

AD-A163 404

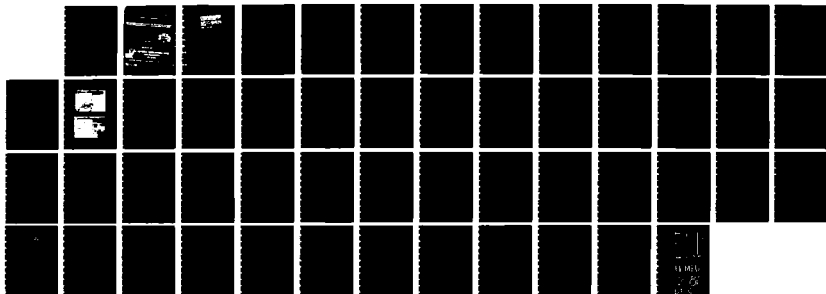
DETECTION OF CRITICAL DEFECTS IN THE 155-MM PROJECTILE  
M483A1 BY AN AUTOM (U) MASON CHAMBERLAIN INC PICAYUNE  
MS G ZANLOOT DEC 85 ARPAD-TR-85003 DAAA09-76-C-4014

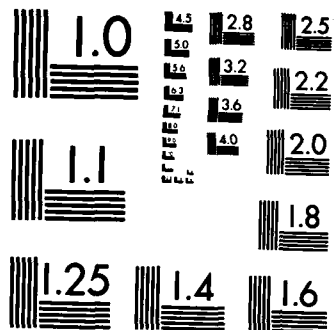
1/1

UNCLASSIFIED

F/G 19/1

NL





MICROCOPY RESOLUTION TEST CHART  
NATIONAL BUREAU OF STANDARDS-1963-A

12

AD-A163 404

AD

AD-E401 428

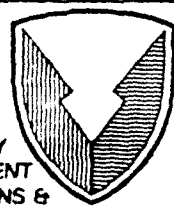
TECHNICAL REPORT ARPAD-TR-85003

**DETECTION OF CRITICAL DEFECTS IN THE 155-MM PROJECTILE M483A1  
BY AN AUTOMATED MAGNETIC FLUX LEAKAGE INSPECTION SYSTEM**

**DTIC  
ELECTE  
JAN 22 1986  
S D D**

GEORGE ZAMLOOT

DECEMBER 1985

	<p><b>U.S. ARMY ARMAMENT, MUNITIONS AND CHEMICAL COMMAND</b></p>
<p>US ARMY ARMAMENT MUNITIONS &amp; CHEMICAL COMMAND ARMAMENT RGO CENTER</p>	<p><b>PRODUCT ASSURANCE DIRECTORATE</b></p>
	<p><b>DOVER, NEW JERSEY</b></p>

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.

**DTIC FILE COPY**

**The views, opinions, and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other documentation.**

**The citation in this report of the names of commercial firms or commercially available products or services does not constitute official endorsement by or approval of the U.S. Government.**

**Destroy this report when no longer needed. Do not return to the originator.**

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER Technical Report ARPAD-TR-85003	2. GOVT ACCESSION NO. AD-A163404	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) DETECTION OF CRITICAL DEFECTS IN THE 155-mm PROJECTILE M483A1 BY AN AUTOMATED MAGNETIC FLUX LEAKAGE INSPECTION SYSTEM		5. TYPE OF REPORT & PERIOD COVERED Final May 1981 - March 1985
7. AUTHOR(s) George Zamloot		6. PERFORMING ORG. REPORT NUMBER
9. PERFORMING ORGANIZATION NAME AND ADDRESS Mason Chamberlain, Inc. Mississippi Army Ammunition Plant Picayune, MS 39466-5000 (cont)		8. CONTRACT OR GRANT NUMBER(s)
11. CONTROLLING OFFICE NAME AND ADDRESS ARDC, IMD STINFO Div (SMCAR-MSI) Dover, NJ 07801-5001		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS D/A project M4250 AMCMS Code 4250-05.4357.1 MMT project 5804357
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) AMCCOM, PAD Tech Office, Tech Br [AMSMC-QAH-T(D)] Dover, NJ 07801-5001		12. REPORT DATE December 1985
		13. NUMBER OF PAGES 54
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited.		15. SECURITY CLASS. (of this report) Unclassified
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
18. SUPPLEMENTARY NOTES This project was accomplished as part of the U.S. Army's Manufacturing Methods and Technology Program. The primary objective of this program is to develop, on a timely basis, manufacturing processes, techniques, and equipment for use in production of Army materiel. This project was awarded Government contract (cont)		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Automated magnetic flux leakage      155-mm M483A1 Inspection system                      Inspection of critical defects M483A1 projectile                      MMT-Nondestructive testing Critical defect detection AMFLIS		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Recent developments in magnetic flux leakage technology have made possible the creation of an inspection system that automatically detects and evaluates surface and subsurface defects in projectile bodies with high reliability and lower costs than competing measurement schemes. The device is capable of detecting external and internal cracks as well as metal occlusions regardless of the orientation. Operating automatically, the system can load, scan, unload, and segregate acceptable and defective parts without operator intervention. (cont)		

DD FORM 1 JAN 73 1473

EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

9. PERFORMING ORGANIZATION NAME AND ADDRESS (cont)

Magnetic Analysis Corporation  
535 South 4th Avenue  
Mt. Vernon, NY 10550

Chamberlain Manufacturing Corporation  
117 King Street  
New Bedford, MA 02745

18. SUPPLEMENTARY NOTES (cont)

DAAA09-76-C-4014 to Mason Chamberlain, Inc. with Government subcontracts from Mason Chamberlain, Inc., to Magnetic Analysis Corporation and Chamberlain Manufacturing Corporation.

20. ABSTRACT (cont)

This device has been installed at the Mississippi Army Ammunition Plant which is inspecting the M483A1 projectile body. This report details the operation of the system and presents the results of the inspections.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

## FOREWORD

Modern warfare requires that U.S. troops be capable of firing an artillery round with such accuracy and reliability that the payload of the first round fired will destroy the target. This goal has become the highest priority for the quality assurance team in the fabrication of munitions. To achieve this goal, engineering has made many innovations in the design and fabrication of projectiles (e.g., thinner walls for increased payload, smoother machined surfaces for accuracy, heat treat/stress relief processes, elimination of flaws (cracks) to prevent malfunctions, geometry changes, etc.).

The development of a nondestructive inspection (NDI) method to detect flaws reliably in a production environment is a continuing quality assurance task. The automated magnetic flux leakage inspection system (AMFLIS), one of the tools designed to achieve this task on the production line, is capable of inspecting the M483A1 projectile body reliably at a rate of approximately 125 per hour using only one inspector. The AMFLIS will provide cost savings of \$360 k per year\* over the present M483A1 inspection method at the Mississippi Army Ammunition Plant (MSAAP) which employs five inspectors at approximately 70 projectiles per hour. Under the MMT program, a project was funded to design and fabricate an AMFLIS (phase 1), perform an application test (phase 2), and deliver the AMFLIS to MSAAP for debugging and implementation on the production line (phase 3).

Accession For	
NTIS CRA&I	<input checked="" type="checkbox"/>
DTIC TAB	<input type="checkbox"/>
Unannounced	<input type="checkbox"/>
Justification .....	
By .....	
Distribution/	
Availability Codes	
Dist	Avail and/or Special
A-1	



\* Cost based on 1980 dollars.

## CONTENTS

	Page
Introduction	1
Operation	3
Mechanics of the System	5
Controls	9
Testing and Results	12
Conclusions and Recommendations	13
Appendixes	
A Excerpts from Application Test Report in 1983 for Automated Magnetic Flux Leakage Inspection System	15
B Excerpts from Final Report in December 1983 for Automated Magnetic Flux Leakage Inspection System	31
Distribution List	47

## FIGURES

1 Principles of magnetic flux leakage inspection	2
2 Shell standard zones A through H for projectile M483A1	4
3 Layout of the automated magnetic flux leakage inspection system (AMFLIS)	7
4 Automated magnetic flux leakage inspection system (AMFLIS)	8

## INTRODUCTION

The application of the magnetic flux leakage principle for flaw detection was first developed in the 1930s and was known as magnetic particle inspection (MPI). MPI is still used to inspect the M483A1 projectile body at the Mississippi Army Ammunition Plant (MSAAP). MPI applies a fine powder of iron particles to the surface of a magnetized projectile body. The particles are attracted by the magnetic field gradients in the vicinity of the flaw and tend to adhere to the surface, visibly indicating the presence of flaws. Some disadvantages of the MPI method are: (1) it requires visual (subjective) inspection of surfaces that are not readily accessible, (2) there is an absence of a permanent quantitative record of inspection, and (3) it requires a high-frequency magnetizing current which limits the method or technique capability to near-surface flaw detection.

The magnetic flux leakage technique used in the automated magnetic flux leakage system (AMFLIS) for detecting flaws (discontinuities) in the M483A1 projectile body "is based on the fact that a near surface discontinuity in the geometry of a magnetized body produces a local perturbation or flux leakage in the field just outside the surface of the body."\* The magnitude of this flux leakage field across the discontinuity/flaw is directly related to the depth of the flaw and is not limited to near surface flaws (fig. 1).

The induction of flux lines into a ferromagnetic material is termed magnetization. The various types of magnetizing methods used in the AMFLIS are related to the material and the tests which are conducted and are classified as follows:

1. Transverse Magnetization. Flux lines enter the material from one pole in a direction normal to the surface. The lines divide equally and flow circumferentially around two segments of the M483A1 shell and exit normal to the surface through a second pole directly opposite the first pole. Transverse magnetization is used to detect (intersect) longitudinal discontinuities/flaws which are parallel to the M483A1 shell axis.

2. Longitudinal Magnetization. Flux lines in the material flow parallel to the axis of the M483A1. Longitudinal magnetization is used to detect (intersect) discontinuities which are circumferential or normal to the M483A1 axis, and are called transverse discontinuities/flaws.

3. Vectored Magnetization. Flux lines in the material flow skewed to the axis of the M483A1. Vectored magnetization used to detect (intersect) transverse or circumferential discontinuities can also intersect and detect longitudinal discontinuities.

---

\* Excerpts from Southwest Research Institute Technical Report NTIAC-80-1, January 1980.

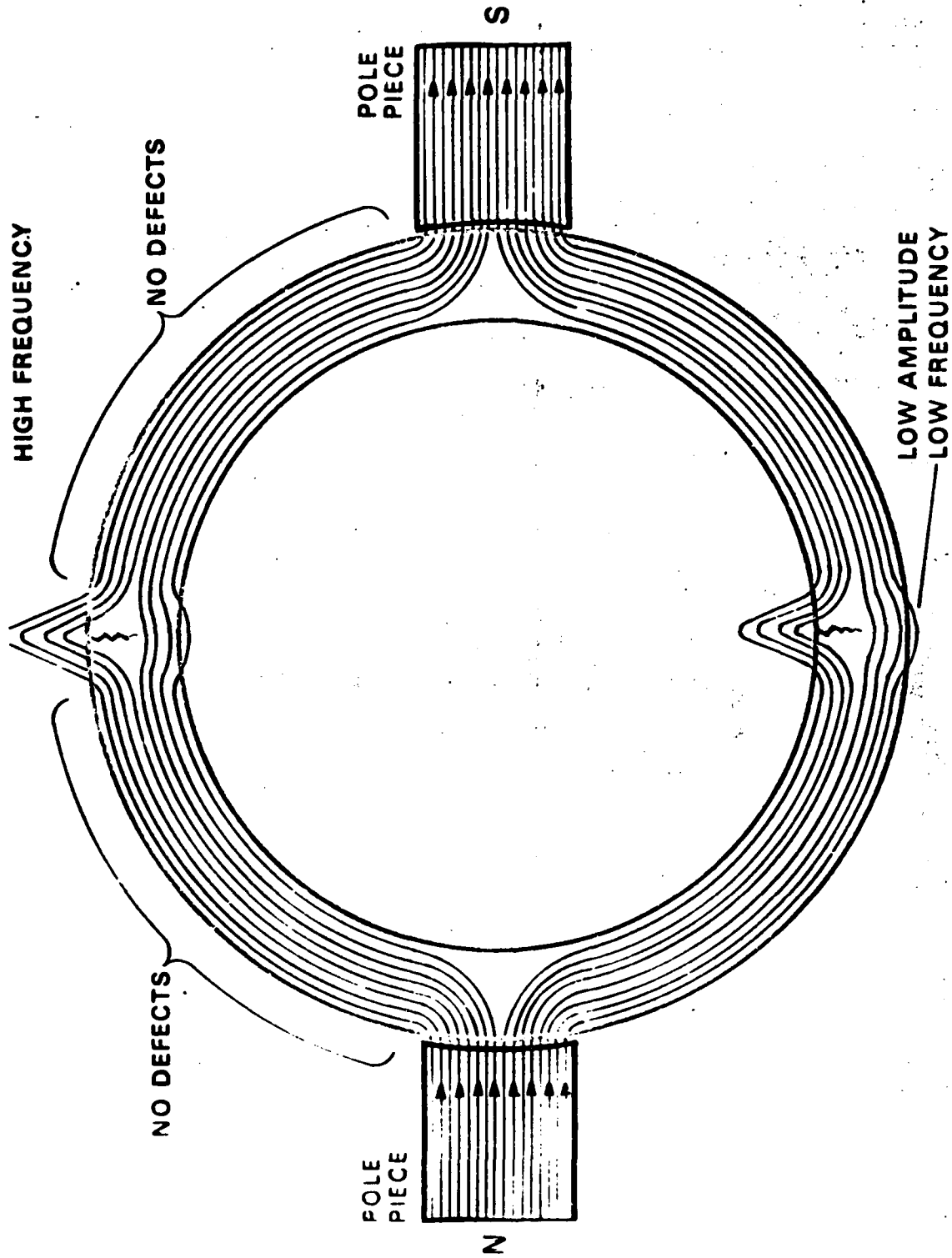


Figure 1. Principles of magnetic flux leakage inspection

Each of the above magnetization methods can be either:

1. Active, when the magnetizing force is maintained during the test, or
2. Residual, when the magnetizing force is removed during the test.

If the M483A1 body is magnetized and brought up to near saturation, both longitudinal and transverse (circumferential) discontinuities on the outside diameter (o.d.), inside diameter (i.d.), and within the walls are capable of being detected. The o.d. and i.d. defects are distinguishable by the flux leakage distribution pattern which results in a specific flaw frequency.

A flux leakage field can be detected by various types of sensors. The inductive coil sensor used by the AMFLIS is independent of temperature and supply voltage and current, and is highly stable. This type of sensor is incorporated into a multiprobe design which can take on any configuration, including the M483A1 projectile contour. Switching techniques enable the selection of the desired individual probe for zone identification as well as variable gain.

Five shell standards have been provided for setup and calibration references. Each standard contains a calibration electro discharge machined (EDM) notch of a specified length, width, and depth (determined by a fracture mechanics analysis) for each of the eight M483A1 shell zones (fig. 2). Each standard is used for initial calibration of the zone gain calibration pots for each instrument channel. The standard is manually scanned by each zone's probe group to set up the gain pots for that zone and the appropriate instrument channel(s). Once all zone gains are set, actual testing of the M483A1 shell can begin. By recording the signals from the setup on a chart recorder, it is possible to verify that each (EDM) notch standard in each zone has been adequately represented as an output threshold trigger. Repeated tests ensure that the AMFLIS remains properly calibrated.

## OPERATION

The automatic M483A1 projectile body tester is custom designed to automatically inspect and test 155-mm shell bodies, using magnetic flux leakage. The device detects metal defects exceeding specified volumetric limits, makes depth measurements, and automatically accepts or rejects the shell bodies. It uses a combination of electric motors and pneumatic cylinders to pick up the shell bodies, one at a time, from the load station, transfer them to a test station, and automatically separate them onto either an accept or a reject station conveyor.

The inspection is performed by the following groups of probes:

1. Longitudinal i.d.
2. Transverse i.d.

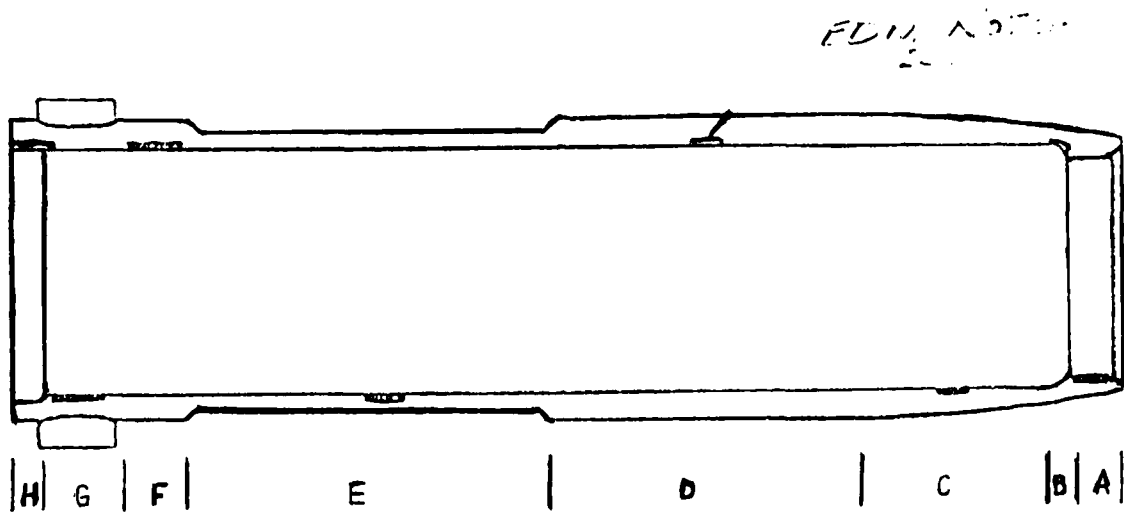


Figure 2. Shell standard zones A through H for projectile M483A1

3. Transverse o.d. moving
4. Transverse H zone-fixed (single probe)
5. Transverse o.d. A zone-fixed

Each group is designed to inspect specific areas of the shell body at pre-selected sensitivity levels. For this purpose, eight separate areas, designated A through H along the length of the shell, are inspected for defects of orientation, depth, and location (fig. 2)

The entire system is operated in an automatic or manual mode by means of an Allen Bradley programmable controller, which not only controls the mechanical movement of the shell, but also coordinates the required changes in instrument settings as the test cycle progresses.

### **Mechanics of the System**

#### **Main Test Assembly (figs. 3 and 4)**

This includes the main test assembly frame (35), the movable probe assembly (26), the magnetization assembly (7), the probe assembly drive motor (24), zone H probe assembly (32), zone A probe assembly (33), the rotary mechanism (4), rotary motor (5), and the clamp unit (13).

When a shell body is lifted into test position by one of the cradles in the load and carriage assembly, the clamp unit (13) locks the shell against the rotary mechanism (4), causing the shell to rotate. The probe assembly drive motor (24) pushes the movable probe assembly (26) and magnetization assembly (7) into and over the shell. Internal probes are mounted on a mandrel which moves through the rotary mechanism into the shell; an external probe moves along the exterior of the shell, in conjunction with two transverse and two longitudinal electromagnets which provide the varying magnetizing fields required. The zone H probe assembly (3) is pivoted into position under the base end of the shell. The zone A probe assembly (33) travels with the clamp of the clamp unit, then pivots into position under the nose of the shell. All probes are activated into test position or moved back from the shell surface by means of individual air cylinders.

The test may be performed during the forward drive of the movable probe assembly or during its retraction. When all probes are safely removed from the surface or retracted into the rotary mechanism, the cradle is raised to catch the shell and the clamp unit releases it.

Attached to the main test assembly frame are the items required for controlling and monitoring the system. A visual display board (28) shows the position of each group of probes as they travel into and over the shell. The flaw light (31) indicates detection of a flaw by flashing red. The jam light (32) indicates a malfunction with a steady red glow. Mounted on top of the

frame, both lights are visible from all sides. The main air dump valve and filter-regulator-lubricator (25), together with actuating valves for each air cylinder, are mounted generally on the left side of the frame. However, the clamp unit and zone A probe assembly have separate pressure regulation and actuating valves adjacent to each other on the right side of the frame.

### **Load and Carriage Assembly**

This includes the carriage (29) mounted on linear ball bushings and hard rails which allow it to be driven from position 1 (fig. 3) to position 2, in which the second cradle (9) is located at test position, and the first cradle (11) is located between the rolls of the main transfer conveyor (34). Each of the two cradles is driven up and down by a separate air cylinder with appropriate activating valve. This hardware travels on the main carriage. A welded frame provides the supporting structure. The incoming feed track (10) is also a part of this assembly.

Shell bodies are loaded on the inclined incoming feed track and roll into pickup position. Sensors check to determine correct position and adequate parts supply. The second cradle (9) is raised, picking the shell off the feed track. When the carriage moves, the shell is moved into test position, and another shell rolls down the feed track into load position.

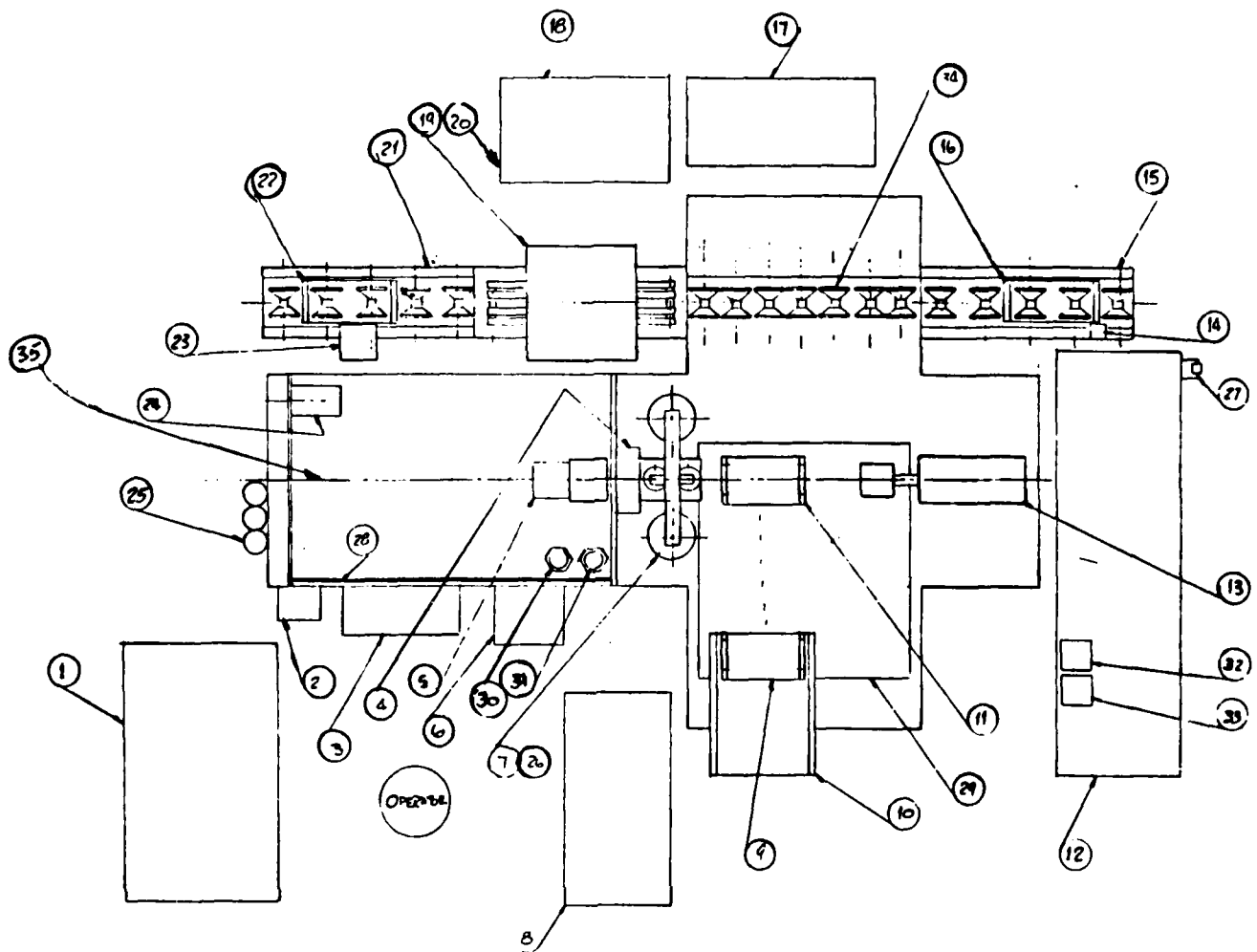
The shell previously tested is dropped into the first cradle (11), and the same shuttle movement of the carriage transfers to a position immediately above the main transfer conveyor. When the first cradle (11) is lowered, the shell rests on the conveyor rolls and is driven into the accept station or the reject station based on the test decision.

While the shell is clamped in the test position, the second cradle (9) is lowered. When both cradles are down, the carriage is driven to its initial load position. The second cradle (9) then elevates to pick the next shell from the incoming track and the other cradle (11) elevates to catch the shell released after the test.

Limit switches are mounted on the welded frame or carriage to assure that the cradles either are up or down and to confirm the location of the carriage as a precondition to the continuing cycle.

### **Accept Station Assembly**

This includes a welded steel frame with conveyor rolls (21), accept throw-off arms (22) operated by an air cylinder, and the associated actuating valve. The stamp unit (23) is mounted over the conveyor rolls so that any shell reaching the end position on the accept conveyor will be stamped before throw-off. The stamp action and throw-off action are initiated when a proximity switch senses that the shell is in correct position. An inclined chute is supplied as part of the welded frame, and accepted shells roll down this chute after throw-off.



- LEGEND:
- |   |  |
|---|--|
| 1. Dual rotoreflex instrument consoles    | 19. Demagnetization coil (model 750-3) |
| 2. Probe calibrator box                   | 20. Conveyor drive motor               |
| 3. Demagnetization control panel          | 21. Accept station                     |
| 4. Rotary mechanism                       | 22. Accept throw-off arms              |
| 5. Rotary motor                           | 23. Stamp unit                         |
| 6. Probe calibration and selection panel  | 24. Probe assembly drive motor         |
| 7. Magnetization assembly                 | 25. Air filter-regulator-lubricator    |
| 8. Control console                        | 26. Movable probe assembly             |
| 9. Cradle 1                               | 27. Main disconnect switch             |
| 10. Incoming feed track                   | 28. Visual display board               |
| 11. Cradle 2                              | 29. Carriage                           |
| 12. Main control enclosure                | 30. Jam light                          |
| 13. Clamp unit                            | 31. Flaw light                         |
| 14. Paint spray (marker unit, model 169)  | 32. Audible flaw alarm                 |
| 15. Reject station                        | 33. Audible jam alarm                  |
| 16. Reject throw-off arms                 | 34. Main transfer conveyor             |
| 17. Demagnetization control enclosure     | 35. Main test assembly frame           |
| 18. Demagnetization transformer enclosure |  |

Figure 3. Layout of the automated magnetic flux leakage inspection system (AMFLIS)

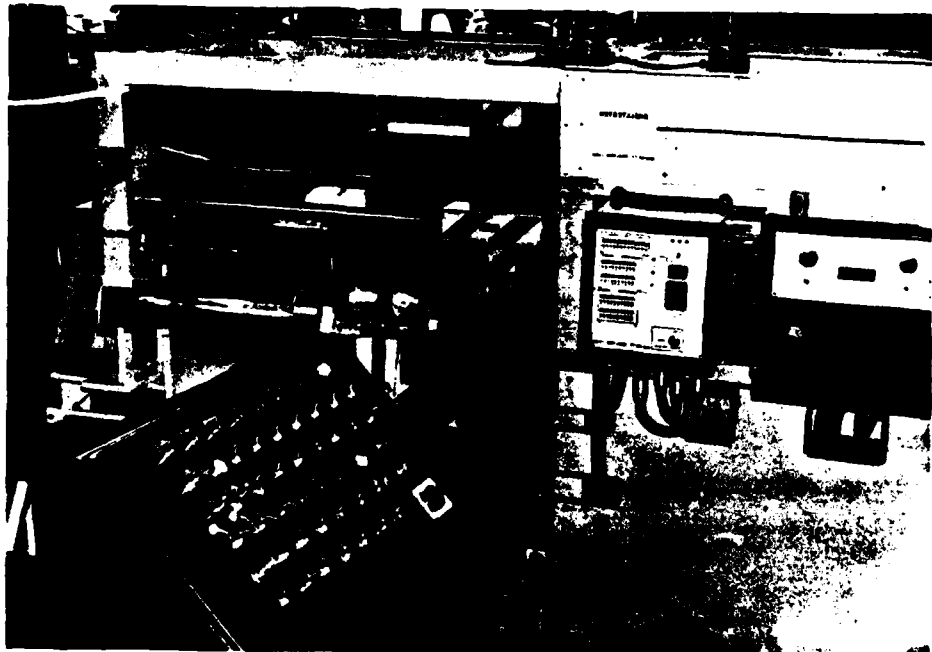
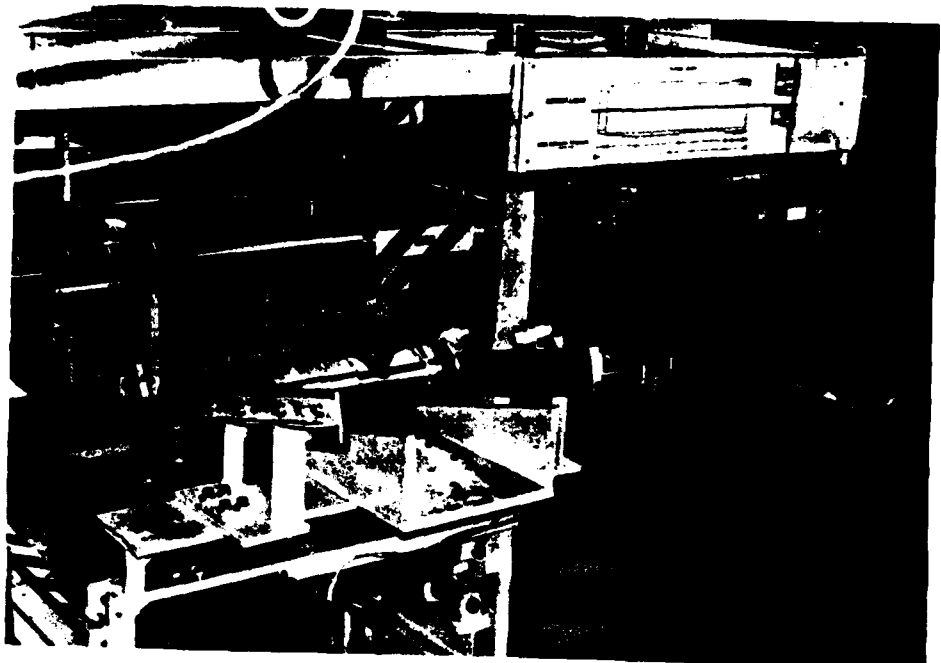


Figure 4. Automated magnetic flux leakage inspection system (AMFLIS)

### Demagnetization (Demag) Station Assembly

This includes a welded steel frame, which supports the demag coil (19), suitable conveyor rolls, and a conveyor belt to transport the shell through the demag coil, and the conveyor drive motor (20). The motor supplies bi-directional chain drive for the accept and reject stations as well as for the demag station, so that the conveyor rolls all drive in the same direction at the same time. Suitable chain guards are included.

### Reject Station Assembly

This includes a welded steel frame containing conveyor rolls and the reject throw-off arms (16). A paint spray (14) is located above the rolls in such a position that all shells are marked with paint before leaving the station. A sensor at the end of the conveyor senses that the shell is in correct position for both marking and throw-off. An inclined chute is part of the welded steel frame, and allows the reject shells to roll down after throw off.

### Controls

The buttons on the control console function as follows:

<u>Buttons</u>	<u>Functions</u>
Power "on" pushbutton	Turns electrical power on to machine.
Power warning lamp	Indicates status of power (power "on" when lit).
Master stop pushbutton	Turns all machine power off.
Main air "on" pushbutton	Turns air on to machine.
Main air "off" pushbutton	Turns air off to machine.
Main air lamp	Indicates status of air (power "on" when lit).
Rotor motor "on" pushbutton	Turns rotor motor "on."
Rotor motor "off" pushbutton	Turns rotor motor "off."
Rotor motor lamp	Indicates status of rotor motor.
Conveyor motor "on" pushbutton	Turns conveyor motor "on."
Conveyor motor "off" pushbutton	Turns conveyor motor "off."

Conveyor motor lamp	Indicates status of conveyor motor.
Power supply "on" pushbutton	Turns power "on" to electromagnets.
Power supply "off" pushbutton	Turns power "off" to electromagnets.
Power supply lamp	Indicates status of power supply.
Probe drive "on"	Turns on power to drive unit.
Probe drive "off"	Turns off power to drive unit.
Probe drive lamp	Indicates status of drive.
Jam lamp	Indicates machine jam.
Jam reset pushbutton	Allows machine to resume automatic operation. (Jam must be cleared in manual mode before automatic operation can be resumed.)
Flux/rpm override lamp	Indicates status of rpm and flux override selector switch.
Flux override selector key switch (normally off)	Allows automatic operation with incorrect flux level. (Should be on only when trouble shooting equipment.)
Override selector (rpm) key switch (normally off)	Allows automatic operation with incorrect rpm. (Should be on only when trouble shooting equipment.)
Standard test override selector key switch (normally off)	Allows test cycle to be completed, when defect is detected.
Mode reset pushbutton	Resets machine cycle.
Manual marker pushbutton	Permits manual operation of paint sprayer. (Paint sprayer will not operate if piece is not present.)
Jog pushbutton	Allows manual operation of probe drive assembly.
Automatic lamp	Indicates machine is in automatic operation.
Automatic pushbutton	Sets machine for automatic cycle.
Manual drive selector switch	Permits manual selection of probe drive scan direction.

Cycle start lamp	Indicates machine is in running position.
Cycle start pushbutton	Starts machine cycle. (The cycle will not start until the part piece is in place on the load track and the full track sensor is energized. The probe drive with magnet assembly and carriage are in home position; cradle 1 and cradle 2 must be in the down position, and all required functions for the machining cycle must be activated.)
Cycle stop pushbutton	Will stop machine cycle. (Machine will stop at end of cycle.)
Manual lamp	Indicates machine is in manual mode.
Manual pushbutton	Set machine for manual operation. (Manual pushbutton must be "on" to operate all other manual operation.)
Manual accept pushbutton	Permits manual accept throw-off to operate. Lifts part off conveyor and into accept chute.
Manual cradle carriage selector switch	Permits manual operation of cradle carriage (1. Cradle carriage cannot go forward unless conveyor is "on." 2. Cradle carriage cannot be returned to home position unless cradles 1 and 2 are down.)
Clamp selector switch	Permits manual operation of part clamp. (1. Clamp cannot be released unless cradle 2 is in "up" position. 2. Clamp cannot be clamped unless cradle 1 is in "up" position.)
Manual reject pushbutton	Permits manual reject throw-off to operate. Lifts part off conveyor and into reject chute.
Manual cradle 1 selector switch	Permits manual operation of cradle 1. (1. Cradle will not go to up position, unless cradle carriage is in home position. 2. Once cradle is in the up position, cradle cannot be lowered unless cradle carriage goes to extended position.)
Manual cradle 2 selector switch	Permits manual operation of cradle 2. (1. Cradle will not go to up position unless cradle carriage is in home position. 2. Once cradle is in up position, cradle cannot be lowered unless cradle carriage goes to extended position.)

Manual i.d. probe selector switch loads L and TID internal scanning probes	Permits manual operation of i.d. probes. (Manual o.d. probes will not operate when probe drive is in home.)
Manual o.d. probe selector switch (momentary - must be held on) Positions: Moving - Loads T-OD scanning probes Fixed - Loads T-OD zones A and H fixed probes	Permits manual operation of o.d. probes. (Manual o.d. probes will not operate when probe drive is in home.)
Conveyor selector switch	Permits manual operation of conveyor to control direction of conveyor in manual mode.
Manual stamp pushbutton	Permits manual operation of stamp unit. (Stamp unit will not operate if piece is not present.)
Hour timer	Records number of operating hours.
Accept counter	Records number of accepted parts.
Reject counter	Records number of rejected parts.
Manual probe selector switch	Permits manual selection on part zone to be tested.

### TESTING AND RESULTS

The AMFLIS was designed, fabricated, and delivered to Chamberlain Manufacturing Corporation (CMC), New Bedford, Massachusetts, an M483A1 projectile body manufacturer. The AMFLIS was installed off the production line. An acceptance test of the ten MPI-accepted projectiles and the five AMFLIS standards was run repeatedly for 14 hours. The system was conditionally accepted by the government (app A) in December 1982.

The application of magnetic flux leakage to the inspection of artillery projectile bodies is new. Production exigencies and the high rate of inspection (125 shells per hour) could stress any design. Because of this, an application test (AT) was performed at CMC to reveal any shortcomings of the AMFLIS by actually performing inspections of the M483A1 body. CMC's newly purchased prototype M483A1 ultra-sonics production inspection system and MPI (presently used by CMC in production to inspect the M483A1) were also used in the AT. Inspection data obtained from the three nondestructive inspection methods were analyzed and compared for accuracy, reliability, and repeatability.

The application test (app A) was modified due to geometry differences between the M483A1 as manufactured by CMC and the proposed projectile body to be manufactured by the MSAAP, Picayune, Mississippi. The AMFLIS to be installed at

MSAAP was designed and fabricated to inspect the M483A1 projectile to be produced there.

The results of the AT revealed the following two shortcomings of the AMFLIS (app A and B): (1) the AMFLIS did not find radial cracks (defects) in the M483A1 projectile band area, and (2) the AMFLIS was not repeatable.

On completion of the AT, the AMFLIS was delivered to MSAAP where it was installed off the M483A1 projectile production line for debugging. Modifications were made to the probes, electronics, calibration procedure, and the AMFLIS program by MAC to correct the two problems. A debug test was performed to see if these shortcomings were corrected and to confirm that the AMFLIS was a viable nondestructive inspection system for detecting defects in the M483A1 projectile body produced by MSAAP.

The results of the debug test completed in October 1984 are summarized below:

a. Sample utilized in the debug test:

46 MPI (MSAAP) rejected projectiles  
10 MPI (MSAAP) accepted projectiles  
7 MPI (CMC, New Bedford) rejected projectiles.

b. Of the ten acceptable projectiles, AMFLIS found one that had a flaw (inclusion of 0.140 in. deep beneath the surface) when the projectile was cut.

c. Of the seven (CMC) projectiles, AMFLIS found five to be acceptable. One of the projectiles was cut and it was verified that a transverse rejectable flaw adjacent to the band was found by the AMFLIS.

d. Of the 46 MSAAP (MP rejectables) projectiles, the AMFLIS found 11 projectiles to be acceptable (five runs). Twenty-six of the 46 were cut up and all rejectable flaws were found by the AMFLIS.

#### CONCLUSIONS AND RECOMMENDATIONS

The AMFLIS results show that it is a viable nondestructive inspection technique for inspecting the M483A1 projectile for defects and should be moved into the production line for long term evaluation.

APPENDIX A  
EXCERPTS FROM APPLICATION TEST REPORT IN 1983 FOR  
AUTOMATED MAGNETIC FLUX LEAKAGE INSPECTION SYSTEM

Chamberlain Manufacturing Corporation  
New Bedford Division

## TABLE OF CONTENTS

- I. INTRODUCTION
- II. SUMMARY OF MAGNETIC FLUX RESULTS
- III. CRITIQUE OF RESULTS
- IV. EVALUATION OF AMFLIS EQUIPMENT
- V. EQUIPMENT ACCEPTANCE TEST RESULTS
- VI. MAGNETIC - FLUX TEST RESULTS
- VII. RESULTS OF DESTRUCTIVE ANALYSIS OF 25 ULTRASONIC  
TEST REJECTS
- VIII. RADIOGRAPHIC RESULTS FOR FIVE MAG. - FLUX REJECTS
- IX. R A M RECORDS
- X. MAGNETIC PARTICLE TEST RESULTS

## I. INTRODUCTION

This report includes and interprets the results of the application test for the automated magnetic flux leakage inspection system.

Since only 150 of the 500 shells population contained no counterbores, only the 150 shells without counterbores were tested. However, each shell was tested three rather than two times.

Because of the inability to correlate the flux leakage indications with magnetic particle, visual, and ultrasonic indications only one shell was sectioned. This shell was also x-rayed and no indication was detected at the location predicted by flux leakage. In addition, five shells were x-rayed without sectioning and only faint indications were present on three of the shells in the zones containing magnetic flux rejects. A study subsequently presented by the equipment vendor makes the claim that correlation between the equipment visual display and reject location was not understood. However, their claims are not precise or well documented.

Summarizing the results herein, we found poor repeatability in the equipment responses. The equipment also apparently failed to detect (or improperly locate) several flaws detected by ultrasonic and magnetic particle testing and verified during destructive testing.

## II. SUMMARY OF MAGNETIC FLUX RESULTS

In this section we summarize the Magnetic Flux results presented in Section VI.

The results summarized here are for the dynamic tests conducted after the recalibration and tuning performed by the equipment vendor. The system adjustments were necessary because of an excessive false alarm rate in the F1 and G1 zone. Each shell was run with the following results.

<u># of Missing Shells</u>	<u># Of Shells Accepted Once Rejected Twice</u>	<u># of Shells Accepted Twice Rejected Once</u>	<u># of Shells Rejected Three Times</u>	<u># of Shells Accepted Three Times</u>
4	23	26	45	52
(# 's 22, 95 104, 118)				

These results represent poor repeatability. Indeed even the shells which rejected more than once did not produce the same indications for each run. The results of tests conducted at reduced sensitivity are contained in Section VI.

### III. CRITIQUE OF RESULTS

As shown in the previous section, there is poor repeatability in the magnetic flux results. There is, therefore, poor signal to noise in the system overall. The origin of the noise is not known.

Referring to section VII which contains the results of destructive testing of twenty-five shells which were rejected by ultrasonic and magnetic particle testing and subsequently tested with the AMFLIS equipment, we find the following results.

<u>Shell #</u>	<u>Defect</u>	<u>Flux Leakage Results</u>			
1	radial crack near band	not seen by MFL			
9	radial crack near band	"	"	"	"
13	craze crack	"	"	"	"
17	radial crack	"	"	"	"
20	radial crack	"	"	"	"
21	radial crack	"	"	"	"

46	radial crack	"	"	"	"
59	"	"	"	"	"
73	"	"	"	"	"
75	craze	"	"	"	"
109	"	"	"	"	"
112	"	"	"	"	"
113	radial crack	"	"	"	"
120	radial crack	"	"	"	"
121	craze crack	"	"	"	"
126	radial crack	"	"	"	"

<u>Shell #</u>	<u>Defect</u>	<u>Flux Leakage Results</u>			
140	craze crack	"	"	"	"
141	craze crack	"	"	"	"
143	radial crack	"	"	"	"
150	" "	"	"	"	"

Thus, the system failed to detect several documented flaws that were detected by both magnetic particle and ultrasonic testing. The possible causes for this failure are poor sensitivity to these flaws or unknown correlation between system indications and flaw location on the shell.

#### IV. EVALUATION OF AMFLIS EQUIPMENT

As noted in Section IX, RAM Records, few system problems were experienced at New Bedford prior to testing. As indicated in the previous section there is poor repeatability in the results consistent with the apparent failure to reliability detect known flaws. In addition certain system inconsistencies become evident during testing.

The following inconsistencies were observed in the threshold level:

<u>RUN #</u>	<u>SHELL #</u>	<u>RESULTS</u>
2	119	reject at 1.6 blocks
2	141	reject at 1.2 blocks
2	143	no reject at 2.7 blocks
2	140	reject at 2.0 blocks
2	137	reject at 2.0 blocks
1	120	reject at 1.8 blocks

These results are inconsistent with the threshold level of 2.5 blocks.

After consideration by the equipment vendor of the failure to locate flaws in the zones with flux leakage reject indications, the vendor presented an analysis which claims to locate the flaws by an indirect interpretation of the display results. The analysis adds or subtracts  $180^{\circ}$  from the observed results and incorporates an unknown angular offset. The origin of the offset is assigned to filter phase shifts.

At this point these claims are not adequately documented. Even if they were valid, the awkward and imprecise correlation between shell position and equipment indication is a major system liability. If these claims can be documented the system display should be altered so that the equipment operator does not have to deal with this issue.

V. EQUIPMENT

This section contains the results of acceptance tests on the flux leakage equipment. As indicated herein the equipment was conditionally accepted. Various relevant correspondence's are also included.

December 9, 1982 .

The scheduled 14-hour acceptance test and an additional special "B" zone test was performed on the m483 Magnetic Flux Leakage Inspection System (MFLIS).

The results are as follows:

- a) 14-hour acceptance test - 22 "B" zone rejects on projectiles 13 & 18 of a total 28 defects for the 1,628 projectiles inspected.
- b) Special "B" zone test - no defects found in zone "B" upon inspection of 4 projectiles (selected randomly from Chamberlain production line), which were cycled for 15 times.

The data provided from the test above has shown that the MFLIS has performed successfully. However, only conditional approval of the acceptance test can be given now due to the inability of the de-mag unit to operate during the test.

The MFLIS will be re-programmed to de-mag the projectiles by Magnetic Analysis Corporation and be rescheduled for a new test at a later date to be decided at the New Bedford facility. The test shall be limited to just de-magnetizing the projectile to 5 oersted or less during a test cycle. The length of the demonstration to be a duration of 45 - 60 projectiles.

September 14, 1983

SUBJECT: MET LAB EVALUATION IN REFERENCE TO M483 ULTRASONIC AND FLUX LEAKAGE TESTING

On August 10, fifty (50) shells were supplied to the lab for the destructive analysis correlating non-destructive testing indications to actual metal defects. Twenty-four (24) shells were selected to represent the flux leakage defects and twenty-four (24) for the ultrasonic defects. Two (2) shells were selected from the magparticle data. Quality Control reported the type and location of the indication found on each shell for each group. The following scope of work per the contract for M483 ultrasonic and flux leakage testing was followed to evaluate the correlation of non-destructive test indications to actual metal defects on the selected shells:

ITEM 8 - Met Lab's Scope of Work:

8. Destructive Analysis Procedure: After all MP, UT and MFL testing has been completed, ARRADCOM (DRDAR-QAR-1) and the non-destructive testing consultant will select from the rejects identified in paragraphs 4 through 7, up to 50 projectile bodies for the following destructive analysis to be performed by the contractor. Prior to the destructive analysis the selected projectiles shall be demensionally inspected to confirm that the

geometry/configuration is acceptable at that point in the production process  
ARRADCOM will provide a drawing with the accept limits.

8.1 Remove the section(s) of body containing each indication, by machining.

8.2 Radiograph each indication. OMIT

8.3 Measure (by Test Systems International Crack Depth Gage) and record  
depth of any indication which was not accessible prior to removal from the  
body. OMIT

8.4 Mill or grind a relief "V" in the section, opposite to and in line with  
the indication. Take care not to cut so deep as to intrude on any existing  
crack. Break the section along the crack using a suitable fixture.

8.5 Measure and record the profile of each pre-existing crack.

8.6 Photograph each crack with appropriate scales included to facilitate  
measurements from the photographic prints.

8.7 Analyze the crack metallurgically for nature and probable cause.

September 14, 1983

8.8 Forward all removed sections, fully identified, to the ARRADCOM Project Engineer.

PROCEDURE: The shells were again magnetic particle tested to determine the actual location of the reported UT and MFL indications. Very poor correlation was found between MFL and MP and further testing is being done on the MFL group. Good correlation was found between reported UT indications and MP indications and the following Metallurgical Evaluation concerns only the twenty-four (24) shells from the UT test and two (2) shells from the MP test.

The location of an indication on a shell was determined by using a metal frame grid work that fit over the shell with the stamped shell number on the shell band as a reference point. The grid was divided longitudinally into seven (7) equal zones "A" thru "G" with "A" zone at the nose of the shell. It was also divided in eight (8) equal zones radially with the junction of zones 1 and 8 located at the shell number stamp.

Table 1 summarizes the correlation between the UT and MP tests. Table 2 shows the test results for the two (2) shells representing magnetic particle indications. A relief "V" was made opposite to and in line with the selected indication on each section of shell examined. A "V" was sawed on pieces broken longitudinally and amchined on pieces borken radially. Sutiabie fixtures were used to break the section along the defect (Sketch I). Sketch

II shows the location of the re-magnetic particle test indications according to the above described grid. Selected test locations are also shown. Figs. 1 thru 26 show photograph of the broken section along with measurements of the crack profile. Figs. 27 thru 34 depict magnetic particle indications on some of the selected samples prior to breaking.

NATURE AND PROBABLE CAUSE OF THE DEFECTS:

Basically there are four types of defects detected:

Radial Cracks	13 Samples
Craze Cracking Associated With The Welded Bank	10 Samples
Stringer Inclusions	2 Samples
I.D. Cold Draw Tears	1 Sample

RADIAL CRACKS: These radial heat treat quench cracks were generated in Sep - Oct 1981 and were the result of multiple heat treating. At this time we were processing steel material that was on the low side of the chemistry range with marginal hardenability and these pieces received more than one heat treatment. During the subsequent heating and quenching operations, the open band end tends to close in and distort. The location of the radial cracks s/16" - 1/4" forward of the machined rotating band corresponds to the forward end of the weld heat affected zone. This is the point of maximum stress developed in the distortion pattern plus the location of the demarcation of the weld affected zone. The combination of these two conditions resulted in some cases in developing radial quench stress cracks. No radial cracks are being generated in our present production.

September 14, 1983

CRAZE CRACKING ASSOCIATED WITH THE WELDED BAND: Craze cracking has been present since the inception of welding bands due to the intergranular penetration of the steel by molten band weld. In plant visual magnetic particle standards were established at the very beginning of manufacture of this round to allow for acceptance of a certain amount of this condition. This condition may in some cases be propagated by heat treatment.

STRINGER INCLUSIONS: This is another defect that has been prevalent throughout the history of this round. In the past, 2-3% of production has been rejected due to surface or sub-surface stringer oxide inclusions that are detected by magnetic particle inspection. This condition may also be propagated by heat treatment.

COLD DRAW TEARS: Due to conditions present during cold drawing such as high material hardness, poor lubrication, scored punches or draw ring, tooling misalignment or incorrect forging configuration, a tear may develop that appears on the ID surface.

APPENDIX B  
EXCERPTS FROM FINAL REPORT IN DECEMBER 1983 FOR  
AUTOMATIC FLUX LEAKAGE INSPECTION SYSTEM

Magnetic Analysis Division  
Mt. Vernon, NY

## TABLE OF CONTENTS

Page No.

- I. Summary of Work Done to Date
- \* II. Description of System Supplied
  - \* A. Theory of Operation
  - B. Description of Major Components
    - 1. Electronics
    - 2. Mechanics
    - 3. Controls
- \* III. Recommendations

\* Included (Excerpts)

## II DESCRIPTION OF SYSTEM SUPPLIED

### A. THEORY OF OPERATION

The basis of the AMFLIS for M-483 shell bodies is well described in a previous report done for the ARMY MATERIALS AND MECHANICS RESEARCH CENTER.

"The magnetic perturbation inspection method essentially consists of establishing a magnetic flux in a ferromagnetic material and then scanning the surface of the material with a sensitive magnetic probe to detect anomalies or perturbations caused in the flux by nonhomogeneities in ferromagnetic material. Figure 1 schematically illustrates this concept. Physically, this is a problem in magnetostatics and analysis of solutions have provided guidance for optimizing conditions and forecasting results. In the upper illustrations, flux is assumed to be directed from right to left, and computer plots of signatures obtained under these conditions from nonferromagnetic regions or flaws as shown in the two lower illustrations. The characteristic shape of the signatures are dependent on the magnetic field component which is sensed by the probe. For the upper signatures the probe is oriented to sense the component normal to the applied field and the scan is in the direction of the applied field. For the lower signatures the probe is oriented to sense the component in the direction of the applied field and the scan is in a direction normal to the applied field. Other configurations are possible and selection is based on analysis of the specific inspection of interest.

Analysis of characteristic signatures provides considerable quantitative information concerning the perturbation source. For example, (in the upper signature of Figure 1), quantities that can be derived include:

- a) flaw location - coincides with the zero crossing
- b) flaw volume - indicated by peak-to-peak amplitude
- c) flaw depth from surface - related to the peak-to-peak separation measured in the direction of the applied field.

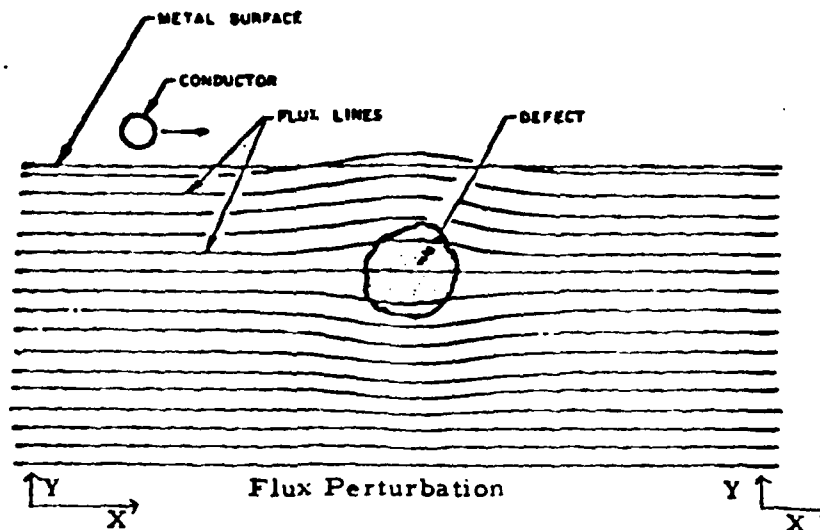
Extensive experimental results show general agreement with many details predicted by theory and also have confirmed that the method provides excellent qualitative and, after calibration, quantitative results. For example, in Figure 2 data obtained from a small fatigue crack show a linear relationship between crack opening displacement, COD, and signal amplitude.

Application of the magnetic perturbation method to the 155mm projectiles is schematically illustrated in Figure 3. For maximum sensitivity to flaws with the major dimension oriented along the axial direction, a circumferential magnetic flux is provided. Under these conditions and with a scan path which is essentially circumferential, but continuously advanced during each revolution (a tight helical scan) characteristic normal component and parallel component signatures obtained from two different size flaws are illustrated.

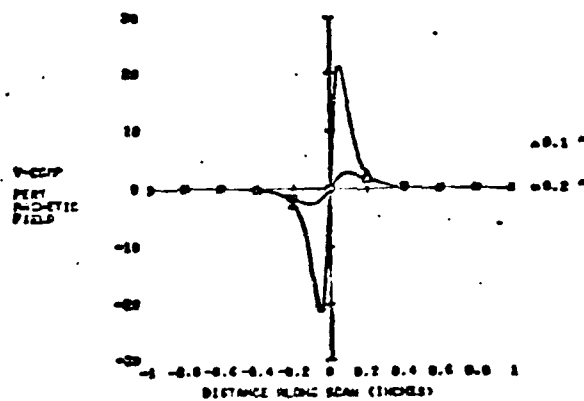
The normal component of magnetic flux is produced by the flaw and on one side the flux is forced out of the surface and on the other side must be forced back into the surface since flux must be continuous. Accordingly, a signature is generated that has an upward directed component which peaks and returns to zero with the zero crossing coincident with the flaw location and then a downward directed component which peaks and then returns to zero. In the illustration signatures obtained on successive scans provide an indication of the length of the flaw in the axial direction. Note that signature A extends over a greater axial direction than B. For the parallel component the signature is essentially unidirectional and is generated by the increase in flux density as the flaw forces flux out into the region above the projectile surface.

With axial magnetization and the probe oriented to sense the normal component and a circumferential scan path slightly to the left of flaws A and B, the outwardly directed component of flux produced by the flaw generates a signature which rapidly rises to a peak and then returns to zero; when the path is slightly to the right of flaws A and B, the inwardly directed component is sensed and produces the corresponding downward signatures A and B. When the parallel component is sensed, the increase in flux above the surface of the projectile causes a corresponding rapid increase in signature which peaks and then returns to the baseline."<sup>1</sup>

<sup>1</sup> Russell D. Williams and John R. Barton, Magnetic Perturbations Inspection of Artillery Projectiles, Southwest Research Institute, San Antonio, Texas, September, 1977.



Effect of Inclusion Upon Magnetic Field for Two Depths for an 0.05-in. Inclusion with Applied Field in X-Direction. Scan is in Either X- or Y-Direction.



Effect of Inclusion Upon Magnetic Field for Two Depths for an 0.05-in. Inclusion with Applied Field in X-Direction. Scan is in Y-Direction.

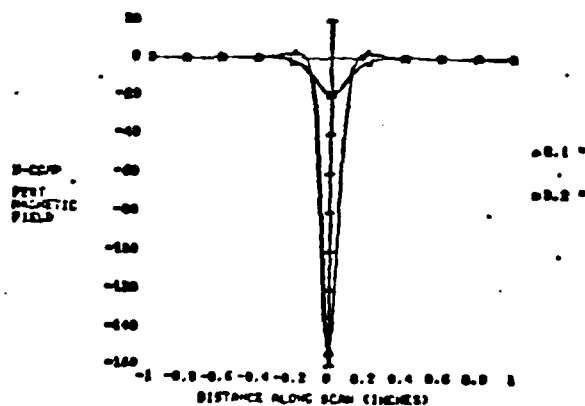


FIGURE 1 SCHEMATIC REPRESENTATION OF MAGNETIC PERTURBATION METHOD AND COMPUTER PLOTS OF SOLUTIONS-SIGNATURES

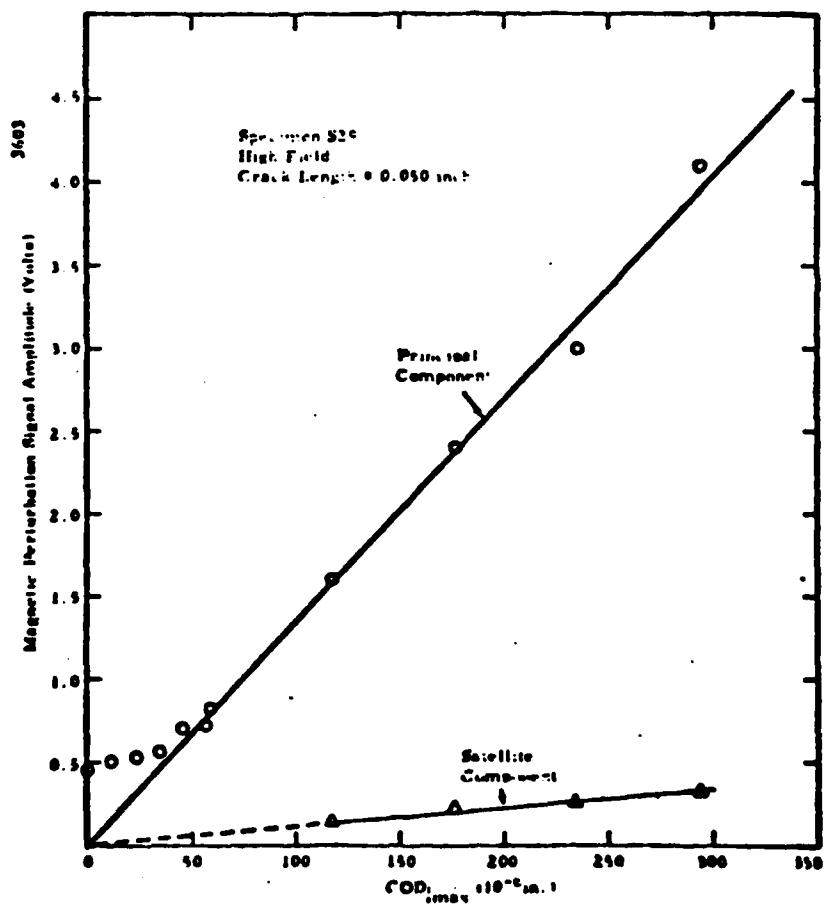
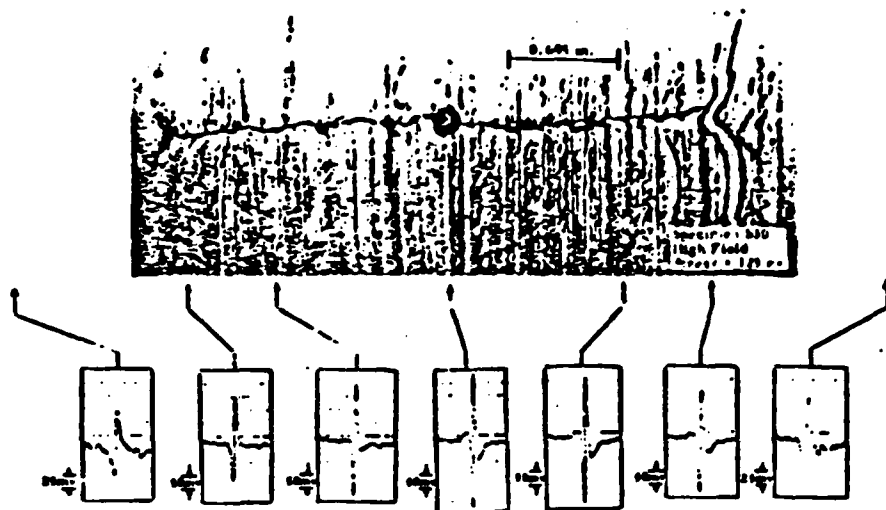


FIGURE 2 FATIGUE CRACK SIGNATURES AND GRAPH OF PRINCIPAL COMPONENT AMPLITUDE VERSUS CRACK OPENING DISPLACEMENT (COD) AT CENTER

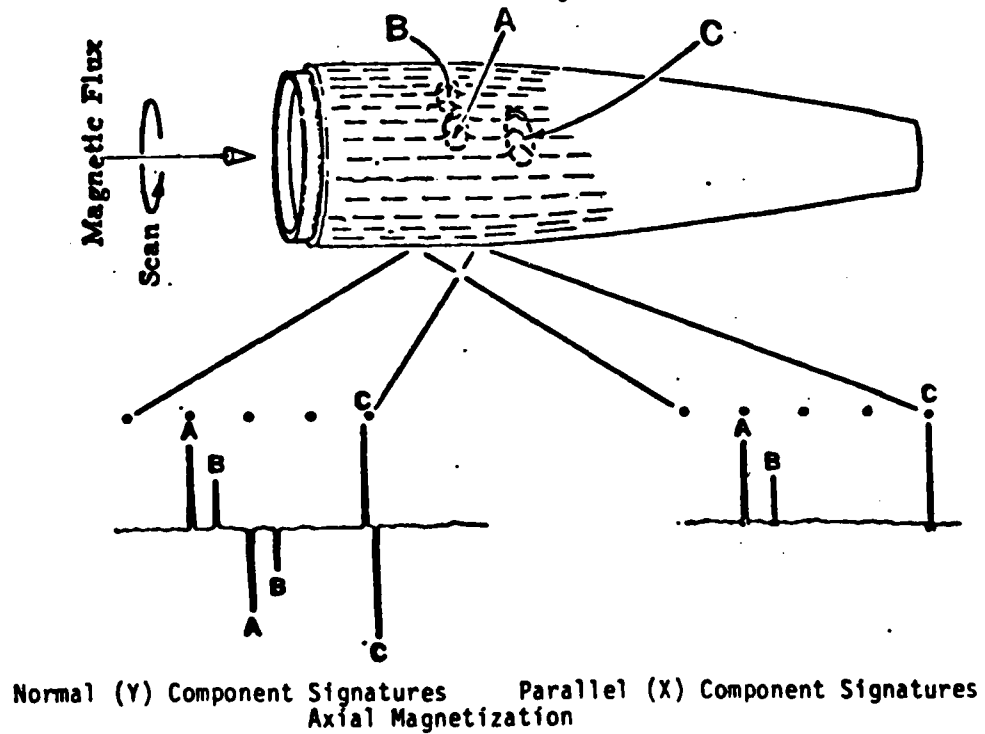
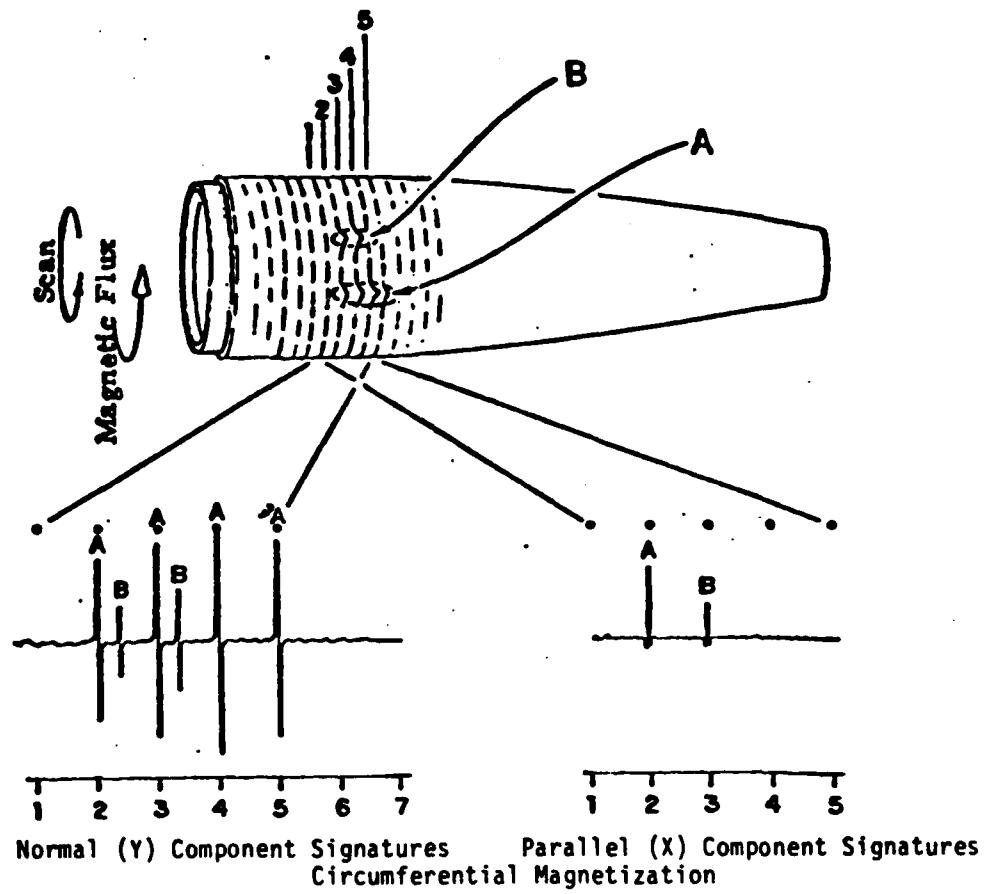


FIGURE 3 SCHEMATIC SHOWING DERIVATION OF MAGNETIC SIGNATURES

### III RECOMMENDATIONS AND COMMENTS BY THE AMFLIS CONTRACTOR, NAMELY MAGNETIC ANSLYSIS CORP., MT. VERNON, NY

It is recommended that the AMFLIS be reevaluated on shells produced at the MSAAP.

The purpose of this proposed study would be to clarify remaining questions as to the validity of the AMFLIS as an inspection method for M-483 shell bodies. Reports have been submitted by Chamberlain Corp. of New Bedford, MA, based upon comparative tests between an automatic ultrasonic system and the AMFLIS as they correlated on previously inspected magnetic particle rejects. Magnetic particle inspection is the method presently specified for this item. The AMFLIS and ultrasonic systems are attractive alternatives to magnetic particle since they can be automated, assuming they can find the specified critical flaws at the required production rate.

The AMFLIS did demonstrate that it was capable of maintaining the required rate but serious questions were raised by the New Bedford report concerning the validity of the flux leakage method, which would dictate certain remedies which can be made in the AMFLIS and suggest other shortcomings which may be explained and rectified. As a preliminary step a more thorough evaluation should be made at Mississippi on their production and the original AMFLIS rejects of New Bedford shells should be examined more thoroughly. Pursuant to this, each problem area is presented here with comments and suggested coursed of action.

## A. Overall lack of correlation

### 1. Description:

The New Bedford report states that the AMFLIS system did not reject the majority of the critical flaws and defects were not found at the sites of AMFLIS indications.

### 2. Comment

The sample chosen is not representative of true production conditions. Since the UT and AMFLIS were tried upon mag particle rejects, a fallacious assumption is made that no critical flaws can exist in the mag particle accepts. Furthermore, the vast majority of these rejects were for circumferential cracks adjacent to the rotating band which the reports say do not normally occur and will not occur in future runs.

Conversely, there is only one example of an inclusion type defect of critical magnitude although the report states that this type of defect historically has been present in 2-3% of

the typical production run. This critical defect was not rejected by the ultrasonic system. The New Bedford report stated that this defect was not indicated by the AMFLIS but this may be due to difficulties in correlating chart recordings with actual defect location.

From an overview, if results were rated on the basis of defects which normally appear in production rather than circumferential cracks adjacent to the band, the report is not as negative as when viewed superficially.

3. Suggested course of action:

- a. In order to better evaluate the AMFLIS relative to the inspection equipment at Mississippi, complete production runs should be put through the AMFLIS and compared to other NDT options on the basis of rigorous metallurgical examination.
- b. New Bedford shells which were rejected by the AMFLIS should be re-evaluated metallurgically.

B. Inability to find circumferential defects adjacent to the band.

1. Description:

As stated in the New Bedford report, the AMFLIS did not find this type of defect.

## 2. Comment

The AMFLIS probes which interrogate the areas adjacent to the band were made less sensitive because many of the shells supplied as acceptable displayed flux leakage indications in this area, coupled with the theory restated in the New Bedford report that circumferential defects would not occur in this area. In retrospect this adjustment should probably not have been made without a thorough investigation as to the source of these indications.

The requirements for inspection in this area need to be unequivocally stated as to whether the AMFLIS is to find this particular condition or not. Another condition which needs to be weighed is the extension of the heat effected zone due to the band welding process into the section of the shell adjacent to the band. If this is a rejectable condition which would then normally be kept under control, the present AMFLIS system can probably indicate circumferential cracks near the band. If the AMFLIS must tolerate this extended heat effected zone and find cracks, the method in this area will need some modification.

### 3. Courses of Action

- a. Redefine the exact requirements adjacent to the band vis-a-vis the welding process.
- b. Introduce a tangential notch adjacent to the band in the final standard made from Mississippi shells.
- c. Evaluate production runs of Mississippi shells.
- d. Re-evaluate samples of natural defects in New Bedford shells which have not been sectioned.
- e. Modify the test system adjacent to the shell if necessary.

### C. Non repeatability of AMFLIS signals

#### 1. Description:

The amplitude of defect signals generated during repeated runs of the same parts varied substantially. Furthermore, attempts to find natural defects in the areas with flaw indications were not successful.

#### 2. Comment

There are a number of explanations for the disparities between defect signals and the ability to verify critical defects in the areas they occurred.

- a. The longitudinal axis of the location of the indications were taken from strip chart recordings. These recordings were run at a fast speed relative to the AMFLIS scan speed and the resulting scale of approximately 1:4 between the chart recording and the actual shell made the linear resolution for the location of the defect inherently inaccurate. Also, since the indication for the defect can come from any one of the multi-probe elements in a given scan, there can be an error of as much as 2".
  
- b. Because the AMFLIS is run at a production rate which nearly exhausts the coverage of the probe elements, there is the possibility that a defect may be seen by the probe system with some difference in intensity during repetitive runs. This condition would be aggravated, somewhat, by differing responses of the strip chart recorder for defects of very short duration since these devices are somewhat frequency dependent.

### 3. Course of Action

In the short range, defects should be located accurately in the manual mode. Care should be taken to ascertain which of the probe elements is producing the critical flaw signal so that the defect is located accurately in the longitudinal direction. In a similar manner, the defect should be located circumferentially as described in Appendix ii and a thorough metallurgical examination made for defects in the indicated area.

In the long run, a scheme for defect verification during the test cycle has been proposed. This would require extensive changes to the existing machine and has therefore been proposed as an addition to any future AMFLIS. This technique is described in Appendix iii.

DISTRIBUTION LIST

Commander  
Armament Research and Development Center  
U.S. Army Armament, Munitions  
and Chemical Command  
ATTN: SMCAR-MSI (5)  
Dover, NJ 07801-5001

Commander  
U.S. Army Armament, Munitions  
and Chemical Command  
ATTN: AMSMC-GCL(D)  
          AMSMC-QAH(D), G. DeMassi (2)  
          AMSMC-QAR(D), D. Moore (2)  
          AMSMC-QAH-T(D) (10)  
Dover, NJ 07801-5001

Administrator  
Defense Technical Information Center  
ATTN: Accessions Division (12)  
Cameron Station  
Alexandria, VA 22304-6145

Director  
U.S. Army Materiel Systems  
Analysis Activity  
ATTN: AMXSY-MP  
Aberdeen Proving Ground, MD 21005-5066

Commander  
Chemical Research and Development Center  
U.S. Army Armament, Munitions  
and Chemical Command  
ATTN: SMCCR-SPS-IL  
Aberdeen Proving Ground, MD 21010-5423

Commander  
Chemical Research and Development Center  
U.S. Army Armament, Munitions  
and Chemical Command  
ATTN: SMCCR-RSP-A  
Aberdeen Proving Ground, MD 21010-5423

Director  
Ballistic Research Laboratory  
ATTN: AMXBR-OD-ST  
Aberdeen Proving Ground, MD 21005-5066

Chief  
Benet Weapons Laboratory, CCAC  
Armament Research and Development Center  
U.S. Army Armament, Munitions  
and Chemical Command  
ATTN: SMCAR-CCB-TL  
Watervliet, NY 12189-5000

Commander  
U.S. Army Armament, Munitions  
and Chemical Command  
ATTN: SMCAR-ESP-L  
Rock Island, IL 61299-6000

Director  
U.S. Army TRADOC Systems  
Analysis Activity  
ATTN: ATAA-SL  
White Sands Missile Range, NM 88002

Director  
Industrial Base Engineering Activity  
ATTN: AMXIB-MT (2)  
Rock Island, IL 61299-7260

Commander  
U.S. Army Production Base  
Modernization Agency  
ATTN: AMSMC-PB(D), R. Perciballi  
C. Gagnon  
Dover, NJ 07801-5001

Commander  
Mississippi Army Ammunition Plant  
ATTN: E. Sampson (MCI)  
Picayune, MS 39466-5000

Chamberlain Manufacturing Corporation  
ATTN: Walter Hewes  
117 King Street  
New Bedford, MA 02745

Magnetic Analysis Corporation  
535 South 4th Avenue  
Mt. Vernon, NY 10550

END

FILMED

2-86

DTIC