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New Console and Control System for the 5.5 Inch Air Gun

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Robert L. Shuman

Prepared by Sandia Laboratories, Albuquerque, New Mexico 87115
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Printed June 1977

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NEW CONSOLE AND CONTROL SYSTEM
FOR THE 5.5 INCH AIR GUN

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ABSTRACT

The 5.5 inch air gun, located in Bldg. 882, was originally operated with manual valves, pressure gages and high pressure plumbing -- all located in close proximity to the operator. This system was replaced with electrically operated valves and controls. All high pressure plumbing was removed from the vicinity of the operator. Many safety interlocks were incorporated into this new design.

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NEW CONSOLE AND CONTROL SYSTEM FOR THE 5.5 INCH AIR GUN

Introduction

The 5.5 inch air gun is a facility used to provide high shock signatures for small components. The facility, located in the Vibration and Shock Testing Division, 9342, Building 882, is a part of the Component Environmental Testing Department, 9340.

The principle of operation of the air gun is the rapid acceleration of a piston inside the gun to impart the shock environment to the component mounted inside the piston. Figure 1 shows the principle of operation.

Air Gun Operation

High pressure air (up to 5000 psig) is introduced around the piston in the breech. "O" rings prevent this high pressure air from reaching the end of the piston at "A". Since the high pressure is normal to the piston cylinder wall, there is no force available to move the piston.

To fire the piston, "fire pressure" is introduced in the small cavity located at "A" which forces the piston out from its seat. Once movement has begun, the high pressure air surrounding the cylinder forces its way around the end of the cylinder and accelerates the piston down the barrel.

The air gun barrel (120 ft long) is closed on the muzzle end. Low pressure (15-25 psig) air is introduced into the muzzle prior to firing. Thus when the piston moves down the barrel, the air ahead of the piston is compressed. As the pressure builds up, the force exerted by this pressure causes the piston to decelerate. When the piston comes to rest in the barrel, the pressure in the muzzle side of the piston is now higher than the pressure on the breech side -- causing the piston to move back in the direction of the breech.

To reduce the reverse movement and acceleration of the piston, a device has been mounted above the muzzle end of the air gun called a muzzle tank. The muzzle tank is connected to the muzzle by a section of tee and ell shaped hardware containing a one-way valve. Air is introduced into the muzzle tank to a value of about 55 psig.

When the pressure ahead of the piston reaches the same value of the muzzle tank pressure, the one-way valve opens and allows the pressure to stay equalized between the muzzle tank and the muzzle. The final pressure of the volume of the muzzle ahead of the piston and the muzzle tank can be in the range of 80-85 psig. When the piston reverses, the one-way valve closes, thus trapping a portion of the air in the muzzle tank, which reduces the energy available to accelerate the piston back toward the breech. This arrangement reduces the movement of the piston which quickly stops somewhere in the muzzle section of the air gun.

After the piston comes to rest with no further movement, then vent valves in the breech section of the gun are opened. The pressure in the muzzle causes the piston to move toward the breech, eventually coming to a stop in the breech section.

At this point the pressure in the muzzle section is vented. After both breech and muzzle sections are at atmospheric pressure, the breech plug and piston are removed.

Prior to any succeeding shot the elevated pressure in the muzzle tank is vented back to the desired level.

Modification

The original console and control system were all manually operated with high pressure air plumbing located in the control console. It was felt that the system was lacking in safety requirements in several areas. There were no interlocks in the system to prevent overpressurizations, etc.

It was decided to place all high pressure components inside a safe box with as much of the high pressure plumbing as possible. The safe box is constructed of 1/4-inch thick

mild steel (see Figure 2 and Figure 3). If a pipe ruptures or a component fails, any shrapnel will be contained inside the box. The box also contains a pressure transducer which provides an electrical output that is fed to a remote indicator.

Remote solenoid valves and pressure transducers were installed to control the pressure in the muzzle tank and the muzzle. By using solenoid operated valves and pressure transducers, all functions are monitored and controlled from a remote location. This allows the control console to be located as desired -- away from all sources of high pressure. Since the control system is electrically controlled, the installation of interlocks was very easy and practical to prevent overpressurization, and to permit firing only when everything is as desired.

All of the original plumbing and control system was discarded except for two high pressure air filters and some of the 1/8-inch high pressure pipe.

Plumbing Installation

The new high pressure plumbing system is made up of 1/4-inch stainless steel tubing with wall thickness of 0.065 inch. All tubing, fittings and devices used have at least 6000 psi MAWP. The complete high pressure plumbing box with all components installed was pressure tested at the High Pressure Lab to 7500 psi. This is $1\frac{1}{2}$ times the maximum system operating pressure of 5000 psi.

The plumbing system as installed is shown in Figure 3.

Electrical System

The electrical system has two separate voltage sources. All solenoid valves and load carrying relays are operated from 115 VAC line. Logic relays and all switch indicating lamps are operated from 28 VDC. Figure 4 shows two relay panels. The relays on the right side are AC, the relay panel on the left is DC powered. The DC power supply is located on the console floor below the DC relay panel.

Figure 5 shows the control console panel with a representation of the gun drawn in the center of the panel. The pressure indicators, comparators, indicating lamps and switches are located on the panel in relation to the representation of the gun to show their function.

Pressure Controls

There are three pressure chambers in the air gun that must be pressurized to the proper value before firing can be accomplished. The desired pressure in each of these chambers is predetermined. The comparator associated with each chamber has thumbwheel switches that allow the desired pressure to be selected. See top instruments in Figure 6. A second set of thumbwheel switches is also located in each comparator that allows the operator to select a lower limit of pressure that would be allowable in each chamber. This was provided to allow some slight leakage that would otherwise cause the interlocks to disable the fire circuit. If the pressure of any one of the three chambers falls below the "lower limit" setting of the comparator, then the test cannot progress until it is within limits.

The system is interlocked so that the muzzle tank (see Figure 1) must be pressurized within the limits set on the comparator before any further actions can be taken. It is not necessary for the piston to be installed in the breech to pressurize the muzzle tank; however, it is necessary that the piston be in place before any further steps can be taken. Another interlock also comes into play at this point -- the access doors to the room must be closed before the muzzle or breech can be pressurized. If at any time previous to firing the access doors are opened, the test is aborted and must be restarted at a prior step.

With the piston in place and the muzzle tank pressurized, then the muzzle can be pressurized. When both the muzzle tank and muzzle are pressurized properly, the breech can be pressurized.

Once all three chambers are properly pressurized, and only then, the fire circuit is energized and firing can take place.

Solenoid operated vent valves are located in each chamber. The pressure can be adjusted to desired values by momentarily energizing the fill or vent valves. The chamber

can also be vented all the way to atmospheric pressure. If the pressure in any one of the three chambers falls below the "lower limit" value of the thumbwheel setting on the comparators, then the fire circuit cannot be energized.

Post Firing Operation

After the air gun has been fired, the next operation is to depressurize the breech and muzzle sections of the gun and remove the piston. Three valves are involved in depressurization. Since the fire valve is a three-way valve, in the deenergized position the gun can vent through this valve to atmosphere. The breech vent valve can be energized to aid in depressurization and, finally, an auxiliary muzzle vent valve located about 10 feet from the breech can be energized. The muzzle vent valve, located out at the extreme end of the muzzle, is not energized at this time because the air in front of the piston is utilized to move the piston back to the breech for removal.

When the piston has reached the breech of the gun and both the breech and muzzle pressure indicators are reading zero pressure, the breech locking ring and plug are removed and the piston is removed.

Purging the Gun Barrel

An instrumentation cable installed from the front of the piston to a feed-through is always sheared off when the piston passes the feed-through location. This cable always winds up as debris near the muzzle end of the barrel. After the piston has been removed and with the breech end of the gun open, the purge operation is initiated. The key is first removed from the "Enable Pressure" lock to the "Enable Purge" lock. When the key is operated, then the purge barrel solenoid valve can be energized. This solenoid valve feeds high pressure air into the muzzle end of the gun barrel and blows out or "purges" the cable out of the open breech.

Subsequent Tests

At this point the gun can be prepared for the next test. The pressure in the muzzle tank is usually about 20 psi too high. This excess pressure is vented to the atmosphere to a level just above the "lower limit." At this point the sequence for preparation for a subsequent firing follows the outline described previously.

Safety Considerations

An electro-mechanical interlock was a part of the original design concept, agreed to by both the using organization (9342) and the design engineer, R. L. Shuman. In this concept, the interlock would be installed on the breech plug to prevent opening the breech if there was any pressure greater than 1 psi. Sid Cook, 9341, designed a pressure switch (see Figure 7) that operates at any pressure in excess of 1 psi and will withstand the pressure in the breech to its full working pressure of 5000 psi (pressure tested to 7500 psi). This pressure switch was electrically interlocked so that an electro-mechanical solenoid lock on the breech plug could not be operated if there is pressure above 1 psi. All the necessary indicating lights, push button switches and relays were mounted on the console panel or in the console relay panels.

Before the job was completed, the using organization decided they did not want this particular feature included in the modification. However the lights, push buttons and relays were all installed. Only the electro-mechanical solenoid was not installed. It is now possible to remove the breech plug while there is pressure in the breech.

Had the electro-mechanical interlock been installed as planned, the breech plug could not be removed with the key in the "Enable Pressure" location. It would have been necessary to move the key to the "Enable Purge" location for energizing the "unlock breech plug" circuit. In this position if pressure above 1 psi were in either the breech or the muzzle, the interlock would prevent operation of the electro-mechanical solenoid lock. The lights would be "Red" indicating pressure. To proceed to remove the breech plug, the pressure in the breech and muzzle have to first be vented.

After pressure has been reduced to atmospheric, the breech plug and piston are removed, then and only then the purge operation may proceed.

Proof Testing

The high pressure portion of the modification to the air gun was proof tested at the High Pressure Lab in Area II by Organization 9515. This included the valves, filters and switch mounted in the safe box (see Figures 2 and 3). The entire box was moved to Area II and high pressure plumbing attached to the bulkhead fittings mounted on the box.

See Appendix A for the report from Organization 9515.

Electrical Schematics

A ladder type electrical schematic for the control and firing system is shown in Appendix C, Drawing T44331, sheets 1 through 6.

Sandia Laboratories

5.5 INCH AIR GUN

Figure 1.

Figure 2. Air Gun Ereech and High Pressure Enclosure

Figure 3. High Pressure Enclosure Showing Filters, Valves, Plumbing, etc.

Figure 4. Console Cabinet, Rear View Showing AC and DC Relay Panels

Figure 5. Air Gun Control Console

Figure 6. Air Gun Control Console

Figure 7. Pressure Safety Switch

APPENDIX A

Sandia Laboratories

Albuquerque, New Mexico
Livermore, California

DATE April 6, 1976

TO M. R. Shannon - 9341, Attn: R. L. Shuman

FROM J. T. Hillman - 9515

SUBJECT Proof Test of a High Pressure Test Enclosure

On April 1, 1976 a "High Pressure Test Apparatus" containing a number of components, electrical and mechanical, and associated plumbing, all encased in a steel cabinet was proof tested to 51.71 MPa (7,500 psi). The only defect noted was a slight leak detected at higher than MAWP, in a line fitting which is quite tolerable.

RCM:9515:hm

Copy to:
9515 PSEL

APPENDIX B

Parts List and Safety Ratings

The following list of parts includes most of the items used in the air gun. The list does not include miscellaneous hardware.

1. Tubing for high pressure lines (5860 psi MAWP)

304 stainless steel, wall thickness 0.065, 1/4 inch OD tubing allowable working pressure has been calculated using ASME formulas with a Factor of Safety of 8.

See Pressure Safety Practices Manual, SLA-73-0065, dated January 30, 1973, page 8-8.

2. High Pressure Fittings, ells, tees, unions, etc.

Swagelok 316 stainless steel

NOTE: Swagelok Catalog C-1072, dated 1972-73, page 2, says: "Exhaustive tests have proven that the tubing will yield before a Swagelok Tube Fitting will leak." Therefore we assume all fittings are adequate for the system pressures.

3. Low Pressure Solenoid Valves for fill and vent of both the muzzle tank and muzzle

4 each Solenoid Valve, Atkomatic Cat. No. 1544OWP, Dymo series, 1" pipe size for use with air, temperature range 0°F to 200°F, 115 VAC, maximum operating pressure 200 psi, for outdoor service.

NOTE: These valves operate on house air with maximum pressure of 150 psi.

4. Intermediate Pressure Solenoid Valve for auxiliary vent valve

1 each Solenoid Valve, Atkomatic Cat. No. 15800-AND10050, tapped female ends with 7/16-20 threads, for use with air, temperature range 50°F to 150°F, 115 VAC, maximum operating pressure 1000 psi, indoor service.

NOTE: Assuming full system pressure of 5000 psi in the breech prior to firing, the calculated maximum pressure at the location of this valve is 610 psi, which occurs after firing and the piston has travelled to the location of this

valve, approximately 7.5 feet from the breech.

5. High Pressure 3-way Solenoid Valve used for the "fire" valve

1 each Solenoid Valve, Circle Seal No. SV21B32P4T for operation on 115 VAC.

NOTE: Circle Seal catalog rates these valves at maximum operating pressure of 6000 psi.

6. High Pressure Solenoid Valve used for fill and vent valves on the breech

4 each Solenoid Valves, Circle Seal No. SV21B2NC4T for operation on 115 VAC.

NOTE: Circle Seal catalog rates these valves at maximum operating pressure of 6000 psi.

7. High Pressure Solenoid Valve used for the purge operation

1 each Solenoid Valve, Atkomatic Valve Co., Inc., type SLP, Cat. No. 7300, for air, temperature range 50°F to 100°F, maximum inlet pressure 6000 psig; minimum inlet pressure 2000 psig, back pressure essentially 0 psig 115 VAC.

NOTE 1: Atkomatic Valve catalog rates this valve at 6000 psi maximum pressure.

NOTE 2: This valve must be controlled from an auxiliary mercury relay furnished by Atkomatic.

8. High Pressure Filter - to filter air coming from system source before it goes into the control system

1 each Filter, Robbins Aviation, Inc., "RAF" mechanical filter, Model RAF-6ABEF, 245 SCFM flow capability.

NOTE: Robbins Aviation catalog rates this filter for 6000 psi service, with a safety factor of 4:1.

9. High Pressure Filter - in series downstream from the filter in 8 above.

1 each Filter, Haskel Engr. Co., Part No. 21051.

NOTE: A memo from Haskel Engr. Co., dated February 3, 1977, describes the chamber as being "...possible SAE 4130 or 4140 heat treated. ...electroless nickel finish and rated for 6000 psi working pressure. The proof test would have been 9000 psi."

10. Check Valves

2 each Union Bonnet Lift Check Valves, Whitey Co., Cat. No. SS-53S4, 316 stainless steel construction, 1/4" Swagelok connections, Whitey Co. catalog NW-273, dated 1973, page 6, rates this valve at 5000 psi @ 70°F.

11. Shut-off Valves

3 each Union Bonnet Valves, Whitey Cat. No. SS-3TS4, stainless 316 steel construction, TFE stem tips, 1/4" Swagelok connections, Whitey Co. catalog NW-972, dated 1972, page 16, rates this valve at 5000 psi @ 70°F.

12. Metering Valve

2 each Union Bonnet Metering Valves, Whitey Co. Catalog SS-31RS4, stainless steel construction, 1/4" Swagelok connections, Whitey Co. catalog NW-572, dated 1972, page 8, rates this valve at 5000 psi @ 70°F.

13. Pressure Transmitter used for measuring the pressure in the muzzle and muzzle tank located at end of muzzle tank and muzzle.

2 each Pressure Transmitters, Rosemount Model No. 1104-G-4-A-1-SO, scaled output 0 to 1 volt DC, pressure 0 to 100 psi.

14. Pressure Transmitter used for measuring the pressure in the breech section.

1 each Pressure Transmitter, Rosemount Model No. 1104-G-8-A-1, maximum pressure 5000 psi, output 0-5 VDC.

15. Comparator for setting pressures for the various chambers of the air gun.

3 each Comparator, Electronic Research Co. Model 2544-04-28.

16. Digital Panel Meters for reading the pressures in the gun.

3 each Digital Panel Meters, ERC Model 3501-28.

17. Fiber Optic Light Source and Detector used to assure the breech plug is in place.

Made up of the following components:

- a. 1 each Fiber Optic Scanner, Skan-A-Matic No. TS-322-3
- b. 1 each Power Supply Module, Skan-A-Matic No. T21012

- c. Trim Pot Indicator Module, Skan-A-Matic No. T21011
- d. Photoelectric Amplifier Module, Skan-A-Matic No. T21004
- e. Form C Driver Module, Skan-A-Matic No. T21003

18. Relays 115 VAC used in the control circuits.

30 each Relays, Guardian Cat. No. 1210N-3C-120A, 3 pole, DT, contacts rated 10 amps at 115 VAC with miniature neon lamp connected across terminals.

19. Relays, 24 volt DC, used in the control and logic circuits.

26 each Relays, armature, miniature, DC type, 4 form C contacts rated 5 amps resistive @ 29 VDC, Sandia Part No. S/N 616744.

20. Weatherproof Enclosures to enclose pressure transducers.

3 each Weather Enclosure, Hoffman No. 16148CH.

21. Timer used to assure proper warmup of equipment.

1 each Reset Timer, Eagle Signal Cycl-Flex Model HP56-A6-07-08, to include keylock and neon indicator.

22. Console -- used to house control circuits and equipment for the air gun.

Purchased from: Borg Warner Corp.
Emcor/Ingersoll Products Div.
1000 W. 120th St.
Chicago, Illinois 60643

The console is made up of the following components:

- a. 1 each Turret Enclosure Frame No. AFRI-745235-00
- b. 1 each Top Panel No. APNS-745235-00
- c. 1 each Back Panel No. APNS-745235-02
- d. 2 each Closure Panel No. APNS-745235-01
- e. 1 each Vertical Frame No. AFRV-745235-00
- f. 1 each Rear Door Left No. ADOL-FKX-002424
- g. 1 each Rear Door Right No. ADOR-FKX-002424
- h. 1 each Bottom Panel No. APNB-745235-00
- i. 1 each Writing Top No. AWTF-745235-00

- j. 1 each Center Angle Kit No. ACAK-745235-00
- k. 1 each Right Side Panel No. ASPR-DIX-252120
- l. 1 each Left Side Panel No. ASPL-DIX-252120
- m. 1 set Casters No. AHWX-240-000002

NOTE 1. One of the closure panels listed in item d is to be painted with EN-2LG light gray.

NOTE 2. The writing top item i is to be 3601GC grey tone color.

NOTE 3. All other items a-m are to be painted with EN-2BU blue.

APPENDIX C

Drawing No. T144331, Control Console

REV	DESCRIPTION	DATE	BY
A	GENERAL REVISIONS C.E. PETTIT, 10/5/70, SHAWHAN	10/5/70	SHAWHAN
B	GENERAL REVISIONS C.E. PETTIT, 10/5/70, SHAWHAN	10/5/70	SHAWHAN
C	ADDED DISPLAY, GENERAL C.E. PETTIT, 10/5/70, SHAWHAN	10/5/70	SHAWHAN
D	GENERAL REVISIONS C.E. PETTIT, 10/5/70, SHAWHAN	10/5/70	SHAWHAN

REV	DESCRIPTION	DATE	BY
A	GENERAL REVISIONS C.E. PETTIT, 10/5/70, SHAWHAN	10/5/70	SHAWHAN
B	GENERAL REVISIONS C.E. PETTIT, 10/5/70, SHAWHAN	10/5/70	SHAWHAN
C	ADDED DISPLAY, GENERAL C.E. PETTIT, 10/5/70, SHAWHAN	10/5/70	SHAWHAN
D	GENERAL REVISIONS C.E. PETTIT, 10/5/70, SHAWHAN	10/5/70	SHAWHAN

FORM 1042-13 744331
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SHEET 5 OF 5

TIMER SCHEMATIC

COMPARATOR 1,2,3 J1-C

COMP #1-Y-BUSS - MUZZLE TANK - COMP #1-19-BUSS

COMP #2-Y-BUSS - MUZZLE - COMP #2-13-BUSS

COMP #3-Y-BUSS - BREECH - COMP #3-13-BUSS

COMP #1-2-2-TB3 - MUZZLE TANK - COMP #1-20-5-TB3

COMP #2-2-3-TB3 - MUZZLE - COMP #2-20-7-TB3

COMP #3-2-13-TB3 - BREECH - COMP #3-20-11-TB3

BLOCK DIAGRAM

CONNECTION DIAGRAM

NOTES:

1-AMPLIFIER SHOWN CONNECTED DARK ENERGIZED.

2-ONLY LOAD 2 IS USED IN THIS SYSTEM WHEN PHOTOCELL IN SCANNER IS LIGHT.

3-LOAD NO. 2 IS ENERGIZED.

4-LOADS MAY BE RESISTORS, RELAYS, SOLENOIDS, ETC.

5-PROTECTIVE DIODES SHOULD BE USED AS SHOWN IF LOAD IS INDUCTIVE.

DIGITAL VOLTMETER 1,2,3 J1-V

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