DEPARTMENT OF COMMERCE * NATIONAL BUREAU OF STANDARDS *

NBS SPECIAL PUBLICATION 640

U.S. DEPARTMENT OF COMMERCE/National Bureau of Standards

Innovation for Maintenance Technology Improvements

MFPG

33rd Meeting

MFPG
Innovation for Maintenance Technology Improvements

Proceedings of the 33rd Meeting of the
Mechanical Failures Prevention Group,
held at the National Bureau of Standards,
Gaithersburg, MD, April 21-23, 1981

Edited by:

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These proceedings were sponsored jointly by NBS and the:

Naval Air Systems Command
U.S. Department of the Navy
Washington, DC 20360

Office of Naval Research
U.S. Department of the Navy
Arlington, VA 22217

National Aeronautics and Space Administration
Goddard Space Flight Center
Greenbelt, MD 20771

U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, Secretary

NATIONAL BUREAU OF STANDARDS, Ernest Ambler, Director

Issued October 1982

Library of Congress Catalog Card Number: 82-600598

National Bureau of Standards Special Publication 640
Nat. Bur. Stand. (U.S.), Spec. Publ. 640, 518 pages (Oct. 1982)
CODEN: XNBSAV

U.S. GOVERNMENT PRINTING OFFICE
WASHINGTON: 1982

For Sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.
Price $11.00
(Add 25 percent for other than U.S. mailing.)

FOREWORD

The 33rd meeting of the Mechanical Failures Prevention Group was held April 21-23, 1981, at the National Bureau of Standards in Gaithersburg, Maryland. The symposium was under the general coordination of the MFPG Technical Committee on Materials Durability Evaluation with A. W. Ruff of the National Bureau of Standards as Chairman. The program was organized under the chairmanship of A. J. Koury of the Naval Air Systems Command with technical support from M. J. Devine of General Technology, D. V. Minuti of the Naval Air Development Center, and M. B. Peterson of Wear Sciences, Inc. Publicity was handled by M. J. Devine. The organizers, the session chairmen, and especially the speakers, are to be commended for an excellent program.

Appreciation is expressed to William A. Willard, formerly of the National Bureau of Standards Fracture and Deformation Division and currently with the Naval Surface Weapons Center, for his assistance in editing, organizing and preparing these proceedings. Where possible, the papers in the proceedings are presented as submitted by the authors as camera ready copy. Some editorial changes and retyping were required.

Gratitude is expressed to Marian L. Slusser of the NBS Center for Materials Science for handling financial matters, to Annette Shives for typing, and to Jo Ann Lorden and Greta Pignone of the NBS Public Information Division for the meeting and hotel arrangements.

This proceedings is the first MFPG publication to go to press since NBS assumed the role as major MFPG sponsor in 1972 without the guidance of Harry C. Burnett. Mr. Burnett, former executive secretary and long time supporter of MFPG activities, died in September of 1981. He is missed by his many friends in MFPG and at NBS. His enthusiasm and genteel manner were an inspiration to all of us.

T. ROBERT SHIVES
Executive Secretary, MFPG

Center for Materials Science
National Bureau of Standards

ABSTRACT

These proceedings consist of a group of 34 submitted entries (32 papers and 2 abstracts) from the 33rd meeting of the Mechanical Failures Prevention Group which was held at the National Bureau of Standards, Gaithersburg, Maryland, April 21-23, 1981. The subject of the symposium was maintenance technology improvement through innovation. Areas of special emphasis included maintenance concepts, maintenance analysis systems, improved maintenance processes, innovative maintenance diagnostics and maintenance indicators, and technology improvements for power plant applications.

Key words: fault detection/location system; lubrication; maintenance; maintenance management; maintenance technology; manpower utilization; reliability assessment.

UNITS AND SYMBOLS

Customary U. S. units and symbols appear in some of the papers in these proceedings. The participants in the 33rd meeting of the Mechanical Failures Prevention Group have used the established units and symbols commonly employed in their professional fields. However, as an aid to the reader in increasing familiarity with the usage of the metric system of units (SI), the following references are given:

NBS Special Publication, SP330, 1981 Edition, "The International System of Units."

ISO International Standard 1000 (1973 Edition), "SI Units and Recommendations for Use of Their Multiples."

IEEE Standard Metric Practice (Institute of Electrical and Electronics Engineers, Inc., Standard 268-1979).

NBS-114A (REV. 2-80)

U.S. DEPT. OF COMM. BIBLIOGRAPHIC DATA SHEET (See instructions)	1. PUBLICATION OR REPORT NO. NBS SP 640	2. Performing Organ. Report No.	3. Publication Date October 1982

4. TITLE AND SUBTITLE

Innovation for Maintenance Technology Improvement. Proceedings of the 33rd Meeting of the Mechanical Failures Prevention Group held at the National Bureau of Standards, Gaithersburg, MD, April 21-23, 1982.

5.

T. Robert Shives and William A. Willard, Editors

6. PERFORMING ORGANIZATION *(If joint or other than NBS, see instructions)*

NATIONAL BUREAU OF STANDARDS
DEPARTMENT OF COMMERCE
WASHINGTON, D.C. 20234

7. Contract/Grant No.

8. Type of Report & Period Covered

Final

9. SPONSORING ORGANIZATION NAME AND COMPLETE ADDRESS *(Street, City, State, ZIP)*

Center for Materials Science, National Bureau of Standards, Washington, DC 20234; Naval Air Systems Command, U.S. Dept. of the Navy, Washington, DC 20360; Office of Naval Research, U.S. Dept. of the Navy, Arlington, VA 22217; National Aeronautics and Space Administration, Goddard Space Flight Center, Greenbelt, MD 20771

10. SUPPLEMENTARY NOTES

Library of Congress Catalog Card Number: 82-600598

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)*

These proceedings consist of a group of 34 submitted entries (32 papers and 2 abstracts) from the 33rd meeting of the Mechanical Failures Prevention Group which was held at the National Bureau of Standards, Gaithersburg, Maryland, April 21-23, 1981. The subject of the symposium was maintenance technology improvement through innovation. Areas of special emphasis included maintenance concepts, maintenance analysis systems, improved maintenance processes, innovative maintenance diagnostics and maintenance indicators, and technology improvements for power plant applications.

12. KEY WORDS *(Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)*

fault detection/location system; lubrication; maintenance; maintenance management; maintenance technology; manpower utilization; reliability assessment.

13. AVAILABILITY

[X] Unlimited

☐ For Official Distribution. Do Not Release to NTIS

[X] Order From Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

☐ Order From National Technical Information Service (NTIS), Springfield, VA. 22161

14. NO. OF PRINTED PAGES

518

15. Price

$11.00

USCOMM-DC 6043-P80

☆U.S. GOVERNMENT PRINTING OFFICE: 1982-360-997/2267

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SESSION I

MAINTENANCE TECHNOLOGY AND MAINTENANCE CONCEPTS

CHAIRMAN: A. W. RUFF
NATIONAL BUREAU OF STANDARDS

MAINTENANCE TECHNOLOGY CONCEPT

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An examination of the scale of mechanical and structural failure can be readily estimated from the list of very recent equipment malfunctions receiving national attention shown on Figure 1. The first concerns a nuclear-power plant closed due to reactor and cooling system failure during October 1980. Not including equipment replacement cost, an expenditure of $800,000/day was incurred for a period exceeding ninety days! The second covers a major recall in automobile history due to the failure of two bolts --- over 6 million autos are involved! Consider several additional failures representing national concern (A) Flow control equipment identified as cause of failure at Three Mile Island Nuclear Power Plant -- estimated cost $1 billion (B) Improper valve component installation resulting in the total loss of a chemical processing plant in Newark, Delaware (C) Motor failure in a steel mill finishing plant -- in this instance a rapid repair costing $400,000 -- avoided a loss estimated at 30 million dollars. (D) Steel Reinforcing rods in concrete and bridge systems have been severely damaged from salt used to prevent highway icing, cost estimates for failures represents millions of dollars expended.

Every major industry, utility and government service involved with equipment operation has described failures of major cost and consequences. These failures also have a direct and significant impact on productivity.

Improvement in failure avoidance and problem solution is a mandatory national requirement. Innovative approaches based on technology clearly focused on safety, durability, reliability and operating economy, of a wide range of machinery and equipment can yield effective solutions.

Mechanical and structural failure prevention is critically dependent on a number of important disciplines listed in Figure 2. Requirements include 1) identification and assessment of the failure process, such processes include wear, corrosion, fatigue and fracture representing the more common modes, 2) the operational environment such as vibration, shock, humidity, temperature, salt, sand and contamination can accelerate severe damage, 3) materials and material processing including composition, heat treatment, surface coatings and surface finishing can be key determinants of service life, 4) assembly, transport and preservation involves training, manuals and publications, handling equipment, and protective materials required for effectiveness, 5) human performance covering knowledge, skill,experience and motivation are vital elements.

Prior to describing the "Maintenance Technology Concept" and the factors involved with successfully linking research and development with failure prevention, a review of current programs for conducting equipment and plant maintenance will be reviewed.

PREVENTIVE MAINTENANCE

In the early days of industrial development and through much of its history, there has been primarily one approach to maintenance: Preventive Maintenance. There are still many adherents today with obvious justification. It only costs $4 to grease a bearing but $400 to replace it. While the bearing is being replaced several million dollars of production may be lost. In preventive maintenance those actions are taken which are necessary to forestall equipment deterioration. Where preventive maintenance is practiced, technology efforts have been mainly directed to improving two areas: management techniques and for improved tools and equipment which shorten the maintenance task times.

Maintenance management has gone from a random scheduling of tasks to a highly organized, minutely scheduled work system with accurate cost accounting and accountability. Computer systems analyse the work load and organize it efficently. CRT terminals have replaced maintenance manuals and provide rapid information acquisition. Some of the maintenance tasks taken over by computers are listed in Figure 3.

Another important development in preventive maintenance is simplified inspection and repair. "In situ" repairs are listed in Figure 4. These include leaks, under-water repair techniques, rebuilding of worn surfaces, repair of FOD damage to turbine blades, repair of composite structures, restoring surfaces which have been damaged by corrosion or erosion, crack repair, and machinery alignment. Analysis has shown that one of the most costly elements of the maintenance process is not the repair but the disassembly, removal and reassembly. Thus, the development of components such as bearings and seals which can be removed without extensive disassembly are particularly valuable.

The realization that many inspections are invalid and frequently unnecessary and often redundant, has led many organizations to abandon preventive maintenance as too costly. Secondly, it has been realized that maintenance actions often are the causes for systems to malfunction; that is, errors are committed during maintenance. Thus, other alternatives were investigated.

ON CONDITION MAINTENANCE

In "on condition" maintenance, actions are taken when inspections or the operating characteristics of the equipment indicate that maintenance is required. Many of us use this approach to automobile maintenance. The literature reports successful use in a wide range of applications such as aircraft, appliances, and plant equipment.

Once success was achieved with certain applications, there was the natural inclination to expand the concept to other more critical ones. For critical applications it was necessary to get an early, positive indication of failure so that maintenance could be accomplished before failure actually occurred. This led to the concept of condition monitoring in which instruments and warning devices replaced the eyes and ears of maintenance and operating personnel. This more sophisticated approach to "on condition" maintenance is described in the following section.

CONDITION MONITORING

During the past 10 years a vast amount of work has been undertaken to develop and improve condition monitoring capabilities. The main thrust of the work has been to develop sensors and appropriate hardware to give some sort of a malfunction warning to the operator.

The concept of condition monitoring is not new. Temperature sensors, oil pressure indicators, fire lights, wear detectors, flow indicators, fluid level gages and power level sensors have always been used to give an indication of the condition of at least one component of a system. What was new was the idea that eventually all sensors would be connected to a single "black box" which would not only warn the operator of a problem but would tell him what was wrong and what to do about it.

The literature shows that condition mointoring has been applied to the types of machinery listed on Figure 5 with various degrees of success. This equipment includes gas turbine engines, diesel engines, turbomachinery, automobiles, trucks, tanks, buses, ships, transmissons, computers, construction machinery, space craft, nuclear power plants, and hydraulic systems. The major systems which have been used are listed on Figure 6. In the first approach critical sensors are specifically selected for each malfunction or component. This might be only a thermocouple or it would be a complete system. For example, the literature describes bearing monitors, structural fatigue monitors, corrosion detectors, wear indicators, misalignment, and a variety of other gages. The difficulty with the critical sensor approach is that in many systems a large number of sensors are required. Approaches were sought for a single technique which would detect a large number of different types of malfunctions. Another approach receiving the most attention has been vibration analysis. In this approach each malfunction produces a characteristic signal which can be recognized and interpreted by the analyser. Oil analysis measures the composition of wear particles in the oils to isolate facility components. Gas path and exhaust analysis monitor the combustion process while IR analysis monitors "hot spots".

Although great strides are being made it is impossible to monitor everything. Monitoring has been most effective in systems of reduced complexity not requiring a multiplicity of sensors.

MODULARIZATION

Modularization is the design approach to maintenance. Essentially a machine is designed with easily replaceable modules. If service problems develop, the modules are interchangeable and replaced while the faulty module is repaired. Although this concept has been used successfully in consumer appliances and electronic equipment for many years, its use in complex machinery is just beginning. For example, a gas turbine engine is built in four modules viz. power turbine, hot section, cold section, and accessory section. The power turbine module consists of the turbine case, the turbine rotor assembly, the turbine drive shaft and the exhaust frame. The hot section includes the combustion liner, the turbine stator and rotor assemblies. The cold section has the output shaft, the front frame, the main frame, the compressor rotor and stator and the diffuser casing. The accessory section contains the various accessories. The main advantage is of course that the whole engine is not down while one part is being repaired. There are, however, disadvantages. The principal disadvantage is that maintenance personnel often take the path of least resistance and remove modules for trivial reasons. It is not uncommon to find a large increase in the "no defect" removals when this approach is used. What is needed is test equipment so that the need for module removement can be accurately determined. Performance records become of limited value since interchangeability can lead to loss of identity. However, the benefits gained in availability usually outweigh the disadvantages. This approach will probably find increased useage as demands for quick response maintainability increase.

RELIABILITY-CENTERED MAINTENANCE

Reliability-centered maintenance (RCM) is a technique for developing scheduled maintenance programs for aircraft, although the technique is equally applicable to other equipment. It was developed by United Airlines in 1965 and has since been adopted in principle by a large number of other airlines. The significant difference between this program and others is each maintenance task is directly related to component failure modes and their consequences. The process begins with the identification of all failure significant components. The functions of these components are then defined and possible failure modes are selected based upon component functions. Consequences of failure are identified as safety, availability, cost or failure producing. With this information, decision diagrams are then used to identify scheduled maintenance tasks. Four scheduled maintenance tasks can be assigned:

On-condition inspection

Scheduled rework

Scheduled discard

Failure inspections

These tasks are then grouped into a specific maintenance program for a specific piece of equipment.

This approach basically selects from an all-encompassing preventive maintenance program (which inspects and repairs all components with equal vigor) those tasks which have a direct effect on maintenance objectives. Where RCM has been used maintenance costs have been reduced significantly. More extensive benefits of this program will be realized when the data base and information is expanded on service failure modes.

ANALYTICAL MAINTENANCE PROGRAMS

With preventive maintenance programs the main flow of work is from the manufacturer, through manuals, to maintenance personnel who effectively schedule and undertake the necessary tasks. With an analytical maintenance program there are strong inputs from maintenance as to what is done, when it is done, and how it is done. The basis for this program is a complete understanding of maintenance objectives and effective measurements of current maintenance operations. Such information is now available with computerized maintenance operations which make available records of all maintenance operations. The Navy 3M system is typical. All maintenance actions are recorded in a computer and can be recalled for review. This is illustrated in Figure 7 where the man hours associated with certain malfunctions are recorded. The malfunctions and the WUC's are pre-selected and the computer sums the maintenance man hours for each part and each malfunction. The value of such data is obvious. Components requiring excessive man hours can be investigated for specific details so that corrective measures can be taken in maintenance. For example, in Figure 8 leaking actuators are summarized. Failure analysis shows that the problem in all cases is actuator rod wear due to dirt trapped in the exclusion seal. A variety of maintenance approaches are available to reduce this sort of problem. These data identify component problem areas; however, additional data yields other kinds of information such as squadron differences, budget data, cost effectiveness, future design modifications, and research directions.

FAILURE CONTROL

With an effective analytical maintenance program equipment users are able to practice what might be called failure control, a positive approach to reducing maintenance costs. This can only be achieved by obtaining a complete understanding of service failures and then applying the appropriate technology to reduce these failures. There is extensive literature on the subject of component failures and ways that these failures can be avoided. This technology is often not considered in design because the designer is unaware of the potential of certain kinds of failure. Once these failures are observed in maintenance, appropriate changes can be instituted. Experience shows that most failures originate because of one of the conditions listed on Figure 9. Much more research is necessary to develop components more tolerable to these conditions and make failure control information available to designers and maintenance personnel so that an effective information linkage is established.

MAINTENANCE TECHNOLOGY CONCEPT

The Maintenance Technology Concept is a scientific approach to failure prevention and maintenance improvements. It stresses the continual application of demonstrated technology and recognizes a multi-disciplinary requirement shown on Figure 10 and involves structures, materials, tribology, corrosion, preservations, fracture mechanics, diagnostics, life predictions, repair processes, quality assurance and the life cycle phases of machinery. Failure prevention and effective maintenance based on this concept emphasizes:

- Research and development clearly focused on maintenance objectives.
- Performance information data base retrievable for design and management decisions.
- Implementation of new technology for performance upgrading and durability.
- In-situ structural monitoring.
- Non destructive inspections.
- Assessment of failure process - standardized classification and description.
- Assessment of repair process including repair verification.

The comprehensive plan for the Maintenance Technology Concept includes requirements for: