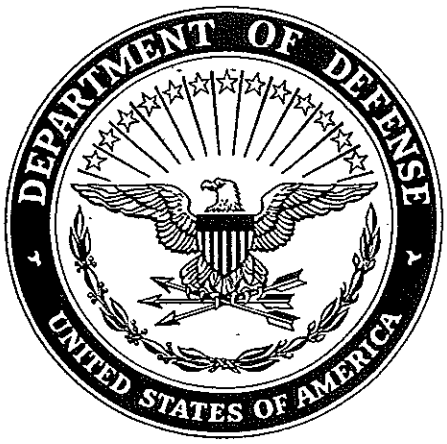

DEPARTMENT OF DEFENSE

TECHNICAL ASSESSMENT

REPORT ON THE INQUIRY ON MAGNETIC PARTICLE INSPECTION FOR NON-DESTRUCTIVE TESTING

REPORT NO. 92-133 SEPTEMBER 2, 1992

Office of the Inspector General

The following acronyms are used in this report

MIL-STD.....Military Standard
USAMTL.....U.S. Army Material Technology Laboratory
ASTM.....American Society for Testing and Materials
SAE.....Society of Automotive Engineering
AMS.....Aerospace Materials Specifications
NIST.....National Institute for Standardization and Technology
AFB.....Air Force Base

INSPECTOR GENERAL
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REPORT NO. 92-133 September 2, 1992

MEMORANDUM FOR INSPECTOR GENERAL, DEPARTMENT OF THE ARMY

SUBJECT: Report on the Inquiry on Magnetic Particle Inspection for Non-Destructive Testing (Project No. 2PT-5001)

This report has been prepared in response to a request by Congressman David Dreier of California to assess allegations made by one of his constituents that a proposed revision to a Military Standard, MIL-STD-1949, "Magnetic Particle Inspection for Non-Destructive Testing," was flawed. The allegations stated that the Government organization responsible for issuing MIL-STD-1949 did not have the facilities and qualified personnel to review the specification and to validate or negate comments received concerning MIL-STD-1949. The author of the allegations also stated that the Department of Defense plans to replace some military standards with what he called "consensus documents". He believed the implications of these plans should be explored further.

The assessment was conducted from October 14, 1991 to April 6, 1992. Our overall objectives were to determine the validity of the allegations and to determine if proper procedures were being followed in the review and validation of MIL-STD-1949. The current version, MIL-STD-1949A, was issued in May 1989 and has been accepted by the Department of Defense and the Non-Destructive Testing community.

We interviewed the author of the allegations; personnel in the Engineering Standardization Branch of the U.S. Army Material Technology Laboratory (USAMTL), the proponent of MIL-STD-1949; and other experts on Magnetic Particle Inspection. We also reviewed applicable documentation.

Not all of the allegations could be substantiated; however, we found several valid points that resulted in recommendations. These recommendations are directed toward improving the efficiency and range of applicability of Magnetic Particle Inspection which should improve the government standard.

Our inquiry disclosed problems with the still-current MIL-STD-1949A and with the third draft version of a revision, called MIL-STD-1949B. Test results, using the latest version of MIL-STD-1949, may not show all detectable flaws. We recommended that the Commander, USAMTL, immediately issue an addendum to MIL-STD-1949A, highlighting the problem areas and alerting the user community to potential problems with use of the illustrations and formulas that could lead to erroneous test results. We also recommended replacing the illustrations and formulas with the correct method of calculation.

Because no study has ever been undertaken to determine the effectiveness of MIL-STD-1949, application of the standard may result in a wide difference in the probability of detection of flaws. We recommended that the Commander, USAMTL, prepare a prioritized list of the identified research efforts, conduct the necessary research, and develop an improved standard. We also recommended that the Commander, U.S. Army Laboratory Command, identify funding for the research efforts necessary to improve MIL-STD-1949.

We could not substantiate the allegation that the Government does not have facilities and qualified personnel to validate the standard. Although some of the Government equipment is not state-of-the-art, we determined that it is adequate to perform validation. We also determined that the Government has qualified personnel to validate the standard.

The courtesies extended to the staff during the inquiry are appreciated. Management comments on the draft report recommendations were responsive and further comments are not required. The agreed-upon actions will be tracked and verified by the Assistant Inspector General for Analysis and Followup. If you have any questions concerning the report, please contact Mr. Kenneth H. Stavenjord on (703) 614-6297 or Mr. Jacob E. Rabatin on (703) 614-6300.

Robert J. Lieberman
Assistant Inspector General
for Auditing

Enclosure

cc:

Commander, U.S. Army Materiel Command
Commander, U.S. Army Laboratory Command

REPORT ON THE INQUIRY ON MAGNETIC PARTICLE INSPECTION FOR NON-DESTRUCTIVE TESTING

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Prepared by:
Technical Assessment Division
Project No. 2PT-5001

REPORT ON THE INQUIRY ON MAGNETIC PARTICLE INSPECTION FOR NON-DESTRUCTIVE TESTING

PART I -INTRODUCTION

Background

This report has been prepared in response to a request by Congressman David Dreier of California to assess allegations made by one of his constituents that MIL-STD-1949, "Magnetic Particle Inspection for Non-Destructive Testing," was flawed. Magnetic Particle Inspection is a non-destructive test method for detecting flaws in magnetic materials. It is widely used throughout the Department of Defense at rework facilities and manufacturing facilities for inspection and acceptance of material that is used in critical applications.

The allegations presented to Congressman Dreier pointed out areas that were considered to have technical errors and others that were judged to be worthy of further study to strengthen MIL-STD-1949. The author of the allegations stated that the Government organization responsible for issuing MIL-STD-1949 did not have the facilities and qualified personnel to review the specification and to validate or negate comments received concerning MIL-STD-1949. He also stated that the Department of Defense plan, to replace military standards with consensus documents, should be explored further.

The original version of MIL-STD-1949 was issued August 1985, and the current version, MIL-STD-1949A, was issued in May 1989. MIL-STD-1949A is in the process of being replaced by the American Society for Testing and Materials (ASTM) document, ASTM E1444, which is an exact duplicate with the exception that it is in the ASTM format. The Society of Automotive Engineers (SAE) is now rewriting the Aerospace Materials Specification (AMS) document, AMS 2640J, to duplicate MIL-STD-1949A. These documents have been accepted by the Department of Defense, many Defense contractors, ASTM, and SAE.

Objectives and Scope

Our overall objectives were to determine the validity of the allegations and to determine if proper procedures were being followed in the review and validation of MIL-STD-1949. The review was conducted by engineers assigned to the Technical Assessment Division, Office of the Inspector General, during the period October 14, 1991 to April 6, 1992.

We conducted our inquiry by interviewing the author of the allegations, personnel in the Government agency responsible for MIL-STD-1949, and other experts on Magnetic Particle Inspection. We also reviewed applicable documents.

We reviewed the procedure for updating MIL-STD-1949 used by the Engineering Standardization Branch of the U.S. Army Material Technology Laboratory (USAMTL), the proponent of MIL-STD-1949, and visited its Magnetic Particle Inspection laboratory in Watertown, Massachusetts. We discussed the concerns of the author of the allegations with personnel in the Engineering Standardization Branch.

We visited the National Institute for Standardization and Technology-Metallurgy Division, Gaithersburg, Maryland, USAMTL's chief consultant on MIL-STD-1949, and discussed its role in the validation of MIL-STD-1949.

Although not all of the allegations were found to be supportable, several have resulted in recommendations for research directed toward improving the efficiency and range of applicability of Magnetic Particle Inspection that will improve the application of MIL-STD-1949.

The results of our inquiry are presented in the following observations and recommendations. Part III of the report is a compilation of the specific allegations and our comments relating to each, some of which contain additional recommendations for improvements to the MIL-STD.

PART II - OBSERVATIONS AND RECOMMENDATIONS

OBSERVATION A

The published version of MIL-STD-1949 contains problem areas. The problem areas were due to lack of rigorous oversight, acceptance of rule-of-thumb criteria without reservation by the Magnetic Particle Inspection community, and nonrigorous calculation of some of the formulas. Use of the present version of MIL-STD-1949 without understanding that the illustrations and formulas are only approximations, useful for initial establishment of magnetization levels, could lead to failure in the detection of flaws in the test articles. Test results may not show all detectable flaws, since the proper application of the present standard depends on training of the writers and users of the test procedures.

DISCUSSION OF DETAILS

The problem areas can be placed in three categories as follows:

Oversight. MIL-STD-1949 (paragraph 5.7.3), which describes fabricated test parts with artificial discontinuities, erroneously refers to the KETOS Ring, which is not used as a test part to establish proper magnetization levels. The KETOS Ring is used for characterization of the magnetic particles used for testing. An attempt to use a KETOS Ring to calibrate a setup would result in an erroneous magnetization level. This is a simple mistake, which could lead to faulty test results, and should be corrected.

Effective Region of Inspection. Figure 3 in MIL-STD-1949, which described an offset central conductor, had no theoretical basis for stating that the effective region of inspection is equal to four times the diameter of the conductor. Figures 4 and 5, which present the effective region of inspection, did not take into account the magnetic permeability of the test article and therefore were only approximations. This condition exists because there has not been sufficient effort expended to determine the exact effective region of inspection. The rules of thumb, which were empirically developed by field experience, have been accepted without reservation by the community since the early days of Magnetic Particle Inspection. At the yearly ASTM meetings, there had been ample opportunity to correct these problem areas but they had not been addressed. Figures 3 through 5 provided guidance for those who did not have the capability to do the necessary calculations to determine the effective area of inspection. These figures were useful for a rough approximation of the effective area of inspection, but cannot be applied to the general case without an understanding of the limitations of the figures and formulas.

Nonrigorous Calculation. MIL-STD-1949 (paragraphs 5.3.1.4.1 through 5.3.1.4.4) present formulas for calculating ampere-turns

for establishing the proper magnetic field strength for testing. The problem with the formulas is that they are simplistic calculations that do not take into account the magnetic permeability of the test article and can result in over-magnetization of the part. To provide accurate results, Magnetic Particle Inspection requires careful analysis that takes into account both the magnetic properties and geometry of the part under test. The formulas were developed when Magnetic Particle Inspection was carried out more as an art than a science. Advances in the fields of materials and manufacturing have created a need to extend the formulas, thereby increasing the usefulness of Magnetic Particle Inspection.

The above problems are not acknowledged by USAMTL and have not been corrected, but USAMTL recognizes that improvements in MIL-STD-1949A are desirable to improve the efficiency, applicability and cost-effectiveness of Magnetic Particle Inspection. USAMTL acknowledged only minor typographical errors, which are being corrected.

Use of the present version of MIL-STD-1949 without question could lead to failure in the detection of flaws in the test articles. Test results may not show all detectable flaws, since the proper application of the present standard depends on training of the writers and users of the test procedures.

RECOMMENDATIONS FOR CORRECTIVE ACTION

We recommend that the Commander, USAMTL:

1. Immediately issue an addendum to MIL-STD-1949 highlighting the above areas and alerting the user community to potential problems with use of the illustrations and formulas, when they do not apply, that could lead to erroneous test results.

2. Replace the above illustrations and formulas with the correct method of calculation for the effective area of inspection and the correct magnetization levels when the necessary work has been done to correct the problem areas.

MANAGEMENT COMMENTS

The Director, USAMTL, concurred in principle with Recommendation A.1. MIL-STD-1949A is in the cancellation process. Its proposed replacement document, ASTM E1444, has been issued by the American Society for Testing and Materials. Revisions to ASTM E1444 covering the problem areas of oversight, effective region of inspection, and nonrigorous calculation, as discussed in the draft report, were submitted by USAMTL personnel to the ASTM on June 15, 1992. The ASTM will decide on the modifications for a second revision by a society ballot. The current proposed revision of ASTM E1444-91 has already passed the ASTM subcommittee ballot. Incorporation of the revision is expected

to be accepted without delay. Should MIL-STD-1949A not be promptly canceled, an addendum to the standard will be issued as outlined in the enclosure (Appendix B - Management Comments from Department of the Army).

The Director, USAMTL, concurred in part with Recommendation A.2. and stated that the present method of calculation is the best available. However, once the pertinent research covered by Observation B is completed, revised illustrations and formulas will be submitted to the ASTM correcting or changing the method of calculation for the effective area of the inspection and magnetization levels for incorporation in ASTM E1444.

RESPONSE TO MANAGEMENT COMMENTS

The USAMTL actions in revising ASTM E1444 meet the intent of the recommendation A.1. USAMTL has submitted the recommended revisions to ASTM. The ASTM decision will not be known prior to January 1993. However, since ASTM documents are not under Government control, we suggest USAMTL ensure that the modifications are incorporated into the next revision of ASTM E1444 before accepting it as a replacement for MIL-STD-1949. Should MIL-STD-1949 be used for more than a year, or should the proposed revision of ASTM E1444 not be accepted, we suggest the proposed addendum be added to all copies of MIL-STD-1949A and ASTM E1444-91 for DoD users.

The USAMTL's proposed action also meets the intent of the recommendation A.2.

OBSERVATION B

The Magnetic Particle Inspection field requires more research to make MIL-STD-1949 a definitive document. While it is definitive concerning the requirements for procedures used to perform Magnetic Particle Inspection, the requirements for quality control, the manner in which records are to be kept, and the way in which inspected parts are to be identified, it does not address nor reference limitations inherent in application of Magnetic Particle Inspection based on MIL-STD-1949. Because no study has ever been undertaken to determine the effectivity of MIL-STD-1949, application of the standard may result in a wide difference in the probability of detection of flaws.

DISCUSSION OF DETAILS

MIL-STD-1949 provided guidelines or instructions for writing test procedures. Each Magnetic Particle Inspection case required the inspector to develop a test procedure to achieve the probability of flaw detection specified by the designer of the part. This may result in a wide difference in the probability of detection of flaws, depending on the capabilities of the writer of the test procedure and performer of the testing. The last study of effectivity of Magnetic Particle Inspection was performed in 1973 prior to the issuance of MIL-STD-1949. It is not known if MIL-STD-1949 has corrected the cause of poor performance found by the 1973 study since no test had been conducted based on it.

MIL-STD-1949 did not provide guidance for reviewing the test procedures generated by the magnetic particle inspectors to determine if the probability of detection being achieved with those procedures met the requirements for flaw detection. In order to determine if the procedure is effective, the test must be conducted. The designer of a part must make the determination of flaw tolerance and then determine what sort of non-destructive testing is required. To provide a benchmark the designer can use to determine if Magnetic Particle Inspection will be effective in finding flaws, MIL-STD-1949 should provide guidance as to the range of flaws that might be expected to be found using Magnetic Particle Inspection.

Magnetic Particle Inspection is one of the most extensively used non-destructive techniques. USAMTL's experience with MIL-STD-1949 and the work of many individuals have emphasized that there are many areas where DoD could do useful research on Magnetic Particle Inspection to enhance its performance. USAMTL personnel recognize the need for further research and have suggested the following near-term research projects on Magnetic Particle Inspection.

1. Develop improved and reliable methods for the characterization of magnetic particle materials.

One defect in the current method for characterizing particles is that fluorescent brightness is not checked under standardized conditions.

2. Develop methods for specifying the surface condition of the test article that will meet all required acceptance criteria.

The detection threshold of magnetic particle inspection varies significantly with the surface texture. The general requirement that the surface be "essentially smooth, clean, dry, and free from oil, scale, or other contaminants" is not a sufficient precaution. This is especially crucial for weld inspection. Surface condition may also affect whether or not shims can be effectively used to establish correct magnetization.

3. Develop criteria for relating magnetic properties to defect detectability.

The only current requirement is that parts be ferromagnetic. This is not sufficient according to several experts. A data base should be produced giving the magnetic properties of steel as a function of composition and thermomechanical treatment and the magnetization levels required on each to meet given acceptance criteria. Required magnetization levels depend on many details of the ferromagnetic properties, and according to experts, some ferromagnetic materials cannot be effectively inspected using Magnetic Particle Inspection.

4. Perform fundamental studies on how the leakage field, particle size and shape, bias field, and particle and part retentivity, interact to form and hold magnetic particles in place.

The results would be used to define a performance standard for Magnetic Particle Inspection.

5. Investigate the use of Hall Effect probes to measure both field intensity and direction under dynamic conditions.

The results would be used to specify magnetization levels, direction, and waveforms for ac, dc, and multidirectional magnetization techniques.

6. Develop computer techniques to specify magnetization levels.

Correct magnetization levels for a part of any geometry can be calculated using finite element analysis coupled with a detailed knowledge of material magnetic properties.

7. Develop performance standards and improved methods for characterizing shims.

Properly calibrated shims would enhance performance of magnetic particle inspection by assuring the proper level of magnetization of parts with complex geometries.

8. Develop improved guidelines to use for acceptance requirements.

The flaw detection capability of Magnetic Particle Inspection for materials would be specified so that performance can be predicted with confidence.

The foregoing list, while not exhaustive, provides an insight into areas of research that would aid the understanding of the Magnetic Particle Inspection technique. At present, the Magnetic Particle Inspection field depends heavily on rules of thumb developed over many years. Use of the present version of MIL-STD-1949 results in too much uncertainty regarding the results of the testing. While training of the inspectors and developers of test procedures has helped to produce more dependable results, a more definitive document would enhance the quality of the process.

RECOMMENDATIONS FOR CORRECTIVE ACTION

1. We recommend that the Commander, USAMTL, in conjunction with the National Institute for Standardization and Technology, prepare a prioritized list of the eight identified research efforts, conduct the necessary research, and develop an improved standard that will enhance the understanding of and implement a precise scientific approach to the Magnetic Particle Inspection field.

2. We recommend that the Commander, U.S. Army Laboratory Command, identify funding for the research efforts necessary to improve MIL-STD-1949.

MANAGEMENT COMMENTS

The Director, USAMTL, concurred in part with Recommendation B.1. USAMTL, in conjunction with the National Institute for Standardization and Technology (NIST), has prioritized the list of eight identified research efforts recommended in the draft report. The research projects compiled by NIST constitute important work needed to improve the theory and understanding of Magnetic Particle Inspection; however, there is no guarantee that the work will improve the probability of detection, which is the key to successful testing. USAMTL cannot consider the research a near-term effort. Most of the research will require the long-term commitment of highly trained personnel. Current testing procedures outlined in MIL-STD-1949A or ASTM E1444-91 are satisfactory for most users, and USAMTL has received no reports

of failures traceable to errors or lack of clarity in MIL-STD-1949. Responsible USAMTL personnel believe that the proposed research should be accomplished on a time available, funding available basis, and extend over several years. The proposed projects are no more important than many other projects in other fields being worked on by USAMTL personnel. Since new funding will be needed, USAMTL will estimate the levels of funding and time needed for the research and forward the estimates to the U.S. Army Laboratory Command for funding consideration by July 31, 1992.

The Director, U.S. Army Laboratory Command, concurred in principle with Recommendation B.2. Upon receipt of USAMTL estimates of the levels of funding and time needed for the research to make improvements in ASTM E1444 (MIL-STD-1949), the U.S. Army Laboratory Command will consider whether to fund the research within the overall context of laboratory priorities.

RESPONSE TO MANAGEMENT COMMENTS

Regarding Recommendation B.1, the USAMTL will estimate the levels of funding and time needed for the research and forward the estimates to the U.S. Army Laboratory Command for funding consideration. This action meets the intent of the recommendation. The comments on Recommendation B.2. were also responsive.

PART III - ALLEGATIONS AND REVIEW COMMENTS

ALLEGATION 1.

MIL-STD-1949B (3rd submission for approval) is flawed. In letters to USAMTL, dated August 31, 1988, and May 24, 1991, and during our interview, the author of the allegations pointed out several flaws in MIL-STD-1949 that he considered to be of vital importance. The flaws are described below along with the results of our review.

1.A LIGHTING INTENSITIES. The author of the allegations believed lighting intensity was one of the most important parameters for Magnetic Particle Inspection. He referred to Rummel's work, "Reliability of Non-destructive Inspection of Aircraft Engine Components, January 1984," at Kelly Air Force Base and his own 30 years of experience to show that the black light intensity at the examining part's surface should be specified at 3000 uW/cm^2 (microwatts per centimeters squared) instead of 1000 uW/cm^2.

1.A REVIEW COMMENTS. We found that the black light intensity of 1000 uW/cm^2 is the minimum intensity required. In establishing the minimum requirements for black light intensities, a large number of factors must be considered. An important factor is the black-light-to-visible-light intensity ratio, since too great a level of visible light will mask the fluorescence of the magnetic particles. This is, however, not the only factor. The maximum useful black light intensity is about 4000 uW/cm^2. At this level, the fluorescent dyes become saturated, and a further increase in black light intensity gives no increase in defect visibility. As the black light intensity is increased, the amount of black light reflected into the observer's eye increases, causing the eye itself to fluoresce, thereby reducing the visibility of fluorescent indications. Therefore, the optimum value lies somewhere between 1000 and 4000 uW/cm^2, and the optimum value will depend on a large number of factors, the three most important being: surface reflectivity of the test article, placement of the light source with respect to the article, and the inspector's visual acuity.

The American Conference of Governmental and Industrial Hygienists has recommended that, for safety considerations, the level of intensity on the human eye and skin should not exceed 1000 uW/cm^2. MIL-STD-1949 is intended to provide guidance on the minimum black light level. However, MIL-STD-1949 does not prohibit use of higher black light intensity, as long as the proper precautions are taken to preclude health hazards.

We recommend that a statement be included in MIL-STD-1949 mentioning the use of higher than minimum black light intensity and warning of the potential health hazard.

1.B PARTICLE CONCENTRATION. The author of the allegations stated that, based on his own and many others' experiences, the best Magnetic Particle Inspection results occur when the wet particle concentration is less than .03 mL. The number of particles available at the point of inspection should be consistent and maintained within narrow limits for the method to be reproducible. The current MIL-STD-1949 range of .01 to .04 mL was attributed to the objection by some manufacturers who did not want to change their procedures.

1.B REVIEW COMMENTS. USAMTL personnel agreed that the number of particles should be consistent and maintained within narrow limits. However, the range is only a guide, and the individual users can specify a value in their test procedures based on their experience and need. The MIL-STD-1949 range of .01 to .04 mL was also attributed to the difficulty of maintaining wet particle concentration at a fixed value.

The present allowable range of .01 to .04 mL is appropriate, but we recommend that a cautionary statement be included warning the inspector of the possibility of masking flaws when use of the upper level of the concentration is specified.

1.C MULTIDIRECTIONAL MAGNETIZATION. The author of the allegations indicated that state-of-the-art multidirectional magnetization equipment is readily available. He mentioned a multidirectional magnetization machine that used an adjustable magnetic yoke, rather than the coil that has been the standard device for many years, to produce the longitudinal field. The author indicated that by using the combination of proper multidirectional magnetization equipment and shims at critical spots on a test article, one can achieve much better and quicker results. The author alleged that MIL-STD-1949 did not attempt to take advantage of the state-of-the-art equipment in multidirectional magnetization, even though the state-of-the-art equipment offers higher probability of detecting flaws.

1.C REVIEW COMMENTS. The current multidirectional magnetization method is acceptable. However, use of existing equipment could require more time to perform multidirectional magnetization testing. The shims serve a very useful purpose in helping to establish the proper magnetization levels, since the shims follow the contour of a test article's surface and in many cases can produce better defect detection results. However, with proper care, the tester can achieve acceptable results without using state-of-the-art multidirectional magnetization equipment and shims. USAMTL personnel have no objection to the Government obtaining state-of-the-art Magnetic Particle Inspection equipment, but cautioned that cost-effectiveness must be considered. The author of the allegations made a useful point; however, MIL-STD-1949 allows the individual user to select equipment and use of shims. We have no recommendation concerning this area.

1.D MAGNETIC FIELD STRENGTH. The author of the allegations stated that the MIL-STD-1949 range of 30 to 60 Gauss field strength is definitely menacing to the inspection of high-strength steels since the high field value will cause masking of the defect indication. He maintained that a value of 5 to 15 Gauss is usually ample for acceptable performance. He also alleged that the 30 to 60 Gauss range is arbitrary, old, and lacks technical backup.

1.D REVIEW COMMENTS. We found the range of magnetic field strength given in MIL-STD-1949 is marginally helpful when the tester attempts to establish the proper magnetization by not using test parts but relying on a gaussmeter alone. If the magnetic field strength is too low, defects will not appear. If it is too high, an obscuring background could form. Therefore, selection of the proper magnetic field strength depends on the tester's expertise. If the tester finds that 30 Gauss is too much, MIL-STD-1949 allows the use of test parts to verify that lower levels of magnetization will meet acceptance requirements. A data base that gave minimum and maximum Gauss levels for each type of steel and heat treatment would aid in providing uniform test results; however, such a data base is not available at this time. Recommendations under Observation B address this issue.

1.E COATINGS. The author of the allegations indicated that since a coating on test articles can cause a requirement for greater magnetic field strength, over-magnetization (which tends to mask defects) is likely to occur. In order to achieve better results, use of a shim should be specified.

1.E REVIEW COMMENTS. We found that, in order to achieve best test results, shims must be in intimate contact with the surface of the test article. This is sometimes impractical because the coating adds a layer between the shim and the part's surface. Since Magnetic Particle Inspection is not a precise science, questions relating to shim calibration may be appropriate when use of a shim is specified in this situation. Recommendations under Observation B address this issue.

1.F MATERIALS. The author of the allegations indicated that the KETOS Ring is useful only for comparison purposes on magnetic particles and not for Magnetic Particle Inspection calibration. MIL-STD-1949 references the KETOS Ring as a setup tool but does not indicate the type and material alloy composition of the ring. KETOS Rings now being used give varying indications because no standard ring has been adopted. Therefore, Table 1 in MIL-STD-1949 has no supporting data and should not be included.

1.F REVIEW COMMENTS. According to USAMTL, the KETOS Ring and Table 1 are necessary components of the specification. It has been known for some time that more holes can be detected on some KETOS Rings than on others. However, the USAMTL position is that this does not invalidate the usefulness of KETOS Rings in the

quality control of magnetic particles. There are two developments under way that should improve this condition. The Society of Automotive Engineers is preparing an annealing specification for the rings, which will reduce the current variability experienced when using the rings, and NIST is planning to issue a test ring with calibrated leakage fields as a standard reference.

The state-of-the-art in Magnetic Particle Inspection is weak in dealing with the composition and the permeability of test articles. Several experts have mentioned the need for a data base for material alloy composition and permeability of different kinds of materials. In order to be meaningful, all the test gauges (shims, Pie-field indicators, KETOS Rings, etc.) should have a standardized permeability. This is a weakness at the present time, since no data base has been established. Our recommendation for Observation B, to do basic research, is one way to alleviate this problem.

1.G OFFSET CENTRAL CONDUCTOR. The author of the allegations indicated that Figure 3 in MIL-STD-1949, which describes an offset central conductor, has no theoretical basis for supporting the statement that the effective region of inspection is equal to four times the diameter of the conductor. Therefore, Figure 3 should be deleted. For a similar reason, Figures 4 and 5 should also be deleted from MIL-STD-1949.

1.G REVIEW COMMENTS. USAMTL personnel acknowledged that the effective region of four diameters of the center conductor is not a calculated value. It is referred to in "Principles of Magnetic Particle Inspection," by Carl Betz, which discusses Figure 3, but does not show how the value was obtained. Recommendations of Observation A address this issue.

1.H USE OF FORMULAS. The author of the allegations indicated that paragraphs 5.3.1.4.1 through 5.3.1.4.4 should be deleted. They present formulas for calculating ampere-turns to establish proper magnetic field strength for testing. The problem with the formulas is that they are basically rule-of-thumb calculations that do not take into account the magnetic permeability of the parts being tested and may result in overmagnetization.

1.H REVIEW COMMENTS. According to USAMTL, use of the formulas produce good inspections for parts of simple geometry. For parts of complex geometry, the use of a gaussmeter or test parts with known defects is more appropriate. The formulas could sometimes give a magnetic field strength that produces excessive background indications. Recommendations under Observation A address this issue.

1.I USE OF TEST ARTICLES WITH DISCONTINUITIES. The author of the allegations pointed out that MIL-STD-1949 states "A reliable method for inspection system verification is the use of representative test articles containing defects of the type, location, and size specified in the acceptance requirements." He contended that the method is not possible since all defects that are potential failures are rarely found in the same part. He suggested the use of properly configured test gauges (such as shims) as a solution to the problem.

1.I REVIEW COMMENTS. We found that the use of test articles for establishing written procedures is a valid method for assuring reliable Magnetic Particle Inspection, even though it is not a problem-free one. Shims can be used as valid gauges for establishing the machine calibration but cannot always match the real test article. A more meaningful way to test the validity of a shim is to compare the ability to see defects on a real part to the indication obtained on a shim. USAMTL personnel pointed out the need to train inspectors to write test procedures in this method. However, USAMTL does not believe it is appropriate to use MIL-STD-1949 as such a training method. Recommendations under Observation B address this issue.

1.J DEMAGNETIZATION OF MAGNETIC PARTICLES. The author of the allegations indicated that MIL-STD-1949 section 5.7.4.1.1 suggests demagnetizing the magnetic test particles prior to determining particle concentration by means of the settling test. He believes if the particles have a residual magnetic field, they are already defective and should be discarded.

1.J REVIEW COMMENTS. USAMTL personnel indicated that the particles used in Magnetic Particle Inspection do not have zero retentivity, and we found no test for retentivity of particles in the requirements. USAMTL personnel stated that other means for establishing particle concentration are allowed if their relation to the settling test has been established. Recommendations under Observation B address this issue.

ALLEGATION 2.

The Government is ready to allow a flawed MIL-STD to be issued.

REVIEW COMMENTS. We reviewed USAMTL's internal procedures in issuing a MIL-STD. The USAMTL personnel first sent out the proposed MIL-STD to industry and Government for comment. After comments were collected and studied, USAMTL personnel called a meeting of the ASTM Committee to discuss and vote on the issues. The comments voted favorably are incorporated into the next MIL-STD-1949 draft. Many comments received from the author of the allegation had been discussed as part of this process.

USAMTL has the approval and issuing authority for MIL-STD-1949. MIL-STD-1949B is in the third draft, and there are some unresolved issues. There is no estimated publication date. USAMTL stated that the ASTM Magnetic Particle Inspection standard currently under development might be used instead, and MIL-STD-1949 may be canceled.

We concluded that the procedure being followed by USAMTL would be reasonable and may eventually result in a good document being published. But, we take exception to the length of time that the process is taking and the potential for errors in the inspection process that may occur until the document is corrected. The original version of MIL-STD-1949 was released in 1985, the A version in 1989, and the B version has been under consideration and has had three draft versions as of May 1991. The changes that have been incorporated since the original version was released have been minor and did not correct the issues pointed out in this report. Recommendations under Observations A and B address this issue.

ALLEGATION 3.

The author of the allegations stated that the Government organization responsible for MIL-STD-1949 does not have the facilities to validate the standard. The Government does not have personnel to validate or negate comments that may be received on Magnetic Particle Inspection. The Government has not taken advantage of studies that can improve test reliability. He stated that this is based on his experience with Government personnel, years of observation, and knowledge about Government facilities.

REVIEW COMMENTS. We found that there are two Magnetic Particle Inspection facilities at USAMTL. One is located in the Material Reliability Division, and the other is located in the Magnetic Particle Inspection school. In addition to the facilities at USAMTL, the Magnetic Particle Inspection facility at NIST is also available for use. Based on our observation and discussion with responsible Government personnel, we determined that, although the equipment is not state-of-the-art, it is adequate to perform validation. Other private organizations have helped in the validation process even though they have no contract with the Government.

During our visit to USAMTL, we were introduced to three Magnetic Particle Inspection experts, all of whom are qualified at level 3, the highest level in the profession. Part of their job is validation of comments received concerning Magnetic Particle Inspection and training new inspectors in the USAMTL Magnetic Particle Inspection school. The NIST Metallurgy Division is USAMTL's chief consultant and participates in validation.

Minutes from several ASTM meetings showed that comments, relating to MIL-STD-1949, from the author of the allegations and others were discussed and either were incorporated or rejected. Based on our discussion, we believe the Government has personnel to review the studies from various sources and to validate or negate any comments that may be received. However, since current knowledge on which Magnetic Particle Inspection is based is inadequate, we have recommended further study in recommendations under Observation B.

ALLEGATION 4.

MIL-STD-1949B as written should result in a 75-percent probability of detection of flaws with a 50-percent confidence level. This is not satisfactory to the author of the allegation. He stated that the last version B had degraded to a point where one could practically guarantee less than 50-percent average probability of detection of flaws. He believes that the average probability of detecting flaws should be in the range of 85 to 90-percent.

REVIEW COMMENTS. The proposed probability of detection and the confidence level are based on personal observations of the author of the allegations. He did refer to a round robin test study conducted by the Air Force in 1973 that was reported in the Gulley paper, "TM AFML/MX 73-5, AF Materials Laboratory, System Support Division, Wright-Patterson AFB (Air Force Base), OH." The testing was conducted in accordance with Military Instruction MIL-I-6868, which is the predecessor to MIL-STD-1949. The conclusion of the study was that the probability of detection of flaws was about 47-percent. Twenty-four articles were tested at Wright-Patterson AFB to establish the total number of flaws. The test articles were then given to 11 manufacturers who performed Magnetic Particle Inspection in accordance with their own test equipment and internal procedures. The highest percentage of flaws detected was 90-percent, and the lowest was 18-percent. The average was 47-percent. The study indicated that the state-of-the-art knowledge was underapplied by all but one of the participants.

USAMTL personnel indicated that if MIL-STD-1949 has raised the probability of detection from 47-percent to 75-percent, something significant has been accomplished. The USAMTL position is that a probability of detection cannot be established in any reasonable way for the standard as a whole. USAMTL personnel stated that probability of detection is more appropriately determined in relation to a specific written test procedure applied to a specific part.

MIL-STD-1949 is useful only as a guideline. It is up to each acceptance test organization to develop its own internal test procedure and acceptable probability of detection for a specific part. Recommendations under Observation B address this issue.

ALLEGATION 5.

The Government will issue MIL-STD-1949B, which will be a consensus document, but not a well-prepared military document. A well-prepared military document can serve the DoD better.

REVIEW COMMENTS. Both the author of the allegations and USAMTL agreed that MIL-STD-1949 is a consensus document. USAMTL personnel acknowledged that use of MIL-STD-1949 does not ensure that a precise probability of detection will be measured and achieved, but stated that it is the best that can be done with the present knowledge. USAMTL also pointed out the difficulty of working out a consensus among all interested parties. USAMTL is planning to participate in generating a new commercial standard that will be formatted for an ASTM Magnetic Particle Inspection ballot. If the new document is acceptable to the ASTM community, a commercial Magnetic Particle Inspection standard will replace MIL-STD-1949.

While the process being used by USAMTL for updating and improving MIL-STD-1949 may eventually result in a document that is without problems, the rate that changes are being incorporated has proved to be extremely slow. Until the recommendations to Observation B are completed and incorporated, the commercial standard will be equivalent to and not a major improvement to the existing MIL-STD.

ALLEGATION 6.

Government personnel are compromising severely with people that have no experimental data to support their position. USAMTL personnel have given in to political pressures.

REVIEW COMMENTS. USAMTL and NIST personnel indicated that most of the data contained in MIL-STD-1949 is backed up by scientific journals but admitted that some of the data in MIL-STD-1949 are residual from the original document.

The Government intention was to improve the document gradually. When the new MIL-STD-1949 revision is published, in accordance with our recommendations, many disputed areas will be addressed. After reviewing the procedures being followed by USAMTL personnel, we saw no evidence of political pressure on them regarding the contents of MIL-STD-1949.

APPENDIX A: LETTER FROM CONGRESSMAN DAVID DREIER

Congress of the United States
House of Representatives
Washington, DC 20515
July 26, 1991

Ms. Susan Crawford
Inspector General
Department of Defense
400 Army Navy Drive
Arlington, Virginia 22202

Dear Susan:

The attached communication from my constituent is sent for your consideration. Please investigate the statements contained therein and forward me the necessary information for reply, returning the enclosed correspondence with your answer. Please mark the materials to the attention of Doug Riggs.

Thank you for your time and assistance.

Sincerely,

David Dreier
Member of Congress

DD:dr
Enclosure

411 CANNON BUILDING
WASHINGTON, DC 20515
(202) 225-2305

112 NORTH SECOND AVENUE
COVINA, CA 91723
(818) 339-9078
(714) 882-2887

DEPARTMENT OF THE ARMY
OFFICE OF THE ASSISTANT SECRETARY
WASHINGTON, DC 20310-0103

SARD-DE

June 22, 1992

MEMORANDUM FOR CHIEF, OPERATIONS DIVISION, ATTN SAIG-PA, OFFICE OF THE INSPECTOR GENERAL

SUBJECT: Draft Report on the Inquiry on Magnetic Particle Inspection for Non-Destructive Testing (2PT-5001)

I reviewed the subject report and the Army Materiel Command (AMC) position on its disposition. I concur with AMC's response and proposed corrective actions to the allegations.

My point of contact is Robert Jordan, 703-695-3515.

Stephen R. Burdt
Director for Program Evaluation

DEPARTMENT OF THE ARMY
HEADQUARTERS, U.S. ARMY MATERIEL COMMAND
5001 EISENHOWER AVENUE, ALEXANDRIA, VA 22333 - 0001

REPLY TO ATTENTION OF

AMCIR-A (36-2b) 12 June 1992

MEMORANDUM FOR HQDA(SAIG-PA) WASH DC 20310-1700

SUBJECT: DODIG Draft Report, Inquiry on Magnetic Particle Inspection for Non-Destructive Testing (AMC No. D9235)

1. We are forwarding the position on subject report IAW AR 36-2. We concur with actions taken or proposed by LABCOM.

2. Point of contact for this action is Mr. Robert Kurzer, 703/274-9023.

3. AMC — America's Arsenal for the Brave.

William B. McGrath

WILLIAM B. McGRATH
Major General, USA
Chief of Staff

Encl
as

DEPARTMENT OF THE ARMY
HEADQUARTERS, U.S. ARMY LABORATORY COMMAND
2800 POWDER MILL RD., ADELPHI, MD 20783-1145

REPLY TO
ATTENTION OF

AMSLC-IR (36-2b) 2 June 1992

MEMORANDUM FOR Commander, U.S. Army Materiel Command,
ATTN: AMCIR-A, 5001 Eisenhower Avenue,
Alexandria, VA 22333-0001

SUBJECT: Draft Report on the Inquiry on Magnetic Particle Inspection for Non-Destructive Testing (Project No. 2PT-5001)

1. Reference memorandum, Department of Defense Inspector General, 16 Apr 92, SAB.

2. The subject report has been reviewed by responsible personnel at the U.S. Army Materials Technology Laboratory and at this Headquarters. Our response and proposed position on observations A and B in the report are at enclosures 1 and 2.

for PATRICK J. KELLY
Major General, USA
Commanding

2 Encls

CF:
AMSLC-AT (Mr. Zastrow)
SLCMT-D
SLCMT-MEE
SLCMT-IR

PROPOSED COMMAND REPLY
DODIG Draft Report Project No. 2PT-5001
Inquiry on Magnetic Particle Inspection
for Non-Destructive Testing

Observation A: The published version of MIL-STD-1949 contains problem areas. The problem areas were due to lack of rigorous oversight, acceptance of rule of thumb criteria without reservation by the Magnetic Particle Inspection community, and non-rigorous calculation of some of the formulae. Use of the present version of MIL-STD-1949 without understanding that the illustrations and formulae are only approximations, useful for initial establishment of magnetization levels, could lead to failure in the detection of flaws in the test articles. Test results may not show all detectable flaws since the proper application of the present standard depends on training of the writers and users of the test procedures.

RECOMMENDATIONS AND COMMAND COMMENTS

Recommendation 1: We recommend that the Commander [Director], USAMTL immediately issue an addendum to MIL-STD-1949 highlighting the above areas and alerting the user community to potential problems with use of the illustrations and formulae, when they do not apply, that could lead to erroneous test results.

Action to be Taken: Concur-in-principle. MIL-STD-1949A is in process of cancellation and its replacement document E1444 has been issued by the American Society for Testing and Materials (ASTM). Revisions, which cover the problem areas: oversight, effective region of inspection and non-rigorous calculation, in the draft report, will be submitted by MTL personnel to the ASTM meeting concerning this document on 15 June 1992 for society ballot for incorporation into a second revision of ASTM E1444. The current proposed revision of ASTM E1444-91 has already passed the ASTM subcommittee ballot. Incorporation of the revisions is expected to be accepted without delay. Should MIL-STD-1949A not be promptly cancelled, an addendum to the standard will be issued as outlined in the enclosure.

Recommendation 2: We recommend that the Commander [Director], USAMTL replace the above illustrations and formulae with the correct method of calculation for the effective area of inspection and the correct magnetization levels when the necessary work has been done to correct the problem areas.

Action to be taken: Concur-in-part. The method of calculation is the best available; however, once the pertinent research covered by OBSERVATION B is completed, revised illustrations and formulae will be submitted to the ASTM correcting/changing the method of calculation for the effective area of the inspection and magnetization levels for incorporation in ASTM E1444.

Proposed Addendum

The following section should be added to all copies of MIL-STD-1949A if not cancelled in a timely fashion.

6.3 . Precautions and clarifications.

6.3.1 Use of KETOS ring. It is not the intention of 5.7.3 that the KETOS tool steel ring detailed in figure 1, or the magnetic field indicators of figures 6 and 7, be used to calibrate a setup. Magnetic field indicators should be used only as quality control tools. The KETOS ring should be used only to qualify magnetic particle materials.

6.3.2 Effective region of inspection. The effective regions of inspection shown in figures 3, 4, and 5 are only rough guides. The effective region of inspection should be verified for each specific part.

6.3.3 Use of formulae. The formulae of 5.3.1.4.1 through 5.3.1.4.4 apply only to simple geometries. For complex geometries the formulae provide only a rough guide and the actual current levels used should be verified by other methods. Care should be taken that use of the formulae does not result in over-magnetization which could mask important indications.

6.3.4 Probability of detection and proper application. No probability of flaw detection has been assigned to this standard. The proper application of this standard depends on training of the writers and users of the test procedures.

PROPOSED COMMAND REPLY
DODIG Draft Report Project No. 2PT-5001
Inquiry on Magnetic Particle Inspection for
Non-Destructive Testing

Observation B: The Magnetic Particle Inspection field requires more research to make MIL-STD-1949 a definitive document. While it is definitive concerning the requirements for procedures used to perform Magnetic Particle Inspection, the requirements for quality control, the manner in which records are to be kept, and the way in which inspected parts are to be identified, it does not address nor reference limitations inherent in application of Magnetic Particle Inspection based on MIL-STD-1949. Because no study has ever been undertaken to determine the effectivity [*sic*] of MIL-STD-1949, application of the standard may result in a wide difference in the probability of detection of flaws.

RECOMMENDATIONS AND COMMAND COMMENTS

Recommendation 1: We recommend that the Commander [Director], USAMTL, in conjunction with the National Institute for Standardization and Technology prepare a prioritized list of the eight identified research efforts, conduct the necessary research, and develop an improved standard that will enhance the understanding of and implement a precise scientific approach to the Magnetic Particle Inspection field.

Action to be Taken: Concur-in-part. MTL, in conjunction with the National Institute for Standardization and Technology, has prioritized the list of eight identified research efforts recommended in the report (see enclosure). The research projects that were compiled by NIST constitute important work needed to improve the theory and understanding of magnetic particle inspection; however, there is no guarantee that this work will improve the Probability of Detection which is the key to successful testing. MTL cannot consider this research as "near term" effort. Most of the research will require the long term commitment of highly trained personnel. The current testing procedures outlined in MIL-STD-1949A or ASTM E1444-91 are satisfactory for most users. Additionally, MTL has received no reports of any failures traceable to errors or lack of clarity in MIL-STD-1949. Responsible MTL personnel feel that the proposed research should be accomplished on a time available, funding available basis, and extend over several years. The proposed projects are certainly no more important that many other projects in other fields being worked on by MTL personnel. Since new funding will be required, MTL will estimate the levels of funding and durations needed for this research and forward those to the U.S. Army Laboratory Command for funding consideration by 31 July 1992.

Recommendation 2: We recommend that the Commander, U.S. Army Laboratory Command, identify funding for the research efforts necessary to improve MIL-STD-1949.

Action to be taken: Concur-in-principle. Upon receipt of the MTL estimate of the levels of funding and durations needed for the research to make improvements in ASTM E1444 (MIL-STD-1949), the U.S. Army Laboratory Command will consider whether or not to fund this research within the overall context of our laboratory priorities.

Research areas in order of priority. The highest priority is listed first.

1. Effect of part magnetic properties: Develop methods for relating magnetic properties to defect detectability. Produce a data base giving the magnetic properties of steels as a function of composition and thermomechanical treatment and the magnetization levels required on each to meet given acceptance criteria. The only current requirement is that parts be ferromagnetic. This is not sufficient. Required magnetization levels depend on many details of the ferromagnetic properties, and some ferromagnetic materials cannot be effectively inspected using MPI.

2. Performance standards for shims: Develop improved methods for characterizing magnetic particle shims using performance standards.

3. Methods for measurement of tangential fields: Investigate the use of Hall probes to measure both field intensity and direction under dynamic conditions. Use this as a means to specify magnetization levels, direction, and waveforms, for ac, dc, and multi-directional magnetization techniques.

4. Acceptance requirements: Provide improved guidelines to use for acceptance requirements.

5. Mechanism of magnetic particle indication formation: Perform fundamental studies on how the leakage field, particle size and shape, bias fields, and particle and part retentivity, interact to form and hold magnetic particle indications in place.

6. Magnetic particle materials: Develop improved and reliable methods for the characterization of magnetic particle materials. Make these, to the greatest extent possible, performance specifications. For example, one defect in the current methods for qualifying particles is that flourescent brightness in not checked under standard conditions.

7. Effect of surface condition: Develop methods for specifying the surface condition needed to meet a range of acceptance criteria. The detection threshold of MPI will vary significantly with the surface texture. The general requirement that the surface be "essentially smooth, clean, dry, and free of oil, scale, or other contaminants" is not a sufficient precaution. This is especially crucial for weld inspection. Surface condition also affects whether or not shims can be effectively used to establish correct magnetization.

8. Use of computer techniques to specify magnetization methods: Finite element analysis is currently developed to the stage where, when coupled with a detailed knowledge of material magnetic properties, it could be used to calculate a correct magnetization method for a part of any geometry. Inexpensive programs which run on personal computers should be possible.

APPENDIX C: REPORT DISTRIBUTION

Office of the Secretary of Defense

Under Secretary of Defense for Acquisition
Assistant Secretary of Defense (Production and Logistics)
Comptroller of the Department of Defense
Director, Defense Research and Engineering

Department of the Army

Secretary of the Army
Inspector General, Department of the Army
Assistant Secretary of the Army (Installations and Logistics)
Assistant Secretary of the Army (Research, Development and Acquisition)
Commander, U.S. Army Material Command
Commander, U.S. Army Laboratory Command

Non-Defense Activities

Office of Management and Budget
U.S. General Accounting Office, NSIAD Technical Information Center

Congressional Committees:

Senate Subcommittee on Defense, Committee on Appropriations
Senate Committee on Armed Services
Senate Committee on Governmental Affairs
Senate Ranking Minority Member, Committee on Armed Services
House Committee on Appropriations
House Subcommittee on Defense, Committee on Appropriations
House Ranking Minority Member, Committee on Appropriations
House Committee on Armed Services
House Committee on Government Operations
House Subcommittee on Legislation and National Security, Committee on Government Operations
Congressman David Dreier, House of Representatives

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Greg Donnellon, Logistics Management Specialist