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Advanced Central Energy Plant Operations and Maintenance

A Summary of Current Technologies

by
Christopher L. Dilks, Lyndell Bowman, Michael K. Brewer, and Ralph E. Moshage

At Army central energy plants (CEPs), demands on maintenance personnel often grow faster than operation and maintenance (O&M) budgets. CEPs typically employ aging equipment, or are renewed with improved (but increasingly complex) technologies. Regardless of the age or condition of its equipment, Army installations depend on facility maintenance staffs to do highly skilled work at an efficient pace.

The U.S. Army Construction Engineering Research Laboratories (USACERL) has helped develop and implement a number of new tools to enhance plant efficiency and worker productivity. Information on these tools is disseminated through a number of forums (workshops, demonstrations, classes, etc.). A periodic, general overview of available new technologies can help installation personnel choose between "the best tool for the job" to quickly and cost effectively resolve long-standing problems. This study identifies technologies for improving operation and maintenance techniques at Army CEPs that are available to the Army O&M staff, and provides a list of references, guidelines, and points of contact to help obtain and implement these new technologies.

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Foreword

This study was conducted for U.S. Army Center for Public Works (USACPW) under Project 4A162784AT45, "Energy and Energy Conservation"; Work Unit EB-XK5, "Central Energy Supply: Advanced Operations and Maintenance." The technical monitor was Dennis Vevang, CECPW-EM.

The work was performed by the Industrial Operations Division (UL-I) of the Utilities and Industrial Operations Laboratory (UL), U.S. Army Construction Engineering Research Laboratories (USACERL). The USACERL principal investigator was Christopher Dilks. Ralph E. Moshage is Acting Chief, CECER-UL-I; Gary W. Schanche is Chief, CECER-UL; and John T. Bandy is Laboratory Operating Chief, CECER-UL. The USACERL technical editor was William J. Wolfe, Technical Resources Center.

COL James T. Scott is Commander and Acting Director of USACERL, and Dr. Michael J. O'Connor is Technical Director.

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1 Introduction

Background

Maintenance staffs at many Army central energy plants (CEPs) are faced with a dilemma: operation and maintenance (O&M) budgets either continuously decrease or—at best—remain constant, while demands on maintenance personnel grow. CEPs themselves often employ aging equipment, or are sometimes renewed with machinery incorporating new and improved (but increasingly complex) technologies. Regardless of the condition of its energy plant infrastructure, today's Army installation depends on its facility maintenance staff to do high quality work at an efficient pace; maintenance personnel must be able to do more work, at a higher level of complexity, in a shorter time than ever before.

The U.S. Army Construction Engineering Research Laboratories (USACERL) has helped develop and implement a number of new tools to enhance plant efficiency and worker productivity by improving operating methods and increasing employee capabilities. As new work on specific technologies is accomplished, the information is published and is transferred to the field through a number of practical forums (workshops, demonstrations, classes, etc.). A periodic, general overview of available new technologies can help installation personnel choose between the many new technologies to find "the best tool for the job" to resolve long-standing problems quickly and cost effectively.

Objectives

The objectives of this study were to: (1) identify technologies studied by USACERL for improving operation and maintenance techniques at Army central energy plants that are available to O&M staff, and (2) offer a list of references, guidelines, and points of contact to help obtain and implement these technologies at Army installations.

Approach

A literature search was done to create a list of available technologies applicable to CEP O&M and to identify commercial vendors of those technologies, where available. Researchers identified eight technologies, which, based on research and experience with those technologies in the private sector, best meet the Army's current needs:

- Predictive maintenance using vibration monitoring tools
- Contractor quality control using vibration monitoring tools
- Maintenance management software
- Boiler load allocation (the CEPLOAD software program)
- Steam Dispatching Control System (SDCS)
- Central Energy Plant Expert System (the CEPES software program)
- Operator training
- HeatMap: District Heating and Cooling System Analysis Program.

Researchers worked with commercial vendors to demonstrate several of the technologies at Army installations. Vibration monitoring, maintenance management practices and equipment, operator training and certification programs, and the Steam Dispatching Control System are all tools or methods widely used in the private sector that require little modification before applicable at Army installations. Training in properly using the equipment, designing functional systems, and providing support to the installations was the main thrust of this portion of the project.

Three USACERL-developed computer programs can assist the Army installations with the operation of their central energy plants. The Boiler Load Allocation Program (CEPLOAD) and the Central Energy Plant Expert System (CEPES) were developed to assist personnel in the day to day operation of their facilities. The HeatMap program, originally developed by the Washington State Energy Office (WSEO), was modified under a contract with WSEO to meet the needs of Army district heating and cooling system designers.

Mode of Technology Transfer

Technology transfer for the technologies described in this study was conducted through field demonstrations and support, software distribution, publication and distribution of Fact Sheets, User Guides, CPW Digest Articles, and presentations at various professional society conferences.

2 Vibration Monitoring

Background

Most Army central energy plants adhere to a "run-to-failure" repair philosophy, which, in essence, allows for equipment repair only after catastrophic failure has occurred. Although this maintenance approach has proven to be the least effective method for maintaining equipment, most facilities continue with it on the justification that budget or manpower restrictions make improvements to their maintenance programs impossible. What is needed is a "tool" to allow Army facilities to cost effectively upgrade existing maintenance practices.

USACERL has been evaluating the different techniques currently used in industry for improving maintenance practices. All types of predictive maintenance tools were examined to determine their potential for effective application at Army energy facilities. Since most of the equipment commonly found in energy facilities is rotary, vibration monitoring analysis was determined to be the most effective tool for problem diagnostics and machine condition assessment.

All of the training and equipment necessary to initiate a vibration monitoring predictive maintenance program is readily available from any one of several different vendors. This would include a FFT (Fast Fourier Transform) data collector and analyzer, with all of its standard accessories, and an 80-386 IBM-compatible (or equivalent) computer. Most major vendors do provide training and support with the purchase of their products. However, due to the diversity of the available products, details as to the specifics of each product will be left to the user to ascertain on selection of a given product.

Implementation of a vibration monitoring predictive maintenance program can provide two principal benefits. First, savings will be achieved from less frequent and less severe machine failure, which will show a decrease in machine damage. Less money will be required for replacement machine parts and for overtime pay to make emergency repairs to failed machinery. Secondly, resulting overall improvement in maintenance operations at the facility will lead to a more efficient (and cost effective) maintenance program.

Field Study/Technology Transfer

Technical Report

USACERL has prepared a detailed technical report describing all facets of the vibration monitoring maintenance program, titled *Vibration Monitoring for Predictive Maintenance in Central Energy Plants* (Moshage et al. September 1993). To verify the findings of this report, USACERL has also conducted some preliminary work in the field in conjunction with a facility in the private sector to develop and implement a detailed vibration monitoring program. The technical report is available to all interested parties. Further information may be obtained from USACERL Utilities Division (Appendix A).

Field Demonstrations

USACERL has demonstrated predictive maintenance via vibration monitoring at two Army installations, and has provided assistance in evaluating and starting a program for an energy facility in the private sector.

The first location considered was the boiler plant at Fort Benjamin Harrison, where the maintenance program was beta-tested. During the test procedure, vibration monitoring identified several machinery fault conditions, including a severely misaligned boiler feed water pump that had just been installed by a contractor. After this problem was detected, the contractor was called back to correct the problem, a step that potentially added years to the service life of the pump.

The second location considered was the boiler plant at Rock Island Arsenal. A beta test was set up to include most auxiliary equipment within the boiler plant, and identified several machine problems. Following the beta test, a major catastrophic failure in the HVAC plant caused management to investigate alternate means of equipment monitoring to pre-empt these types of failures. Vibration monitoring was a natural choice since the technique was already being used on production side equipment, and very little additional effort was needed to extend the practice to the HVAC equipment. This program is continuing at the time of this report.

The private sector facility considered was the Abbott power plant at the University of Illinois. Lower management showed considerable interest in initiating a vibration monitoring program and USACERL developed a guideline and a program plan for this facility, and began collecting data for research purposes. The vibration monitoring program was conducted through a beta run.

3 Contractor Quality Control via Vibration Monitoring

Background

Another way to improve maintenance levels while reducing expenditures is to contract out some or all of the facility's maintenance tasks. For some, it may prove cost effective to turn the entire program over to a contractor, while others may find it most effective to keep some tasks in house, and merely downsize their staff. Either way, as long as the contractor performs at a satisfactory level, the facility stands to save some money. An important issue in contracting maintenance is quality control. In other words, how will a facility know if it is receiving all of the work it is paying for through contract, and how will it know that this work is being completed satisfactorily. A simple and inexpensive tool is required to allow a facility manager to periodically check the quality of the contractor's work.

One effective, yet inexpensive, tool to check the performance of the contractors is a vibration meter. This simple device measures the vibration level in a machine, after which readings can then be compared to industry standards to verify that the machine is operating within acceptable limits of vibration. The machine's quality of performance (and hence, the contractor's performance) can easily be evaluated by merely comparing the level of vibration within a machine to that of acceptable industry standards.

If the use of contractors has proven to be an effective means to meet maintenance demands for a given facility, additional benefits may be achieved with the implementation of a vibration monitoring quality control program. The use of vibration monitoring as a quality control tool guarantees a basic quality level for new equipment installation and maintenance. Secondly, savings will accrue from more efficient machinery operation and consequent decreased energy consumption.

USACERL has reviewed existing standards and machine specifications to prepare basic guidelines for facility managers to use for contractor quality control checks (Appendix B). A literature review and field tests were done using a vibration data collector to verify the applicability of the method to Army energy facilities. A subsequent final report was published that contains guidelines that facility personnel can use to check that contractors are doing proper maintenance work. The guidelines are a combination of existing standards, supplemented by new guidelines that fill in areas where previously there was insufficient information available (Moshage et al. September 1993).

Field Study/Technology Transfer

USACERL has prepared a detailed user guide describing all facets of the vibration monitoring maintenance program (Appendix B). To verify the findings of this report, USACERL has conducted some preliminary work in the field. The user guide will be available to all interested parties. Further information may be obtained from USACERL Utilities Division (Appendix A).

4 Maintenance Management

Of the different techniques currently used in industry for improving maintenance practices, the use of maintenance management software packages holds promise for many Army facilities. Increasingly complex maintenance procedures create greater amounts of paper work and similar associated "secretarial" duties. This additional paperwork can often bog a manager down with details, which, with the aid of a computer and some simple software, might otherwise prove to be no burden.

Most facilities will see a vast improvement in the overall efficiency of their maintenance department simply by improving organizational skills. Not only will facility managers have more time to perform their duties, but the level of performance of each employee should also improve. This is due primarily to the elimination of "dead time," which is inherent in any disorganized system.

All of the training and software necessary to initiate a maintenance management program is readily available from any one of several different vendors. This would include a one-time purchase of some simple software, and possibly future expenditures for additional training. There is also a need for a 386 or equivalent computer for scheduling, assigning, and tracking tasks. Most major vendors do provide training and support with the purchase of their products. However, due to the diversity of the available products, details as to the specifics of each product will be left to the user to ascertain on selection of a given product.

The use of maintenance management software could prove beneficial in two ways, particularly since it inherently leads to the use of some preventative maintenance practices. First, savings will be achieved through improved maintenance operations via an increase in overall staff efficiency. The savings should offset (with some to spare) the money needed to initiate the changes in the maintenance program. Secondly, since most maintenance management software packages allow for the prescheduling of many tasks, each facility can, with very little additional effort, switch from a run-to-failure mode of operation to a preventative maintenance program. In turn, this will lead to a decrease in the number of equipment failures experienced at each facility, and also to a decrease in the amount of damage that will arise from the remaining failures.

USACERL has reviewed several available software programs that facility managers can use to improve their overall organizational skills and techniques. Many such off-the-shelf packages are too detailed and elaborate to be of much use to U.S. Army energy facilities. In other words, software that is too complex to use is money wasted. However, some software packages provide the basic tools which would prove beneficial to Army facilities, without extra “frills.” USACERL has prepared a special report that contains guidelines to be used by facility personnel in selecting and implementing an improved maintenance program and includes a list of several vendors of products that meet a basic list of requirements (Bowman and Moshage September 1994).

5 Boiler Load Allocation Program (CEPLOAD)

Background

Improving methods for coordinating the operation of boilers in Army central heating facilities offers a potential for significant energy savings Historically, plant operators have tended to run their facilities conservatively, to accommodate the uncertainty of imminent loads while ensuring plant reliability. Because a boiler's operating efficiency depends primarily on its load and most boilers experience their peak efficiencies in the range of 80 to 100 percent of their rated capacity, a preferred operating method would maintain each boiler's load as close as possible to the point of maximum efficiency. The conservative approach causes multiple boilers to operate when fewer boilers could accommodate the load more efficiently, even if one is set on standby, or "banked."

Most loads experienced by Army central energy plants are weather-related; much of the load is from heating or cooling demands. As a result, it is possible to forecast the loads that should be experienced within the next few hours or days to allow a reasonable assessment of the need for boilers or chillers within the time required to adjust boilers. Given a reliable forecast model for future loads and an evaluation of boiler (or chiller) operating parameters, an optimum load allocation strategy may be developed. The Army could improve the efficiency and reduce the operating costs of large central heating facilities at many installations by implementing such a strategy.

USACERL developed a central energy plant boiler load allocation expert system that includes a provision for facilities operating on coal, oil, and natural gas in unison or individually by boiler. The load forecasting model is a central element in the program to project the immediate future demands placed on the facility before they occur.

Field Study/Technology Transfer

The USACERL interim report, *CEPLOAD: A Load-Allocation Program for Central Energy Plants* (Dilks et al., September 1994), describes the development of system models and their incorporation into the expert system. Appendix B includes a user manual for the computer program, which is available to all interested parties. Further information may be obtained from USACERL Utilities Division.

In its interim form, CEPLOAD was a data intensive program that required substantial input from the operator. Forty-eight hour temperature forecasts and hourly boiler load data input was required for the program to work effectively. It was felt that the program in its current form would not be used properly, if at all, in the central energy plant environment; money was therefore directed towards more promising technologies. However, the current availability of electronic weather forecasts from the INTERNET, advances in electronic monitoring and control instrumentation, and increased computer processing speed and reliability provides an optimal environment to develop a standalone load allocation program that could efficiently distribute the boiler or chiller loads in a central energy plant.

6 Steam Dispatching Control System (SDCS)

Background

Currently, most military district steam heating systems operate by maintaining a constant steam pressure regardless of actual steam demand. While practical, this method of operation is often the source of significant energy losses. Consequently, researchers at USACERL examined the Steam Dispatching Control System (SDCS).

SDCS is a control system for reducing the losses in a distribution system by controlling the steam pressure. Lowering the steam pressure to slightly above the amount needed to meet the thermal demand reduces the steam temperature with only slight reductions in steam enthalpy. At the lower temperature, thermal losses are reduced and leak losses are diminished. The past success of SDCS in industry has indicated that SDCS could be successfully applied to military district heating systems.

Field Study/Technology Transfer

Technical Report

USACERL has prepared a detailed technical report describing the demonstration of a SDCS installed at Fort Benjamin Harrison, titled *Steam Dispatching Control System Demonstration at Fort Benjamin Harrison* (Dilks, Moshage, and Lin July 1993). The technical report is available to all interested parties. Further information may be obtained from USACERL Utilities Division.

User Guide

USACERL has prepared a detailed User Guide containing step-by-step instructions necessary to design and install the Steam Dispatching Control System, titled *User Guide for Steam Dispatching Control System (SDCS)* (Dilks and Moshage August 1993). The user guide is available to all interested parties. Further information may be obtained from USACERL Utilities Division.

Feasibility Study

USACERL performed a feasibility study for the Iowa Army Ammunition Plant (IAAP) to determine the cost effectiveness of SDCS at their base. The study showed a potential annual savings of over $50,000 with a payback of just under 5 years. This system would include an FM radio system to control the pressure-reducing valves from a central location. Additional savings would be seen by using the valves to isolate sections of the steam system during periods of inactivity, such as weekends and holidays.

USACERL can visit the site and survey the DHC system, create the DHC model to match a site's equipment, and perform a feasibility study on a reimbursable basis.

Field Demonstrations

USACERL has demonstrated the steam dispatching control system at one Army installation, Fort Benjamin Harrison. Results of this study were documented in the cited User Guide. The User Guide is available to interested installations and provides step-by-step instructions for performing a feasibility study and some preliminary designs.

Facilities Engineering Applications Program (FEAP) Flyer

USACERL and CPW prepared a flyer describing the demonstration of the Steam Dispatching Control System at Fort Benjamin Harrison to aid in technology transfer (ET-8/January 1993).

7 Central Energy Plant Expert System (CEPES)

Background

Rising operation and maintenance (O&M) costs of central heating plants have forced the Army to seek alternative methods of running these facilities. Computer technology offers a great potential to automate the plants and to help diagnose equipment malfunctions and failures. An automated diagnostic tool for coal-fired heating plant equipment could reduce the demand for human labor and free personnel for higher priority work; reduce downtime for repair; promote thermal efficiency; and improve online reliability.

In the course of developing the CEPES software, USACERL researchers collected troubleshooting information (electronic) files to help distinguish problems caused by operational procedures or equipment deficiencies from those caused by inadequate coal quality. While the troubleshooting files presented sufficient information for diagnosing many central plant problems, an expert system that incorporates this information along with additional information relating to noncoal quality based operational and equipment problems would have even greater utility to a plant. Expert systems can provide on-line, convenient access to knowledge. In this project, USACERL developed an expert system to help plant personnel analyze and solve central plant operational and coal quality problems for spreader stoker type coal plants. The starting point was the information already contained in the troubleshooting files and additional documentation provided by users and prior USACERL research.

The CEPES (Central Energy Plant Expert System) editor is a companion tool to the CEPES troubleshooting software. Both CEPES and the CEPES Editor perform on PCs running Microsoft Windows®. Both were written with KAPPA, an object-oriented programming tool sold by Intellicorp, Inc. of Mountain View, CA, and both require a runtime version of Kappa.

CEPES is unique in that it has an editor program that will allow field engineers to develop and edit a software configuration without having to program in C++ or LISP code. The expert system designer is only required to have a working knowledge of DOS and Windows 3.1™ procedures.

Field Study/Technology Transfer

Special Report

USACERL has prepared several reports describing the development and use of the software titled, *Application of Expert Systems for Diagnosing Equipment Failures at Central Energy Plants* (Moshage et al., December 1993) and *Development and Use of Coal-Fired Central Energy Plant Operations Expert System (CEPES)* (Moshage et al., August 1993). USACERL has also prepared a user manual titled, *Coal-Fired Central Energy Plant Operations Expert System and Editor (CEPES Version 4.3 and CEPES Editor Version 2.4) User Guide* (Moshage et al. 1995). The reports are available to all interested parties. Further information may be obtained from USACERL Utilities Division.

Field Demonstrations

USACERL tested and demonstrated the CEPES and CEPES Editor on a coal-fired co-generation plant (Abbott Power Plant, Champaign, IL) and an industrial sized coal stoker boiler plant (Rock Island Arsenal, IL). Boiler operators at both sites who had previous experience with computers were enthusiastic about using the software. Users with no computer experience had to be trained in general computer usage. Once they had become accustomed to the computer, the users were pleased with the software's capability. The CEPES program, once it is loaded, relies on pointing device (mouse) input only. The minimized keyboard input was an aspect appreciated by the end users.

Copies of the software are available from USACERL, Utilities Division. The user manuals will be available from USACERL or NTIS once the report is published. Although the software is designed to allow a field engineer to install and edit, USACERL can install and edit the software to match a site's equipment on a reimbursable basis. USACERL can visit the site and embed electronic images of local equipment as well as interview plant operators and provide computer training.

8 Operator Training

Background

The variety of equipment found in typical Department of Defense (DOD) central energy plants and the complexity of the overall operation and maintenance of these plants demands that the operators be highly qualified personnel. Army Regulation AR 420-15 requires that "All utility plant supervisors (e.g., foreman), operators, ... will be properly certified." In addition to requiring operator certification, the regulation stipulates the implementation of mechanisms for ensuring that personnel have the opportunity to acquire the required skills, specifically that "...formal and/or informal training programs will be established for those employees requiring additional training to upgrade their skills, to qualify them for certification, and to provide for their career development." Additionally, AR 420-15 encourages that "Advantage should be taken of existing training programs within the Department of Defense (DOD), Department of the Army, industry, and Federal or State Governmental agencies." Specific details for execution of these training and certification requirements are the responsibility of the Major Commands.

Given the complex nature of boiler systems and the serious danger posed by improperly operated boilers, the heating and power industry has maintained some sort of licensing or certification process to establish minimum credentials for their employees for many years. Additionally, the 1990 Clean Air Act Amendments (CAAA 1990) (Appendix A) have recognized the importance of properly trained and certified operators of high-capacity fossil fuel plants toward improving air quality. The U.S. Environmental Protection Agency (USEPA) has been tasked by the CAAA 1990 to develop model training and certification programs for the operators of high-capacity, fossil-fueled plants. These USEPA training and certification mandates may eventually be applied to DOD installations. Much of the federal environmental law enforcement has been delegated to the state environmental agencies. Currently there are certain positions, such as waste treatment plant operators, where state licensing is required of federal employees due to the arrangement where the state is enforcing federal mandates.

The DOD operates nearly 100 installations in 12 jurisdictions that currently have boiler operator licensing requirements in the interest of public safety. Although the federal government has historically held itself immune from many state licensing programs, federal mandates to the state on environmental issues could override that immunity. Additionally, certification has been used in several federal agencies to establish minimum credentials for certain occupations. Three services in the DOD (U.S. Army, U.S. Navy and U.S. Air Force) have investigated implementing boiler operator training and certification mechanisms since at least 1987. These investigations have identified the benefits and liabilities of at least three different strategies to implement a training and certification program. The first option examined was to utilize the available state and municipal license. This was ruled out since the DOD could be exposed to protests due to lack of uniformity and fairness in testing requirements. A second option was to establish a government certification and testing board. Although the standard would be uniform, the start-up and execution costs of such a program may be excessive in a fiscally austere climate. The third option was to use the National Institute for the Uniform Licensing Power Engineers (NIULPE) standard since it is already in existence and is uniform in those 28 states that currently have chapters. A U.S. Navy initiative on boiler certification indicated its preference for using a nationally recognized third party licensing standard such as NIULPE instead of establishing a new U.S. Navy certification infrastructure or attempting to comply with a variety of jurisdiction particular standards that have limited reciprocity and unequal standards.

The DOD is one of the largest operators of central heating plants in the United States. It is in the interest of the DOD to minimize the impact of operating these plants on the environment both locally and nationally. Additionally, with the downsizing of the Army, the available operating resources are being reduced both in personnel and money. It is also in the interest of the Army to be proactive in meeting the intent of the CAAA 1990 by using an interim model training and certification standard. Furthermore, the Army must be prepared to operate its plants with fewer personnel and lower fuel costs to free resources for higher priority programs as part of the downsizing of the nation's forces continues.

The objective of this project was to identify the knowledge and technical skills required to safely and efficiently operate DOD central energy plants. Based on these requirements, a pilot program was executed to identify and test training methods and to validate certification mechanisms.

Field Study/Technology Transfer

Technical Report

USACERL has prepared a detailed report describing all facets of the pilot program titled *The Department of Defense Central Heating Plant Operator Training and Certification Program: An Overview* (Brewer and Moshage November 1994). The report is available to all interested parties. Further information may be obtained from USACERL Utilities Division.

Pilot Program

USACERL conducted a training and certification pilot program funded jointly by the Army and Navy at eight installations (five Army and three Navy). The program consisted of a study guide, a technical library, a 1-week course, and a certification examination. To measure the course's effectiveness, pre-test and post-tests were given. At the end of the course, a NIULPE Fourth Class Power Engineer examination was given. In addition to the program courses, one base was so enthusiastic about the course that they procured an additional course with their funds to train the rest of their boiler operators.

At the outset of this training program operator knowledge level ranged from poor to very good. At installations where operators had previously held licenses or had prior naval service as boiler operators, the level of knowledge seemed higher. At all installations, the supervisory personnel were enthusiastic and supportive of the boiler operator training.

Boiler Operator Training Course Delivery Order

As a result of the pilot program the U.S. Army Center for Public Works (USACPW) has established an agency wide indefinite delivery order from which DOD activities can procure a 1-week training and certification course (Contract Number DACA31-93-D-0096). This short course is useful to help meet some of the fundamental training needs at the installations.

9 HEATMAP

Background

HEATMAP is a program designed by the Washington State Energy Office (WSEO) to model district heating and cooling (DHC) systems. The program is separated into three major parts: (1) the HEATMAP interface, (2) the HMACAD interface, and (3) the LFLOW-2F distribution analysis program. The HEATMAP interface controls the project data base and allows modifications to the data base fields and libraries used in the modeling calculations. It also provides a means of exchanging data with AutoCAD and LFLOW-2F. The HMACAD interface provides the user a graphic representation of the DHC system. Pipe length and orientation are calculated from the map. Menus allow the user to quickly input or modify consumers, producers, and nodes. The LFLOW-2F program is the system flow modeling program. It can calculate many system variables such as flow, pressure, and temperature and has an optimizing routine used to calculate required pipe in the DHC system. It works with both steam and water systems. HEATMAP also includes an economic analysis program that creates an input file used by the Life Cycle Cost in Design (LCCID) program to calculate life-cycle costs.

Field Study/Technology Transfer

Field Demonstrations

USACERL developed steam-use models for three areas at the Iowa Army Ammunition Plant (IAAP) for use in a feasibility study. The results of the models were compared to results from data provided from the base and results from models created using the Steam Heat Distribution Program (SHDP). Steam use calculations from the two models compared favorably to the actual steam use data provided by the base. USACERL provided the HEATMAP program and the steam models to IAAP personnel.

Copies of the software are available to DOD installations from USACERL, Utilities Division. Other users may contact WSEO about purchasing the software. The user manuals will be available from USACERL or WSEO once the new manuals are published. Although the software is designed to allow a design engineer to install the software and develop the DHC system, USACERL can visit the site and survey the DHC system, install the software to a base computer, and create the DHC model to match a site's equipment on a reimbursable basis. USACERL can also provide training.

Training Course

USACERL sponsored a training course taught by WSEO personnel at USACERL on 7 and 8 December 1994. All attendees were provided a training manual and a copy of the software. Future training courses will be available.

10 Conclusion

Continuing decreases in O&M budgets dictate that practices at Army central energy plants must improve if operations and maintenance staff are to maintain the high quality of work demanded of them. Improved practices translates into two necessary components: (1) purchase and installation of better, more efficient equipment, and (2) training in its use. Properly trained operators using modern operation and maintenance technologies are necessary for the safe, efficient operation of CEPs at U.S. Army installations in the future.

This study identified technologies studied by USACERL for improving operation and maintenance techniques at Army CEPs that are available to Army installation O&M staff, and compiled a list of references, guidelines, and points of contact to help obtain and implement these technologies at Army installations. Most of the technologies identified in this study can improve maintenance or operations with a simple payback of less than 5 years if the system is implemented properly and the operators are appropriately trained in its use.

Appendix A: Further Technical Information and Points of Contact

Technical Reports and User Guides

Bowman, L., and R.E. Moshage, *Improved Maintenance Management for Army Central Energy Plants*, Special Report (SR) FE-94/03/ADA286445 (USACERL, September 1994).

Brewer, M.K., and R.E. Moshage, *The Department of Defense Central Heating Plant Operator Training and Certification Program: An Overview*, Interim Report (IR) FE-95/03/ADA289481 (USACERL, November 1994).

Dilks, C.L., and R.E. Moshage, *User Guide for Steam Dispatching Control System (SDCS)*, Facilities Engineering Applications Program User Guide (FEAP-UG) 93/24 (USACERL, August 1993).

Dilks, C.L., R.E. Moshage, J.A. Kinast, R. Beiderman, and C.F. Blazek, *CEPLOAD: A Load-Allocation Program for Central Energy Plants*, IR FE-94/22/ADA289242 (USACERL, September 1994).

Dilks, C.L., R.E. Moshage, and M.C.J. Lin, *Steam Dispatching Control System Demonstration at Fort Benjamin Harrison*, Facilities Engineering Applications Program Technical Report (FEAP-TR) FE-93/15 (USACERL, July 1993).

Moshage, R.E., K. Madhavi, G.W. Schanche, M. Metea, and C. Blazek, *Application of Expert Systems for Diagnosing Equipment Failures at Central Energy Plants*, Technical Report (TR) FE-94/04/ADA276909 (USACERL, December 1993).

Moshage, R.E., L. Bowman, C. Bethea, R. Chesser, D. Burch, and D.F. Dyer, *Vibration Monitoring for Predictive Maintenance in Central Energy Plants*, TR FE-93/25/ADA273548 (USACERL, September 1993).

Moshage, R.E., T. Magliero, R.T. Lorand, and M. Kantamnemi, *Development and Use of Coal-Fired Central Energy Plant Operations Expert System (CEPES)*, IR FE-93/07/ADA273216 (USACERL, August 1993).

USACERL Fact Sheets:

Fact Sheet UL 14, *Central Energy Plant Boiler Load Allocation Program (CEPLOAD)* (USACERL, May 1995).

Fact Sheet UL 15, *Steam Dispatching Control System Demonstration at Iowa Army Ammunition Plant (IAAP)* (USACERL, June 1995).

Fact Sheet UL 16, *Department of Defense Central Heating Plant Operator Training and Certification Pilot Program* (USACERL, May 1995).

Fact Sheet UL 23, *HEATMAP* (USACERL, June 1995).

Available Software and Users Manuals:

Dilks, C.L., R.E. Moshage, J.A. Kinast, R. Beiderman, and C.F. Blazek, *CEPLOAD: A Load-Allocation Program for Central Energy Plants*, IR FE-94/22/ADA289242 (USACERL, September 1994).

Moshage, R.E., T. Magliero, R.T. Lorand, and M. Kantamnemi, *Development and Use of Coal-Fired Central Energy Plant Operations Expert System (CEPES)*, IR FE-93/07/ADA273216 (USACERL, August 1993).

HEATMAP Program and Users Guide, Washington State Energy Office, 920 Plum Street, SE, Town Square Building #4, PO Box 43165, Olympia, WA 98504-3165

USACERL Points of Contact:

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Olympia, WA 98504-3165
206/956-2016

Appendix B: Quality Control Standards for U.S. Army Central Energy Facilities: A Users Guide

Introduction

Background

For many decades, most maintenance work at U.S. Army energy facilities has been done in house either by facility operators, or by a trained staff of maintenance personnel. Recent budget cuts, however, have necessitated the use of contractors at some facilities. Many of these facilities have converted completely to contractor-provided maintenance. Other facilities primarily use outside assistance only for emergency repairs. This trend to outsource maintenance work continues, with even more emphasis being placed on downsizing the number of plant personnel at each facility.

Additional contract work is frequently purchased to install new equipment. This is partly due to a lack of personnel, necessary tools, or knowledge necessary to complete the installation. Even though some machinery vendors include installation in the cost of the equipment, simple installation must often be supplemented by additional repairs to the equipment environment, performed at an additional cost.

To quantify how much is being spent annually on contracted maintenance, consider the following figures obtained from the U.S. Army Engineering and Housing Support Center (USAEHSC)* for fiscal year (1992):

Total number of facilities considered:	101
Total spent for contracted maintenance:	$22,404,278.00
Average cost per facility:	$221,825.00

This survey shows that a substantial amount of money is being spent on contracted maintenance. To ensure that the expenditure on contracted maintenance is cost

* Now known as the U.S. Army Center for Public Works (USACPW).

effective, it is important for the Army to evaluate the contracted work, whether tasks are being omitted, or carried out haphazardly. It is essential for energy facilities to have a reliable means to monitor the performance of contracted maintenance work.

Objective

The objective of this work is to provide guidelines to U.S. Army Energy facility personnel for maintaining a satisfactory level of quality control. These guidelines will serve two purposes: (1) to establish a minimum requirement on machine condition for newly installed equipment at Army facilities based on initial machine vibration data, and (2) to establish a checking system that facility personnel can use to verify contractor performance when outsourcing maintenance tasks. Such guidelines could be used on a job-by-job basis, or as a blanket to cover all maintenance operations.

Approach

A literature and vendor search was performed to obtain information pertaining to existing standards, as well as to identify potential products to help meet this goal. Field tests were done to verify the usefulness of these standards and products. A set of guidelines was then developed to help Army energy facility personnel maintain quality control.

Mode Of Technology Transfer

Army-wide implementation of these guidelines will be achieved through planned field demonstrations, publication of a USACERL fact sheet, and publication of a DEH Digest article.

Vibration Monitoring as A Quality Control Tool

Users

Any facility using contractor assistance to perform maintenance tasks should consider implementing a procedure that will provide quality control or quality assurance. To accomplish this, there must be a baseline to measure a minimum level of performance. Of all available tools, the use of a vibration meter for periodic performance checks appears to provide the easiest, most cost effective means to this end. Standards and guidelines for acceptable levels of vibration for different types of machines are already available. These standards can serve as the baseline for both installation procedures and for daily maintenance procedures.

Facilities that perform all installation and maintenance procedures in house may also wish to consider using this tool. Periodic checks of the performance levels of their machines help ensure they are operating in the most efficient manner possible. Note that vibration monitoring should *not* be used to monitor or judge employee performance. If facility personnel perceive this process as a way to grade personnel performance level, a sense of resentment may actually cause an overall decline in their performance levels. Thus, for facilities with no contracted maintenance, it is essential to emphasize this tool is to provide information pertaining to machinery performance, not employee performance.

Necessary Equipment

The only equipment required to implement this type of quality control program is a vibration meter. There are several different models offered by a wide range of vendors, but a model that offers the greatest simplicity in use is recommended. In general, the price range for these different meters is from $1400.00 to about $3000.00; the price range generally reflects different methods of data display. Vendors can provide further information regarding specific products. A list of vendors offering this type of product is given in Annex A.

Another piece of equipment worthwhile in any vibration monitoring program is a computer. Although it is not absolutely essential to program success, a computer greatly simplifies data storage. This becomes important when facility personnel want to compare the current performance of a given machine to its performance at an earlier date. Granted, this recordkeeping *can* be done without the aid of a computer, but the associated paper drill is complex, time consuming (expensive), and—over time—less reliable than the automated alternative. The current cost of a 386 caliber machine and some simple software is approximately $1500.00. Note that vibration monitoring requires no special software, merely a simple spreadsheet type program for data storage, and a simple word processor for report generation.

Benefits

Reduction In Capital Costs

The use of vibration monitoring for machinery condition analysis has been shown to increase machine life by 10 to 20 percent. This extension of machine life can lead to a reduction in capital expenditures by as much as 10 percent (Rockwood October 1991). These savings alone justify the initiation of a quality control program.

Reduction In Operating Costs

A quality assurance program that ensures a reduction in machine vibration to acceptable levels will also reduce fuel consumption. Vibration from misalignment and unbalance are by far the two most commonly detectable machinery fault conditions. In one case, a 125 HP motor analyzed for potential electric savings after an alignment showed a typical electrical consumption decrease of 1 to 2 percent after a balance, and 3 to 5 percent after an alignment. In this instance, the motor was given as a 125 HP, 460 volt, 3-phase electric induction motor with a power factor of 0.9 and a FLA of 140. The motor is assumed to experience a 3.5 percent decrease in electrical consumption (5 amp) after the alignment (Lowe February 1994), by the following energy savings calculation:

$$E = [(3)^{1/2} (I_i - I_f) (V) (PF)]/1000 \qquad \text{[Eq 1]}$$

where:

E = energy savings in kilowatts
I_i = initial current in amps
I_f = final current in amps
V = rated voltage in volts
PF = power factor.

This example shows an energy savings of 3.59 kW. To obtain an annual monetary savings, multiply the above electrical decrease by the approximate number of hours the machine operates during a year, and then by the electric rate for the facility:

$$\$ = (E)(H)(R) \qquad \text{[Eq 2]}$$

where:

$ = annual monetary savings in dollars
H = the approximate number of hours a machine operates in a year
R = electric rate in dollars per kW-hour.

For the above example, the machine operated approximately 7000 hours a year, with an electric cost of $0.067/kW-hour. This computes to a savings of $1684 per year for a single machine. Similar calculations should be made for all equipment at a facility to obtain an estimate for total savings. However, any estimates should consider that:

1. The above example assumes a power factor of 0.9, which may be too high for many motors found in Army energy facilities. A more appropriate estimate might be 0.85.

2. The above example assumes that the motor is operating at full load, thus the calculation uses the full load current. Again, this has not proven to be the case from field tests taken at different Army facilities. A more reasonable estimate would be that most machines operate near 80 percent full load so that 80 percent of the FLA should be used for energy savings calculation.
3. The above example only considered an alignment. Additional savings should be obtained from a balance as well.
4. Verification of energy savings for a given motor can only be made if the motor is operated under the same load conditions both before and after the alignment or balance. Any change in load conditions will also have an affect on electrical consumption.

Annex B lists some typical motors found in Army facilities, along with their rated voltages, currents, and potential savings for a balance or alignment. This Annex, along with the above sample calculation, should be used by facility personnel to determine approximate energy reductions for their plants.

Verification Of Contractor Performance

Use of a vibration meter to check machinery condition provides a simple, quick, inexpensive way to verify whether a contractor is performing the assigned duties according to the contract. If he is, then the facility will be receiving the benefits mentioned above. If not, facility personnel will have enough documented proof to enforce a better level of service. It is important to note that the acceptable level of vibration must be precisely specified in the maintenance contract for this tool to be effective. Annex C includes some sample clauses that could appear in a contract to specify the acceptable level of vibration.

Keep in mind, however, some vibration will always exist. Just because a machine is vibrating, it does not mean that the machine is in fault condition. In fact, some machines have a track record of fairly high levels of vibration while operating satisfactorily. In these instances, an exception may be made to the original specifications, but only at the discretion of facility personnel, with the approval of the contracting officer and not those people working for the contractor. On replacement of the machine in question, all new machinery should be forced to adhere to the vibrational parameters specified in the contract.

Vibration Guidelines

Figures B1 to B8 show recommended levels of acceptable vibration for various types of equipment. It should be stressed that these are only guidelines. Often exceptions will be required for some equipment, but only at the discretion of facility personnel, with the approval of the contracting officer. Under no circumstance should the contractor, or any representative thereof, be allowed to deviate from the contract without appropriate approval prior to any such deviations.

Furthermore, these guidelines are to be used only in the absence of manufacturer's specifications. When available, the specifications set forth by the manufacturer should be incorporated into the contract. The contractor should then be required to adhere to these conditions.

To use the figures given below, one needs to first identify the type of equipment which is being checked. For example, if information pertaining to the condition of a feed water pump was desired, then Figure B3 would be used. Next, merely compare the value of the measured vibration from the pump with the figure. From this comparison, the appropriate action can then be determined, if any. For the pump example, suppose a value of 0.24 in./second peak was measured, which, when compared to the figure indicates that the contractor is to repair the machine within 30 days. For ease of use, a conversion table has been provided in Annex D, so that the user can easily convert the units used by his vibration meter to those given in the figures. Note that the contracting officer, who is informed via facility personnel, is responsible for notifying the contractor of any violations of the contract. However, this can usually be avoided with a simple phone call or letter to the contractor indicating what equipment is operating in fault condition, and what actions are required to bring the equipment up to specified levels of performance.

One final caution: often a substantial amount of background "noise" occurs when equipment is located near, or is connected to, other machinery. Although background noise is not necessarily good for nearby equipment, it does not have a bearing on its operating condition. Thus, if it is suspected that some background noise is present, then a baseline reading should be taken while the equipment is offline. This reading should then be subtracted when a reading is made while the equipment is operating.

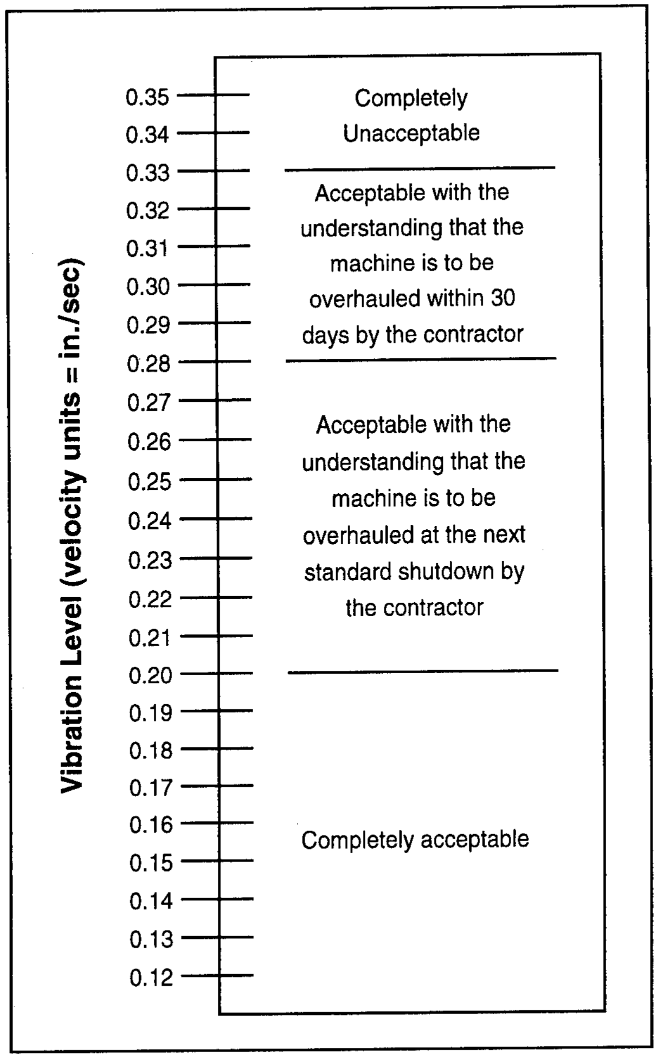

Figure B1. Vibration guidelines for low-speed cooling tower fans (< 1200 rpm).

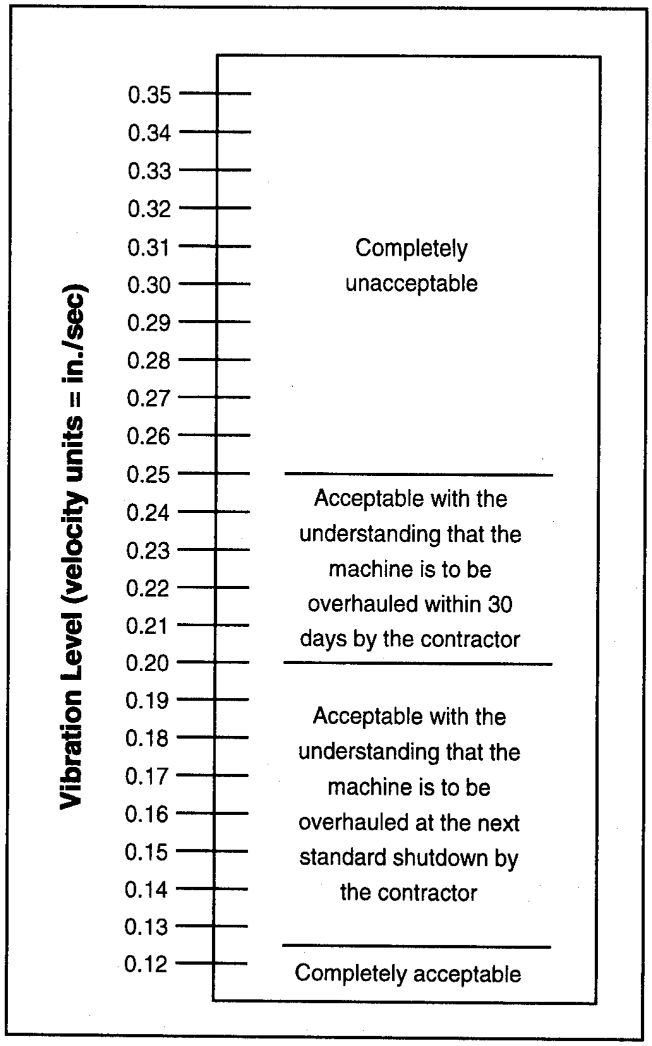

Figure B2. Vibration guidelines for high-speed cooling tower fans (>1200 rpm).

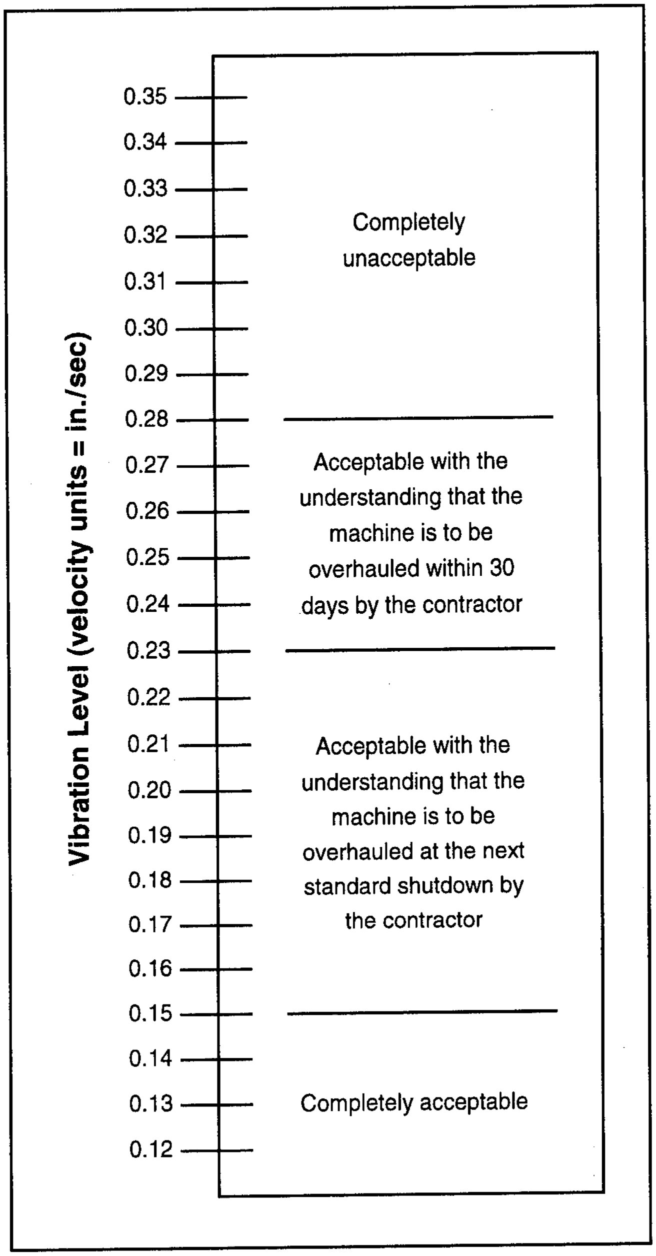

Figure B3. Vibration guidelines for service pumps (including, but not limited to, feed water and condensate return).

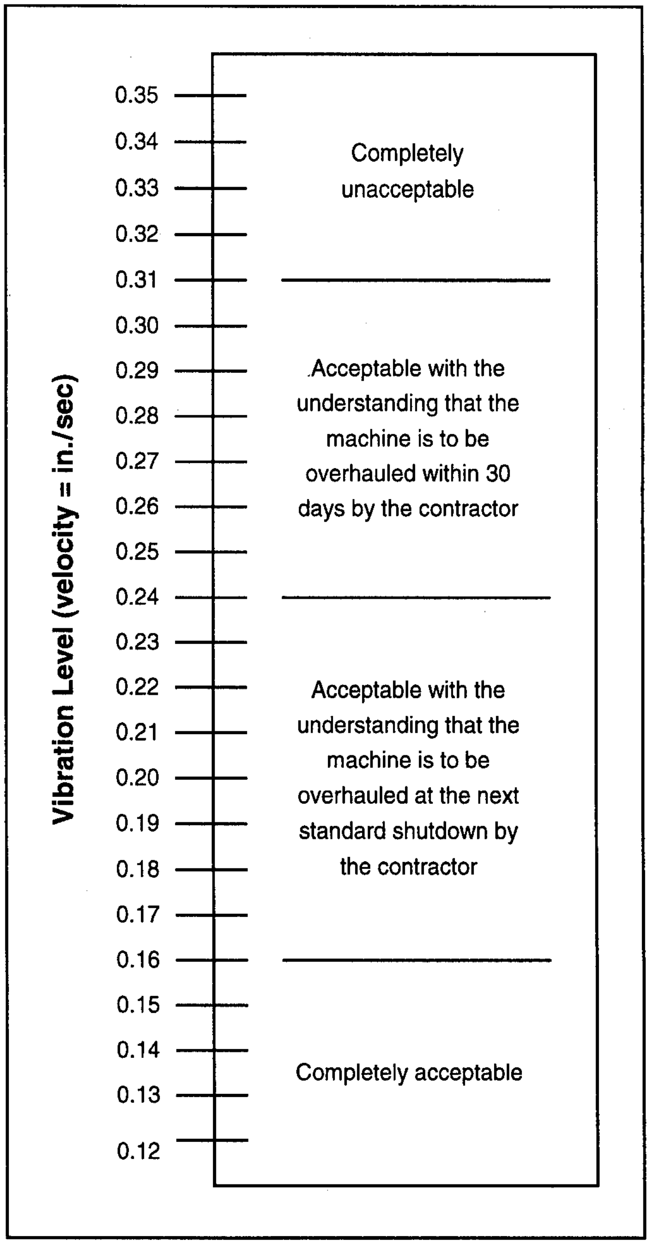

Figure B4. Vibration guidelines for general noncritical equipment.

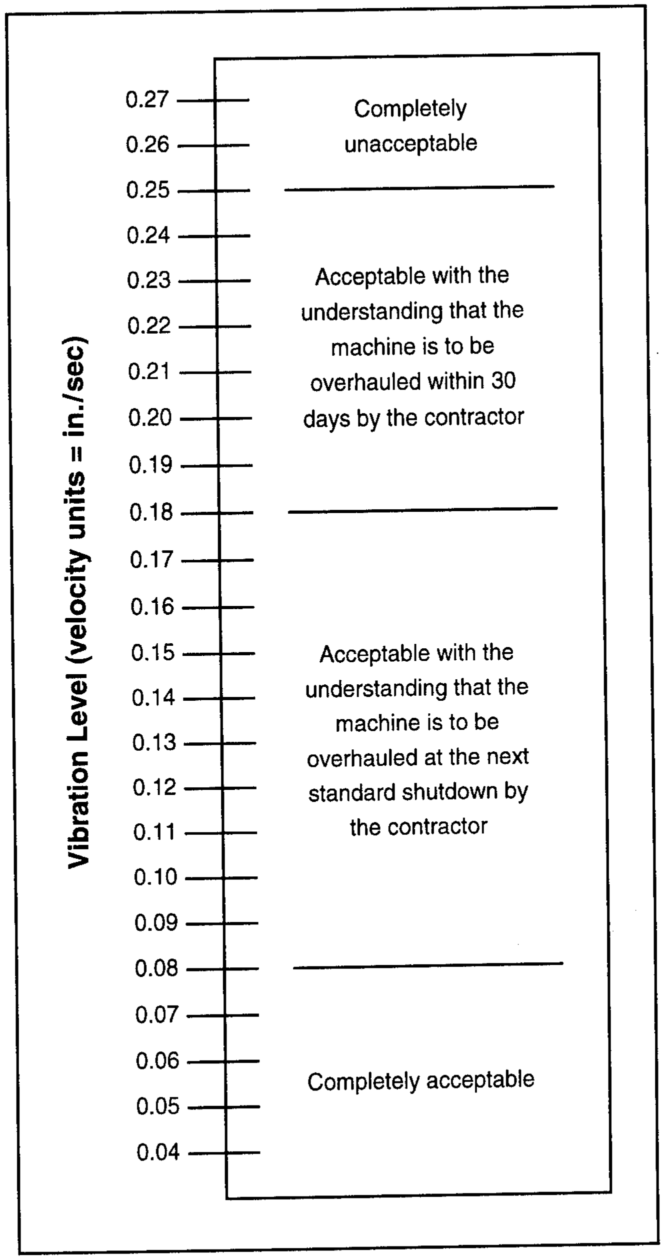

Figure B5. Vibration guidelines for electric motors.

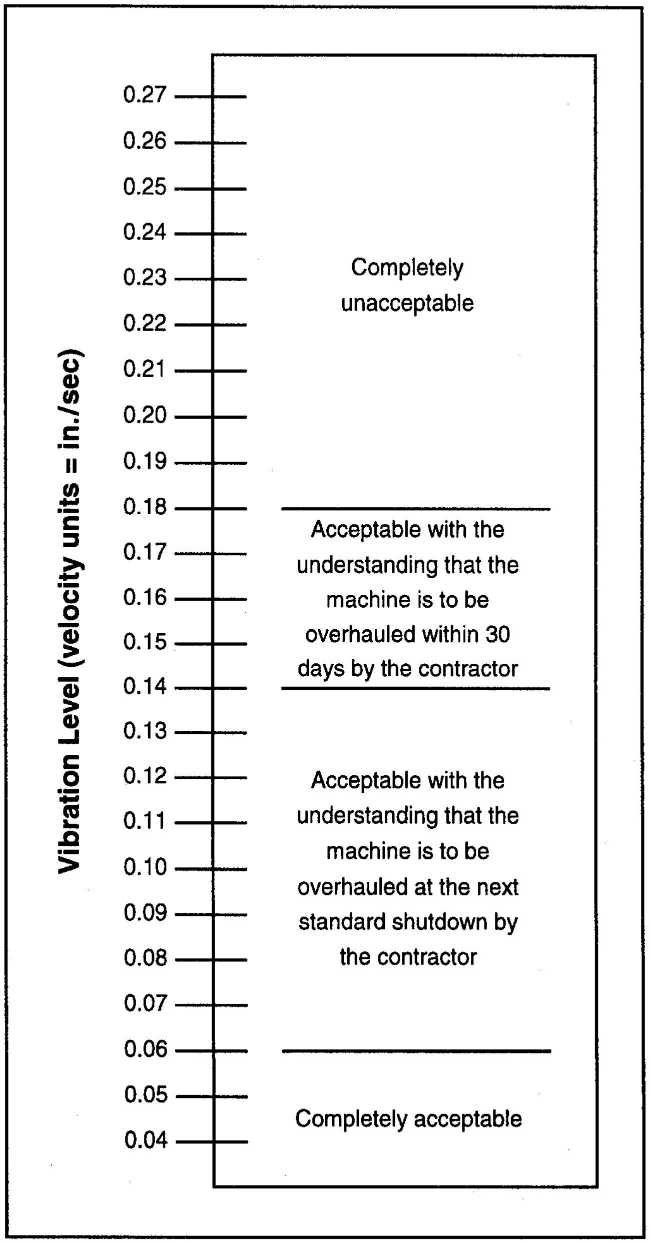

Figure B6. Vibration guidelines for general critical equipment.

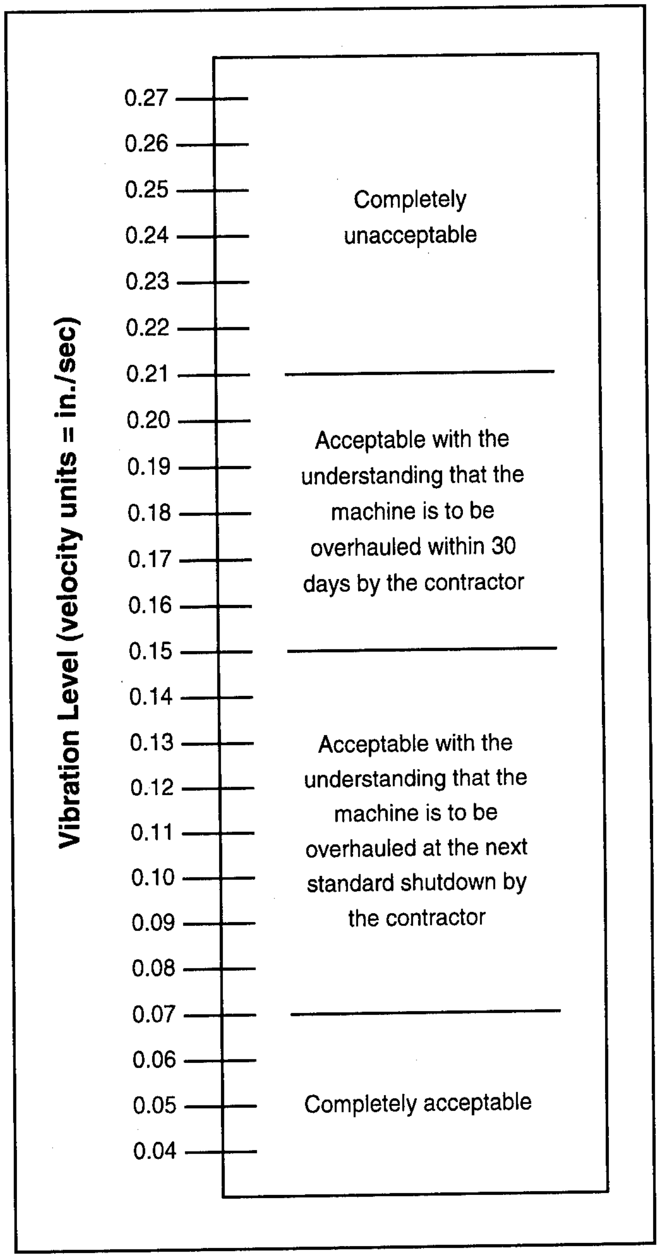

Figure B7. Vibration guidelines for compressors.

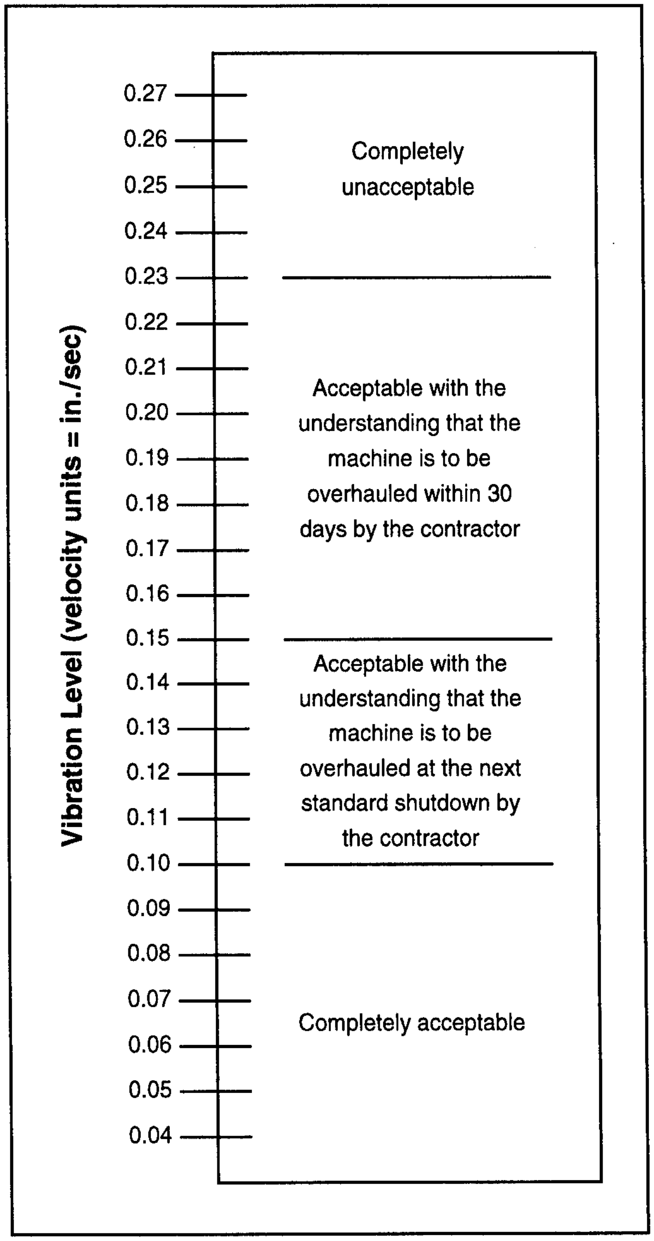

Figure B8. Vibration guidelines for gear trains (readings to be taken on gear housing).

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Miller J., Sr., and J. Miller Jr., "How To Conduct Predictive Machinery Vibration Programs," *PIMA 70* vol 8 (July 1988), pp 34-36.

Moshage, R.E., L.V., Bowman, et al., *Vibration Monitoring for Predictive Maintenance in Central Energy Plants*, USACERL Technical Report (TR) FE-93/25/ADA293548 (U.S. Army Construction Engineering Research Laboratories [USACERL], September 1993).

Rockwood, R.M., "Identifying Barriers to Maintenance Productivity," *Maintenance Technology*, vol 10, No. 4 (October 1991), pp 31-34.

Samdani, G., et al., "Predictive Maintenance," *Chemical Engineer*, vol 99, No. 11 (November 1992), pp 30-33.

Stephens, F., *Predictive Maintenance Program Cost Justification Work Sheet*, Form No. 2266A (IRD Mechanalysis).

Annex A: Vibration Meter Vendors

Vendor	Address	Phone
Beta Monitors and Controls, Ltd.	200, 1615-10 Ave. S.W. Calgary, Alberta, Canada T3C 0J7	403/245-5300
Bently Nevada, Corp.	1617 Water St., PO Box 157 Minden, NV 89423	702/782-3611
Bruel & Kjaer Instruments, Inc.	185 Forest Street Marlborough, MA 01752	508/481-7000
Computational Systems, Inc. (CSI)	835 Innovation Drive Knoxville, TN 37932	615/675-2110
Data Signal Systems, Inc.	P.O. Box 1608 Friendswood TX 77546	713/482-9653
DLI Engineering Corp.	253 Winslow Way West Bainbridge Island, WA 98110	206/842-7656
IRD Mechanalysis	6150 Huntley Road Columbus, OH 43229	614/885-5376
Ono Sokki Technology, Inc.	2171 Executive Drive, Suite 400 Addison, IL 60101	708/627-9700
PCB Piezoelectronics, Inc.	3425 Walden Avenue Depew, NY 14043	716/684-0001
PMC/Beta Corp.	4 Tech Circle Natick, MA 01760	617/237-6920
Schenck Corp.	535 Acorn Street Deer Park, NY 11729	516/242-4010
SKF Condition Monitoring	4141 Ruffin Road San Diego, CA 92723	619/496-3400
Technology for Energy Corp.	PO Box 22996 Knoxville, TN 37933	615/966-5856
VCI	5733 South Dale Murphy Hwy. Tampa, FL 33611	813/839-2826
Vitec	23600 Mercantile Road Cleveland, OH 44122	216/464-4670
Walker Associates	PO Box 58224 Webster, TX 77598	409/925-3074

Annex B: Savings Potential From Balance or Alignment for Typical Motors at Army Energy Facilities

The following table was derived from a list of typical motors found in Army facilities. The calculations were made using the equations given in section 2C2, along with the assumptions given below.

Motor Size (HP)	Rated Voltage (Volts)	Rated Current (Amps)	Power Factor*	Savings From Balance** in $	Savings From Alignment** in $
1	460	1.6	0.85	5.70	14.24
2	460	3.1	0.85	11.03	27.59
3	460	4.2	0.85	14.95	37.38
5	460	7	0.85	24.92	62.29
7.5	460	9.3	0.85	33.10	82.76
10	460	13	0.85	46.27	115.68
15	460	19	0.85	67.63	169.08
20	460	25	0.85	88.99	222.47
25	460	32	0.85	113.90	284.76
30	460	37	0.85	131.70	329.26
40	460	50	0.85	177.98	444.94
50	460	60	0.85	213.57	533.93
60	460	70	0.85	249.17	622.92
75	460	90	0.85	320.36	800.89
100	460	118	0.85	420.02	1050.06

* The power factor has been approximated at 0.85. Generally, the power factor for motors may vary between 0.77 for typical small motors, up to 0.92 for high efficiency large motors. If the exact power factor is known for a given motor, then that value should be used for this calculation. Otherwise, 0.85 is a reasonable approximation.

** The monetary savings were derived using the following assumptions:

1 The motor is operating at 80% load. This has proven to be a good estimate from field data for Army facilities. Again, if the actual operating load is known, then that number should be used in this calculation.

2 The motor is assumed to operate at exactly one half time, or 4380 hours per year. As before, the actual amount of time a given motor operates should be used in this calculation.

3 The electric rate was assumed to be (on average, including demand and peak charges, etc.) $0.075/kWh. The actual electric rate for a given facility should be used for this calculation.

It can be seen from the above table that spending time performing additional maintenance such as balancing or alignment may not always pay for itself for small equipment from an energy standpoint, but other factors should be considered as well. In general, less money is spent overall on maintenance when machinery is kept in proper working order.

Annex C: Typical Contract Clauses To Ensure Quality Assurance

The following list of clauses could be used when formulating a contract with outside maintenance contractors. The use of such clauses will help ensure that the contractor is actually performing the work being paid for at a satisfactory quality level. It is important to note, however, that in some special instances, exceptions to the clauses may be required, but should only be accepted after approval from facility personnel and the contracting officer.

> Suitable data collector shall be defined as a portable battery powered unit capable of performing data collection via a magnetically mounted transducer. The unit shall be capable of interfacing with a computer to allow further analysis if desired, and shall be capable of collecting at least 500 data points prior to requiring a new battery or battery charge.
>
> A) "Upon completion of installation for (equipment name or ID), the level of measurable vibration using a suitable data collector, which has previously been specified or defined in the contract if different than above, shall not exceed (value from charts or tables)."
>
> B) "Periodic routine maintenance on (equipment name or ID) will be provided such that the level of measurable vibration using a suitable data collector, which has previously been specified or defined in the contract if different from above, shall not exceed (value from charts or tables)."
>
> C) "Upon random sampling of equipment, if more than 5 percent of the equipment vibrates in excess of the pre-established acceptable limits, the contractor will be considered in breach of contract. Immediate action must be taken by the contractor to bring all equipment up to standard within thirty days."

This sample list is by no means intended to be all-inclusive, but should instead serve as a template from which each facility can prepare the exact clauses necessary to ensure they receive the best contractor service possible. If additional questions should arise while formulating the contract, facility personnel are encouraged to contact their contracting officer.

Annex D: Velocity Conversions

V-dB	in/s - Peak	in/s - RMS	in/s Peak to Peak	cm/s - peak	cm/s - RMS	cm/s Peak to Peak
72	2.2162E-03	1.5674E-03	4.4325E-03	5.6292E-03	3.9811E-03	1.1258E-02
73	2.4867E-03	1.7586E-03	4.9733E-03	6.3161E-03	4.4668E-03	1.2632E-02
74	2.7901E-03	1.9732E-03	5.5801E-03	7.0868E-03	5.0119E-03	1.4174E-02
75	3.1305E-03	2.2139E-03	6.2610E-03	7.9515E-03	5.6234E-03	1.5903E-02
76	3.5125E-03	2.4841E-03	7.0250E-03	8.9217E-03	6.3096E-03	1.7843E-02
77	3.9411E-03	2.7872E-03	7.8822E-03	1.0010E-02	7.0795E-03	2.0021E-02
78	4.4220E-03	3.1273E-03	8.8439E-03	1.1232E-02	7.9433E-03	2.2464E-02
79	4.9615E-03	3.5089E-03	9.9231E-03	1.2602E-02	8.9125E-03	2.5205E-02
80	5.5669E-03	3.9370E-03	1.1134E-02	1.4140E-02	1.0000E-02	2.8280E-02
81	6.2462E-03	4.4174E-03	1.2492E-02	1.5865E-02	1.1220E-02	3.1731E-02
82	7.0083E-03	4.9564E-03	1.4017E-02	1.7801E-02	1.2589E-02	3.5602E-02
83	7.8635E-03	5.5612E-03	1.5727E-02	1.9973E-02	1.4125E-02	3.9947E-02
84	8.8230E-03	6.2397E-03	1.7646E-02	2.2410E-02	1.5849E-02	4.4821E-02
85	9.8996E-03	7.0011E-03	1.9799E-02	2.5145E-02	1.7783E-02	5.0290E-02
86	1.1107E-02	7.8554E-03	2.2215E-02	2.8213E-02	1.9953E-02	5.6426E-02
87	1.2463E-02	8.8139E-03	2.4926E-02	3.1656E-02	2.2387E-02	6.3311E-02
88	1.3983E-02	9.8893E-03	2.7967E-02	3.5518E-02	2.5119E-02	7.1036E-02
89	1.5690E-02	1.1096E-02	3.1379E-02	3.9852E-02	2.8184E-02	7.9704E-02
90	1.7604E-02	1.2450E-02	3.5208E-02	4.4715E-02	3.1623E-02	8.9429E-02
91	1.9752E-02	1.3969E-02	3.9504E-02	5.0171E-02	3.5481E-02	1.0034E-01
92	2.2162E-02	1.5674E-02	4.4325E-02	5.6292E-02	3.9811E-02	1.1258E-01
93	2.4867E-02	1.7586E-02	4.9733E-02	6.3161E-02	4.4668E-02	1.2632E-01
94	2.7901E-02	1.9732E-02	5.5801E-02	7.0868E-02	5.0119E-02	1.4174E-01
95	3.1305E-02	2.2139E-02	6.2610E-02	7.9515E-02	5.6234E-02	1.5903E-01
96	3.5125E-02	2.4841E-02	7.0250E-02	8.9217E-02	6.3096E-02	1.7843E-01
97	3.9411E-02	2.7872E-02	7.8822E-02	1.0010E-01	7.0795E-02	2.0021E-01
98	4.4220E-02	3.1273E-02	8.8439E-02	1.1232E-01	7.9433E-02	2.2464E-01
99	4.9615E-02	3.5089E-02	9.9231E-02	1.2602E-01	8.9125E-02	2.5205E-01
100	5.5669E-02	3.9370E-02	1.1134E-01	1.4140E-01	1.0000E-01	2.8280E-01
101	6.2462E-02	4.4174E-02	1.2492E-01	1.5865E-01	1.1220E-01	3.1731E-01
102	7.0083E-02	4.9564E-02	1.4017E-01	1.7801E-01	1.2589E-01	3.5602E-01
103	7.8635E-02	5.5612E-02	1.5727E-01	1.9973E-01	1.4125E-01	3.9947E-01
104	8.8230E-02	6.2397E-02	1.7646E-01	2.2410E-01	1.5849E-01	4.4821E-01

V-dB	in/s - Peak	in/s - RMS	in/s Peak to Peak	cm/s - peak	cm/s - RMS	cm/s Peak to Peak
105	9.8996E-02	7.0011E-02	1.9799E-01	2.5145E-01	1.7783E-01	5.0290E-01
106	1.1107E-01	7.8554E-02	2.2215E-01	2.8213E-01	1.9953E-01	5.6426E-01
107	1.2463E-01	8.8139E-02	2.4926E-01	3.1656E-01	2.2387E-01	6.3311E-01
108	1.3983E-01	9.8893E-02	2.7967E-01	3.5518E-01	2.5119E-01	7.1036E-01
109	1.5690E-01	1.1096E-01	3.1379E-01	3.9852E-01	2.8184E-01	7.9704E-01
110	1.7604E-01	1.2450E-01	3.5208E-01	4.4715E-01	3.1623E-01	8.9429E-01
111	1.9752E-01	1.3969E-01	3.9504E-01	5.0171E-01	3.5481E-01	1.0034E+00
112	2.2162E-01	1.5674E-01	4.4325E-01	5.6292E-01	3.9811E-01	1.1258E+00
113	2.4867E-01	1.7586E-01	4.9733E-01	6.3161E-01	4.4668E-01	1.2632E+00
114	2.7901E-01	1.9732E-01	5.5801E-01	7.0868E-01	5.0119E-01	1.4174E+00
115	3.1305E-01	2.2139E-01	6.2610E-01	7.9515E-01	5.6234E-01	1.5903E+00
116	3.5125E-01	2.4841E-01	7.0250E-01	8.9217E-01	6.3096E-01	1.7843E+00
117	3.9411E-01	2.7872E-01	7.8822E-01	1.0010E+00	7.0795E-01	2.0021E+00
118	4.4220E-01	3.1273E-01	8.8439E-01	1.1232E+00	7.9433E-01	2.2464E+00
119	4.9615E-01	3.5089E-01	9.9231E-01	1.2602E+00	8.9125E-01	2.5205E+00
120	5.5669E-01	3.9370E-01	1.1134E+00	1.4140E+00	1.0000E+00	2.8280E+00
121	6.2462E-01	4.4174E-01	1.2492E+00	1.5865E+00	1.1220E+00	3.1731E+00
122	7.0083E-01	4.9564E-01	1.4017E+00	1.7801E+00	1.2589E+00	3.5602E+00
123	7.8635E-01	5.5612E-01	1.5727E+00	1.9973E+00	1.4125E+00	3.9947E+00
124	8.8230E-01	6.2397E-01	1.7646E+00	2.2410E+00	1.5849E+00	4.4821E+00
125	9.8996E-01	7.0011E-01	1.9799E+00	2.5145E+00	1.7783E+00	5.0290E+00
126	1.1107E+00	7.8554E-01	2.2215E+00	2.8213E+00	1.9953E+00	5.6426E+00
127	1.2463E+00	8.8139E-01	2.4926E+00	3.1656E+00	2.2387E+00	6.3311E+00
128	1.3983E+00	9.8893E-01	2.7967E+00	3.5518E+00	2.5119E+00	7.1036E+00
129	1.5690E+00	1.1096E+00	3.1379E+00	3.9852E+00	2.8184E+00	7.9704E+00
130	1.7604E+00	1.2450E+00	3.5208E+00	4.4715E+00	3.1623E+00	8.9429E+00
131	1.9752E+00	1.3969E+00	3.9504E+00	5.0171E+00	3.5481E+00	1.0034E+01
132	2.2162E+00	1.5674E+00	4.4325E+00	5.6292E+00	3.9811E+00	1.1258E+01
133	2.4867E+00	1.7586E+00	4.9733E+00	6.3161E+00	4.4668E+00	1.2632E+01
134	2.7901E+00	1.9732E+00	5.5801E+00	7.0868E+00	5.0119E+00	1.4174E+01
135	3.1305E+00	2.2139E+00	6.2610E+00	7.9515E+00	5.6234E+00	1.5903E+01
136	3.5125E+00	2.4841E+00	7.0250E+00	8.9217E+00	6.3096E+00	1.7843E+01
137	3.9411E+00	2.7872E+00	7.8822E+00	1.0010E+01	7.0795E+00	2.0021E+01
138	4.4220E+00	3.1273E+00	8.8439E+00	1.1232E+01	7.9433E+00	2.2464E+01
139	4.9615E+00	3.5089E+00	9.9231E+00	1.2602E+01	8.9125E+00	2.5205E+01
140	5.5669E+00	3.9370E+00	1.1134E+01	1.4140E+01	1.0000E+01	2.8280E+01

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