate, and 3) a yearly bottom sample is that drawn from each tank to test for the presence of microbiological organisms.

The monthly test is a simple test using water indicating paste on the bottom of a gauge stick. The paste will turn color if water is present. If water is detected, it is pumped out. The presence of water in diesel fuel is a prime environment for microbiological organism growth. Micro-organisms can cause fuel filter plugging and starve the engine of fuel. Also, the acidic by-products of these micro-organisms can severely corrode a steel storage tank causing unacceptable levels of suspended particulate in the fuel and could possibly result in a release of fuel to the environment. If the presence of micro-organisms is found in any of the storage tanks during the annual sampling and testing, a biocide additive will be added to the tanks to kill the existing micro-organisms and to prevent any future organism growth. Also, large quantities of water present in the storage tank could cause the engine not to operate properly or could even shut it down completely. For example, in 1993 ANL-West was performing a weekly run test on one of their diesel driven fire pumps, and the engine immediately shutdown because of a slug of water was pumped from the tank into the fuel line. In this case, water contaminated fuel was used to fill the storage tank for this diesel driven fire pump. However, in most cases, the accumulation of water on the bottom of day and storage tanks is the result of condensation within the tank.

Quarterly a four ounce all-level fuel oil sample is drawn from each storage tank and tested for unacceptable levels of particulate contamination. A sample thief is used to begin drawing the sample no closer than six inches from the tank bottom. The sample thief is raised as the sample is being drawn to ensure all levels of fuel are sampled. This sample will contain a good representation of particulate that is suspended in the fuel. Generally, new fuel will have particulate levels under 10mg/L. Depending on storage additives and conditions, with time the suspended particulate levels may increase. The levels are not of serious concern until it reaches 20mg/L. At this point the fuel must be cleaned or replaced. Increased levels of particulate can result from fuel oil aging, the presence of micro-organisms, tank corrosion products, and inattention to detail when filling the tanks and allowing dust, dirt, and other debris to enter the tank. Excessive fuel deterioration and contamination can lead to out of specification fuel, plugged filters, fouled injectors, and increased wear.

New fuel oil that arrives at ANL-West for the diesel generators, is sampled prior to transferring the fuel from the delivery truck to the generator tanks. Even though the fuel manufacturer can certify that the fuel oil is of the proper quality at the refinery, they have very little control to maintain quality once it is sold to fuel brokers. Fuel quality can be lost and contamination introduced during shipping and at interval storage areas prior to reaching its final destination. Therefore, fuel samples will undergo a series of quick screening tests on-site and then a series of fuel quality verification tests that will be performed at an off-site laboratory. The results from the initial screening tests must be found acceptable within six hours of transferring the diesel from the delivery truck to the storage tank. The results from the off-site quality tests must be found acceptable within two weeks of fuel oil delivery.

First, a fuel sample will be visually checked for clarity and brightness[7] at the delivery truck. Clear and bright is a condition in which the fuel contains no visible water drops or particulates, and is free of haze or cloudiness. Then, two 32 ounce bottom fuel oil samples will be taken from the delivery truck for the on-site screening and off-site quality tests. One of the samples will be sent to the ANL-West Analytical Laboratory (AL) for immediate testing of API gravity, kinematic viscosity, flash point, and water and sediment. An API Gravity test is needed to verify the fuel oil is of the proper grade and is not any other fuel or liquid, such as gasoline or diesel contaminated with gasoline. The kinematic viscosity must also be within range in order for adequate fuel oil flow through the piping and injection nozzles, and for acceptable spray patterns and droplet size from the injection nozzles. A flash point test will reveal if the diesel fuel has been contaminated with a highly volatile and flammable material such as gasoline. The water and sediment test will verify that the water and particulate contaminants are within acceptable levels.

The remaining 32 ounce fuel sample will be sent to an off-site laboratory for analysis, and tested for fuel quality in accordance with Table 1 of ASTM-D975, Standard Specification for Diesel Fuel Oils. Table 1 shows the minimum testing and acceptance requirements that ASTM-D975 fuel must meet. Table 1 includes all of the above on-site screening tests (with the exception of API gravity), as well as distillation temperature recovery test, ash content, sulfur content, copper strip corrosion test, cetane number, cloud point temperature, and carbon content. With the exception of cloud point temperature, the test acceptance requirements for ASTM-D975 fuel is very specific and non climate related. However, it is important that fuel oil user specify a maximum acceptable cloud point temperature when ordering diesel fuel. Cloud point is the temperature at which a cloud or haze of wax crystals appears in the fuel. Therefore, if the diesel fuel was subjected to temperatures below the cloud point, there is a good chance the fuel filters will immediately clog, the fuel flow rate will be reduced, fuel spay patterns will be altered, and the fuel quality will be substantially degraded, all of which will contribute to the diesel engine not starting. An acceptable cloud point temperature will be much different in Florida than that in Idaho.

Also, ANL-West will add a biocide additive and long term storage additive (LTSA) to all new diesel generator fuel oil shipments arriving at ANL-West. As mentioned above, the biocide will prevent the growth of microbiological organisms within the storage tanks. The LTSA will help prevent particulate formation and fuel oil degradation during long periods of fuel storage.

When this surveillance program began back in 1993, two of the 13 storage tanks were found to have both water and large quantities of microbiological organism present. A biocide was added to the fuel to kill the micro-organisms. A week after the biocide was added, a bottom fuel sample and appropriate test verified that the biocide killed the micro-organisms. Then, the water was pumped out from the bottom of the tanks. Also, two of the tanks were found to have unacceptable levels of particulate contamination. The fuel from these tanks were replaced with new fuel. In order to obtain an initial baseline on fuel quality within the storage tanks, 32 ounce all-level samples were also pulled from each of the storage tank and tested for fuel oil in accordance with Table 1 of ASTM-D975. All fuel was found to be within the acceptable quality limits.

C. Improved Techniques for Testing High Efficiency Particulate Air Filters

ANL-W facilities, having been built and modified over the last 35 years, differ greatly in the revisions of specifications used as the design basis. Thus ventilation systems with high efficiency particulate air (HEPA) filtration have been constructed with various provisions for in place leak testing, depending on the revision of the test specification in effect at the time the system was constructed or modified. In most cases, current revisions of the standard for testing of nuclear air-cleaning systems are more specific and less flexible than previous revisions.[8,9]

One specific change is that the current testing standard requires a single downstream sample point that is downstream of a fan, or a qualified sample manifold shall be used. While it is desirable to upgrade older ventilation systems to provide qualified downstream sample manifolds to meet current specifications, it is not always economically feasible. As an alternative, more rigorous testing techniques can be utilized to demonstrate that the testing meets the intent of current standards.

On one system ANL-W followed the qualification methodology[9] to demonstrate the validity of a single downstream sample point of an installed system. The sample point was located downstream of several elbows and a relatively long section of pipe; therefore, testers were quite certain that the air exiting the HEPA filters had sufficient turbulence to be thoroughly mixed by the time it reached the sample point. However, it had never been previously, physically demonstrated that air through a leak at the filter would be thoroughly mixed with the filtered air by the time it reaches the sample point. This was demonstrated by simulating leaks at 10 different points around the filter to housing seal and across the filter face. Small quantities of dioctyl phthalate (DOP) aerosol were injected at each point and the air stream was tested downstream at the sample point to verify thorough mixing. The duct at the sample point was traversed to verify uniform concentration of DOP in the duct. A specific grid pattern was established for the traverse. It was found that each sample was within 20% of the average concentration for all the grid sample points. This was repeated for each of the 10 simulated leaks at the filter. The test confirmed that the selected sample point provides a valid, representative sample and that a leak through or by the filter will be properly detected in future, periodic leak tests.

D. Battery Capacity Testing

Although ANL-W has not experienced a large number of backup power failures, the DOE community as a whole has experienced many failures of backup power sources, the most notable being the failure of emergency diesel generators (EDGs) to start and assume load when required. A recent DOE Augmented Evaluation Team (AET) review reported that the majority of EDG power failures involved a failure of the diesel starting system.[10] One of the findings documented in the report is that problems associated with batteries in EDG starting systems were found to be the dominant contributor to EDG failures, and were identified as an outlier adversely affecting EDG reliability. The DOE AET reported that for any emergency or backup power application, the battery is almost always the least reliable component in the system. The report further states that two of the three DOE sites studied place undue reliance on battery specific gravity and voltage readings in lieu of battery capacity discharge tests to detect incipient or developing problems or degradation.

ANL-W has thirteen diesel generators that utilize nickel cadmium batteries for starting. These generators provide standby, backup, or emergency power to support facility operations. ANL-W also uses nickel cadmium batteries for several large UPS systems and other battery systems that provide backup or emergency power to systems such as emergency lighting and criticality monitoring equipment.

ANL-W does not perform capacity tests on any of its diesel starting batteries. The only discharge these batteries experience are the short discharges used to perform the periodic start tests (weekly or monthly). Some of the UPS and other important batteries are periodically load tested by applying varying system loads or fixed resistor banks (not constant current). These tests are useful if properly trended, but do not provide any data to indicate the remaining capacity of the battery as compared to the manufacturers ratings.

Nickel cadmium batteries are dependable and are typically designed for a service life of up to 25 years. Nickel cadmium batteries are also easier to maintain than their lead acid counterparts, are more forgiving and reliable when subjected to temperature extremes, and can survive over/under charging abuses much better than lead acid batteries. The only significant detractor from using nickel cadmium batteries is the high initial procurement cost. With over 20 systems that use nickel cadmium batteries at the ANL-W Site, a significant investment has been made and a thorough battery maintenance program is essential to protect and maximize this investment.

The implications of diesel generators failing to start on demand can vary from minor inconveniences to extreme expense, major equipment damage, or potential hazards to the environment, workers, or public. Some of the UPS battery systems are more important than diesel generators in mitigating the effects of loss of normal power.

The biggest challenge faced when attempting to guarantee the availability of these systems is trying to verify the integrity of the battery itself. Conventional techniques such as cell voltage measurements and cell electrolyte analysis (specific gravity for lead acid cells, carbonate content for nickel cadmium cells) does not provide enough information to determine the health of batteries. Battery impedance testing equipment is starting to be more widely used, but the results are subjective and are not always conclusive.

The only way to know the real health of a battery is to perform capacity testing. A capacity test is performed by applying a constant current load to discharge the battery to a designated terminal voltage. The load must be capable of being incrementally adjusted during the test to maintain constant current as the overall battery voltage decreases. The test data is then evaluated to determine if the battery meets the design requirements of the system or it is compared to the manufacturers and the percent of remaining capacity is calculated. IEEE Standards[11,12] provide criteria for battery replacement and increased testing periodicity based on the percent of remaining capacity.

ANL-W has recently initiated a program to perform constant current capacity testing. ANL-W has procured constant current capacity equipment consisting of two portable load banks, a laptop computer, and a data acquisition unit. During a battery discharge, the testing equipment continuously records and displays individual cell voltages, overall battery voltage, current, intertier connections and alarm parameters. One of the load banks handles all of the 12, 24, and 32 volt diesel starting batteries and the other handles all other batteries from 88 to 125 volts. The use of two different load banks for different applications adds considerably to the equipment portability.

The following benefits can be realized from capacity testing of batteries:

1) Capacity testing allows the user to determine whether the battery meets the manufacturer's rating. This is commonly referred to as acceptance testing.

2) Capacity testing allows the user to periodically determine whether the performance of the battery, as found, is within acceptable limits. This is commonly referred to as performance testing.

3) Capacity testing allows the user to verify that the battery meets the design requirements of the system to which it is connected. This is commonly referred to as service testing.

4) Significant cost can be saved by avoiding the premature replacement of batteries that are suspected to be bad. A potential for even greater cost savings exists in making the backup, standby, and emergency power as reliable as possible to prevent the costs associated with damaged equipment or lost operating time due to backup, standby and emergency equipment failure.

5) Capacity testing identifies individual cell manufacturing defects. The earlier that these problems are brought to the attention of the manufacturer, the easier it is to get warranty claims processed and the affect of a defective cell on the rest of the

cells is minimized. Additionally, the test data leaves little argument for the manufacturer to dispute that a problem exists.

6) Capacity testing can be used to help detect faulty inter-cell connections and weak cells within the battery string.

7) Capacity testing allows the battery to be periodically discharged and then charged. This helps to maintain the individual cells at uniform voltages and prevents cell drifting.

8) Capacity testing is the major contributor to the effectiveness of an overall battery maintenance program. Capacity testing will not prevent all possible failures of standby, backup, and emergency system batteries but will increase the overall reliability of these systems and bring battery maintenance into compliance with existing standards.

When the capacity testing program is fully implemented at ANL-W, capacity tests will be performed on all nickel cadmium and lead acid batteries in critical applications or that provide significant importance to the ANL-W Mission. Since these batteries range in age from new to 30 years old, ANL-W expects some surprises that may lead to some rapid battery replacements. Based on the initial test results, a testing periodicity for the individual batteries will be determined based on the recommendations of IEEE Standards.[11,12]

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