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Technical Report ARPAD-TR-88004

IMPROVED NONDESTRUCTIVE TESTING OF 60 mm M720 MORTAR PROJECTILE
MAGNETIC FLUX LEAKAGE INSPECTION SYSTEM OF M720 MORTAR

George Zamloot

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August 1988



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19. ABSTRACT (CONTINUE ON REVERSE IF NECESSARY AND IDENTIFY BY BLOCK NUMBER) Recent developments in magnetic flux leakage technology has made possible the creation of an inspection system that automatically detects and evaluates surface and subsurface defects in mortar bodies with high reliability and lower costs than competing measuring schemes. This report documents the efforts for the design and fabrication of standards and a breadboard that will be used to establish parameters for basic outline drawings (concept design) of an automated magnetic flux leakage inspection system (AMFLIS) for the detection of anomalies/flaws in the M720, 60-mm mortar projectile bodies.						
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INTRODUCTION

The objective of this project was to provide basic outline drawings (BOD) for the concept design (level 1) and specifications of an automated magnetic flux leakage inspection system (AMFLIS) for detecting anomalies/flaws within the projectile body of the 60 mm mortar. A breadboard unit and (AMFLIS) M720 standards was designed and fabricated to establish the design criteria (concept) for the AMFLIS. A statement of work (SOW) was written (app A); however, due to a lack of funding, only tasks 1 through 5 were performed to meet the objective. A contract was awarded to Magnetic Analysis Corp., Mt. Vernon, NY on March 29, 1985 and the project was completed and a demonstration to all concerned was performed in April 1987.

The inspection of the M720 mortar projectile body for anomalies was performed by magnetic particle inspection (MPI) followed by visual inspection before and after painting the projectile using normal light. MPI cannot indicate the depth of a crack (anomaly); therefore, as per the item specification, no cracks in the projectile body shall be accepted and thereby increase the cost of the projectile body due to false rejects.

Prior to this project, a feasibility assessment was performed using the magnetic flux leakage (MFL) technique for nondestructive inspection of the M720 mortar projectile bodies. Anomalies/cracks with depths as small as 0.010 were detected and characterized.

It is proposed that the BOD and specification of the AMFLIS be provided for inclusion into the 60 mm M720 mortar technical data package (TDP). The BOD was confirmed by a demonstration of the M720 standards and various rejected M720 projectiles using the breadboard unit. The MFL technique may also be adapted for the inspection of the 81-mm and 120-mm mortar.

DISCUSSION

The basic principles of MFL are shown in figure 1. The item tested was rotated in the field of a magnet and was magnetically saturated. In the absence of defects (discontinuities), the magnetic flux lines (saturated) continue to be contained and flow within the interior of the test item. If any defects were present, they forced some of the flux lines to flow external to the surface of the test item (fig. 1), producing a leakage field. This leakage can be detected and characterized by placing a probe/sensor adjacent to the item surface. Various type of probes are available (e.g., induction coil, hall effect, magnetoresistive, etc). The probes selected should provide the largest signal-to-noise ratio of the detected (leakage flux) frequency. Defects on the outside or inside diameters of the test item or within the wall regardless of orientation can be detected and characterized. The magnitude of the leakage flux field across a discontinuity is directly related to the depth of the cracks.

The following tasks were accomplished:

1. The breadboard unit (figs. 2 through 4) was designed and fabricated. It was demonstrated and used at the contractor's plant to establish the design criteria for the AMFLIS. The breadboard unit was delivered to the government and demonstrated by the contractor to all concerned in April 1987.
2. Six M720 motor bodies were used to design and fabricate the government approved standards (figs. 5 through 10) to set up the breadboard unit for the inspection of the motor body. The standards were also used with the breadboard unit to determine the basic outline design and specifications for the AMFLIS.
3. The basic outline design of the AMFLIS (fig. 11) was completed and delivered Jan 87.
4. Proper probe selection (e.g., signal-to-noise ratios) and type or probe criteria were established).*
5. The operating manual for the 60 mm M720 mortar breadboard unit was delivered Jan 87.
6. The sequence of operation for the basic outline design of the AMFLIS was delivered Jan 87 (app B).

CONCLUSION

Using the breadboard unit and the 60 mm M720 mortar body magnetic flux leakage set of standards and also various mortars (with and without defects), it was demonstrated that the MFL technique is a viable method for nondestructive testing (NDT) of the M720 mortar. Anomalies in the inside diameter, outside diameter, or within the walls, regardless of orientation, were detected. Accept/reject decisions were obtained and demonstrated with cracks having depths as small as 0.015 inches.

Basic outline drawings (concept design) and design specifications were provided by the project/contractor for an automated flux leakage inspection system for inspecting the M720 mortar body.

* Operating Manual for the 60 mm, Mortar Shell Magnetic Flux Leakage Inspection Breadboard.

RECOMMENDATION

It is recommended that the specifications of the 60 mm M720 mortar body be revised to incorporate the magnetic flux leakage (MFL) technique as an improved nondestructive testing for the inspection of anomalies (defects).

This MFL technique may also be used for the inspection of the 81 mm and 120 mm mortar bodies.

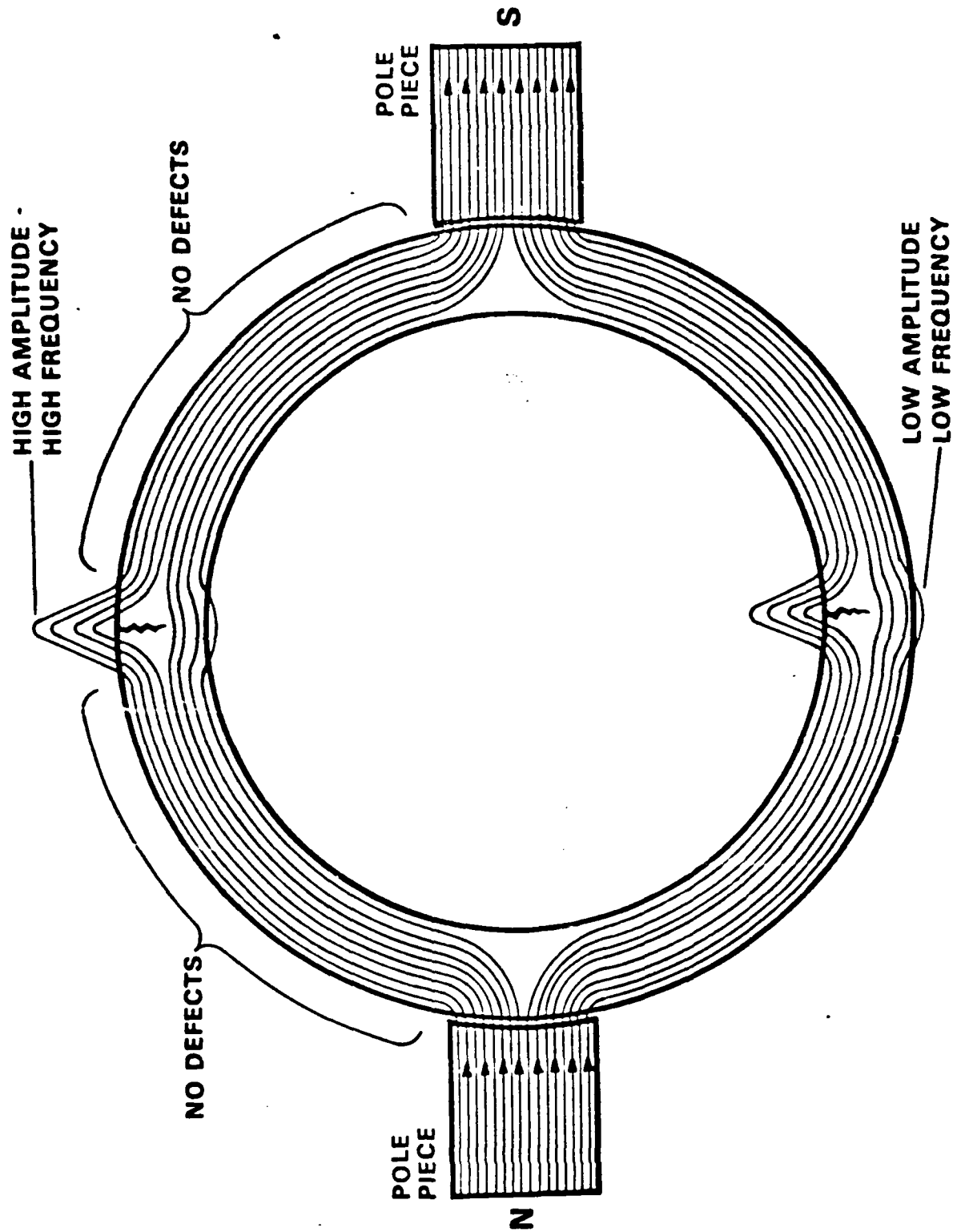


Figure 1. Basic principles of magnetic flux leakage

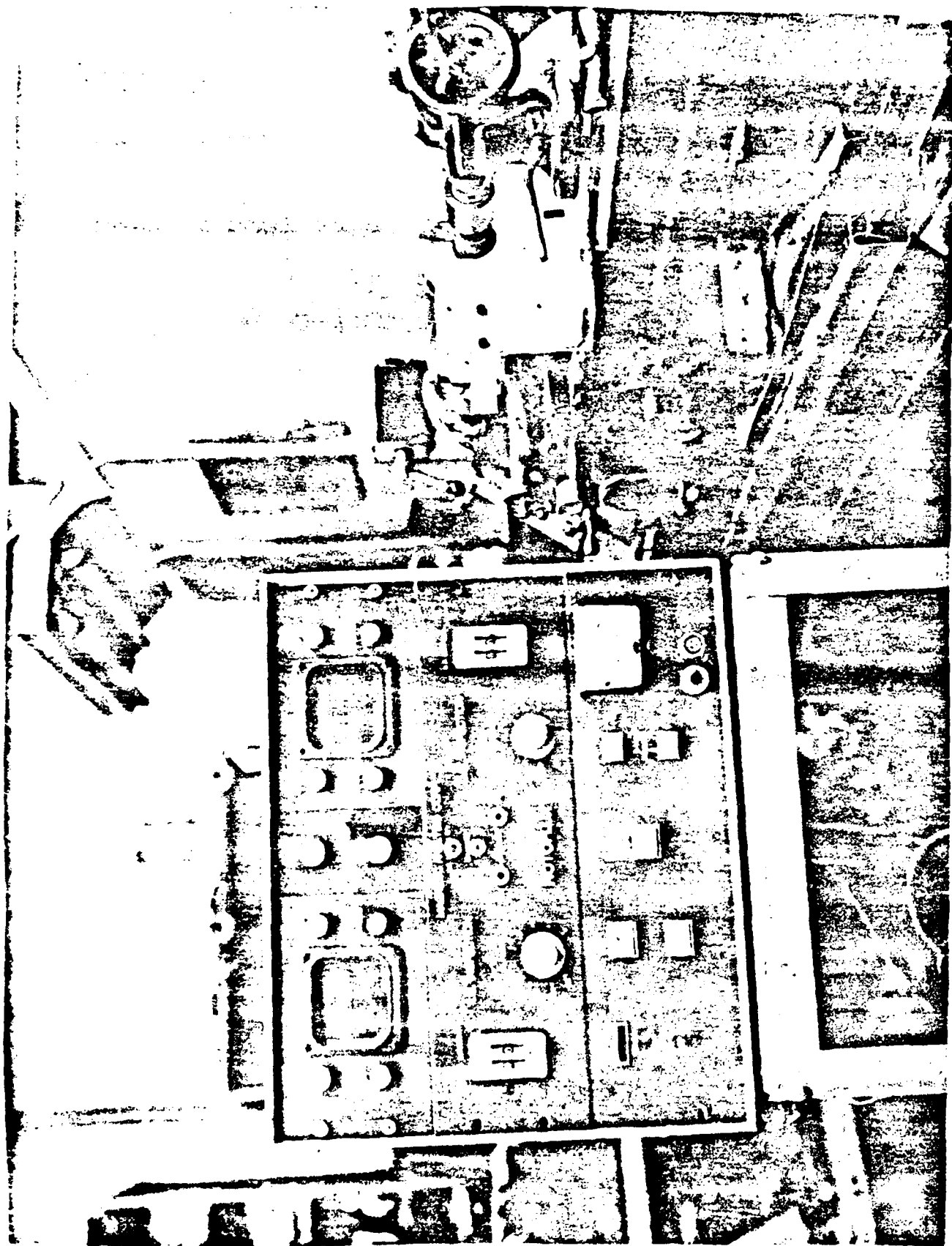
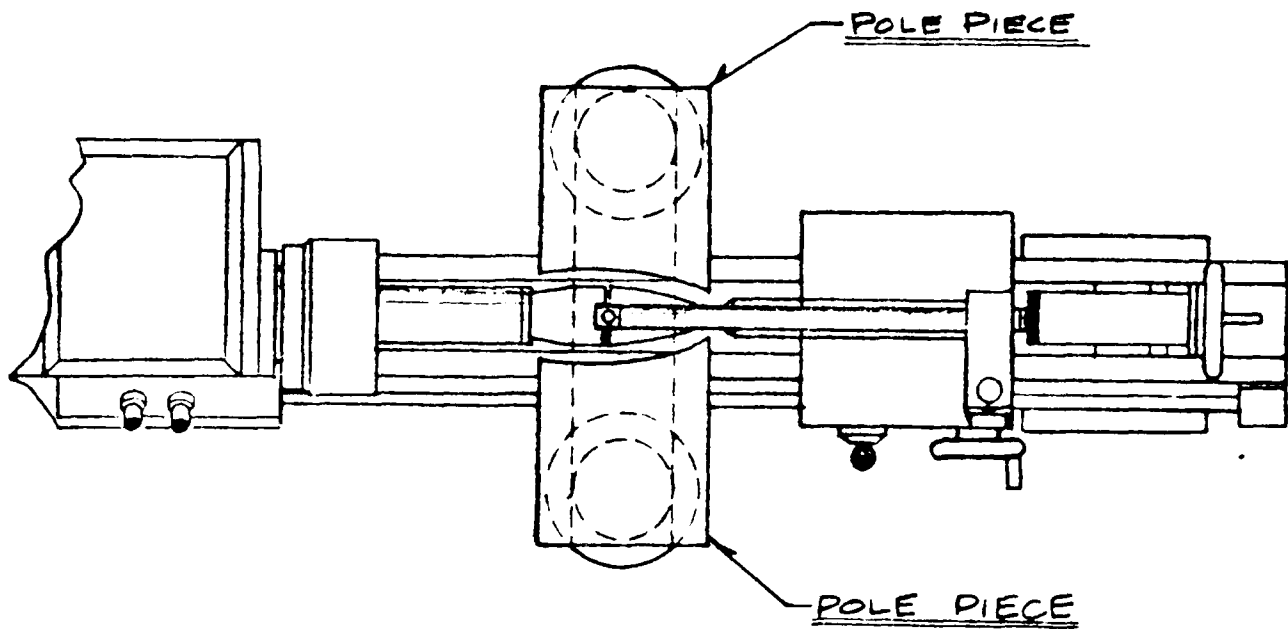


Figure 2. Instrumentation (breadboard unit)



TRANSVERSE MAGNETIZATION TEST

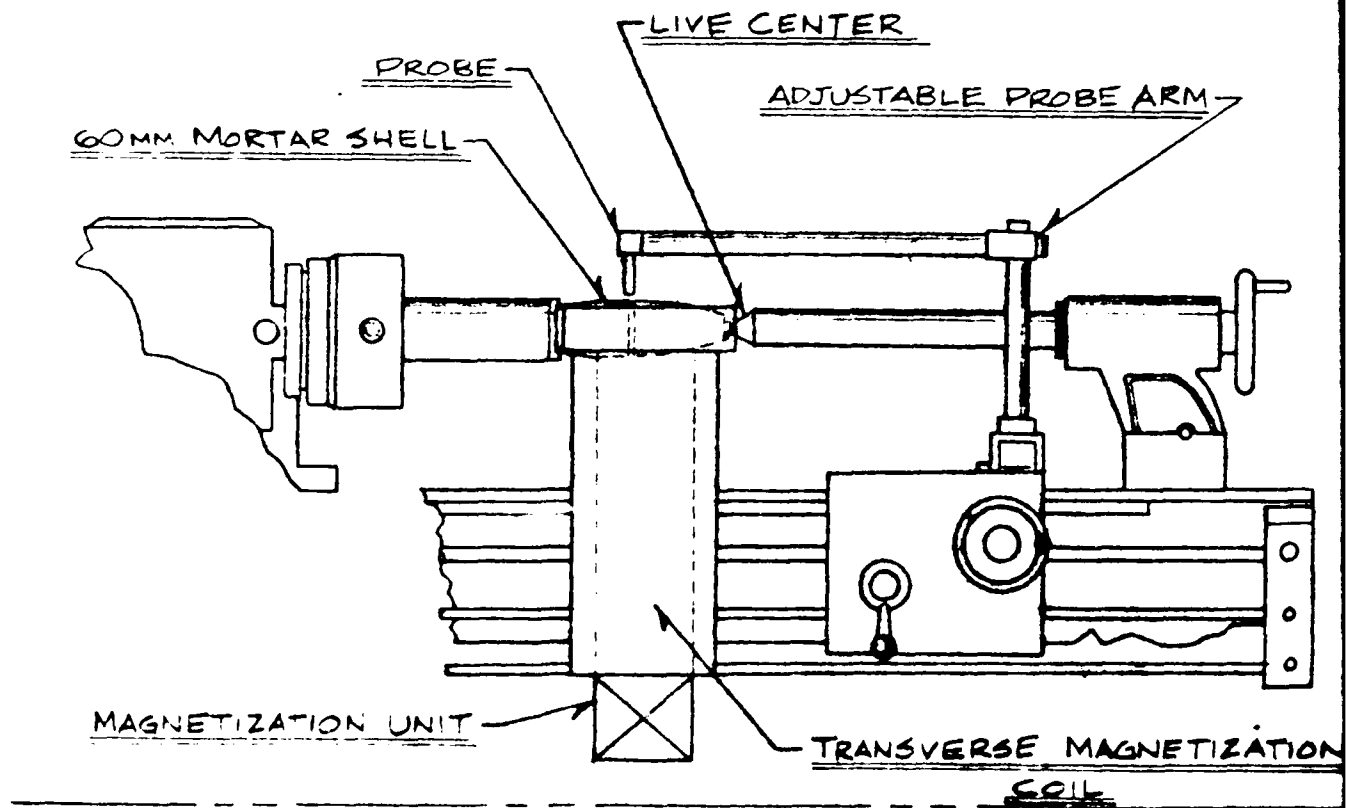


Figure 3. Transverse magnetization

LONGITUDINAL MAGNETIZATION COIL

CHUCK

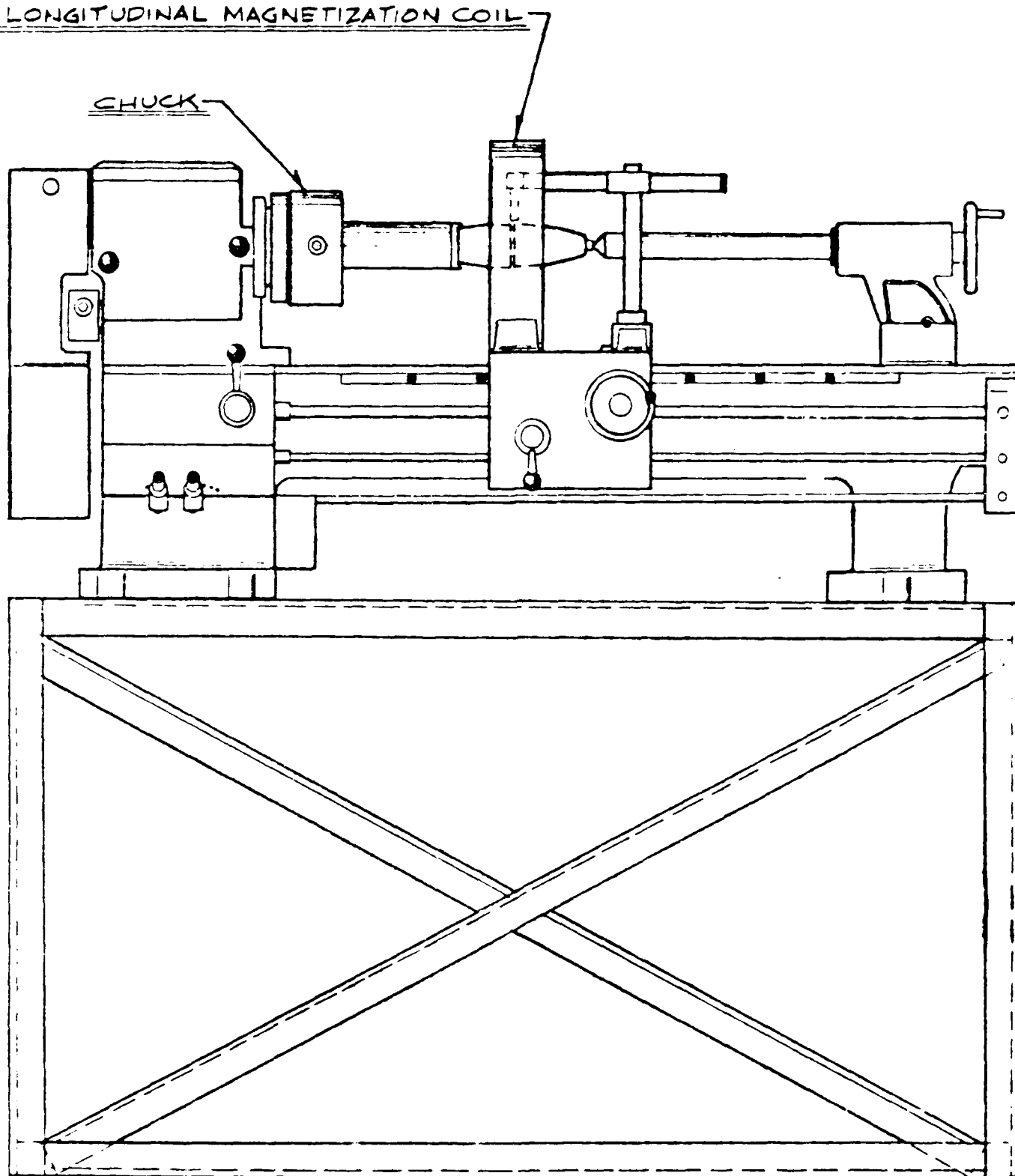
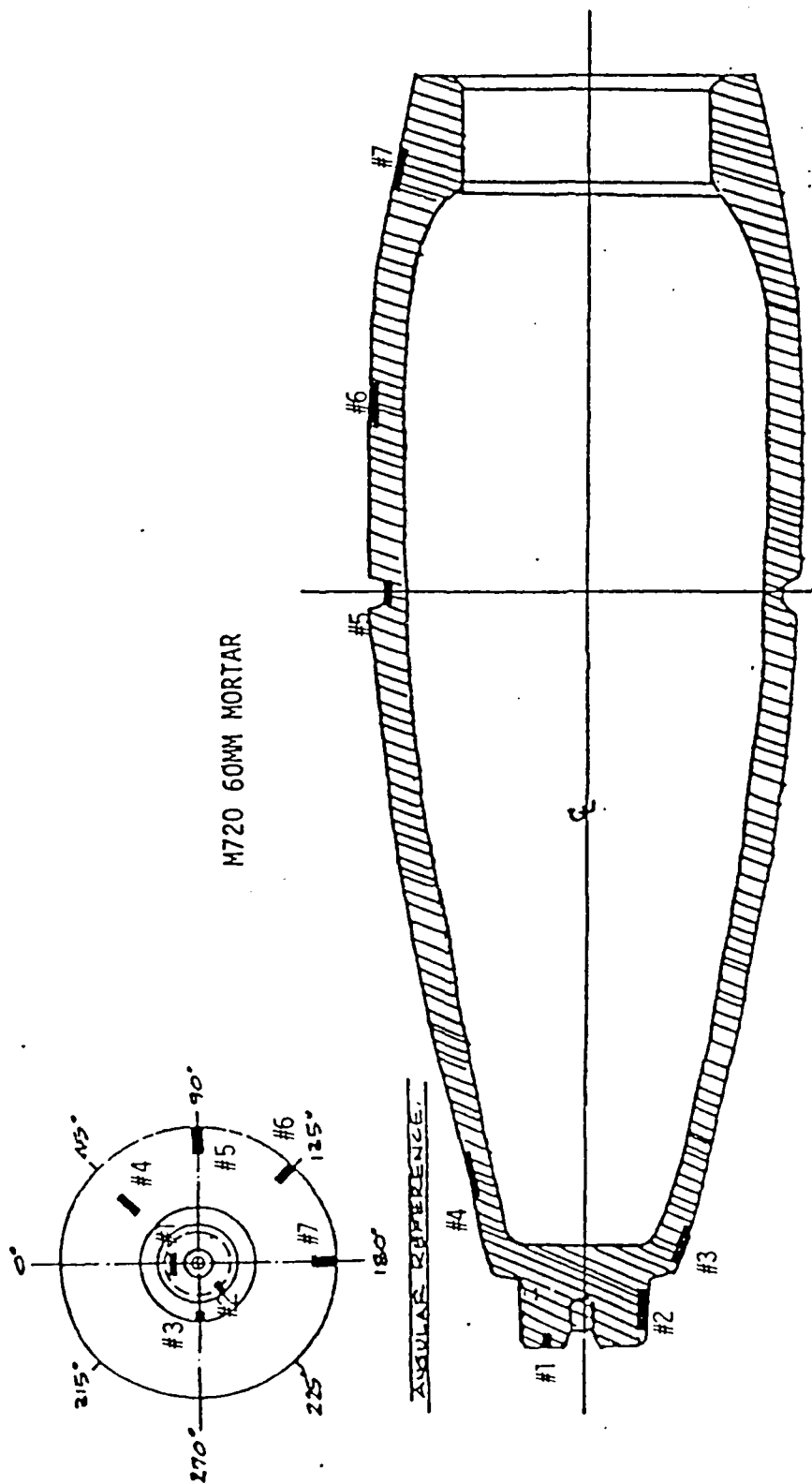
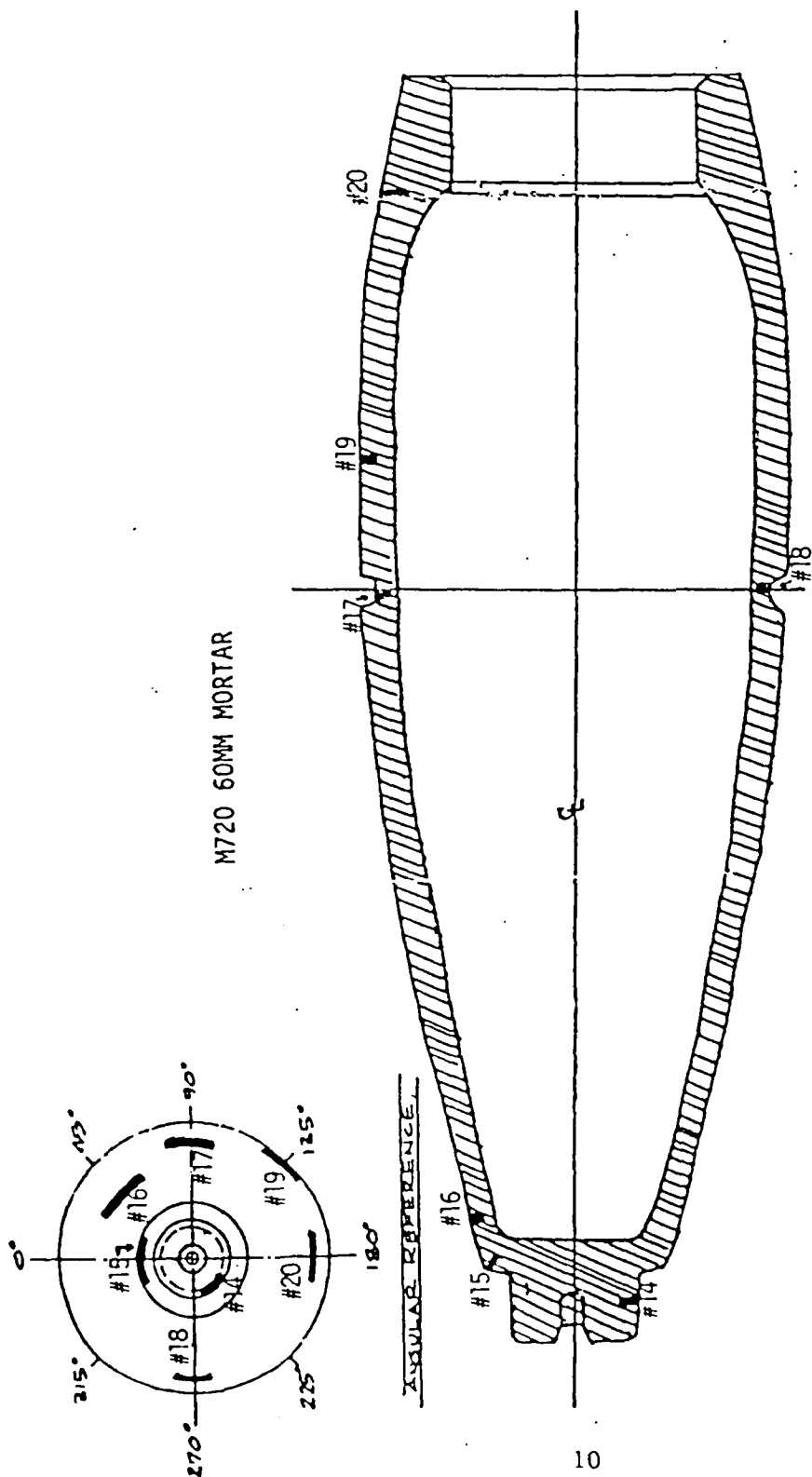


Figure 4. Longitudinal magnetization



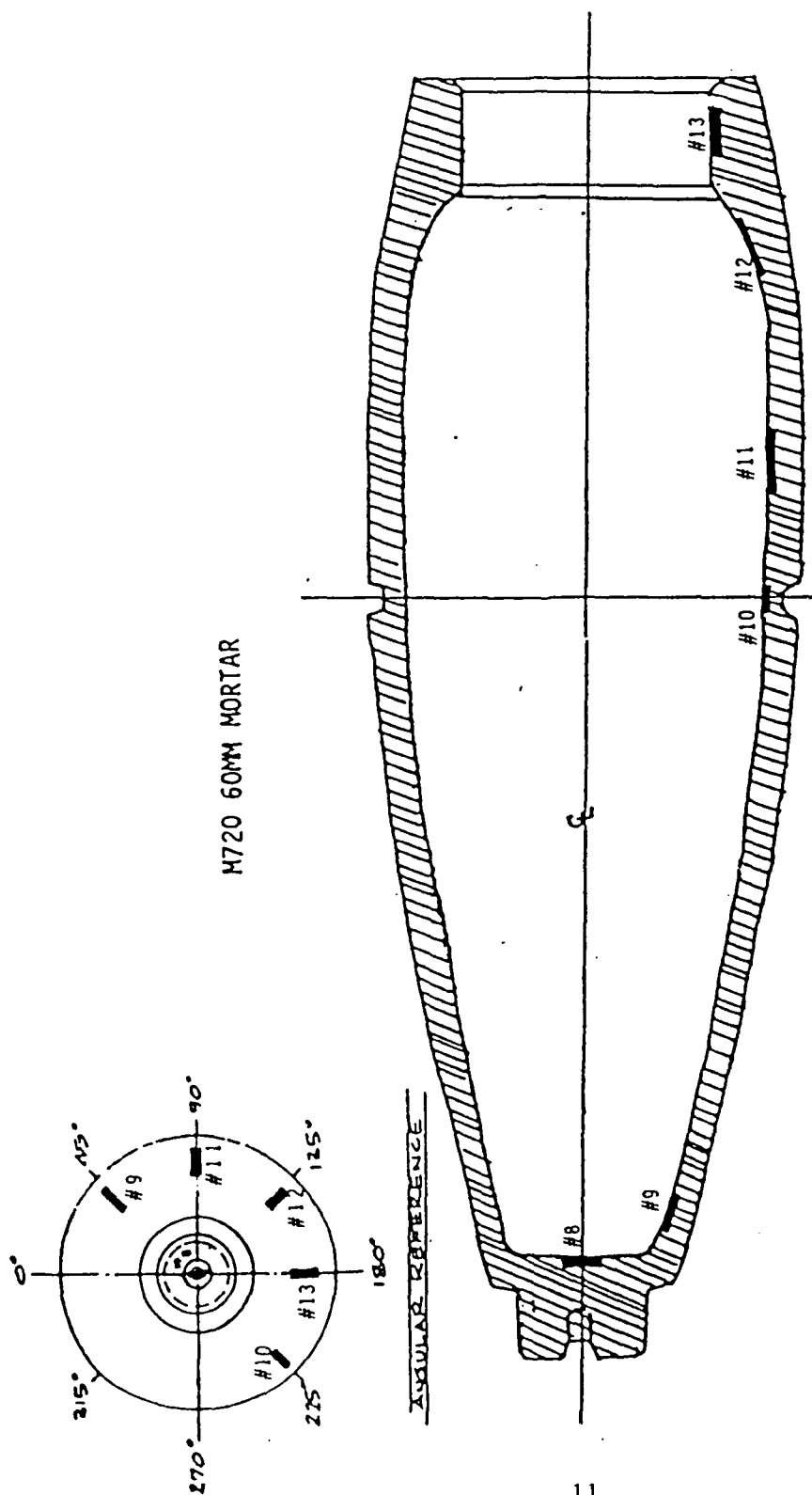
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NO	DEPTH	LENGTH	WIDTH	ID	OD	TRANS
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2	.0700"	.2550"	.0080"		X	X
3	.0304"	.2040"	.0070"		X	X
4	.0245"	.2500"	.0070"		X	X
5	.0155"	.1250"	.0070"		X	X
6	.0250"	.2500"	.0070"		X	X
7	.0300"	.2500"	.0080"		X	X

Figure 5. Standard no. 1



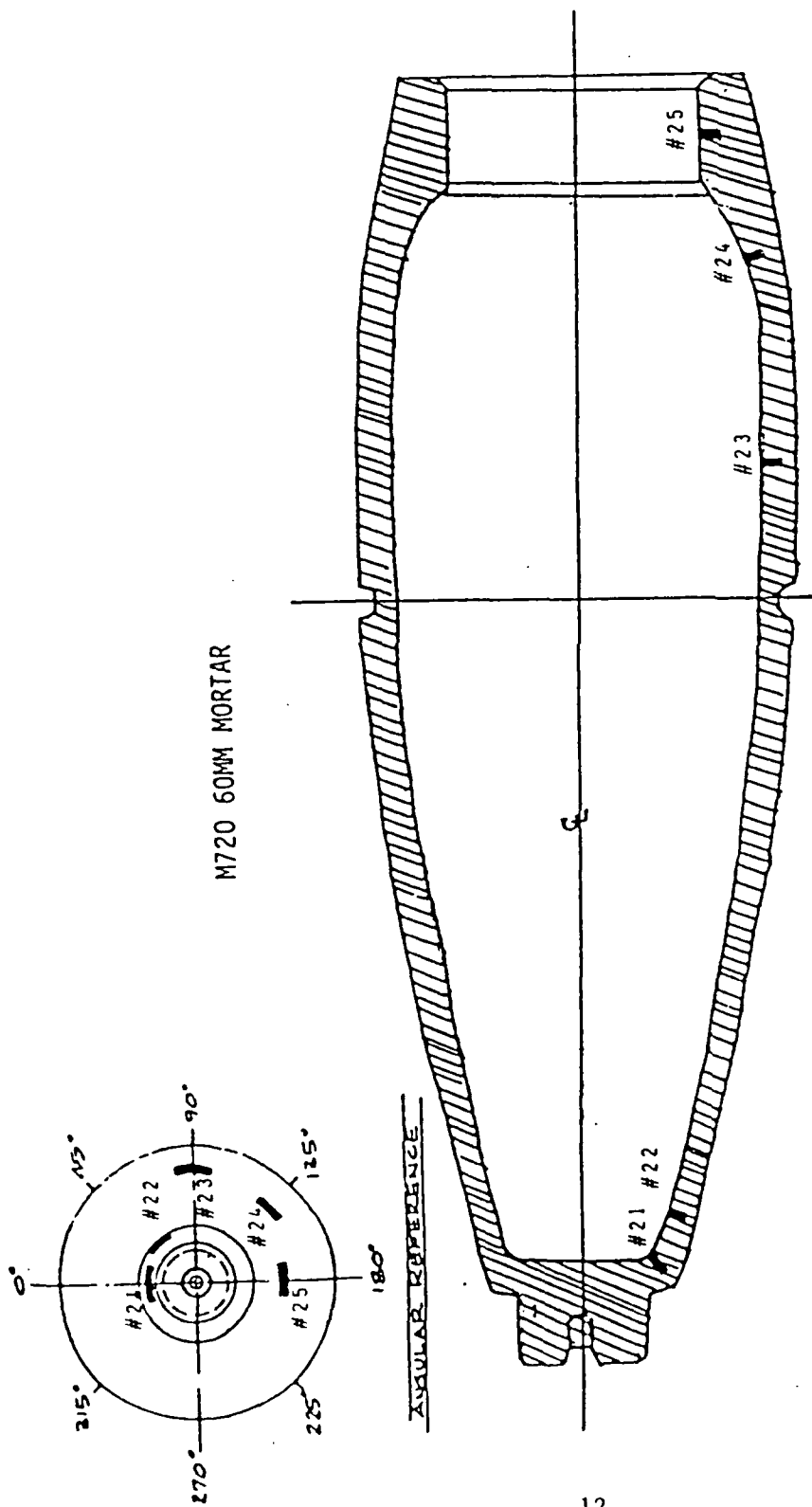
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15	.0306"	.2460"	.0080"		X	X
16	.0250"	.2500"	.0075"		X	X
17	.0160"	.2500"	.0060"		X	X
18	.0150"	.2500"	.0068"		X	X
19	.0255"	.2500"	.0062"		X	X
20	.0300"	.2500"	.0080"		X	X

Figure 6. Standard no. 2



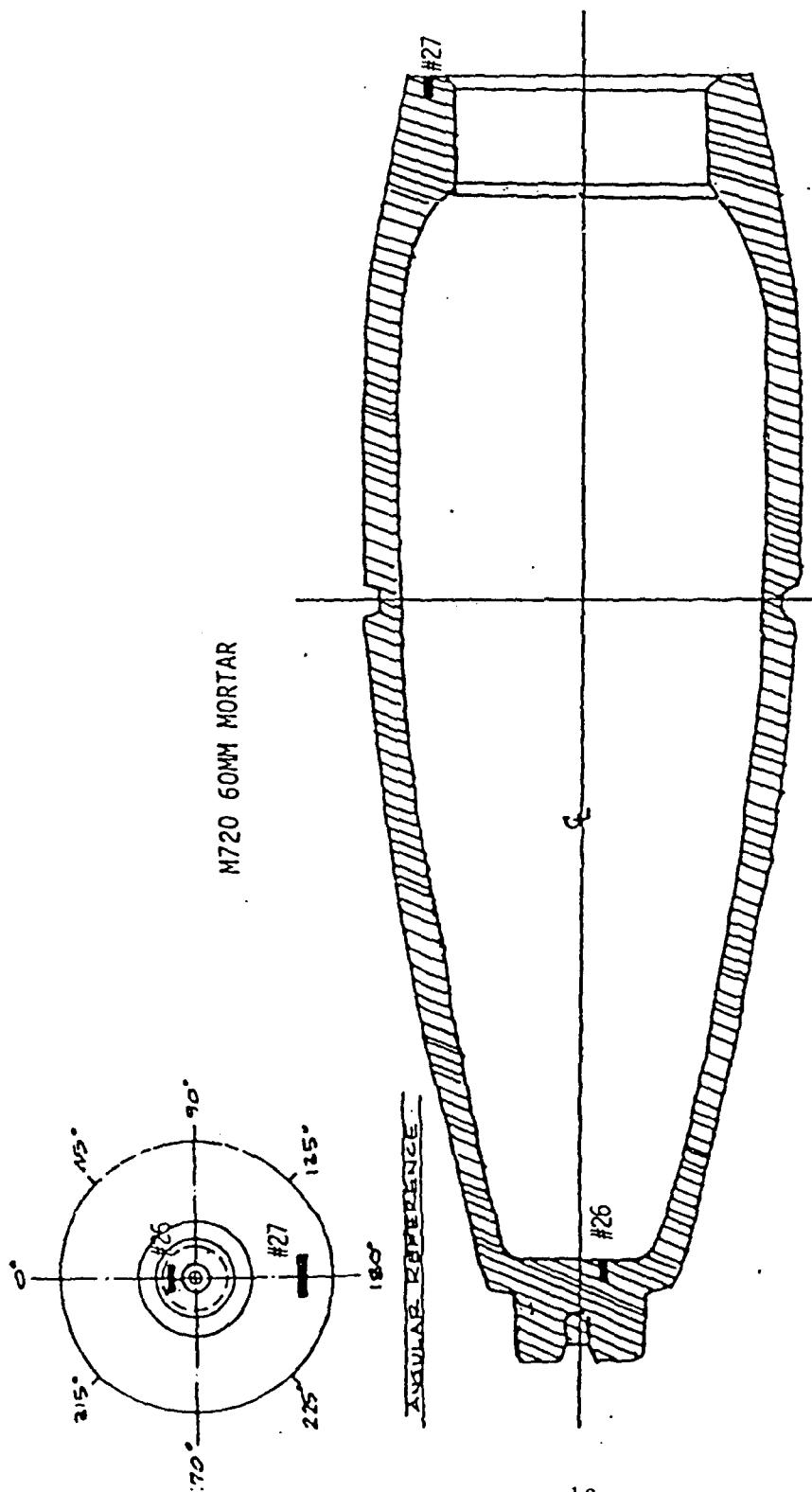
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NO	DEPTH	LENGTH	WIDTH	ID	OD	TRANS
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9	.0262"	.2450"	.0065"	X		X
10	.0150"	.1250"	.0060"	X		X
11	.0260"	.2500"	.0070"	X		X
12	.0305"	.2500"	.0080"	X		X
13	.0700"	.2450"	.0084"	X		X

Figure 7. Standard no. 3



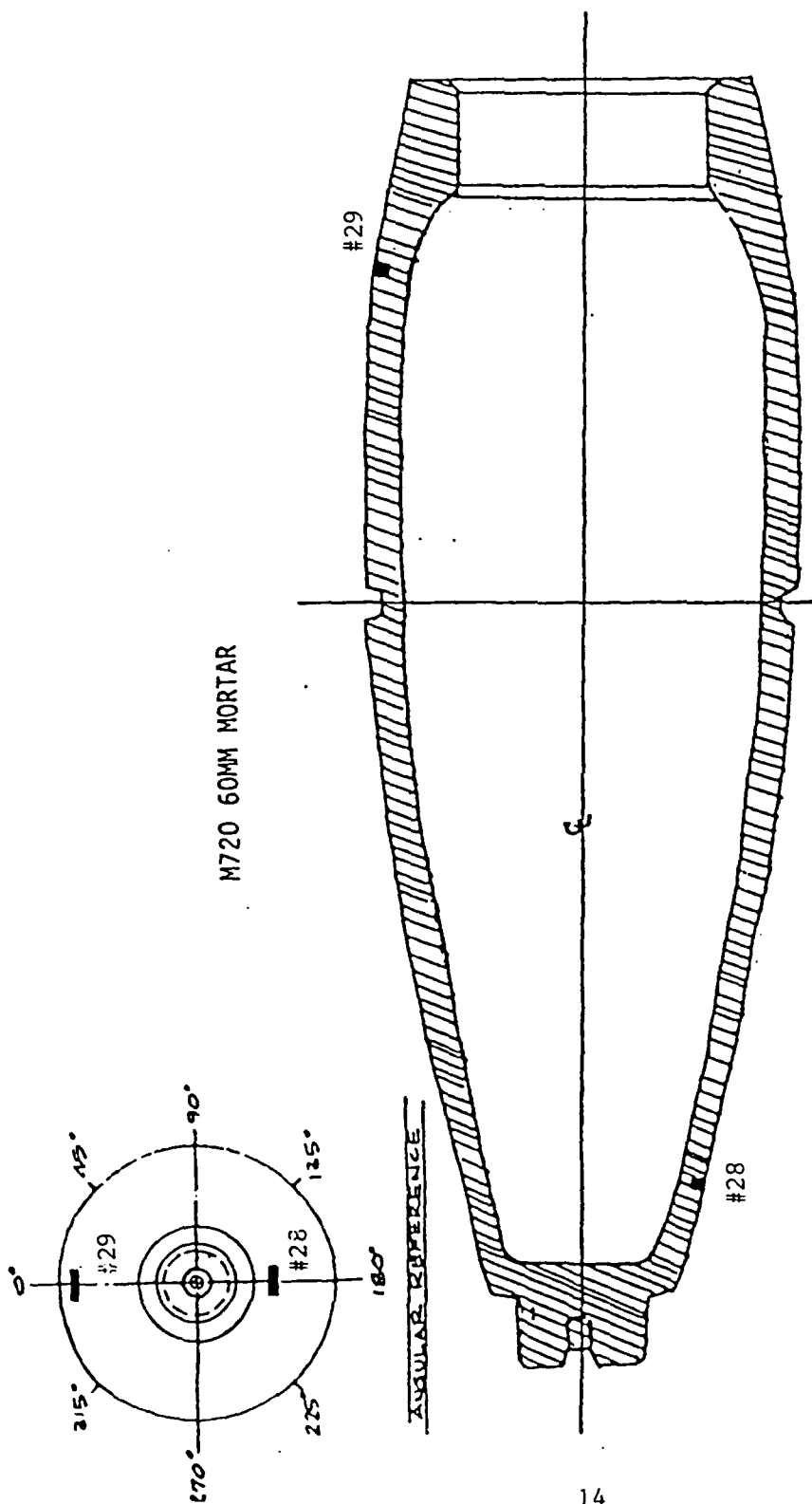
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22	.0232"	.2450"	.0068"	X		TRANS
23	.0250"	.2450"	.0060"	X		X
24	.0210"	.2450"	.0065"	X		X
25	.072"	.2450"	.0063"	X		X

Figure 8. Standard no. 4



DEFECT DIMENSION			LOCATION		ORIENTATION	
NO	DEPTH	LENGTH	WIDTH	ID	OD	TRANS
26	.0570"	.2450"	.0080"		X	X
27	.0612"	.2450"	.0080"	X		X

Figure 9. Standard no. 5



DEFECT DIMENSION			LOCATION		ORIENTATION	
NO	DEPTH	LENGTH	WIDTH	ID	OD	TRANS
28	.0257"	.1250"	.0070"		X	X
29	.0302"	.1250"	.0076"		X	X

Figure 10. Standard no. 6

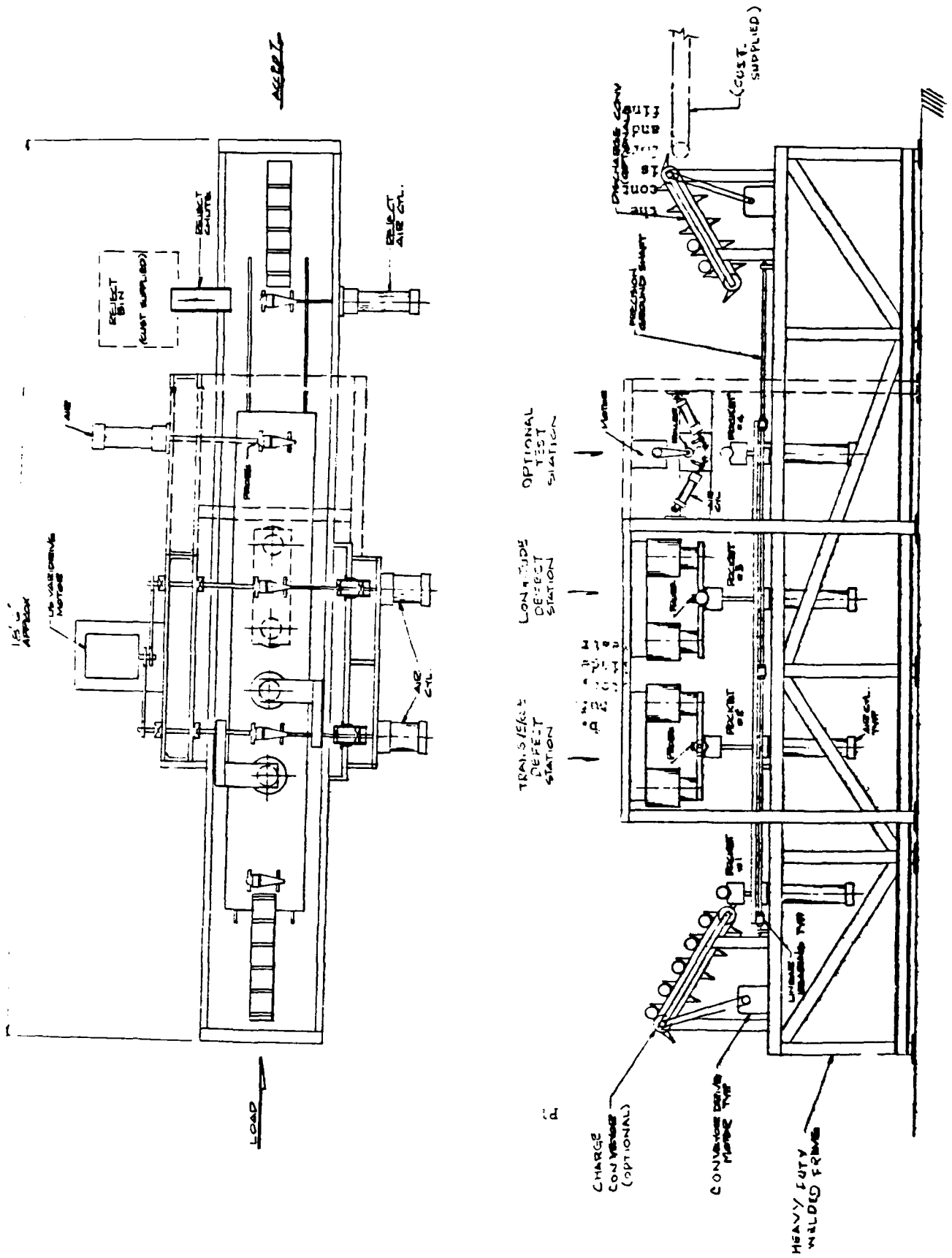


Figure 11. Basic outline design of the AMFLIS

APPENDIX A
STATEMENT OF WORK (SOW)

1. Objective: The contractor shall devote his personnel and resources not to exceed eight months from the effective date of contract to perform the necessary breadboarding and provide a (1) Technical Data Package (TDP) for the design of a Magnetic Flux Leakage Inspection System (MFLIS) and (2) a design and fabrication of standards for the 60 mm, M720 Mortar, drawing 11751151.

2. Requirements:

2.1 Provide a TDP for the design of an automated MFLIS to perform a non-destructive inspection of the 60 mm, M720, mortar bodies (MPTS) for anomalies, such as cracks, internal inclusions, folds, laps, and seams regardless of orientation. The system shall have the capability to detect defects throughout the entire body regardless of defect orientation. Conformance with this requirement shall be determined by a series of inspections conducted on standards designed and fabricated by the contractor. The MFLIS will interpret the anomalies (flaw indications) to determine whether the mortar bodies should be accepted or rejected. The MFLIS shall inspect the entire mortar at a rate of 500 mortars per hour. Applicable drawings and specifications are:

60 mm, M720 mortar body -- Dwg 11751151

81 mm, M374A3 mortar body -- Dwg 10543027

MIL-STD-454 -- Standard Requirement for Electronic Equipment

MIL-C-45662 -- Calibration Requirements

MIL-I-45208A -- Inspection System Requirements

2.2 The contractor shall accomplish the total objective of this SOW within 8 months of contract award as per the following schedule:

<u>Task no.</u>	<u>Task</u>	<u>Initiation month</u>	<u>Completion month</u>
0	Contract Award		0
1	Preliminary Design (Level 1) Drawing (BOD)	0	2
2	Standards Design and Fabrication	0	3
3	Design and Fabricate Breadboard	0	3
4	Demonstration/Feasibility of Level 1 Design (BOD)	3	4
5	Design Review/Revision	3	4
6	Final Design of the MFLIS TDP	4	6
7	Deliver Breadboard Unit	6	7
8	Acceptance of Final TDP Design	7	8
9	Final Report	4	8

2.3 The MFLIS shall be designed for adjustable heights to interface with the loading and unloading handling system of a 60 mm M720 mortar body production line. The

contractor shall interface with Riverbank Army Ammo Plant, Riverbank, CA as a reference only for his design of this interface, however the design shall provide adjustments in the interface, however the design shall provide adjustments in the interface to obtain versatility if utilized at other 60-mm mortar manufacturers. The MFLIS shall operate in two modes to detect anomalies; (1) automatic and (2) manual.

2.3.1 In the automatic mode, the material handling within the system will have a one position park station to place the mortar at the entrance of the inspection system. The system will then automatically move the part within the unit test positions for inspection, perform the inspection on the entire body for defects, and identify acceptable and rejectable mortar bodies. The system shall make automatic decisions to segregate the bodies to the proper accept or reject chute. The system shall inspect the entire mortar body for flaws on the ID surface, OD surface, or within the walls, regardless of the flaw orientation.

2.3.2 In the manual mode, the control of the system shall allow for the stoppage of the spindle rotation or any inspection scanning mechanism at any point within the inspection cycle.

2.4 A visible red light shall be automatically energized and reset when a defect is detected and the defect shall then be segregated by means of the reject mechanism. No defects (rejectable flaws) shall be accepted.

2.5 The system design shall be "FAIL-SAFE" by requiring a positive action for the acceptance of a mortar body. An audible and visible alarm shall be provided if the transfer or scanning mechanisms are jammed or obstructed. The alarm and visible red light when activated will continue to function until manually reset.

2.6 The MFLIS shall be designed for minimal effect of "LIFT OFF" variation to accommodate some eccentricity of the mortar body during rotation while being inspected.

2.7 The system shall be designed to be provided with two six-digit automatic production counters, one for acceptable mortar bodies and one for rejects; and a third counter that will automatically record the total number of operating hours. A counter shall also be provided for each defect zone to record the number of bodies having defects in each zone. All counters shall be resettable, except for the counter that records the total number of operating hours.

2.8 The system design shall be provided with adjustable controls for all parameters which need to be varied to assure accurate decision-making and optimum operation of the system. A locked cover shall limit access to such controls to authorized personnel.

2.9 The system design shall have a (CRT) scope and also a recorder (print out) to record amplitudes/frequencies, etc. for system setup and calibration.

2.10 The system design shall have a magnetic field strength monitor and interlocks provided to assure minimum field strength during inspection. If the field strength drops below the minimum level, the inspection system shall reject all mortars being inspected, clear the mortars from the system and prevent further inspection (until the problem is resolved), and indicate the reason for the stoppage.

2.11 The system shall be designed to ink and permanently mark all accepted mortars. The location of this mark shall be in the area adjacent the groove, the color of the ink shall be white.

2.12 The system shall accept the mortars in a horizontal position and the mortars shall also exit in a horizontal position.

2.13 The system shall be designed to completely demagnetize each mortar body after being inspected to a level of less than 3 oersteds on a standard magnetic field indicator.

2.14 The system shall be designed utilizing solid state circuitry where possible to conserve space and increase reliability. Software shall be developed using a high order language (Fortran, Pascal) and shall be government approved by AMCCOM (AMSMC-QAS-T(D)), Picatinny Arsenal, NJ.

2.15 Commercial OFF-THE-SHELF components and assemblies shall be utilized in the design of the MFLIS where practical. Components not standard commercial design must be approved by the government in accordance with DI-A-5026A, DD Form 1423. No software shall be proprietary.

2.16 The MFLIS shall be designed capable of operating in a production environment having temperature ranges from 40°F to 110°F and a relative humidity range of 30% to 99%. The operating voltages must be 110 volts or 220 volts, single phase. Special electrical protection during lay away mode shall be specified.

2.17 STANDARDS: The contractor shall design and fabricate a set of standards utilizing the critical flaw sizes, zones, and locations as per drawings, GZ SKT #1-M720 and GZ SKT #2-M720. The designed standards shall be used for setup and calibration of the system so that anomalies within the M720, 60-mm mortar body regardless of orientation will be reliably detected and rejected. Government approval, in writing, of the designs shall be obtained by the contractor prior to fabrication. The fabricated

standards shall be dimensionally certified by an authorized Gage Laboratory as per the requirements of the approved designs and MIL-C-45662. The fabricated standards shall be available during the contractor's breadboard setup (task 4 and task 8) demonstration test at the contractor's site.

2.17.1 The standards shall provide means to calibrate and setup each individual probe in the system under operating conditions.

2.17.2 The contractor will be supplied (GFM) with one hundred M720, 60 mm mortar bodies, which were inspected and accepted by one of the mortar manufacturers. The contractor shall inspect the bodies using the magnetic flux leakage technique to confirm that the bodies are free of flaw indications. These mortar bodies shall then be used for fabrication of the standards by the contractor.

2.18 The MFLIS shall be designed to inspect the entire mortar body at a minimum rate of 500 complete inspection cycles per hour.

2.19 The contractor shall design and fabricate a breadboard unit, having the necessary instrumentation, adjustable/(variable) magnetizing coils, power supplies, electronics and mechanical (holding and rotating) adaptation of the 60-mm, M720 mortar for the MFL inspection to simulate and demonstrate the feasibility of the level 1 (TDP) design task 4. The breadboard shall also be adaptable to the 81 mm (dwg 10543027) for a feasibility and demonstration of the MFL technique and a possible future system.

2.19.1 The breadboard unit (above) shall then be revised/modified accordingly to demonstrate the level 2 (TDP) design (task 8). A preliminary acceptance test shall be performed at the contractor's plant prior to delivery. This test shall be the same test as the final acceptance test, paragraph 2.21.

2.20 The breadboard unit, the standards, and TDP are to be delivered to AMCCOM, ATTN: AMSMC-C.H-T(D), George Zamloot, Picatinny Arsenal, NJ.

2.21 ACCEPTANCE: The acceptance of the final TDP (Task 8) shall be at AMCCOM, Picatinny Arsenal, NJ. The acceptance shall be a demonstration of the breadboard unit as per paragraph 2.19.1 and witnessed by the government (AMSMC-QAS-T(D)). The contractor shall demonstrate the following:

2.21.1 The calculations and the setting of the field strength for magnetic flux saturation to MFL each mortar and the proper RPM calculation for demonstration.

2.21.2 The detection of all critical flaws (transverse and longitudinal) utilizing the contractor's design and fabricated standards (60 mm, M720).

2.21.3 That the acceptable flaw signal can be set and 99% minimum of the acceptable mortars will not be rejected.

2.21.4 The signal-to-noise ratio of 5 to 1 (min) for flaws in any zone locations.

2.21.5 Provide adequate probes to demonstrate the above for transverse and longitudinal critical flaws.

3. PROCEDURE: The contractor shall accomplish the objective and requirements of this scope of work as follows:

3.1 Task 1--The contractor shall, within 2 months after contract award, submit two copies of the preliminary design prepared in accordance with DI-E-7031, level 1, as per DD Form 1423, to the Contracting Officer for review and approval. The government [AMCCOM, AMSMC-QAS-T(D)] will review the drawings within 1 month after receipt and furnish its comments and or approvals.

3.2 Task 2--The contractor shall, within 45 days after the contract award, submit two copies of the design of the standards prepared in accordance with DI-E-7031, level 2, as per DD Form 1423, to the Contracting Officer for review and approval. The government [AMCCOM, AMSMC-QAS-T(D)] will review the drawings within 1 week after receipt and furnish its comments or written approval. The contractor shall within 1 week make any necessary corrections to address the government comments and resubmit the drawings in the same manner as above. The contractor, upon receiving written design approval from the government, will initiate the fabrication of the standards to the approved design. The fabricated standards shall be completed within 3 months after contract award.

3.3 Task 3--The contractor, within 3 months after contract award, shall design and fabricate a breadboard unit which will have the necessary instrumentation, adjustable magnetizing coils, electronics and mechanical (rotating and holding) adaptation of the 60 mm and 81 mm mortars for MFL inspection to simulate and demonstrate the feasibility of the 60 mm M720 level 1 design.

3.4 Task 4--Upon completion of tasks 1 through task 3, the contractor shall demonstrate (utilizing the breadboard unit) the feasibility of the level 1 design.

3.5 Task 5--The contractor, having demonstrated the approved level 1 design during task 4, shall schedule a design review. The contractor and government shall review the results of task 4 and discuss any shortcomings (if any) in the level 1 design of the TDP. All necessary revisions shall be made to the drawings for government approval. The revision of the drawings shall be completed during the final design (task 6).

3.6 Task 6--Final drawings in accordance with DI-E-7031, level 2 and operating, calibration, and maintenance procedures shall be provided by the contractor and should comply with the design requirements outlined in this scope of work (SOW) and constitute the Technical Data Package of an MFLIS to meet the objective of the SOW. Documentation shall consist of the following:

3.6.1 A complete set of drawings including schematics and block diagrams. Software shall be documented with the software development plan submitted by the contractor and approved by the government in the same manner as paragraph 3.2.

3.6.2 Two copies and an original of the operating instructions and maintenance manuals, including trouble shooting procedures for hardware and software (predicted) shall be submitted to the Contracting Officer for review and approval (same as in paragraph 3.2) 60 days prior to the acceptance of the final TDP design. The operational and maintenance manual shall include:

3.6.2.1 A description of the MFLIS.

3.6.2.2 Theory of operation.

3.6.2.3 Detailed operating instructions.

3.6.2.4 Detailed set-up procedures.

3.6.2.5 Preventative maintenance instructions, including a suggested spare parts list, applicable schematic diagrams with check points, a signal flow-block diagram, a lubrication schedule (predicted), and all additional information necessary for preventative maintenance.

3.6.2.6 Trouble shooting procedures with instructions for locating and repairing any predicted areas which may malfunction. The contractor shall provide diagnostic programs for trouble shooting the logic control circuitry.

3.6.2.7 Two copies and an original of the contractor's recommended procedure for storage (lay-a-way, standby, and reactivation) of all electronics including the logic control system, magnetizing coils (see NBS Special Publication 522 for guidelines).

3.7 Task 7--The contractor shall deliver the breadboard unit, the set of standards and all documentation to AMCCOM, ATTN: AMSMC-QAS-T(D), George Zamloot, Picatinny Arsenal, NJ and install the breadboard unit to perform an acceptance demonstration of the final (TDP) design.

3.8 Task 8--The contractor shall prepare a final report and deliver two copies and the original in accordance with data item DI-S-5030B, DD Form 1423.

4. REPORTS: The following items shall be prepared and delivered by the contractor as listed in the attached DD Form 1423:

4.1 Report, progress, letter type, as per data item DI-A-2090.

4.2 Final report as per Data Items DI-S-5039B.

4.3 Preliminary drawings as per paragraph 3.1 in accordance with DI-D-7031, level 1.

4.4 Final drawings as per paragraph 3.6 in accordance with DI-E-7031, level 2.

4.5 Technical manuals as per paragraph 3.6 in accordance with DI-M-24042A.

4.6 Contractor developed specifications as per paragraph 2.15 in accordance with DI-A-5026A.

4.7 Acceptance tests as per paragraph 2.21 in accordance with DI-T-5147.

4.8 Software development as per paragraph 2.14 in accordance with Data Item DI-A-2176.

4.9 Program package document as per data item.

5. SAFETY:

5.1 The TDP (final design) of the MFLIS shall meet the safety requirements of local, state, federal, and OSHA standards.

6. PERIOD OF PERFORMANCE:

6.1 The contractor within 8 months after the effective date of the contract award shall perform all services, called herein in accordance with the attached DD Form 1423 as per the schedule outline in paragraph 2.2 of this SOW.

7. SECURITY:

7.1 The highest classification of materials involved in this contract is unclassified.

8. POINT OF CONTACT (POC): Mr. George Zamloot, AMSMC-QAS-T(D), shall be the POC for AMCCOM, Picatinny Arsenal, NJ. Telephone AUTOVON 880-2135/4758 or Commercial (201)724-2135/4758.

APPENDIX B

SEQUENCE OF OPERATION FOR THE AUTOMATIC 60 MM M720 MORTAR
SHELL TESTER

The automatic 60 mm M720 mortar shell tester is a custom design system to automatically handle and test, through nondestructive means of flux leakage, 60 mm shell bodies for defects exceeding specific depth limits.

The system uses a combination of electric motors and pneumatic cylinders to pick up the shell bodies, one at a time, from the load station and transfer them through the test stations, and hence to the discharge conveyor to either the accept or reject discharge.

The inspection is performed by three groups of probes, at three inspection stations. Third test station is optional.

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

In order for the test cycle to begin, the charge conveyor must have a minimum of five parts. Proximity sensors are used to halt the cycle in the event of the following:

1. Charge conveyor as insufficient amount of shells to be tested.
2. No shells exists in the load station for pocket 1.
3. Shell orientation is incorrect.

The following is a sequence of steps of the system that deals with the functions which take the test shell from the charge conveyor through the test stations and sorted for the accept or reject discharge:

1. Pocket 1 receives a shell and shuttles to the transverse defect station.
2. At the transverse defect station, pocket 1 is energized upward by an air cylinder.
3. The "clamp" air cylinder secures the test piece on center, holding the test piece on its' ends.
4. Pocket 1 is dropped by unenergizing the air cylinder. The pocket is now clear to shuttle back to home position and available for another test piece.
5. Once proper RPM and flux density is achieved, the probes (test elements) are turned on to start testing. This station examines the shell body for inner and outer diameter transverse oriented defects.

6. After the test is complete, pocket 2 is energized upward, (simultaneously, pocket 1 is loaded with another shell) and the "clamp" air cylinder releases the test piece onto pocket 2.

7. With the test piece, pocket 2 shuttles to the longitudinal defect station.

8. Pocket 2 is energized upward, and the "clamp" air cylinder secures the test piece on center, holding it on its' ends.

9. Pocket 2 is dropped to clear the test area and shuttles back to its position.

10. Once again, proper RPM and flux density is required, and probes are turned on. This test station examines the shell body for inner and outer longitudinal oriented defects.

NOTE: All test stations test simultaneously for the same duration of time.

11. After the test is complete, pocket 3 is energized upward. The "clamp" air cylinder releases the test piece onto pocket 3.

12. With the test piece, pocket 3 shuttles to the third test station (optional test station).

13. At this station, the shell is held by pinch rollers on the outer diameter of the shell.

14. Pocket 3 is unenergized, drops, and shuttles back to position.

15. The test shell is rotated, and a probe is driven into the shell body to examine for both the transverse and longitudinal defects located in the inner diameter wall of zone 1.

16. The test probe is retracted out of the test piece by reverse operation.

17. Pocket 4 is energized upward and the pinch roller releases the test part onto it.

18. Pocket 4 is dropped and shuttles to the discharge conveyor.

19. The discharge conveyor is activated to collect the test piece:

ACCEPT--the test piece is allowed to continue on the conveyor.

REJECT--the test piece is deflected off the conveyor into a customer supplied bin or chute.

Reject signals are stored in the Allen Bradley controller memory. The reject cylinder is activated accordingly from all three test stations.

Pockets 1 through 4 are synchronized and operate on positive command only. All four pockets shuttle simultaneously, but all four pockets must be in the down position for shuttling to occur. The pockets shuttle from left to right with shell bodies, and shuttle from right to left only when shell is not present.

Having discussed the overall functions of the shuttle cycle, we can now focus on the test stations. Each test station is composed of two large coil windings, connected in parallel, called electromagnets. These electromagnets are energized with an external power supply to magnetize the shell body under test. The first test station is the transverse defect station. This station magnetizes the shell body with longitudinal magnetization to provide flux lines parallel to the axis of the shell body that allows transverse flaw detection. Detecting the flaw is a multi-probe array following the same length and contour of the shell body. The probe can be adjusted for the desired air gap or to a surface ride if needed. The second test station is the longitudinal defect station. This station magnetizes the shell body with the transverse magnetization to provide flux lines perpendicular to the axis of the shell body. This allows longitudinal flaw detection. Another multi-probe of the same length and contour of the shell body is used.

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