New Techniques for Operating and Maintaining Federal Facilities: Proceedings of a Symposium (1985)

Pages
72

Size
5 x 9

ISBN
0309323207

Consulting Committee on Operations and Maintenance; Federal Construction Council; Building Research Board; National Research Council

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Federal Construction Council
Building Research Board
2101 Constitution Avenue, N.W.
Washington, D.C. 20418

Technical Report

No. 82

New Techniques for Operating and Maintaining Federal Facilities

Proceedings of a Symposium

Federal Construction Council
Consulting Committee on Operations and Maintenance

NATIONAL ACADEMY PRESS
Washington, DC

1985

FEDERAL CONSTRUCTION COUNCIL
CONSULTING COMMITTEE ON
OPERATIONS AND MAINTENANCE

PREFACE

Faced with rising costs, static budgets, increasingly complex equipment and systems, a high personnel turnover rate, demands to save energy and the need to rely more on private contractors, those charged with operating and maintaining federal facilities have been forced to seek new and better ways of carrying out their responsibilities. Consequently, many new procedures, materials, management tools, and pieces of equipment have been used or experimented with over the past few years by operating and maintenance personnel in different agencies in an effort to save money and do a better job. The results of many of these innovations and experiments have now been documented, and the Federal Construction Council (FCC) of the National Research Council (NRC) has undertaken the task of disseminating the information to federal agencies. As part of this effort, the FCC Consulting Committee on Operations and Maintenance organized a symposium on the subject.

The symposium was held at the National Bureau of Standards (NBS) on May 7, 1985, as part of the Federal Workshop Series for 1985 of the NBS Center for Building Technology. Twelve presentations were made by representatives of federal agencies and private organizations. The speakers were asked to prepare summaries of their remarks and it is these summaries that comprise this report. The speakers were given no precise specifications regarding summary format; therefore, the summaries vary in length and form.

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INTRODUCTORY REMARKS

David Williams
Naval Facilities Engineering Command

Public works and facilities managers face a constant challenge. Over the years plant value grows, the increasing complexity of facilities makes maintenance planning and operations execution difficult, and plants continue to age without modernization or replacement. In addition, public sector funding as a share of the gross national product is half of what it used to be years ago. Not everyone experiences all these problems, but all will agree that facilities do not have the glamor of operational functions and, therefore, resources and improvements do not come easily and the management of facilities is a challenging and sometimes frustrating occupation.

The need to look at our business creatively and to get the maximum mileage from our dollars and assets is mandatory. New technology has provided new maintenance procedures, methods, and tools that help us provide more cost-effective maintenance, better manage our resources, and better determine facility condition. However, we must not forget old technology. Sometimes we must dust off the old and revitalize it and embrace it as if it were new.

What you will hear at this symposium is a blend of new and old. Three general subjects will be addressed:

- Maintenance management,
- Public sector contracting, and
- Maintenance technology and techniques.

Not too many years ago the first two subjects would rarely have been considered at a symposium on facilities operation and maintenance. Today, these subjects must be given major attention.

The first four papers reflect the amazing advances made in the world of computers. The availability of minicomputers and microcomputers permits us to do things in facilities that could only have been dreamed of just a decade ago. Equally amazing is our ability to discuss these topics without getting lost in automated data processing (ADP) jargon and procedures. In fact, our increased use of ADP technology has resulted as much because ADP professionals are not needed to run our computer equipment as because equipment is so affordable.

A COMPUTER-ASSISTED SYSTEM FOR MANAGING CUSTODIAL SERVICES

Clyde E. Burchett
Allied/Bendix Aerospace, Kansas City Division

INTRODUCTION

In today's world of advanced technology, where the smallest particle of foreign material may cause malfunction of microminiature components, housekeeping and cleanliness have become increasingly important. The Allied/Bendix Aerospace, Kansas City Division (BKC) has a system, designed around its individual facilities' requirements, that increases custodial productivity and provides a satisfactory level of cleanliness. BKC, a prime contractor for the Department of Energy (DOE), is a manufacturing facility located on a 122-acre site in south Kansas City, Missouri.

Manufacturing operations are grouped in three primary areas: mechanical, electrical/electronics, and plastics. The mechanical area includes both heavy machining of large parts such as structural cases and precision machining of miniature components; the electrical/electronics area includes fabrication and assembly of microminiature components where clean rooms and controlled environment facilities are required; and the plastics area includes such activities as the injection molding of filled elastomers and the encapsulation of electronic components. The total facility has approximately 3.5 million square feet of floor space.

The Building and Grounds Department, one of six in the BKC Facilities Maintenance Organization, is responsible for all custodial activities, grounds maintenance, cafeteria and rest room cleaning, furniture relocation, and pest control.

The department operates three shifts daily to support plantwide activities that likewise are on three shifts.

It consists of 1 superintendent, 3 general supervisors, the 13 supervisors, and 194 Custodians. Manpower is assigned to shifts consistent with production workloads.

OBJECTIVES

The following objectives have been established for the BKC housekeeping program:

1. To achieve the required level of cleanliness for particular use of individual areas.

2. To distribute workloads reasonably and equitably for maximum utilization of resources.

3. To optimize productivity.

STAFFING BY APPLYING WORK STANDARDS

Staffing requirements are determined by using engineered standards to identify the manhours required to perform the cleaning tasks in each area in conjunction with the task frequencies required. Reasonable and equitable work assignments are necessary for employee morale and for accurate evaluation of an individual worker's performance. The use of work standards offers several advantages:

1. It is an effective staffing tool.

2. It is an effective headcount budget tool.

3. It results in equitable work assignments.

Production environmental requirements have a major influence on staffing requirements. General Process Instructions (GPI) prepared by the Engineering Division specify the minimum acceptable environmental cleanliness levels for all clean rooms (42,000 square feet), electronic assembly areas with conductive tile floors (175,000 square feet), and painting facilities. Cleaning tasks and frequencies are jointly defined by the Engineering and Building and Grounds Departments to achieve the desired results.

HOUSEKEEPING ACTIVITIES

Housekeeping activities are generally classified as follows:

- Routine Cleaning--The cleaning that is performed on a frequent basis and is the main cleaning that an area receives. Examples are trash collection, dust mopping, sanitizing, and spray buffing.

- Project cleaning--Those cleaning activities that are performed on an infrequent basis yet may require considerable effort. Project cleaning is not performed at a predetermined frequency but on an as-required basis. Examples are chip removal from machines, carpet shampooing, and stripping and refinishing floors.

- Policing--The cleaning performed between routine cleanings. This cleaning is primarily intended to maintain an area in an acceptable condition until the next scheduled routine cleaning. Examples are mopping up spills and refilling rest room dispensers.

- Programmed Maintenance--Those cleaning activities that are performed to keep production equipment operable. Examples are cleaning of dust collectors, paint booths, and ovens.

WORK ALLOCATION

Individual work assignments are established based on standards and set up on a computer. Notification in the form of a computer output card is sent to each supervisor eight working days prior to the scheduled work completion date for the following week's work. This eliminates manual recordkeeping by the supervisor, ensures that the work is scheduled, and eliminates variables in the workload. The cards identify:

1. Tasks to be performed,
2. The frequencies of performance, and
3. A standard of performance for each task.

Each supervisor has a manual that contains a definitive breakdown of task activities, frequencies, and area description for each work assignment. Computerizing the contents of the manual is the next planned step in our computerization program.

MEASUREMENT

Since there are no absolute means of measuring cleanliness, its definition is dependent on the subjective judgment of individuals and what is acceptable to one may deviate from the personal standards of another. To overcome this obstacle we have specified housekeeping objectives, or the desired quality of cleanliness, by defining for various types of areas (such as clean rooms, conductive floors, and rest rooms) the tasks that will be performed and their frequency. The basis for determining the tasks and their frequency of performance is directly related to the importance placed on the results achieved.

Generally, the tasks can be grouped as follows from most to least important:

1. Those tasks that relate to the health and safety of building occupants.

2. Those tasks that directly affect the mission of the group occupying the area.

3. Those tasks that are economically justifiable from a property life standpoint.

4. Those tasks that relate only to the appearance of an area.

Since there is no "one" effective practical means of measurement, a combination of measurements is used at BKC to determine the effectiveness of the system:

1. Daily inspections by first line supervision to determine if the workers are achieving the desired results.

2. Sign-off sheets to be initialed upon completion of tasks in areas controlled by product specifications.

3. Inspections twice monthly by second and third level supervision of each first level supervisor's area of

responsibility with findings and subsequent corrective actions documented.

TRAINING PROGRAM

Numerous training programs and sources of training materials are available. Slide presentations with oral commentary are used at BKC for training of new employers. The program consists of 35-mm slides that show our employees at work within the facilities using our methods and techniques. Training classes are 45-minute sessions conducted by the employees' immediate supervisor. Nineteen classes are required to complete the program. New employee training and retraining are done on an as-needed basis.

FACILITIES DESIGN

The Building and Grounds Department has the opportunity to review preliminary facilities design drawings and specifications to evaluate required cleaning and housekeeping tasks. As necessary, we recommend design changes prior to finalization of the design by the BKC Facilities Engineering Department. We also participate in and submit comments on an area occupancy inspection conducted before final acceptance is made.

USE OF SMALL COMPUTER

James M. Walton
U.S. Army Corps of Engineers

The Army Corps of Engineers (CoE) is changing its maintenance policy from the old "find and fix it" approach to a scheduled maintenance approach. It has long been recognized that scheduled maintenance is desirable; however, implementation was not considered feasible prior to the development of the desk-top computer system.

The new Scheduled Maintenance System (SMS) will be a computer-based stand-alone system that uses off-the-shelf hardware and software. The system will be able to link to other computer systems that support asynchronous communication.

The SMS will be capable of linking with an Energy Monitoring and Control System (EMCS) to obtain a report on equipment run-time and event-initiated status conditions; e.g., filter differential pressure alarm and water-low level alarm. The two systems (EMCS and SMS) can be operated as stand-alone systems with the operator providing the link until software can be developed to provide for complete automatic data retrieval. This will permit the installation of an SMS on a facility where an EMCS is installed and operating. It should be noted that an EMCS is not required since all maintenance events for the SMS can be initiated by elapsed time.

The system will be set up to print out work orders during "low traffic" times to permit the operator to organize them for distribution to designated personnel with minimum lost time by workers and supervisors. Printing may be automatically initiated by the system or manually initiated by operator request.

The system will offer flexibility with respect to "input" data entry instructions. To accommodate the constant requirement to change the data base, the manner of handling and displaying the data will be "site specific" and operator changeable through the keyboard.

To prevent unauthorized revision of control data, including actual hours versus planned hours, and other critical data, access to these areas will be limited. A minimum of two-level access will be incorporated.

Separate scheduling for daily, weekly, quarterly, semi-annual, and preventive maintenance will permit maintenance personnel to priority rank the work from shortest to longest period to maximize personnel effectiveness. The system will automatically segregate the work orders by building/area to minimize inter- and intra-building travel time.

Such standard reports as the following will be available to the operator: maintenance order summary report, deferred maintenance report, maintenance in-progress report, completed maintenance report, and actual versus projected maintenance report. The system also will have a report generator that will allow the operator to develop special reports to accommodate any site-specific requirement.

In general the key aspects of the system are:

1. Flexibility to add and delete work orders and equipment,

2. Capacity and capability to add functions and equipment as operating personnel become more familiar with the overall capabilities and benefits of the system, and

3. The ability to function as a stand-alone system.

THE APPLICATION OF COMPUTERS TO THE MANAGEMENT OF PUBLIC WORKS FUNCTIONS IN THE NAVY

David Williams
Naval Facilities Engineering Command

The Navy has felt for years that certain ingredients are required for a successful maintenance management system: the proper level of skills managing the program and the appropriate tools to help manage the program. Assuming the Navy can attract the type of personnel necessary to manage the program, high on the list of tools is automation. One characteristic of a maintenance management program that makes it difficult to operate is the large amount of data--and status information--that must be generated. This is the primary reason our managers become bogged down in the manual system.

The Naval Facilities Engineering Command (NAVFAC) is responsible for providing facilities management techniques and guidance to Navy shore activities. The basic system was initiated in the 1950s. Engineered Performance Standards for blue collar workers were added in the 1960s. In the late 1970s these functions were reviewed to determine if changes were needed. One of the problem areas noted was that it was difficult to fully utilize the system in the manual mode because of the large number of transactions occurring daily within the public works environment. In shop loading, for example, every time a new job was entered into the system at the last minute all the craft availability changed and impacted other jobs in the system. To make these changes manually for a department with over 300 personnel was a mammoth undertaking. To correct this problem, NAVFAC sponsored, through a productivity improvement program, a proposal to automate the medium to large operations. Previous attempts to automate departments failed because of reliance on large main frame computers out of the jurisdictional control of public works personnel. Also, batch-operated operations on this type of computer did not satisfy the need for real time data so crucial in the flexible operations of public works.

The new system is titled the Base Engineering Support Technical (BEST) system. The objective of the BEST system is to increase productivity and management capability in public works by providing a simple flexible "on line" automated data processing (ADP) system to be operated and controlled by existing functional personnel. The system is composed of standard, user-friendly software and hardware and features independent, functionally oriented modules using minicomputers. It is an on-line management system, not a management information system, that basically duplicates the existing manual system. Thus, management information is a by-product, not the end in itself. To complement the installation of the system, several organizational changes are being recommended. One involves creating an organization that will focus on productivity and analysis and will specialize in selecting information from the automated system that will be valuable in improving operations.

In the full BEST system, each major functional area--facilities, transportation, and housing--will have its own equipment suites. Each suite will have a central processing unit (CPU) and storage unit, work stations, and printers. The size of the CPU and storage devices and the number of work stations and printers in each suite will vary. The Navy is installing the BEST system at 80 activities of various sizes, some of which do not have all three functions.

To understand the design of the BEST system it is necessary to have a general idea of how a Navy Public Works Department is organized. There are six major functions: administration, maintenance control, contract administration, engineering, housing, and shops (maintenance, utilities, and transportation).

A Public Works Department is part of the command organization and draws support from the command as well as providing it. For example, material support comes from the Supply Department, financial information from the Comptroller, and personnel support from the Personnel

Department. Since the BEST system was designed for the Public Works Department only, it does not include interfaces with material procurement, financial information, or personnel systems.

The BEST system is being installed through the Field Division of NAVFAC and the contractor (Honeywell Information Systems). Installation includes preinstallation visits, on-site training, and follow-up visits to assist in problem resolution. On-call assistance also is available to solve those problems that typically occur during the period just after installation of new systems. The total installation schedule is planned over three years.

The three BEST modules are described below:

1. The maintenance and utilities subsystem automates the processes of identifying, scheduling, and tracking facilities maintenance. It also provides the information needed to manage production, distribution, and usage of utilities at these bases. These functions are performed by the input of status information into base inventories of the facilities, workforce, and utilities components.

2. The transportation subsystem is used to facilitate utilization and maintenance of vehicles supporting the base operations. This is accomplished by indicating the availability of dispatchable vehicles while simultaneously tracking the operating costs of these vehicles. Maintenance work and costs also are covered.

3. With the family housing subsystem, the base can improve the assignment of family housing units as well as provide a referral service when all of these units are occupied. It provides this by generating an inventory listing of the housing assets available on the base as well as one indicating rental units in the vicinity.

PROGRAMS FOR IDENTIFYING, PRIORITY RANKING, PLANNING, AND SCHEDULING MAINTENANCE AND REPAIR PROJECTS (PAVER, ROOFER AND PIPER)

Robert W. Williams
U.S. Army Corps of Engineers

A systematic approach to pavement management--the PAVER Pavement Maintenance Management System--has been developed, tested, and used at several locations. PAVER operates at the overall pavement network level to identify, priority rank, and budget for maintenance and repair requirements. The objective of this management approach is the development of strategies that will minimize life-cycle maintenance costs while maintaining predetermined levels of pavement serviceability. PAVER's key features are its objective determination and rating of facilities condition, its prediction capabilities, and its technically based computer programs. The PAVER approach may revolutionize the way facilities engineering thinks about maintenance management. Derivative systems currently are being developed for railroads, roofing, bridges, and utilities.

PAVER was designed by the Construction Engineering Research Laboratory (CERL). It is an improvement over the traditional "seat of the pants" subjective approach because it provides an objective condition rating; permits maintenance alternatives to be analyzed; and provides the engineer with a practical and systematic decision-making procedure for identifying cost-effective maintenance and repair actions for roads, streets, parking areas, and airfields. The Army Facilities Engineer (FE) has the responsibility to see that an installation's pavements are maintained in the best possible condition. The task becomes increasingly difficult with limited resources. PAVER is a valuable tool for managing and allocating available resources to optimize the overall pavement network condition.

The system can be used in either a manual or automated mode for data storage and retrieval. In the manual mode, data are recorded and stored on printed forms. In the automated mode, the data are stored in a central computer that, provides the user with reports on critical information. The information generated by PAVER allows for more objective decision-making.

PAVER provides its users with many important capabilities including: data storage and retrieval, pavement network definition, pavement condition rating, project priority ranking, inspection scheduling, identification of maintenance and repair (M&R) requirements, formulation of maintenance strategies, performance of economic analysis, resource planning, budget optimization, project development, and assets accounting.

A key element of PAVER is a meaningful and repeatable condition rating procedure. The procedure used by PAVER is based on the Pavement Condition Index (PCI). The PCI is a score from 0 to 100 (with 100 being excellent) that measures pavement structural integrity and surface operational condition and it agrees very closely with the collective judgment of experienced pavement engineers. The PCI has been field validated and proven to be very useful in establishing M&R priorities and justifying pavement M&R projects. The automated data storage and retrieval system was designed to perform computations such as life-cycle cost-analysis and PCI rating.

Users of PAVER include Army, Air Force, and Navy installations and cities under a technology transfer program sponsored by the American Public Works Association.

NAVY EXPERIENCE WITH LARGE OPERATION AND MAINTENANCE CONTRACTS

Larry Ayres
Naval Facilities Engineering Command

OVERVIEW

Since the mid-1970s when the Navy's first multifunction Base Operations Support (BOS) contract was awarded at Submarine Base, Bangor, Washington, numerous BOS contracts have been awarded at additional stateside and overseas locations. Current BOS contracts provide essential mission support and services to Diego Garcia; Submarine Base, Kings Bay, Georgia; Naval Station, Midway Island; Naval Air Station, Whiting Field, Florida; Naval Weapons Center, China Lake, California; and Naval Air Station, Memphis, Tennessee. They are also used to fill growing Fleet support requirements in East Africa.

These contracts were awarded as a direct result of new Navy operating requirements at locations lacking organic government public works capability (e.g., at Bangor, Kings Bay, and Diego Garcia), as well as head-to-head competition with the government force under A-76 program at Whiting Field, Memphis, and China Lake. The majority are fixed price, incentive-fee (FPIF) contracts with the remainder fixed-price with no incentive or award provisions. The approximate $70 million in annual BOS contracts support within the $3+ billion annual Navy BOS budget is considered an essential element of the Navy's ability to effectively perform its mission in an efficient manner.

SUBASE BANGOR, WASHINGTON

As the Navy's first and most widely known BOS contract, the Submarine Base Bangor, Washington, contract is frequently cited as an example in discussions and this discussion will be no different.

Some aspects of the Subase Bangor contract are as follows:

1. Scope
   - 2500+ buildings, 8.6+ million square feet
   - 12,400+ acres
   - 10,000+ personnel supported (including dependents)

2. Contractor Effort
   - FY 78, $14 million, 536 contractor employee
   - FY 82, $37 million, 1,250 contractor employee
   - FY 83, $36 million, 1,200 contractor employee

3. Contract Approach
   Fixed price incentive fee with 70 percent performance specification, 20 percent level of effort, and 10 percent watchstanding.

4. Services Included
   Building and structures maintenance, custodial, grounds maintenance, pest control, utilities and transportation, operations and maintenance, solid waste disposal, street sweeping, supply services, mess attendant services, BEQ/BOQ management, guard mail services, ADP services, fire protection services, security services, photography/graphic arts services, and engineering services.

5. Significant Problems Encountered
   - Preparing performance specification in place of prescriptive specifications
   - Enjoined for failure to follow small business set-aside decision process procedures
   - Initial contractor interest level low
   - Inclusion of firefighting services became an issue
   - Less than desired interest in recompetitions

6. Results
   Working well! Superlatives used by those receiving services--"flexible," "responsive," "cost effective," "superb performance," "innovative." Single negative comment--"expensive."

SINGLE OR MULTIPLE CONTRACTS?

A thorough review of experience to date and an objective study of the specific circumstances are critical in deciding whether to use one, several, or many contracts to provide support at any given location. Some major factors to be considered are as follows:

1. Single Contract Pro's
   - Interfaces reduced
   - Economy of scale
   - Better appeal

2. Single Contract Con's
   - Limits competition
   - Requires/results in greater contractor sophistication
   - Individual contract actions more difficult
   - No readily available contract back-up

3. Other Considerations
   - Small business prime contracting policies
   - Balance/split between contractor "control" by procurement versus technical experts
   - Increasing regulations may combine to make single-contract approach impractical in the future

FUTURE PLANS

The Navy will soon test a fixed price award fee (FPAF) BOS contract at a stateside location to compare it with our fixed-price, incentive-fee BOS contract approach. Numerous A-76 commercial activity competitions are scheduled for 1985 and 1986 at stateside locations (The Naval Air Stations at Whidbey Island, Washington; The Naval Air Station at Fallon, Nevada; and the Naval Weapons Center, China Lake, California). Each may result in award of a BOS contract. Overseas, particularly in East Africa, the State Department is negotiating government-to-government agreements for clearances to permit BOS contract support to recently constructed Navy facilities.

SUMMARY

BOS contracts are and will continue to be an important method of providing responsive, quality, cost-efficient operations and maintenance support to expanding Fleet requirements (i.e., Surface action group homeporting, etc.).

USE OF INCENTIVES IN OPERATIONS AND MAINTENANCE CONTRACTS

Robert G. Long
National Aeronautics and Space Administration
Kennedy Space Center

INTRODUCTION

One of the major goals of the National Aeronautics and Space Administration (NASA) is to make the Space Transportation System (STS) fully operational and cost-effective in providing routine access to space for domestic, foreign, commercial, and government users. The Kennedy Space Center (KSC) has introduced significant changes in contracting philosophy for the STS operations era. These changes are a result of many years of analyzing the STS program at KSC and planning the most cost-effective contracting methods. Studies dating as far back as 1976 (Aerospace Study) culminated in the selection of the base operations contract (BOC) at KSC in December 1982, using a cost-plus-award fee/incentive fee (CPAF/IF) arrangement. The BOC was followed with the inception of the shuttle processing contract (SPC) in October 1983. Completing the triad for the STS operations era will be the cargo processing contract (CPC), currently scheduled for inception in October 1986.

The individual missions of these three contracts differ significantly from each other and, therefore, the fee arrangements and incentives differ and are tailored to suit each mission. Together, they form the complement necessary for STS operations at KSC that are:

- BOC-- Institutional services, operations, and maintenance
- SPC-- Shuttle vehicle preparation, checkout, launch, and landing
- CPC-- Cargo preparation, checkout, integration with Shuttle

SUMMARY OF THE BASE OPERATIONS CONTRACT

Government facilities, systems, and equipment at KSC support the day-to-day processing of the STS hardware and a workforce of approximately 15,000. Historically, KSC evolved from a government launch team. The transition to the use of contractors for hands-on Operations and Maintenance (O&M) of KSC was not completed until the Apollo program. During that era, support services contracting was mainly accomplished through two arrangements: level of effort and modified mission. Neither of these arrangements stimulated the contractors to seek cost efficiencies.

Institutional support at KSC was combined into one contract for the STS operations era--the BOC. The functions of 14 individual contracts that became the BOC included utilities, facilities, administrative services, technical operations, and health and protective services.

The combination of many contracts into the three major STS contracts was expected to strengthen the STS launch function by achieving clear contractor responsibility and reducing the number of functional and physical interfaces between the contractors. NASA placed more emphasis on the contractor's conceptual approach to O&M processes while reducing the government's day-to-day serial involvement. In turn, the contractor's prerogatives in approaching and accomplishing the work were strengthened and, through cost-sharing arrangements, they were stimulated to achieve immediate and long-term cost reductions.

A 10-year contract was established with the BOC beginning with three priced years and seven unpriced options. Both the fee and the target cost were negotiated for each of the first three years. For the seven-year options, the target cost and fee for the full seven years is scheduled to be negotiated by December 1985. Negotiating the full seven years is expected to result in enhanced incentives for the contractor to implement cost efficiencies since the greater the payback, the more likely the contractor will be to incur cost associated with the implementation of new ideas.

Fee arrangements have been specially tailored for the BOC. For the current contract year, the maximum available award fee is 3 percent of target cost and the maximum available incentive fee is 7 percent of target cost. Award fee is earned through the government's subjective evaluation of the contractor's performance and is paid as a linear percentage of the contractor's grade from 0 to 100. Incentive fee is based on the dollar amount the contractor overruns or underruns the negotiated target cost with the maximum fee possible of 7 percent of negotiated target. The government-to-contractor share ratio of overrun or underrun for the current contract year is 75:25. As a protective measure to ensure the contractor's performance does not slip below an acceptable level, no incentive fee is available for an evaluation period should the award fee grade fall below 60 for that period.

In order to negotiate the target costs, a statement of work (SoW) was developed describing the scope in terms of mission support; limitations of support; and, where possible, projected workload indicators. Ongoing changes to the SoW are made only through the government contracting officer upon the request of the contract manager. Both the government and the contractor must maintain up-to-date knowledge of the contract scope.

The contract manager (Director of Center Support Operations at KSC) establishes award fee criteria that will be emphasized for evaluation during an upcoming award fee period. This not only allows the contractor time to improve in weak areas but also ensures the government that proper emphasis is placed on the proper functions. Contract manager representatives (division chiefs in center support operations) provide technical guidance to the contractor in their specific areas and provide award fee evaluation data to the contract manager.

RESULTS AND LESSONS LEARNED WITH THE BOC

Throughout the process of planning, obtaining, and managing the BOC, both the contractor and the government continue to achieve new goals and refine the use of incentives in O&M contracting. With the proper planning, willingness to change and a cooperative management team, incentive contracting works. Following is a summary of some of the results of lessons learned at KSC to date:

1. An extensive planning and educational period is required when significantly changing management approach.

2. Solicit innovation. State the concept, but let the contractor propose his approach and details of implementation.

3. Total transition to a new approach takes more than a year.

4. CPAF/IF contracts are considerably more difficult to administer than CPAF/FF (fixed fee) contracts.

5. CPAF/IF contracts are much like fixed price contracts. They require a very thorough review of requirements because if something is not in the SoW, it is a contract change.

6. Provide for a threshold limit for equitable adjustments to avoid being deluged by change orders.

7. Budget fluctuations are harder to accommodate.

8. Both civil service personnel and contractors must know the SoW to make it work.

9. Careful development of the fee concept is required. Do not go too light on the award fee to the point performance suffers.

10. Better collective bargaining agreements are obtained by consolidated contracts.

11. Small business does not have to suffer. Negotiate a small business plan.

12. Contractor investment for long-term payback requires long-term commitment.

13. The cost incentive works. The contractor strives for better ways to get the job done.

14. Bottom line results with BOC: The first-year savings was 15 percent and the second-year savings 18 percent.

SHARED SAVINGS ENERGY CONTRACTS

D. M. Hannemann, PE
Naval Facilities Engineering Command

Shared savings energy service contracts can potentially reduce Department of Defense energy costs between $75 million and $300 million annually. However, legislation is required to provide multiyear contracting authority using annual appropriation before we can effectively use this contracting technique.

Shared savings contracting is a new concept whereby a contractor uses his energy conservation expertise to identify energy conservation opportunities. The contractor then uses his capital to modify our facilities so they will use less energy. He also may operate and maintain this equipment, and possibly other energy consuming equipment, for the term of the contract. His payment is a share of the avoided cost for the energy saved by his actions. The majority of the contracts would be for terms of between 7 and 10 years, but longer authority is desired to permit future flexibility. To some degree, the capital provided by the contractor can be considered as a loan that will be amortized from the contractor's share within the contract term. Shared savings offers several contracting challenges that will be explored during the first contracts. Some of these challenges are discussed below.

In typical construction or service contracts the contractor prepares his bid on government-furnished plans and specifications. However, a shared savings energy service contractor would have to conduct extensive field surveys and studies to identify potential savings. He then would need to prepare a detailed proposal identifying exactly what he would do during the entire term of the contract to save energy. It is unreasonable to expect a high level of financial commitment in mere anticipation of selection in a large competitive field. Contractor selection needs to be simplified to reduce both the contractor's bid preparation costs and the government's evaluation efforts leading to selection.

We also need to allow the shared savings contractor to operate and maintain all energy consuming equipment. This will prevent claims that the government failed to operate or maintain equipment properly and that this failure caused a reduction in contract payments for which the contractor should be compensated. The contractor should not have to depend on government mechanics, a labor force he does not control. Although contracts still may be awarded if A-76 studies are not waived, savings will be significantly reduced if the contractor is not allowed to operate and maintain energy consuming equipment.

In a shared savings contract, each offeror could propose different ways in which to achieve energy and cost savings. Since there is no common basis for bids, there is no way to determine in advance what will be done or to prepare the A-76 cost estimate. If the government were to wait to prepare its cost estimate until after the winning contractor was selected, the government then would have privileged information that could be used during the preparation of our bid. This would be unfair to the contractors and probably would be protested.

Not allowing the contractor to operate and maintain equipment limits the savings that can be achieved, and does not provide a true test of the shared energy savings concept. Additionally, by eliminating most opportunities for contractor operation and maintenance, we basically have a contract in which the only opportunities remaining are to install capital equipment that will reduce energy consumption. This either reduces the amount of equipment the contractor would install or requires a longer contract term for the contractor to recover his investment.

What would happen if we assume that a fair cost comparison could be prepared and the government won some of the operation and maintenance functions the contractor has proposed? First, we would remove some of the business opportunity that was the basis for selection of the winning contractor's proposal and possibly would make the remaining elements of his proposal unprofitable. Second, if we won and did not perform the function to the contractor's satisfaction, he could claim that his projected savings are not being achieved because of our failure to properly operate and maintain equipment. We then could be liable for a contractor's claim. Finally, if it was possible to conduct a cost comparison for every contractors bid, the actual best bid might not be the apparent best bid.

Energy baselines are extremely important to both the contractor and the government. Actual energy use is compared to the baseline and the difference would be the amount of energy saved by the contractor's actions. The value of these savings then would be split between the contractor and the customer in accordance with the terms of the contract. The energy baseline is a mathematical formula that compensates monthly for the variables affecting energy (e.g., as weather and population). It is developed using three to five years historical data. We have established a field office to develop the baselines ourselves rather than allow the contractor to determine the baseline.

The Navy is the lead service for shared energy contracting within DoD. The first three pilot sites are the Naval Hospital at Long Beach, California, administration building at Great Lakes, Illinois, and the commissary and exchange at Quantico, Virginia. Two other sites will be added to the Navy's pilot program. The Army and the Air Force also are participating in the pilot shared savings contracting program. Solicitations are being developed and contracts will be awarded as soon as we get legislation authorizing multiyear contracting for shared savings.

POWER TRANSFORMER DISSOLVED GAS-IN-OIL ANALYSIS: A USEFUL MAINTENANCE TECHNIQUE

Donald D. Gibbs
Western Area Power Administration

Power transformers are very important pieces of electrical equipment. Until about 10 years ago in this country, diagnostic maintenance techniques were limited to tests of such things as insulating oil dielectric strength, filtering of the oil, electrical resistance measurement of the transformer winding and connections, and measurements of the insulation quality by use of power factor techniques such as Doble testing. All of these tests serve a particular purpose and are a necessary part of a sound electrical equipment maintenance program.

About 20 years ago, researchers in Europe began experimenting with the concept of analyzing certain dissolved gasses that appeared to be discharged into the insulating oil by an electrical fault, (e.g., arcing or excessive heat). The significant dissolved gasses are hydrogen (H_2), oxygen (O_2), nitrogen (N_2), carbon monoxide (CO), carbon dioxide (CO_2), methane (CH_4), ethane (C_2H_6), ethylene (C_2H_4), and acetylene (C_2H_2).

The common insulation media used in transformers are mineral oil and cellulose materials. The electrical defects (or faults) such as heating, arcing, and/or electrical discharges cause the insulation media to decompose. An initial result of the decomposition process is the generation of gasses. Present day empirical methods tempered with sound judgment and a history of gas-in-oil for a transformer has proven to be a very useful method for early detection of internal problems and, therefore, the prevention of catastrophic failure.

The presence of combustible gas in transformer oil has been a known phenomenon for many years. The typical gas collection relay, or Bucholz protection system, is based on this principle. The gas collector relays are activated by free gas in the cushioning or blanketing space above the oil. The gasses of concern are highly soluble in oil; therefore, considerable gas (to the point of saturation) may be contained in the oil before detectable quantities are found in the "headspace" above the oil level. The faulty condition usually has been active for some time before it is detected by these gas-relaying devices. The analysis of the gas-in-oil by the process known as chromatography has become the preferred diagnostic technique. The chromatograph can detect gasses in the parts per million (ppm) range.

Diagnosis is not as absolute as it is comparative, judgmental, and empirical. Both the concentration of an individual gas as well as the ratio of concentration of a particular gas to certain other gasses allow determination of a type of fault. Key factors in diagnosis based on concentration of individual gasses are as follows:

1. Acetylene--Nearly always the symptom of an electrical fault since temperatures of greater than 500°C are required to produce this gas.

2. Ethylene--Without the presence of acetylene, ethylene represents thermal degradation (heat); large quantities may be produced at lower temperatures.

3. Carbon Monoxide--Produced by the thermal aging of paper or partial discharges in the solid insulation.

4. Hydrogen--Relatively large quantities are formed by the electrolysis of free water or by partial discharges (corona) into the oil.

In general terms, the following guidelines concerning the total concentration of gasses have found acceptance in the absence of any prior trend information:

1. Very low levels of dissolved gasses (0-500 ppm) indicate that the transformer is operating satisfactorily and that no special action is required.

2. Accumulation of more than 1000 ppm dissolved gasses indicates that decomposition is significant. Action should be taken to establish a trend in the accumulation of the gasses with time to see if the fault is becoming progressively worse.

3. Accumulations of more than 2500 ppm indicate that substantial decomposition has occurred. The integrity of the insulation may have been affected to the extent that catastrophic failure may be likely. Monitoring is essential.

4. Very high concentrations of dissolved gas require that the equipment be taken from service and the fault located and rectified.

5. Any reference to a "normal" level of dissolved gas is not particularly meaningful unless related to a trend.

There have been more elaborate diagnostic techniques developed to analyze various concentrations of one gas in relation to another. One of the easiest to apply is a nomograph developed in the mid 1970s by J. O. Church, Bureau of Reclamation, Department of the Interior. Church's nomograph system allows for plotting the concentrations of gasses and then making a judgment based on the slope of the lines.

An actual plot on the nomograph and a description of the findings by Church are shown in Figure 1.* In the first column (indicating the concentrations of hydrogen and acetylene) from left to right, the greater the slope upward, the greater the probability of arcing; as the slope of the line nears horizontal, the cause is indeterminate; and as the line slopes downward, the indication is that heating is the cause.

*The chart suggests arcing initially with heat deterioration following. Solid insulation has also deteriorated. Examination revealed that a braided connection between the HV winding and a bushing had been sparking to a surrounding isolated copper tube and had eroded away sufficiently to cause overheating.

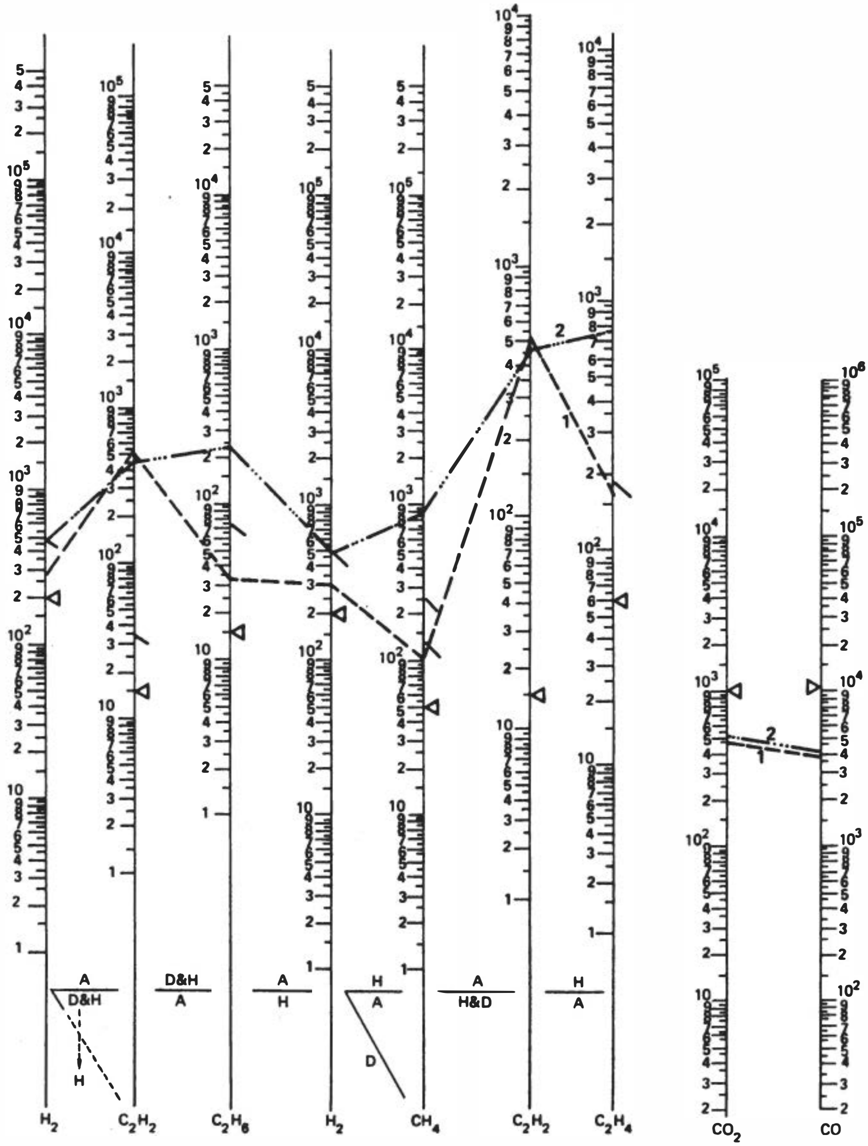

FIGURE 1 Dissolved gas-in-oil analysis diagnostic chart for a 120-MVA autotransformer.

It should be pointed out that the present day techniques discussed herein are for analyzing only mineral insulating. To date, dissolved gas-in-oil analysis of the broad class of nonflammable, synthetic, chlorinated, hydrocarbon insulating liquids, (commonly called polychlorinated biphenyls) PCBs, is only in the experimental stages.

The gas-in-oil monitoring program has proved to be both functional and cost-effective for the Bureau of Reclamation and the Western Area Power Administration. Other utilities utilizing gas-in-oil testing programs report similar achievements. To date, the cost of a test is in the $50 to $100 range. Since a 50-MVA power transformer costs about $1.5 million, the economy of early diagnosis and corrective action is obvious. The concentrations reported by a number of laboratories analyzing the same oil can vary considerably. It is best, therefore, to utilize the same laboratory, equipment, and/or test method consistently. Although not an exact or absolute science, present day techniques tempered with sound judgment provide maintenance personnel with a strong diagnostic tool to be used along with conventional tests and measurements.

THERMAL LINE SCANNING OF ELECTRICAL EQUIPMENT

John J. Thayer, PE
Department of Energy

As part of the Department of Energy (DoE) weapons complex, my office is responsible for maintaining and enhancing the reliability of the utility systems required to preserve DoE's mission capability. To this end we have been investigating the use of an infrared scanning device to locate impending failures in plant electrical equipment.

There are basically three types of thermal (infrared) scanners available today:

1. Infrared Thermometer--This is usually a compact "gun" type of device that, when pointed at an object gives a digital temperature reading of the object or point. These are low-end, easy-to-use items that can be bought for less than $1,000.

2. Infrared Imager--This is a complex video camera type of device that displays an entire field of view in shades of black to red, depending on the ambient and object temperatures in the field of view. These shades then may be interpreted as varying temperatures. Imagers often require battery packs and argon gas cylinders to support the unit, and accessories such as cameras and video cassettes are available to record the scans. Use of this type of infrared equipment usually requires a trained technician to handle the support equipment and to interpret the varied shades (temperatures) of the display. These imagers are high-end items costing $30,000 and up.

3. Infrared Line Scanner—This is sort of a hybrid of the above two types of scanners; an entire field of view is displayed with an infrared horizontal baseline in the center of the view and a horizontal top-of-scale reference line at the top of the display. Items in this field of view that are crossed by the baseline are represented by a trace that is easily scaled versus the ambient temperature while maintaining a full view of the object being observed. A line scanner costs about $10,000 completely configured with a recording camera and tripod.

After investigating the types of infrared equipment available, we selected an infrared line scanner with a camera and tripod option to record traces if desired.

Our thermal line scanner* is a portable unit with an integral, rechargeable battery pack weighing only 9 pounds. A battery pack will last for approximately 4 hours of use; for more continuous use, additional battery packs can be purchased or a 120-volt power source may be used. The scanner is compact enough to be hand held for long periods of use or it may be placed on a tripod. When using the camera option, it is necessary to use the tripod.

The line scanner's controls and settings are minimal and allow even first-time users to easily, effectively, and successfully operate the scanner. They include:

*"ThermAtrace" Thermal Line Scanner from Barnes Engineering Company, 30 Commerce Road, Stamford, Connecticut 06904, 203/348-5381. Model 12-750 includes the ThermAtrace, an internal rechargeable battery pack, three scanning mirrors (for low, medium, and high light conditions), a neck strap, a battery charger/AC adaptor, and a carrying case for $8,950.00.

Model 12-750P (photographic option) includes the model 12-750 equipment above plus a Polaroid SX-70 camera, a camera adaptor, a tripod adaptor, and a heavy-duty tripod for $10,325.00. Additional battery packs are available for $185.00 each. Prices cited are from Barnes Engineering, March 22, 1985, and are subject to change without notice.

1. Temperature range selection of a 10, 30, 100, 300, or 1,000 degree C (above ambient) scale.

2. Distance slide to focus the unit (from 4 feet to infinity).

3. Zero offset adjustment to magnify small temperature details for examination (the scanner is accurate to 0.5 degrees C at 25 degrees C ambient).

4. Hot or cold baseline switch to select the mode of operation (switch to hot baseline inverts the normal display for the viewing and measurement of cold objects).

5. Interchangeable scanning mirrors (low, medium, and high densities) to allow the trace to be comfortably viewed in very dark or brightly sunlit areas.

To operate the unit, simply turn it on and allow it to warm up for a few minutes until the infrared line stabilizes in the display. Adjust the distance slide if necessary and select the temperature scale. Make sure the zero offset knob is set to zero. Look through the eyepiece at the object of interest and press the acquisition trigger built into the left handle of the scanner. This trigger doubles the speed of the infrared trace and makes the trace easy to view for faster scanning.

The baseline in the center of the display "clamps" to the ambient temperature of the area being viewed. Any objects that are touched by the baseline show up as a trace above the baseline. The height of the trace versus the selected scale indicates the temperature of the object. Since the trace is superimposed over the field of view, it is very easy to rapidly scan across busbars, circuit breakers, connections, and cables and to immediately locate abnormal heat sources and accurately estimate their temperatures. Since most electrical components are rated for 40 to 60 degrees C, we have found use of the 30-degree-C scale to be very convenient. If something in the field of view makes a significant trace on this scale, we take a closer look at it. In most cases it is only a circuit loaded to near capacity that can be identified by a more even heat trace over the circuit breaker, connection, and cable as opposed to the spike trace of a hot spot. The electrician can quickly verify the situation with his clamp-on ampmeter.

We are in the process of incorporating this infrared capability into our electrical equipment preventive maintenance program. Previously we used a three-year lug-tightening and inspection routine for our switchboards and panelboards, but several recent electrical failures and near failures have caused us to rethink this approach.

The recent requirement for electrical equipment manufacturers to include torque values with their equipment has resulted in more information being made available on the subject of properly made electrical terminations. This information indicates that it is absolutely essential to torque every electrical connection during installation per the manufacturer's instructions. The consensus of opinion seems to be that once this proper connection is made, it should be left alone unless some indication of heating is found (discoloration of lug or busbar, charring of insulation, etc.). Our experience indicates that our periodic checking and resulting overtightening of an electrical connection can eventually ruin even a copper connection, leading to high resistance and, eventually, a failure.

Rather than to continue our present program, we have decided to institute the following program:

1. Provide torque screwdrivers and wrenches to each electrician with instruction on their proper use and care.

2. Mandate that all electrical power connections from 20-ampere wiring device screws to 4000-ampere busbar connections be torqued at installation in strict accordance with the manufacturer's instructions.

3. Infrared scan all connections annually using our thermal line scanner.

We believe that the making of connections using torque tools will not require any extra time. Preventive maintenance on panelboards previously required 1-1/2 manhours per panel (this includes premium time since equipment had to be shut down). We have conservatively estimated that infrared scanning will require only 1/2 manhour per panel. This will allow us to triple the frequency of inspection without any additional cost. Also, no downtime or premium time is required since the scanning is safely done on energized equipment during normal working hours.

Statistics show that 90 percent of electrical problems occur at terminations or because of improper terminations. Studies have indicated that 70 percent of all mechanical termination failures can be eliminated by the proper torquing of terminations. We believe that annual thermal scanning in addition to torquing these terminations could nearly eliminate this major source of electrical failure. We also believe that other types of electrical failures will be prevented with the increased frequency of inspection and additional diagnostic capabilities provided by infrared scanning.

HVAC CONTROLS—CAN THEY BE MADE TO OPERATE PROPERLY?

David Johnson
U.S. Army Construction Engineering Research Laboratory

The quest to tame runaway energy costs has inspired countless inventions including complex pneumatic temperature control systems. In theory, these schemes would save power by tightening control over heating, ventilating, and air-conditioning (HVAC) systems, allowing more careful regulation of energy expended and taking full advantage of favorable outdoor conditions. However, complaints that the controls do not work have been widespread. In response, the U.S. Army Construction Engineering Research Laboratory (USA-CERL) investigated these devices and found some did perform poorly—components drifted out of calibration rapidly, were difficult to adjust, and provided only marginal control.

USA-CERL began a vigorous research program seeking to develop better HVAC controls. The results to date have been surprising: simpler is better. That is, less complicated control schemes that use accurate components and that have a proven track record still provide the best control. On this premise, USA-CERL identified three steps for designing more effective controls.

1. Use accurate, reliable sensors and controllers.

2. Include all essential diagnostic components on a single panel to eliminate the need for special instruments and tools.

3. Use only factory-calibrated components that can be replaced easily should they become defective.

USA-CERL's researchers have tested several prototype control panels using standard platinum temperature probes and high-quality analog electronic controllers to afford the needed accuracy. Coupled with the proportional-plus-integral control action, these components bring actual discharge or mixed air temperature to the exact setpoint.

The panels' easy maintenance is a huge advantage. No field calibration is needed because the equipment is preset during manufacture. Although that means faulty parts must be replaced, the manpower saved in maintenance easily offsets the cost.

USA-CERL's HVAC control panels are designed to include all needed diagnostic equipment. The voltmeter has a selector switch to display temperatures, setpoints, and controller voltages. "Push to Test" buttons let operators quickly identify defective components that, thanks to modular construction, can be replaced easily.

These panels are tamper-resistant, with all parts concealed behind a locking outer door that is part of the heavy, metal enclosure. They can be installed on most HVAC systems with little or no modification to the existing equipment.

How much will these controls save and how much will it cost to start saving? Results so far suggest that USA-CERL's HVAC control panels can save up to 25 percent of heating and cooling energy costs. This figure would be compounded if it were possible to quantify the savings in maintenance and repair over that associated with less reliable systems. The installed cost for these control panels also may be lower than for field-constructed pneumatic systems. Additional cost savings will accrue with the building's improved comfort, which increases worker productivity.

Two companies so far have built Variable Air Volume (VAV) control panels based on USA-CERL's design--Staefa in conjunction with Technical Services, Inc. and the Johnson Controls Company. USA-CERL has tested these panels at its full-scale HVAC test facility, has installed them on in-house air handlers, and is helping several Army and Air Force installations bring them on line as part of a demonstration program.

Besides a hybrid VAV system, two other control systems have been developed and are ready for field use. One is for controlling fans used in VAV systems (static pressure control) and the other is a hot water temperature control panel for boilers, steam-to-hot-water converters, and high-temperature-to-low-temperature hot-water converters. These systems include USA-CERL's design principles.

When properly installed, the Army believes that the retrofit control systems will allow easy identification of component failures, facilitate repair, and minimize system failures.

CATHODIC PROTECTION: FACT, FICTION, AND FACILITIES MANAGEMENT

Bruce Flowers
Naval Facilities Engineering Command

INTRODUCTION

The use of cathodic protection to limit the deterioration of facilities due to corrosion, and their resulting failure and loss of use, has gained tremendous momentum over the past 10 years in both the private and public sectors. According to figures compiled by the National Association of Corrosion Engineers (NACE), total expenditures on cathodic protection (including materials, construction, and engineering) in the United States, by all industrial categories was approximately $373 million in 1975, $775 million in 1981, and an estimated $1.48 billion in 1985. Figures for government expenditures (3.51 percent of NACE user membership) are $9 million, $17.7 million, and $37 million for 1975, 1981, and 1985, respectively.

One of the objectives of the Department of Defense Real Property Maintenance Activities (RPMA) program is to maintain and repair all active real property to a standard that will permit continued use for designated purposes in the most cost-effective manner. In the Naval Shore Establishment, a corrosion control program is a must in order to meet this RPMA objective. Currently, corrosion losses in the Naval Shore Establishment are estimated to be $0.5 billion annually, and often these losses result in facilities being downgraded or removed from operation. Corrosion related costs and the adverse impact on mission readiness are of increasing concern. With renewed interest in corrosion control the Naval Facilities Engineering Command in 1982 assigned responsibility for this area to the Facilities Division (Code 100) with an emphasis on establishing and maintaining an effective corrosion control program within the Naval Shore Establishment.

The development of a Navy-wide shore facilities corrosion control program has been structured around Naval Facilities Engineering Command Instruction 11014.51, Corrosion Control of Shore Facilities, (Appendix A), which was issued in October 1983. The policy adopted in this instruction is that corrosion control systems shall be installed, monitored, and maintained for various types of facilities along with those already covered under the Code of Federal Regulations, Title 49, Parts 192 and 195. Further, the instruction defines the responsibilities and required interaction between the various levels of the Shore Establishment, including a reporting system for corrosion control system performance, development of a Navy-wide shore facilities corrosion control inventory, and a system of technological support for activity public works centers/departments.

A key to the successful development of this corrosion control program is the effective application and maintenance of cathodic protection on a wide range of facilities. This can only be accomplished when facility managers and engineers at all levels understand the concepts and benefits of cathodic protection engineering.

CATHODIC PROTECTION ENGINEERING

With the advent of the use of cathodic protection to maintain and extend the useful life of facilities, government facility managers now must deal with a complex yet seemingly simple science, that, depending upon who you listen to, is either voodoo or the next best thing to ice cream. To properly incorporate the use of cathodic protection in an overall facilities management plan, it is necessary to understand the concepts of cathodic protection engineering as they apply to facilities management.

Cathodic protection engineering is an engineering discipline that is heavily dependent upon a strong understanding of the other traditional disciplines (i.e., civil, mechanical, electrical, and chemical engineering). To be effective, an understanding of the electrical, mechanical, and electrochemical properties of cathodic protection systems and coatings must be coupled with a solid understanding of the design and function of the various types of facilities to be cathodically protected.

The following various types of work are generally performed as a part of cathodic protection engineering:

1. Electrochemical potential surveys of facilities.

2. Soils and water analysis (including resistivity, pH, etc.).

3. Design of cathodic protection systems including coordination with and input on facility component design.

4. Nondestructive testing including radiographic, ultrasonic, pressure, and volumetric (leak) testing.

5. Research into facility documentation including review of as-builts, specifications, leak history records, system maps, etc.

6. Statistical analysis.

FACTS

Cathodic Protection Works

Cathodic protection is a proven means of effectively minimizing corrosion of facilities in a variety of environments. It has been utilized on pipelines, water tanks, offshore structures, etc., all over the world since its first application in the 1930s. Cathodic protection has been a requirement of the Code of Federal Regulations governing interstate pipelines and tank farm facilities since 1972. The Federal Highway Administration has gone on record as taking the position that "cathodic protection is the only effective means to stop corrosion of reinforcing steel in chloride contaminated concrete." If a cathodic protection system does not stop corrosion, it is because the application is defective due to a lack of proper engineering, installation, or maintenance.

Cathodic Protection Saves Money

As a general rule of thumb, the cost to install cathodic protection on a facility is usually about 1 to 3 percent of the estimated construction cost or current plant value. Generally the cost of installing cathodic protection during the initial construction of the facility is much less than retrofitting the same facility after construction is complete. The types of facilities that receive cathodic protection are, by nature, generally part of the facilities infrastructure, and as such, are replaced only when they fail (most of the time) or become operationally obsolete. Therefore, when performing an economic analysis on the inclusion of cathodic protection in a construction project, the increased useful life of the structure provided by the cathodic protection system should be utilized. In almost every case, cathodic protection will win hands down.

Most Cathodic Protection Applications Are Simple

Generally, 90 to 95 percent of all existing and potential applications of cathodic protection on government facilities are relatively simple. That is to say, the necessary technology is readily available, the applications have been successfully employed in previous projects or in private industry many times over, and the methods of procurement (i.e., construction contract, maintenance service contract) are readily available. The difficulties encountered in cathodic protection applications usually relate to the definition of the necessary components for effective cathodic protection--proper engineering, installation, and maintenance. When one of these three components is not performed, even the simplest of cathodic protection applications can go sour in a hurry and in a big way. Hence, the knee-jerk reaction is that cathodic protection is overly complicated and complex.

FICTION

Cathodic Protection Is Black Magic

The principles of physics and chemistry upon which cathodic protection engineering are founded are identical to those that have given us the car battery and electric motors. When properly engineered, installed and maintained, cathodic protection does minimize corrosion on the facility it is protecting. The problem that arises, in many cases, is that one of the three (engineering, installation, maintenance) is not done properly, unbeknownst to the facility manager involved, and the result is an ineffective cathodic protection system and subsequent facility failure.

Cathodic Protection Repairs Damaged Structures

Contrary to a frequently encountered belief, cathodic protection cannot reverse the process of corrosion and restore to original condition facilities that have experienced corrosion damage. The same principles of physics and chemistry previously mentioned prevent this from occurring. Existing facilities that have experienced corrosion damage and are retrofitted with cathodic protection may still experience problems due to corrosion that occurred prior to the retrofit; however, any further corrosion of the facility will be arrested.

Set It and Forget It

Cathodic protection systems, whether impressed current or galvanic, do require a certain amount of attention and fine tuning. Cathodic protection systems are, by nature, interactive with the facility they are installed to protect and the environment they are installed in. The following general schedule should be used to determine when periodic testing of cathodic protection systems should take place:

1. For impressed current systems, check the rectifiers monthly and the structure to electrolyte potentials semiannually.

2. For galvanic systems, check the anode outputs semiannually and the structure to electrolyte potentials semiannually.

Other readings should be taken as the need arises to identify problems with the system. Testing intervals for cathodic protection systems are dependent upon the following variables:

1. Impact of failed cathodic protection system on operations, life safety, etc.

2. Changes in the environment such as seasonal, new construction nearby, climatic, etc.

3. Alterations to the facility.

4. Need to establish historical data for cathodic protection system.

5. Damage to the cathodic protection system.

FACILITIES MANAGEMENT

A primary goal of facility managers within the Department of Defense is to meet the objectives of the Real Property Maintenance Activity Program that include "to maintain and repair all active real property to a standard which will permit continued use for designated purposes in the most cost effective manner." Incorporation of cathodic protection engineering in all phases of facilities management will make it easier for facility managers to meet this and other objectives.

During the facilities planning/design stage, cathodic protection engineering can be used to:

1. Determine the existing physical condition of underground or underwater structures in conjunction with other methods of inspection and testing.

2. In conjunction with item 1, more accurately determine the necessary scope of work to replace or repair facilities to provide a net effective level of service.

3. Plan and design new and/or replacement facilities to minimize potential for corrosion damage and maximize effectiveness of cathodic protection systems.

During the facilities construction stage, cathodic protection engineering should be used to determine what remedial measures may be necessary to maximize effectiveness of cathodic protection systems.

During the operation and maintenance stage, cathodic protection engineering should be used to maintain facilities by:

1. Performing periodic testing and executing repairs to cathodic protection systems determined necessary by the testing.

2. Periodically evaluating (testing) facilities that do not have cathodic protection but, due to changing conditions, may require it to remain in an operable condition.

Further, during the operations and maintenance stage, cathodic protection engineering can be utilized as an effective tool to provide the minimum level of inspection necessary to ensure the continued use of a facility for its designated use.

Following are two examples of the application of cathodic protection engineering in facilities management. The first involves the repair of an existing facility whereas the second involves the construction of a new facility. Both examples are indicative of the advantages of including cathodic protection engineering in the planning stage.

Repair and Inspection, Diesel Storage Facility

This project involved a Naval shipyard diesel oil storage facility constructed during the 1940s. The facility consists of five aboveground storage tanks with a combined storage capacity of 332,800 barrels, 4,000 lineal feet of distribution piping, pump house, loading racks, etc. The current plant value of the facility is approximately $6 million. The underground piping and tank bottoms have never received cathodic protection. During 1983 it was determined that underground piping was leaking after unsuccessful pressure tests.

The shipyard's original approach to remedying this situation was to develop a repair project to replace all underground piping in the facility at a cost of $400,000, and not install cathodic protection. After consulting with the shipyard's public works department, the following alternative course of action was developed:

1. Task the project architect/engineer with acquiring the necessary subcontractor services to perform cathodic protection engineering work during the site investigation phase of project design including

the following: (a) close order potential survey of all underground piping and tank bottoms, (b) soil resistivity survey, (c) stray current testing, and (d) excavation and physical inspection of selected segments of buried piping to establish a relationship between task (a), (b), & (c) data and the actual condition of the buried piping.

2. Re-evaluate the project scope in light of the data obtained to determine the extent of repairs needed to provide a reliable facility.

3. Proceed with revised (if necessary) project.

The results of this different approach towards solving the problem were significant:

1. The amount of pipe replacement was reduced to 500 linear feet ($50,000).

2. Cathodic protection on the entire facility was installed ($50,000).

3. Cost to provide a reliable facility was reduced from $400,000 to $100,000.

4. Project savings were redirected towards providing necessary improvements to the facility to meet current environmental and operational standards.

The cost to the government to obtain the additional engineering services was $12,000. It is interesting to note that according to current criteria the shipyard would have needed to install cathodic protection as part of their original project scope. The cathodic protection engineering work performed is required in order to do a proper design of a cathodic protection system. However, by doing the cathodic protection engineering prior to pipe replacement, it was possible to more accurately determine the extent of deterioration of existing piping and the repairs necessary to put it back into a reliable, operable condition.

New Construction, Ship Berthing Facility

This example involves a bulkhead/relieving platform to be built in conjunction with the homeporting of a Naval

Surface Action Group. This example represents the advantages of utilizing cathodic protection engineering during the design phase of new facilities.

The facility to be constructed is approximately 1,500 feet in length and will be used to provide frigate and small craft mooring and other services to ships while in port. The section consists of a sheetpile retaining wall anchored by a prestressed concrete pile relieving platform. The estimated cost for this structure is $9 million ($6,000 per linear foot). The original design concept calls for providing coal tar epoxy coating for both sides of the sheetpiles and a galvanic anode cathodic protection system for the waterside of the sheetpiling. This is in accordance with generally accepted practices for dealing with corrosion of waterfront (sea water) structures.

Further review of the site conditions, however, indicated that cathodic protection should be considered for the land side of the bulkhead because of the following:

1. The presence of an extremely low resistance, (50 ohm-cm) 25-feet-deep layer of river mud along the entire site.

2. The presence of higher resistance soils above and below the river mud layer (clean fill above, dense sand below).

3. Embedment of sheetpiling in concrete cap structure along with presence of concrete relieving platform.

These conditions, which are unavoidable in order to accommodate the most cost-effective structural design, are those that could result in the formation of an aggravated galvanic cell between the steel in concrete, clean fill, and dense sand (cathode) and the steel exposed to the river mud retained behind the wall (anode). This situation would further be aggravated by the coating on the sheetpiling (i.e., large cathode driving small anode).

Once the structure is in place, it will be extremely difficult and costly to perform any tests that could conclusively indicate that accelerated corrosion is or is not taking place on the backside of the sheetpiling.

Further, the cost to retrofit the structure after construction, with cathodic protection will be much higher (two to three times) than if cathodic protection is done as a part of the original project.

The estimated cost of installing cathodic protection on the backside of the sheetpiling structure is $75,000, which represents 0.8 percent of the estimated construction costs. The maintenance and operation costs for this cathodic protection system are approximately $2,500 per year. The total cost of this system over its 20-year life is $125,000, which is still less than 1.5 percent of the estimated construction costs.

When considered in view of the Department of Defense Construction Criteria (DOD 4270.1-M) design requirement to "provide highly functional facilities at the lowest practicable construction costs, with due regard for economy in maintenance and operation of the facility," the addition of cathodic protection for the backside of the sheetpile structure is appropriate.

CONCLUSION

The efforts we have made to utilize cathodic protection engineering in the management and design of facilities have resulted in noticeable improvements in our ability to maintain and extend their useful lives. This technology, which is proven with 50 years of experience in the private sector, should be integrated into the facilities management procedures of the Shore Establishment.

MINIMIZING FAILURES OF ROTATING EQUIPMENT THROUGH BETTER VIBRATION ANALYSIS

Fritz Coressel
Rockwell International
North American Space Operations

A very profound maintenance man made the statement: "Every machine manifests itself by its own degradation." If we clearly understand this statement and have the means of witnessing this degradation, then we know the condition of the machine and can predict its further collapse. Vibrational analysis is one of the means of measuring a machine state.

We all practice vibration analysis to a small degree. For example, we have all learned that funny noises coming from an automobile or a piece of household equipment often indicate a problem has developed and repairs will soon be needed. From this simple concept of using the human senses to detect machinery problems, the technology of predictive maintenance analysis has advanced to a sophisticated science. During the 1960s and 1970s, the U.S. Navy, the petrochemical industry, and the nuclear power industry invested heavily in developing predictive maintenance technologies to evaluate the condition of critical equipment. By the early 1980s, the instrumentation and analytical skills required for predictive maintenance had been developed to quite an elaborate level.

This presentation will address only a very small part of predictive vibrational analysis. It will not touch on vibrational theory but purely on systems that use that theory. It focuses particularly on portable vibration analysis systems and how they are utilized at the Rocky Flats Plant that is operated for the Department of Energy by the North American Space Operations of Rockwell International.

The Rocky Flats Plant employs approximately 6000 people and is located 16 miles northwest of Denver, Colorado, near the eastern foothills of the Rocky Mountains. It covers about 10 square miles (more than 6,500 acres) near the northern boundary of Jefferson County. The plant consists of more than 115 buildings, occupying approximately 400 acres in a Perimeter Security Zone (PSZ) and an Exclusion Zone (Non-PSZ). The remaining acreage provides a buffer zone surrounding the exclusion work area. The buildings comprise approximately 2.25 million square feet of manufacturing, chemical operations, laboratory, office, and storage facilities. The plant is serviced with aboveground and underground utilities, railroads, and cafeterias.

The mission of the Rocky Flats Plant is the manufacture and fabrication of nuclear components for weapons. As a result, various hazardous metals are used in the production process.

In order to provide a safe environment for the production worker, a great number of air handling systems are a necessity. It is the need for continuous operation of these air systems that prompted Rocky Flats to become interested in the use of vibrational analysis to guarantee operation of the systems.

At Rocky Flats, 35 percent of the plant's energy requirements are utilized in these air handling systems. There are in excess of 300 major fans ranging in size from 15 to 300 horsepower for a total of 6000 horsepower. Fan systems such as these are a very basic and ideal apparatus to incorporate into a vibrational analysis predictive maintenance system.

In 1977 the Maintenance Department at Rocky Flats began experimenting with vibration measurement utilizing an IRD Mechanalysis Vibration and Noise Meter. This was a hand-type direct-reading meter driven by a velocity transducer. It produced a composite velocity reading in inches per second, peak to peak. This reading was recorded on a field form and later transferred to a display plot to determine trends. The readings referred to in this report actually consist of a series of three measurements per shaft bearing: vertical, horizontal, and axial vibration. On a fan-motor combination, measurements are made on the inboard and outboard bearings of both the fan and motor for a total of 12 measurements.

A machinist was given one day of training and a $3,500 IRD instrument and our program began on 15 identical fans in Building 776. At first this endeavor required an average time of eight hours per fan-motor combination, but with experience the machinist shortened the time to six hours. Readings could be made every two weeks utilizing the one machinist full time on these 15 fans. However, management wanted to expand the program since good results were being experienced, and the readings were extended to a monthly frequency when additional equipment was added to the initial list. The monthly frequency should represent the maximum period between readings for a good monitoring program.

Problems soon appeared in the program in the form of questionable readings that could not be reproduced. A PMC 208 Vibration Analyzer/Balancer was procurred in 1979 with a strobe, a Hewlett-Packer TI-59 programmable calculator, and a X-Y plotter at a cost of $5,545. Now we were in the "balance in place" program as well as vibrational measurement. Vibrational readings were plotted at 2 to 3.33 KHz spectrum and were no longer questioned relative to accuracy due to the use of the plotter. Our technician now became a packhorse; the plotter was large and heavy and a special cart was required to move the equipment; however, the time for a fan-motor reading was now cut to four hours.

In 1982 the Maintenance Department again expanded the program by obtaining a B&K Type 3517 Vibration Analyzer and Balancing Set. If you add a strobe and strip chart, costs are at $20,000. Accelerometer transducers are utilized with this analyzer, enabling measurements from 0.2 Hz to 20 KHz with a $\pm$ 2 percent sensitivity. With this equipment our technician now is covering three fan-motor combinations per day, approximately 2-2/3 hours per unit. If all 300 of our fans are incorporated in the program, readings will only be taken every three to four months.

We had reduced measurement time from 6 hours to 2-2/3 hours per unit over the 5-year period but still felt the time was excessive. Our target time for the measurements was a minimum of once per month, approximately 30 minutes per unit.

In 1984 the Maintenance Department acquired an instrument called the "Data Trap." The "Data Trap" is manufactured by Beta Monitors and Controls Ltd. of Calgary, Canada. Recently, Technology for Energy Corporation of Knoxville, Tennessee, marketed a similar type of instrument called the "Smart Meter" that has some features not available in the "Data Trap." The "Data Trap" is a portable instrument utilizing a Z80 microprocessor that guides the technician through a preselected route, advises which vibrational readings are to be taken, records and analyzes them, and reports readings to a data base computer. The instrument has a capacity of 500 vibration readings from 2 Hz to 50 KHz. Our technician is now obtaining readings of four fan-motor combinations per hour, 15 minutes per unit. Our target is 250 readings per day enabling a repeat of readings every 2 weeks. Through the rapid strides in the electronics field, we had not only reached our desired goal but greatly exceeded it.

The system, however, requires more than just the "Data Trap." An IBM AT Computer, a monitor, keyboard, software and printer brings the system cost up to $20,000.

A minimum of two persons are required for the "Data Trap" system: a junior level technician to take the readings, and one engineer or trained technician to supervise and analyze reports.

The "Data Trap" system functions as follows:

1. The machines, test points, and routing of the technician are entered in the computer data base.

2. Vibrational alarm points are determined for each machine and entered into the computer data base.

3. Preliminary frequency of the readings are determined.

4. All of the foregoing is developed in the computer as circuit information for the technician and loaded from the computer into the "Data Trap."

5. The technician runs his circuit and daily or every other day dumps the information from the "Data Trap" back into the computer.

6. The computer then produces an exception report of the readings, predicts the next readings, and sets a new inspection frequency. It will also highlight a reading that exceeds the set point.

7. The computer also produces a summary report of all readings and trend reports for any point on any piece of machinery.

We basically have attained a concept sought in 1977 and in the process acquired additional profitable systems in our quest. The spinoffs of "balancing in place" and "diagnostics" have proven almost as valuable as the predictive vibration analysis systems. An explanation of these spinoffs would require a presentation for each of them to give the reader a feeling of the true merit of each.

The predictive vibration analysis program gives many benefits. The greatest are as follows:

1. Increased plant availability resulting in greater output. Machine running time can be increased by maximizing the time between overhauls. The state of the machine is known.

2. Reduced maintenance costs. Overhaul time can be reduced because the nature of the problem is known, and the spare parts and manpower can be readied. Consequential damage can be reduced or eliminated.

3. The lead time given by condition monitoring enables machines to be stopped before they reach a critical condition, especially if instant shutdown is not permitted.

4. More efficient plant operation and more consistent quality obtained by matching the rate of output to the plant condition. The operating load and speed on some machines can be varied to obtain a better compromise between output and operating life to the next overhaul.

5. More effective negotiations with equipment vendors regarding initial acceptance or repair work, backed up by systematic measurements of conditions. Measurements of equipment performance when new, at the end of the guarantee period, and after overhaul give useful comparative values.

Rocky Flats Plant has acquired seven years experience in establishing a program that is just beginning to mature. We have found normal bearing failure is highly predictable and have experienced almost zero losses due to normal wear over the past four years. Bearing failures due to other than normal wear have occurred. Two such failures occurred in 1984 due to improper lubrication by a new employee. The bearing purge plugs were not removed and overlubrication caused overheating and failure of the bearings. We recommend that a vibration reading be made at the startup of equipment that has undergone overhaul or extensive repairs. In the past, we have found 75 percent of the fan unit repairs were done improperly due to inexperienced craftspeople. Coupling and bearing alignment and bearing adjustment were the predominant problems. Equipment should not be permitted to operate until an acceptable signature spectrum is obtained. This is an assurance that the work is done properly and maximum running time will occur between repairs.

If a successful predictive vibration analysis program is to survive and accomplish its intended purposes, management must be willing to commit the manpower and equipment investment resources and to insist on the adoption of vital recordkeeping and information exchange procedures.

The costs associated with establishing a comprehensive vibration monitoring program on a broad population of the equipment (100 to 500 machines) in a large industrial plant are likely to be $15,000 to $100,000 for equipment and require 1 or 2 trained engineers and/or technicians (Myrick, 1982). There is, of course, a trade-off between equipment and manpower requirements.

A major study of condition monitoring and its potential for application in British industries was performed by Neale and Associates (1978, 1979). As a general guide, it suggests that a reasonable level of initial investment for a typical industrial plant is about 1 percent of the total capital value of the equipment that is monitored. Furthermore, the average gross savings for gas, electricity, and water utilities was found to be 2.1 percent of the added value output (gross sales minus gross costs of raw materials). Typical cost/benefit ratios of well-managed programs achieved about $5 savings for every $1 expended.

No cost/benefit studies documenting results from any American utilities vibration monitoring programs have been published. Scientific Atlanta (1983) published a report that identifies typical petrochemical industry maintenance costs to be $11 to $13/horsepower-year. The experience of this industry with different types of maintenance is as follows:

1. Run to failure--$17 to $18/horsepower-year.

2. Preventive (time-scheduled)--$11 to $13/horsepower-year.

3. Predictive (on-condition)--$7 to $9/horsepower-year.

Two particular examples of the potential returns afforded by vibration monitoring programs are offered by Jackson and Dodd. Jackson (1979) notes that a large petrochemical operation can have annual maintenance expenditures of $10 million, of which 25 percent is for rotating equipment. It has been his experience that a 10 percent improvement ($250,000 per year) in these maintenance expenditures can be expected during the first five years of implementing a program. Dodd (1978) states that Chevron reduced average maintenance costs for all turbomachinery at a major plant from $6.60 to $4.40 per horsepower per year (in 1976 dollars) over a 7-year period. Further, Dodd and Hudachek (1976) report that complete overhaul cycles for major machinery were extended from a three-year inspection overhaul to an estimated seven- or eight-year interval. Chevron realized other savings that were difficult to document from reductions in downtime and equipment saved from destruction.

Two other well-documented studies of the impact of vibration monitoring programs aboard ships have been reported. Glew (1975) reports that a program the

Canadian Navy started in 1966 resulted in an overall reduction of 45 percent in maintenance costs on a fleet of 20 destroyers. The average savings of $100,000 per ship per year. Another study (Loynes, 1978) done in the United kingdom in 1976 on large oil tankers indicates that a 37 percent reduction in maintenance manhours resulted within 12 months after the initiation of a condition monitoring program.

Both corporate and plant management must be willing to commit the necessary resources to the newly initiated program for a minimum of two years. Frequently, a year or more will be required to optimize the measurement and information exchange procedures. When too much is expected too early, barriers are created that seriously hamper program acceptance even after effective operational procedures have been established. Manual programs require manpower that is always scarce around plants. When equipment runs properly, the incentives to monitor become less visible. After the initial flurry of problems is identified and "saves" reported, problems may become less frequent and management may decide the program has solved most of the problems and is no longer necessary or that the manpower is needed elsewhere.

An effective preventive maintenance program rests on management support; trained personnel dedicated to the vibration surveillance program; up-to-date measurement and analysis equipment; procedures that guide personnel and program efforts; and a record keeping system that tracks machine histories, maintenance costs, and the successes or failures of diagnostic endeavors. Programs that ignore or omit these important elements may still have a positive impact on plant operations and maintenance costs, but it is unlikely that these programs can achieve their maximum potential.

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