Establishing a Condition-Based Maintenance program for Buildings and Facilities

Richard N. Wurzbach, Maintenance Reliability Group, LLC
Donna Phillips, National Institutes of Health
Ken Gilliam, US Navy, Naval Sea Logistics Center

ABSTRACT

The National Institutes of Health is the Federal focal point for medical research in the United States. On the main campus in Bethesda, MD, some 20,000 doctors, researchers, and scientists work in over 60 buildings to advance the state of medical knowledge and research.

The Building Maintenance Team (BMT) provides operation and maintenance support to the Division of Property Management for the care of all campus buildings. This includes routine and emergency maintenance on electrical, mechanical, structural including utilities and a vast distribution system for steam, chilled water and compressed air from a main plant on campus. Critical environments include Bio-hazard Level 3 and 4 facilities, animal facilities, and patient care units. Over the last 6 years, the BMU has partnered with the Naval Sea Logistics Center (NAVSEA) to provide program support, diagnostic technologies, and expertise to transition from a reactive maintenance environment to a strategic Condition-Based Maintenance (CBM) program.

Efforts to date include vibration analysis, infrared thermography, lubricant analysis, motor circuit analysis, ultrasonic leak detection, and electrical testing. Training has also been a significant aspect of the program, providing level-of-awareness classes for the diagnostic technologies and maintenance strategies, and targeted pro-active maintenance workshops in the use of maintenance tools such as laser alignment and steam trap leak detection.

Key equipment included in the program are pumps, exhaust fans, air handling units, electrical distribution systems, and steam systems. The program has demonstrated improvements in equipment reliability and reduction of recurring failures. By identifying improper equipment installation, design issues, and root-causes of failures, the BMU Team has been able to address underlying equipment deficiencies, and allow the NIH to fulfill their mission for Public Health.

INTRODUCTION

The Naval Sea Logistics Center (NAVSEA) provides a wide variety of engineering and logistic services to the Department of Defense (DoD) and other government entities. One of their primary missions is the orderly relocation of major facilities as government organizations strive to reduce infrastructure. Another is the overhaul, installation, and maintenance of Technical Training Equipment. In this capacity, NAVSEA personnel have recognized the opportunity to utilize PdM technologies to improve the reliability of the Technical Training Equipment, by verifying the operating condition of the overhauled or new equipment. As they developed these technology capabilities over the last ten years, they also saw the opportunity to apply them in existing facilities in support of the regular maintenance activities.

Presently, NAVSEA personnel are overseeing a Condition-Based Maintenance (CBM) program at the National Institutes of Health (NIH) in Bethesda, MD, in support of ongoing maintenance efforts. In developing these programs, the effort has been primarily focused on utilizing PdM technologies of Vibration Analysis, Infrared Thermography, Lubricant Analysis, Airborne Ultrasound, and Motor Circuit Evaluation, and developing optimized maintenance programs. NAVSEA has identified numerous opportunities for improvement in reliability and maintenance expenditures in these installations, by pinpointing the root-causes of discovered problems, and directing proactive changes to improve equipment performance and reduce recurring maintenance issues.

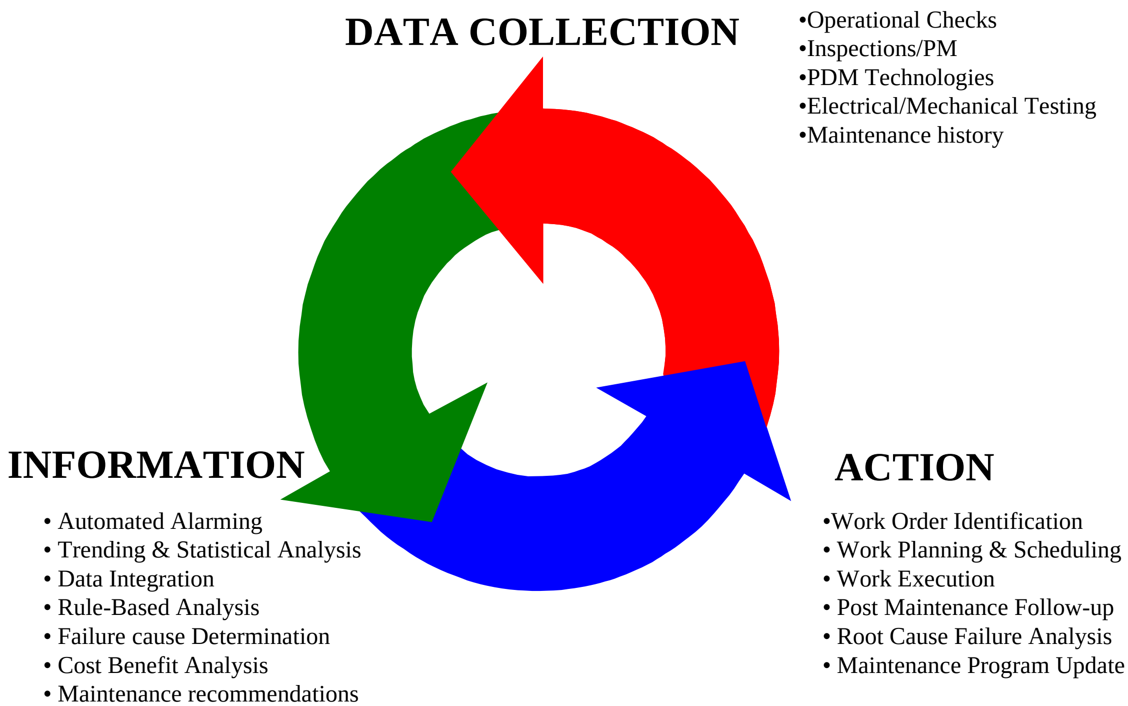
While CBM diagnostics were the starting point for these programs, it has become clear that corrective and proactive maintenance practices for facility equipment have a significant impact on customer satisfaction (as tracked by trouble calls), and in overall maintenance costs and manpower requirements. Tracking root-causes of failures and excessive maintenance has identified key trouble areas. Through proactive equipment improvement and targeted training programs for the maintenance staff, measurable improvement is being made in the condition and performance of facility machinery, and in the capabilities and confidence of the maintenance staff.

The approach that has evolved over the past six years in the program at the National Institutes of Health is a comprehensive Condition-Based Maintenance program. This includes a combination of diagnostic technologies in scheduled routes, response to equipment problems with diagnostic evaluations and root-cause analysis, operational data collection with hand-held data collection devices and building automation systems (BAS), targeted training to increase the advanced maintenance skills of the staff, and proactive maintenance through design changes in low-reliability machinery and parts.

DIAGNOSTIC TECHNOLOGIES

The core technologies in use at NIH are vibration analysis, infrared thermography, oil analysis and ultrasonic monitoring. Routine routes are established for critical equipment, and supporting technologies are used to troubleshoot problems and provide more detailed analysis of identified issues. Playing an important role in troubleshooting are Power Quality data loggers, motor circuit evaluation (MCE) and on-line motor power signature analysis (E-MAX), grease analysis, and component failure analysis. Together these technologies allow accurate assessment of equipment condition, and enable the identification of problem root-causes. Once recurring failure modes are identified, and root-cause corrective actions implemented, a reduction in required maintenance is experienced, and equipment reliability and customer satisfaction are improved.

The data collection process is only one part of the evaluation cycle. Data must be translated into Information, which requires knowledge of the system under test, and a

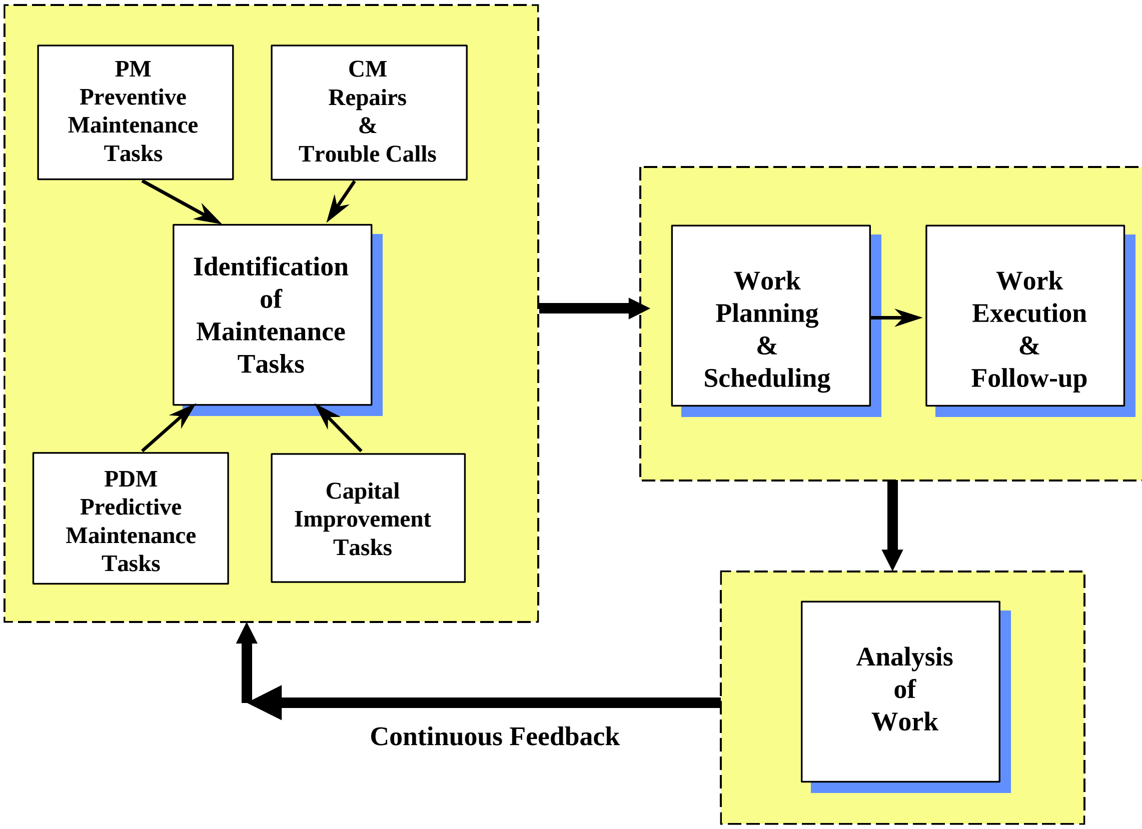


course of Action effectively communicated to stakeholders. It is important that such information is then translated into Action, which is integrated into the work management process. Once the Action is taken, feedback is obtained through post-maintenance testing, proactive design and equipment changes, and re-baselining of equipment diagnostic data trends. This ensures problems have been adequately resolved so that future re-occurrence is minimized.

The CBM Program is designed to support the operation, maintenance, installation, alteration, repair, and re-engineering of facility equipment. This includes support systems for heating, ventilating, and air conditioning (HVAC), electrical distribution, chilled water, compressed air, and building automation (BAS) systems. The CBM program utilizes a mix of advanced maintenance strategies and technologies to ensure the safe and reliable operation and maintenance of the facilities equipment. The following components make up the requirements for operating and maintaining equipment:

- Program Management
- Preventive Maintenance
- Predictive Maintenance/Condition Monitoring
- Corrective Maintenance (Repairs & Trouble Calls)
- Capital Improvement
- Facility Commissioning / Assessments

All activities performed in support of the CBM program are documented, tracked, and managed in various Data Management Systems. These systems are maintained by the site facilities maintenance personnel and/or NAVSEA Team performing maintenance, repairs, and operations.



To support such efforts, many organizations have redefined their concept of asset management. One of the foundations of this new Asset Management strategy is the incorporation of certain Reliability Centered Maintenance (RCM) principles to identify critical systems and components, and the establishment of Preventive (PM), Predictive (PdM), and Proactive (PAM) tasks. It has been sufficiently demonstrated in many industries and institutions that a commitment to an integrated program as described here can be implemented cost-effectively, with the result being fewer functional equipment failures and maximized reliability of system functions. The results already experienced in applying these principles to a critical research facility like NIH show this to be true in the facility maintenance environment as well.

The following sections give an overview of the technologies in the CBM program at NIH, how they are established, and where responsibilities lie within the CBM Team.

Periodic Vibration Analysis

Vibration monitoring is typically performed on critical rotating equipment on 1-3 month intervals. Once baselines have been established and initial problems have been addressed, the frequency of monitoring is optimized on a machine-specific basis. NIH provides technical support and some data collection resources for this technology.

NAVSEA provides baseline data collection, troubleshooting support, data analysis, recommendations, and post-maintenance acceptance testing.

The NIH Building Engineers are responsible for coordinating data collection, supporting troubleshooting, initiating action, coordinating post maintenance follow-up testing, and case history documentation and closure. Once baselines are established through detailed spectrum analysis, the Building Engineer or his designee typically takes periodic overall vibration level readings with vibration pen, ultrasonic detector, or similar device to monitor vibration trends over time. This overall vibration monitoring activity is supplemented by less frequent spectrum analysis on critical machines to ensure certain types of machinery faults do not go undetected. As part of this program, coordination of vibration monitoring and lube oil analysis data is important. The technologies are complementary, and improve the ability to diagnose problems and determine root causes.

Infrared Thermography

Routine infrared inspections (IR) are typically performed on 6-month intervals. Once baselines have been established and initial problems have been addressed, the frequency of monitoring is optimized based on the type of equipment being monitored and its criticality to the overall NIH mission. IR is used on rotating equipment, electrical equipment, and steam system components. NIH provides technical resources to support inspections. This includes individuals to open electrical enclosures and obtain electrical load data where needed.

NAVSEA has provided initial IR certification for NIH personnel and continues to provide analysis support when needed. The IR certification program has been established in accordance with the American Society of Non-destructive Testing (ASNT) Recommended Practice SNT-TC-1A. Thus far, one NIH staff electrician has completed 40 hours of classroom training, 210 hours of field training accompanied by a Level I or higher infrared thermographer, and passed an exam developed for NIH by an ASNT Certified PdM Level III. This in-house certification is governed by an NIH approved written practice, and all certification records are maintained by NIH supervision.

The NIH Building Engineers are responsible for coordinating inspections, initiating action, and coordinating post maintenance follow-up testing; NAVSEA personnel or the NIH Level I certified Thermographer is responsible for case history documentation, PMT inspections, and case closure.

Motor Circuit Analysis

Online Electrical Testing on critical facility motors is performed at varying frequencies from 12-months to 36-months, depending on equipment size and application. On other motors, it is used on an as-needed basis, and particularly to troubleshoot issues identified from vibration analysis, IR, or ultrasound. NIH provides technical support resources to support testing. This includes individuals to open electrical enclosures and obtain electrical load data where needed. NAVSEA provides trained MCE/EMAX technicians to perform testing and document results. The Building Engineers are responsible for coordinating testing, initiating action, and coordinating post maintenance follow-up testing; NAVSEA is responsible for case history documentation, PMT tests, and case closure.

Lube Oil Analysis

Lube oil analysis is used to quantify and track bearing and lubricant condition in driving and driven equipment. Periodic oil sampling and analysis on critical rotating equipment is typically performed on 3-6 month intervals. Once baselines have been established and initial problems have been addressed, the frequency of monitoring is optimized. We also sample and analyze large oil-filled transformers to determine oil quality and dissolved gases that are present. Transformer oil samples are taken on 6-month intervals. NIH personnel carefully extract and visually inspect all oil samples. The samples are properly packaged and mailed or hand-delivered for analysis by a laboratory associated with the NAVSEA Team.

The resulting oil analysis data is provided to NAVSEA for initial review. The Building Engineers are responsible for coordinating sampling, initiating action, coordinating post-maintenance testing, and documenting case histories; NAVSEA provides assistance if needed. As part of this program, lube oil analysis results are used to determine proper oil change intervals. The method of sampling oil from bearing reservoirs is critical to the success of this technology; consideration is given to utilizing sample ports and proper sampling procedures, in order to provide repeatable data. NAVSEA provides assistance in determining the proper methods for sampling equipment and/or the use of sample fittings to improve the process.

Since the majority of the equipment on the campus is grease lubricated, the use of oil analysis is, while effective, limited in scope. Numerous critical machines are present that are grease lubricated, and some experience degradation or failures related to lubrication. The desire to have a tool to analyze the grease lubricated critical components led to the adoption of grease analysis. For pillow block bearings, the used or excess grease is generally pressed out past the shields and accumulates on the surface of the housing. With care, it is possible to obtain a sample of the grease which can provide information about incompatible grease mixing, oxidation, accumulation of wear, and loss of consistency. In other locations, such as electrical motors, work is underway to investigate the benefits of substituting engineered grease sampling fittings in place of existing drain plugs, to allow grease purging while protecting the bearing housing. Such fittings can also provide capture of any drained grease for subsequent analysis.

Ultrasonic and Acoustic Leak Detection

Ultrasonic and acoustic leak detection surveys are performed on compressed air and gas systems, critical steam traps, and other applicable process equipment to identify leaks. Ultrasonic and acoustic leak detection surveys are performed on 12-month intervals, or as-needed to identify leakage sources observed through downward trending header pressures or high compressor runtimes. Building Engineers establish a survey route and perform routine surveys with assistance from NAVSEA as needed.

Ultrasound is also used to complement IR inspections of electrical equipment, and vibration analysis of mechanical equipment. The Building Engineers are responsible for coordinating inspections, assigning problem severity, initiating action, coordinating post-maintenance follow-up testing, and documenting case histories and work closure information. Coordination of ultrasound leak detection data with Infrared Thermography data is important especially for steam trap and valve leakage inspections.

Ultrasonic leak detection of air systems is especially important in facilities. Much of the automated operation of equipment, dampers, etc., is achieved through pneumatic systems. Excessive leakage in the supplied air headers or distribution tubing can result in lower than required air pressure, and may cause these systems to operate improperly. Also, the excessive leakage causes high cycling rates of building air compressors, increasing wear, reducing life cycles, and increasing energy costs to run the compressors.

Siemens Building Automation System (BAS)

The Building Engineers perform a regular review of process data and alarms from the BAS system. There is a large amount of data that can be utilized to proactively manage equipment conditions and prevent equipment failures. The team works to develop methods for capturing this data for use in equipment performance analysis, trending, and optimizing certain PM activities. For example, differential pressure readings can be used to determine when to change filters; run-hour readings can be used to determine lubrication intervals; air flow readings can be used to determine when control problems and/or damper problems may exist; compressor cycle times can be used to indicate compressor performance and capacity degradation.

Process data from this system is also integrated and correlated with data collected from PdM activities to improve the condition assessment of systems and equipment. Opportunity exists to leverage PdM data to improve the capabilities of the BAS, and vice-versa. PdM data is used, where applicable, to help establish alarm types and levels for BAS monitoring points. Likewise, BAS system data and trends are reviewed to optimize PdM activities. This is accomplished by scheduled meetings that include the Facility Containment Specialists, Siemens Automation support personnel, and NAVSEA.

Preventive Maintenance Inspections

Because the CBM approach strives to optimize traditional PM activities, there are only a few recommended PM tasks that are defined in the CBM matrix. The actual scope of this work is determined using condition data that exists from other CBM elements. Certain tasks like routine regreasing, instrument calibrations, functional testing, and/or system adjustments are still required. However activities that can be deferred or eliminated based on the periodic diagnostic monitoring tasks are removed from the time-based PM scope.

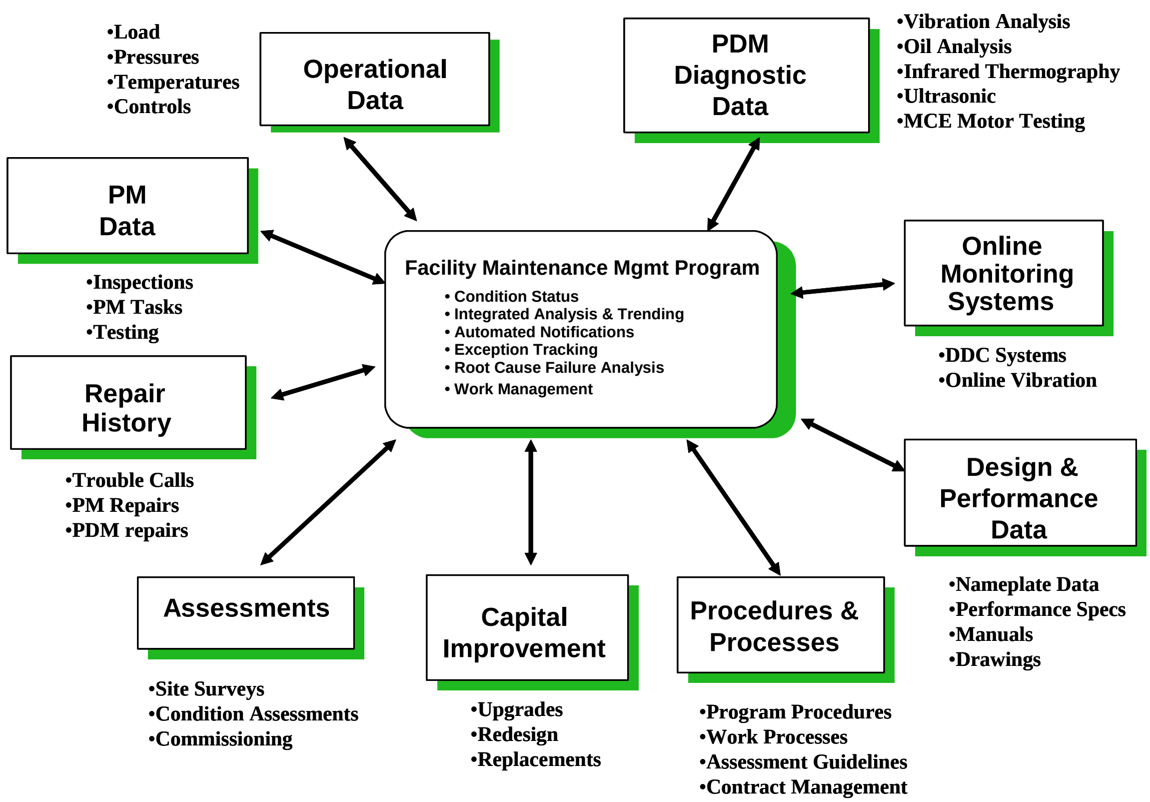
BIO-SAFETY LEVEL 3 AND 4 LABORATORIES

The National Institutes of Health has established an initiative to obtain and maintain Bio-Safety Level 3 and Bio-Safety Level 4 status for certain campus facilities to support research activities and US Government strategic initiatives. Key in the process to establish this designation is the development of a plan to ensure the reliable operation of critical assets that support building operation and use. In order to operate more efficiently, optimize maintenance activities, and improve asset reliability, a Condition

Based Maintenance program has been developed for all NIH Bethesda campus Bio-Safety Level 3 and 4 facilities. These labs, and the equipment that serve them, are the highest priority equipment on the campus. The need to establish compliance with regulatory requirements for BSL 3/4 facilities directly led to the establishment of a comprehensive CBM program at NIH.

One of the foundations of this advanced strategy is the incorporation of Reliability Centered Maintenance (RCM) principles to identify critical systems and components, and the proper mix of Preventive (PM), Predictive (PdM), and Proactive (PAM) tasks required to maximize equipment reliability. The use of technology (i.e. on-line monitoring systems, advanced diagnostics, and automation tools) plays a significant role in this Condition Based Maintenance approach to optimize asset performance. By understanding the current condition of equipment through the application of condition monitoring technologies, more effective decisions can be made regarding equipment operation and required maintenance tasks. When adopted in an environment of continuous improvement, this program approach results in significant benefits including:

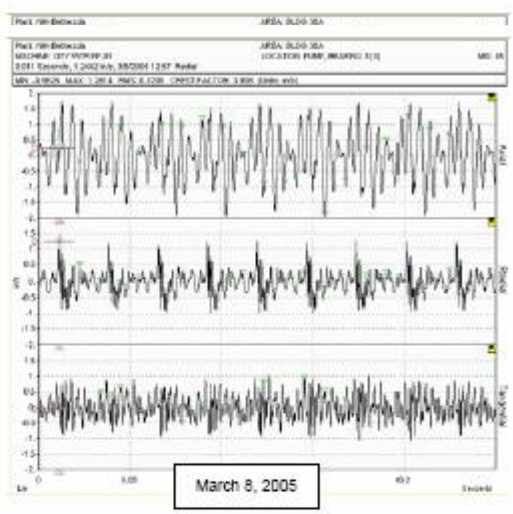
- Increased Equipment Reliability
- Reduced Failures
- Reduced Facility Operating Costs
- Reduced Manpower requirements to maintain equipment
- Optimization of Maintenance Tasks
- Improved Customer Satisfaction
- Improved Process for Work Identification

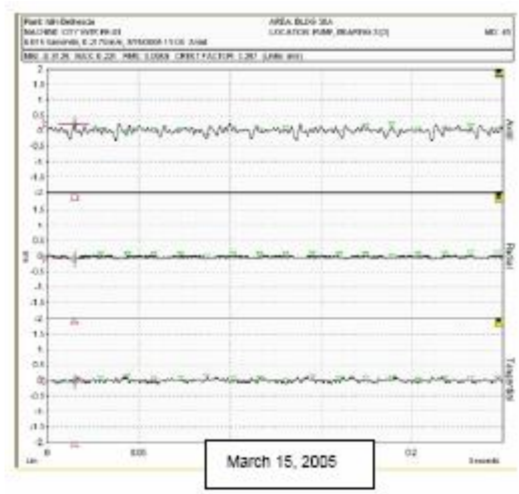


SUCCESSES IN FACILITY CBM

Success has been realized in the NIH CBM program through reduction of trouble calls, elimination of long-standing recurring maintenance failures, and specific instances of troubleshooting with diagnostics to eliminate emergent equipment problems. More recently, government initiatives have been reinforced to stress the need to improve energy efficiency in government operations. To support this area of focus, cost-benefit analyses are regularly performed on equipment exceptions to document avoided maintenance costs and energy use reductions.

Case Example: Addressing coupling failures and noise



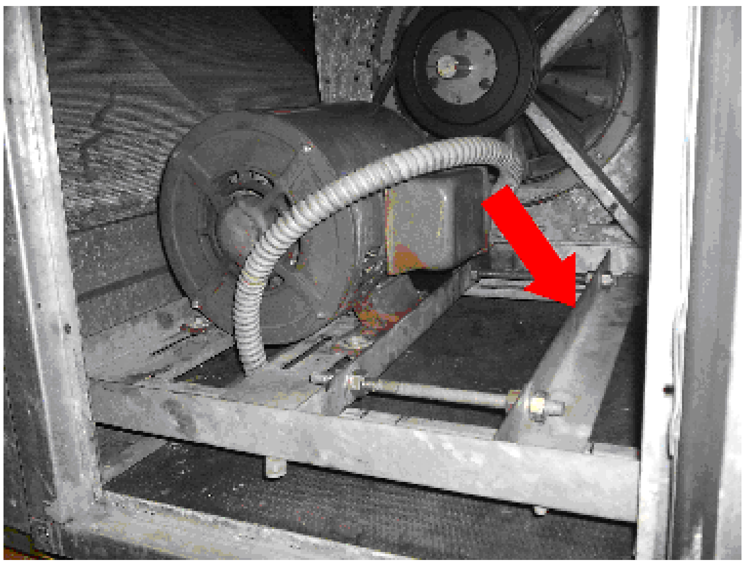


A Building Engineer requested NAVSEA assistance to evaluate an unusual noise coming from a city water booster pump. Vibration analysis indicated a condition of looseness and the Ultraprobe 9000 pinpointed the problem at the coupling. Above at left, you can see the actual waveform taken from this water pump on March 8, 2005. This shows a severe vibration that needed to be addressed immediately. The waveform showed a peak vibration of nearly 1.0 inches per second. The center spectrum, from the radial direction, also indicates an impact, or heavy hit, once per revolution of the shaft. The NIH Building technicians disassembled the coupling. Contact between the motor half key and the face of the pump coupling hub along with a significant misalignment of the shaft were found to be contributing factors to the vibration. The coupling was reassembled after relocating the shaft keys, and a recommendation was made to realign the pump, and documented into the TEAMM online system. On March 15, 2005 NIH building technicians and NAVSEA Team members realigned the pump. With the motor alignment being out as much as 95 thousandths, shims were installed to bring the alignment down to just 4 thousandths. Vibration measurements were taken after the alignment and the resulting waveform is shown above, at right. The scale on this spectrum is the same as the spectrum at the left. Ultimately, it would be desireable to align this unit even closer, but certainly the life has been significantly extended as a result of these actions. Without these corrections, this pump would have soon suffered a catastrophic failure.

Case Example: Resolving frequent belt failures

The Building Engineer in an animal research facility was getting tired of changing belts in a two-belt driven fan that was experiencing frequent failures. "The first belt you couldn't keep on, and the second belt would break within a week or two," the engineer said. He had taken to writing the dates of belt replacement on the fan door, and they testified to the frequent failures.

The Building Engineer reviewed the equipment with the NAVSEA Team to determine what could be done. Together, they initially noticed a couple of problems, including a loose mounting bolt in the base. The sheaves were also worn, so new ones were ordered.

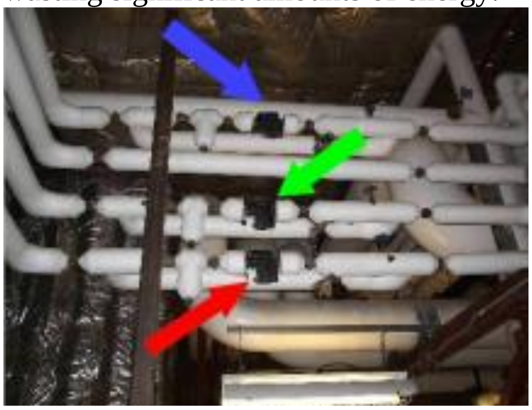


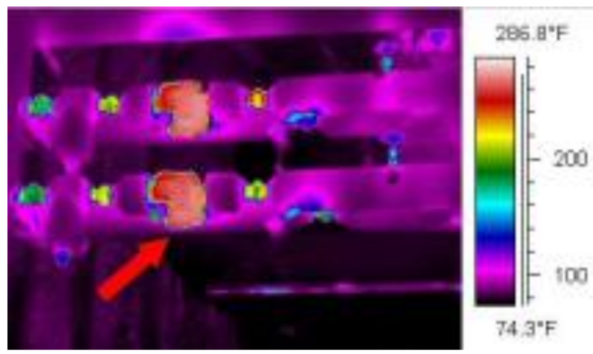
When the new parts arrived, the sheaves were replaced and the belts installed. Applying knowledge from a recent NAVSEA training class on Belt-driven equipment maintenance, it was determined that the belt size did not match the sheave size. While new B-size belts needed to be ordered to match the B-pitch of the sheaves, the unit needed to be returned to service in the meantime. The team worked together to align and tension the belts. Using a metal straightedge and a belt tension gauge, the all-thread jacking bolts were adjusted to achieve proper tension and alignment. During the repair, the team noticed that the alignment was being lost as the last few jacking turns were made, frustrating the effort. Closer inspection revealed that the back-plate for the jacking bolts was bent (see red arrow in image above), and allowed the motor to kick out when tension was applied. This was likely causing the significant misalignment and short belt life.

The jacking bolt arrangement was replaced by a solid mounting plate with integral jacking bolts. This strengthened the support for the motor, and allowed the unit to be properly aligned. "We've set some kind of record", commented the Building Engineer on the performance of both belts on the unit, achieving 1 year of uninterrupted runtime to date. There is still more to be done. The goal is to reduce vibration levels so that the belts can run without failure for 3 or more years when properly installed. When this is achieved, the workload of maintaining this critical fan will drop significantly, allowing the building maintenance team to focus their efforts on resolving other issues that will help improve equipment reliability and customer satisfaction.

Case Example: Improving energy savings in steam systems

A significant amount of steam is generated by the campus central utility plant, and utilized in the buildings for sterilization, equipment operation, and general area heating. Without proper maintenance and attention, such systems will gradually develop component failures that result in excess steam being ejected through the building vents, wasting significant amounts of energy.





In this case example, Building Engineers were trying to determine the source of excessive condensate in a medical research facility, that was accumulating in the condensate tank and bubbling out through the roof vent. The engineers teamed up with NAVSEA personnel to perform an infrared and ultrasound inspection of the system. Initially, the infrared camera showed that one of the steam traps was cold. The building engineers investigated and found a valve had been inadvertently left closed. After restoring the valve to the proper position, it appeared as though the steam trap failed to hold steam behind the trap. (See green arrow in the image above). Each trap that appeared to have steam temperatures on both sides was checked with ultrasound for the hissing of steam leaking by. When properly operating, these bucket traps should intermittently dump condensate, and then hold for a period of time. The suspected traps gave the sound of steadily leaking steam. In total, 3 traps were identified in the system as potentially faulty, and the team replaced the traps to restore proper operation. It was calculated that each faulty trap was wasting about $3,000 per year in lost energy.

Case Example: Indentification of grease-related bearing failure

During a scheduled vibration data collection task, it was discovered that a major Air Handling Unit was in service, but that the fan was not rotating. Closer inspection revealed that the pillow block bearing had been destroyed, dropping the shaft several inches, and throwing the belts. The motor continued to run, but the fan was not rotating.

A look at the bearing showed residue from the grease, which was gathered and analyzed. The analysis showed that two incompatible greases had been mixed, and the result was loss of the lubricating oil from the grease, leaving behind the non-lubricating soap residue. While the mechanics on the scene described the bearing as “rusted out”, grease analysis revealed the real culprit, and started an investigation of lubrication practices, existing grease guns, and followup grease analysis of similar bearings subject to grease mixing. Several bearings were identified with mixed incompatible greases, and a flushing procedure was applied to clean out these greases, and to restore the bearings to proper lubrication.

CONCLUSION

Diagnostic technologies and advanced maintenance strategies have been well established in applications such as power generation, manufacturing, and other heavy industries. The joint efforts of NAVSEA and NIH in this CBM program have demonstrated that there are significant benefits to be gained by applying these technologies and strategies to facilities as well. The comprehensive CBM program at the National Institutes of Health is a strong example of such success, and the program continues to grow to transition facility maintenance from a reactionary environment, to a planned and proactive program to optimize available resources and reduce the consumption of energy in these operations.