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NUCLEAR DIVISION

BOLT INSTALLATION AND REMOVAL TOOL

P/N 113835

Final Report

To

George C. Marshall Space Flight Center
National Aeronautics and Space Administration

Contract NAS 8-30026

AN-1709

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TO

GEORGE C. MARSHALL SPACE FLIGHT CENTER
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

FINAL REPORT

BOLT INSTALLATION AND REMOVAL TOOL
P/N 1135835

CONTRACT NAS 8-30026

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I. INTRODUCTION

This final report presents the work conducted by Aerojet-General Corporation under Contract NAS 8-30026, for development, design, fabrication, and proof testing of a bolt installation and removal tool. This report covers the design criteria, development, detailed parts description, and recommendations for improving and space qualifying the tool.

II. DESIGN CRITERIA

A. BOLT SIZES

The bolt installation and removal tool (BIRT) for space applications shall be capable of the installation and removal of five sizes of type MS 21250 external wrenching, 180,000 psi bolts, 1/4-28, 5/16-24, 3/8-24, 7/16-20 and 1/2-20 inch. During the installation and removal operations, the tool will grip and retain the bolt to eliminate handling loose bolts and also the socket will retract or extend into or from the basic tool as the bolt is removed or installed so the operator need not expend physical energy to continually move the tool to hold the tool in the correct relative position during use. The complete operation shall be accomplished utilizing only one hand.

B. POWER SOURCE

The BIRT will be operated from a regulated $12 \pm 1/2$ v. d. c. power source with an output capacity of 50 amperes. The regulated power source is necessary for the timing cycle of the impactor which is initiated by the value of the impact current as well as for maintaining a constant motor speed.

C. REVERSING ROTATION

Reversing the rotation of the BIRT shall be accomplished by means of a switch that is actuated by the same hand that holds the tool while wearing a simulated astronaut glove.

D. ADJUSTABLE IMPACT TIMER

The impact time shall be adjustable within the electrical control unit (ECU) to allow sufficient impacting time to produce the proper bolt torque.

E. WEIGHTLESS ENVIRONMENT

The tool shall be capable of operating in a 1/6-zero gravity (G) without the operator expending physical energy to maintain a fixed tool position. The reaction torque when the tool is operating shall not exceed 57 inch pounds under all operating conditions.

F. PHYSICAL CHARACTERISTICS

1. Weight

The weight of the BIRT with the largest socket assembly attached shall not exceed 10 pounds excluding the weight of the power cord.

2. Length

The overall size of the tool shall be as small as practical and shall be governed by the operating requirements.

III. DESIGN REQUIREMENTS

A. TORQUE

The torque will be developed utilizing a spring loaded, cam

actuated impact wrench which is commercially available.

B. SOCKET ASSEMBLIES

Five socket assemblies will be supplied with the impact wrench.

1. Interchangeable Use

Each of the five socket assemblies will be interchangeable for use with one impact wrench.

2. Fixed Torque

Each socket assembly will be capable of delivering rated torque for the bolt size used. The bolt sizes and torques are as follows:

<u>Bolt</u>	<u>Torque (Inch-Pounds)</u>
MS 21250H04004, 1/4 size	70 - 90
MS 21250H05004, 5/16 size	140 - 200
MS 21250H06004, 3/8 size	200 - 350
MS 21250H07004, 7/16 size	500 - 750
MS 21250H08004, 1/2 size	700 - 950

C. IMPACT TIME

The impact time will be initiated by the electrical control unit (ECU) and after the desired impact time has expired, the impacting will automatically stop. The impact time will be adjustable from 0-30 seconds by an externally adjusted control on the ECU.

D. BOLT RETENTION

Each socket assembly will pick-up and retain the bolt size for which it is designed during the installation and removal operations.

IV. DEVELOPMENT (Preliminary)

A. REVIEW OF TOOLS

During the preliminary development of the BIRT three commercially available impact tools were investigated. This investigation was conducted in order to survey what methods of torque control were commercially available. The data recorded as a result of the analysis and testing conducted on the off-the-shelf wrenches were utilized in the development of the design criteria.

1. Black and Decker

A standard Black and Decker impact wrench without a variable torque feature was used extensively during the development testing. Torque was applied to a bolt socket through an impactor. The impactor was a spring loaded, cam-actioned hammer. Results of these early tests are as follows:

Impact time -	Torque varies with impact time.
Tool Perpendicularity -	Maximum torque is achieved with the tool perpendicular to the work. With the tool offset approximately 10° from the perpendicular, 2/3 of the torque is achieved.
Impact Spring Force -	Varying the pre-load spring force varied the output torque. Varying the maximum load (top of cam action) of the

spring did not measurably affect this output torque.

Point of Impact -

Increasing the radius of the point of impact between the hammer and anvil increased the output torque. Reducing the radius to a certain point reduced the output torque, but beyond that point the output torque was unaffected.

2. Montgomery Ward

During the development testing, a standard Montgomery Ward variable torque wrench was also used. It was found that it was not possible to achieve repeatable torques over the advertised range of 0-250 ft-lbs. The minimum torque for a five second impact period was 30-40 ft-lbs, and the maximum torque for the same impact time was 100 ft-lbs. It was judged that the wrench would be useful only for commercial applications. The principle of the wrench is a torsion bar with a fairly rigid rubber cylinder providing both the cam action and the variable force to change the rigidity of the torsion bar. A variation of this principle where the rubber cylinder was replaced by a metal diaphragm or spring might have potential. However, it appeared that a more satisfactory design can be achieved with the spring loaded cam/torsion bar combination.

3. Ingersoll-Rand

The design of a commercially available Ingersoll-Rand

variable torque wrench was also reviewed during the development phase. The unique feature of this wrench is the use of an adjustable preloaded torsion bar in the output shaft. Output torque is controlled when the preload of the torsion bar is reached and the hammer rebounds up a cam and trips the pneumatic motor off-on switch. Several problems in adapting this tool to a space environment tool exist. The range of torques exceeds any one torsion bar, necessitating a rather intricate disassembly/assembly operation to go from one bolt size to another. Also, the standard size wrench does not go down to 6-8 ft-lbs; the design of the wrench does not lend itself to the bolt retention requirements for the BIRT.

B. TORQUE REDUCTION PROGRAM

During the preliminary design phase of the torque reduction program, many variables were found to adversely affect the delivered output torque to the socket assembly, namely the type of torsion bars used, the number of anvils, and the spring torsion of the cam-hammer in the impactor. Many hours of experimental laboratory time were spent to reach a compromise of the three parameters.

1. Overlap Between Anvil and Hammer

The original idea of developing the required but variable torque for different sizes of bolts was to vary the overlap between the anvil and hammer. This would allow the hammer to ride up and over the anvil using a minimum of spring deflection and consequent less driving force. This had the effect of causing more torque to be developed with a large overlap and

conversely less torque as the overlap became smaller. This scheme did produce a variance in the torque, but the torque differential was not great enough to cover the range of torques for the various bolts.

2. Impact Radius

Another scheme was to vary the interface radius between the anvil and hammer as measured from the center of rotation of the anvil. This also caused torque variation but not enough to satisfy the design requirements.

3. Slotted Anvil

Expanding the concept as described in 1, above, slots were machined in the anvil so as to waste some of the impact energy by the flexure of the anvil. Various slot widths and varying numbers of slots were tried, but the end results were not favorable.

4. Number of Anvil Ears

It was found experimentally that varying the number of anvil ears had a great influence on the velocity of the hammer during the impact cycle which affects the output torque. Increasing the number of ears from two to four reduced the torque 60 percent due to the decreased hammer speed. This feature was utilized as part of the final design in achieving the desired torque of the five socket assemblies. The 1/2 inch socket assembly has two anvil ears, whereas the other four sizes, 1/4, 3/8, 5/16 and 7/16 inch have four anvil ears.

5. Preload Spring

It was found during laboratory testing that the spring force which preloads the cam which drives the hammer down during the impact cycle affects the output torque. The spring force was varied by using springs with different force values; shims were added to further vary the spring force. Varying the maximum spring force of the return spring at the top of the cam action had little effect. A spring with a 10.5 in-lb force was selected in the final design; this spring produced an output torque of 86-94 ft-lbs.

6. Torsion Bars

As discussed in paragraphs B.2 and B.3, altering the anvil ears was unsuccessful in varying the torque. The final design uses a torsion bar to absorb energy between the impactor and the socket drive. The desired output torque using this method was achieved by the trial-and-error method of "tuning" the shaft, that is machining the diameter of the torsion bar to arrive at the desired torque for each of the socket assemblies. Figure 10 shows a plot of output torque versus shaft diameter, Item 2 of Figure 4 shows the torsion bar configuration for the torsion member.

7. Final Configuration

Figures 4 and 5 show the final configuration of the socket assembly for the BIRT. As discussed above, socket sizes for the 1/4, 5/16 and 3/8 inch bolts utilize a torsion bar in the socket mechanism to absorb impact energy. These torsion bars are combined with four eared anvils to achieve rated torque. The 7/16 and 1/2 inch sockets do not have

a torsion bar. The 1/2 inch socket utilizes a two eared anvil and full output energy of the impact tool. The 7/16 inch socket incorporates a four eared anvil and full impact energy of the tool.

C. TIMER DEVELOPMENT

The BIRT impact time was experimentally determined to be one of the more critical items in producing the desired torque. From experimental data it was determined that rated torque for a 1/2 inch bolt was achieved by impacting with full impact force for from 4-1/2 to 5-1/2 seconds. As a result of this investigation it was determined that impact time of the tool should be established at $5 \pm 1/2$ seconds for all sockets and should utilize the previously described mechanical methods for torque control. A timer was developed in conjunction with personnel at the Marshall Space Flight Center which timed the length of impacting and automatically cutoff after rated time. The principle utilized in the timer was to sense the current rise in the motor associated with the higher load required for impacting. The initial timer in early development tests appeared to be adequate; however, during Acceptance Testing it was found that the timer did not always repeat because it was too voltage sensitive. The timer was modified to use a constant voltage reference source which thus resolved the problem. Subsequent development of the timer disclosed that the constant voltage source could be eliminated by modification to the circuitry so that it was insensitive to the load variation of the motor. A final configuration of the timer is shown schematically in Figure 6.

V. FABRICATION AND DEVELOPMENT

A. HOUSING AND INSERT

As shown on Figures 4 and 5, the socket retracts into the housing during bolt removal operations so that the reference plane of the tool handle does not have to be changed with respect to the work piece as the bolt is installed or removed. The initial design incorporated a brass housing so that no galling of threads would occur between the socket and the housing. During the test program the brass threads in the housing were damaged during the impacting cycle of the tool with the result that the socket would not reengage the threads during the following cycle of the socket retraction. The problem was corrected by installing a hardened steel threaded insert in the housing. All socket assemblies have this insert; however, the 5/16 and 1/2 inch sockets which had already been fabricated retained the brass housing. In subsequent manufacturing of the 1/4, 3/8, and 7/16 inch sockets the housing material was changed to aluminum for weight savings. In any further fabrication of the sockets all housings should be aluminum.

B. BOLT GRIPPER

The bolt gripper or bolt retention mechanism in each socket assembly must be capable of maintaining the bolt in the socket assembly during the installation and removal phase of the operation. In the initial design this was accomplished by utilizing an expanding collet arrangement which expanded into the hole in the bolt head automatically as the socket

retracted into the housing to grip the bolt on a friction principle. This design was based on the successful bolt gripper mechanism in the Bolt Removal Tool developed under Contract NAS 8-20796. However, in the BIRT the high speed of the motor, combined with slight misalignment of the bolt in the socket, created sufficient unbalanced force on the bolt to cause the friction grip on the collet to slip and the bolt to drop from the socket.

The design approach to resolve the problem was to install wire fingers in the collet so that expansion of the collet into the bolt head hole would automatically extend the wire fingers into the lock wire holes of the bolt. From a bolt holding standpoint this approach was highly successful. However, if the bolt was accidentally removed from the socket while the wire fingers were gripping the lock wire holes, the fingers would be damaged sufficiently to require rework prior to reuse of the tool.

In the final configuration, the expanding collet arrangement without wire fingers was utilized. To reduce the unbalance forces on the bolt during the free spin operation of the tool, the speed of the motor was reduced by approximately half. This was achieved by modifying the timer, adding a resistance in the circuitry which was bypassed during the impacting cycle of the tool. Thus, in operations, during free spin of the tool or run in of the bolt, approximately half current is applied to the motor. During the impact portion full current is applied to the motor. The net result of these changes created a hesitance of a few milliseconds at the switch-over from spin to impact which can be felt by the tool operator. This is due to the time required

to saturate components in the timer. Testing has shown that this slight hesitation does not affect tool performance.

VI. ACCEPTANCE TEST AND PROOF TEST

A. ACCEPTANCE TEST

The acceptance test for the BIRT was conducted in two phases: phase number one was a bench test to verify the performance of the timer, the impact unit and two socket assemblies (5/16-24 and 1/2-20). This phase was conducted at the Marshall Space Flight Center (MSFC) and the results of this test are given in MSFC interim report number IN-S&E-ME-M-69-1. The basic concept was accepted with recommendations for improvements in the electrical and bolt gripping systems.

Phase two of the final acceptance test was conducted at the Aerojet-General Corporation San Ramon Facility. The final acceptance of the BIRT was approved after it was demonstrated by proof testing that the BIRT fulfilled all criteria and design requirements.

B. PROOF TEST

The proof test consisted of the installation and removal of five sizes of bolts, recording the tightening and breakaway torque and the impact time. The results of the proof test are shown in Figures 8 and 9. The Proof Test Procedure is detailed in AGC Report Number AN-1697.

VII. RECOMMENDATIONS

A. TOOL IMPROVEMENT

Development testing of the tool revealed very little that should be improved upon in any follow on work. In testing and developing the tool for one hand operation the tool became useable for right handed operators only. This is caused by the location of the reversing toggle switch. It is believed that the switch could be changed to adjustable action type which would then make the tool useable by either the right or left hand.

Components in the timer are susceptible to temperature and voltage fluctuation. Consequently, the timer could be improved; however, within the environment of the development and acceptance testing, the timer adequately maintained the impact time within the allowable specifications.

It is believed that a different approach to the timing aspects of the tool could be developed. This would be a scheme wherein the number of impacts would be counted. It is believed, although not confirmed by testing, that correct torques for each bolt size could be achieved by limiting the number of impacts, i. e., relatively few impacts for a 1/4 inch bolt and hundreds of impacts for a 1/2 inch bolt. If this type of device were developed, some components such as anvils, torsion bars, etc., could be eliminated. This would result in simplification of the tool and permit standardization of parts.

B. SPACE QUALIFICATION

In order to make the BIRT suitable for installing and removing

bolts in a 100-300 nautical mile earth orbit, the tool must be capable of operating in a 1.0×10^{-6} mm Hg vacuum over a temperature range of -54°F to 160°F . It must also operate in the five psi oxygen atmosphere of an orbital laboratory and must be capable of being operated in a zero gravity by an astronaut in a space suit. In order to achieve the capabilities, a comprehensive test program should be initiated.

The electric motor in the tool could either be an a. c. motor, a brushless d. c. motor, or a conventional brush d. c. motor. It is our understanding that brushes capable of operation in the vacuum of space are being developed. The following test program would apply to any type of motor.

The test program should include development testing, qualification testing, and acceptance testing. Development tests should be conducted to investigate the environmental effects on the operating characteristics and materials of the space tool; furthermore, a space glove compatibility test and zero gravity tests should be included. Conditions normally encountered during handling, transportation, and storage of the tool should be included in the qualification tests. Acceptance testing will verify the tool conformance to applicable specifications and drawings.

1. Development Test Plan

- a. Scope

This plan covers the tests required to develop a Space Bolt Installation and Removal Tool (SBIRT) for use in the zero gravity and vacuum conditions of a 100-300 nautical mile orbit.

(1) The SBIRT will be tested under the temperature extremes (-54°F to 160°F) and vacuum (1.0×10^{-6} mm Hg) expected in orbit. The SBIRT will be modified to correct or improve various characteristics of the tool to make it acceptable for use under the vacuum, temperature, and operational conditions of space.

(2) A SBIRT will be tested to verify that the tool meets the design criteria for use under space conditions. The design verification tests will consist of vacuum, temperature, and functional tests to prove that the SBIRT will operate properly under the projected space conditions.

b. Discussion

(1) General

The development tests will consist of those tests necessary to supply design information to prove that various design concepts are operable under the space environmental conditions. Tests to be performed are functional tests, operational tests, and selected environmental tests.

NOTE 1: Unless otherwise specified, the tool shall be brought to room conditions, operated, and inspected at the conclusion of each test.

The operational testing of the tool shall consist of installing and removing a preselected number of bolts from a test fixture as rapidly as possible. The bolts shall be inspected to

determine that no damage to the bolts has been caused by the tool. The motor temperature shall not exceed 140°F during this operation and no lubricant leakage, smoke, or other signs of malfunction shall be observed.

The inspection of the tool shall consist of examining the unit for cracks, discoloration, seal leaks, or other signs of damage; the electrical insulation, brushes (if it is a brush type motor), and switches for evidence of deterioration; the mechanical mechanism for evidence of cold welding. Failure of the unit to meet any of these conditions will constitute a failure to pass the test.

(2) Initial Development Tests

The initial development tests will consist of operating the SBIRT in a vacuum of 1.0×10^{-6} mm Hg under temperature conditions of -54°F to 160°F . These tests will determine the ability of the brushes, bearings, gear-boxes, lubricants, and electrical circuitry to function under the space conditions, or identify modifications that will be required to make these units operable under the space conditions. The two tests to be conducted during this initial phase are described below:

(a) The SBIRT shall be first operated at 1.0×10^{-6} mm Hg vacuum, 160°F temperature (five minute soak), and cycled at no load for five minutes. If the unit operates with no visible signs of failure and the case temperature does not exceed 200°F , then the tests

shall be repeated with a 100 in-lb load with the tool being cycled for 30 seconds at six minute intervals for one hour, and the same criteria for success apply. Upon completion of this test, the unit shall be inspected and operated in accordance with Note 1.

(b) The SBIRT will be modified by removing the motor cooling impeller. The unit shall then be operated at 1.0×10^{-6} mm Hg vacuum, 160°F temperature (five minute soak), and cycled at no load for five minutes. The case temperature shall be compared with the temperature of the case during the previous tests under similar conditions. The unit shall then be operated under the same vacuum and temperature conditions except that it shall be loaded to 100 in-lbs and cycled for 30 seconds at six minute intervals for one hour. The temperatures shall again be compared to the temperatures of the similar tests with the impeller. The tool shall then be inspected and operated in accordance with Note 1. If the temperature without the impeller is considerably (10°F) lower than the comparable temperature with the impeller, the final design will eliminate the impeller.

If during tests (a) and (b) the grease from the Space Bolt Removal Tool gear-box outgasses excessively, additional tests of the unit will be performed utilizing dry lubricants, different seals, and relief valves to maintain a specific pressure. The condition of the gear-boxes shall be observed and compared with that observed in the previous tests to determine the best method for lubricating gear-boxes.

(3) Final Development Tests

The data accumulated from the tests described above will be utilized in designing the tool for qualification testing. Prior to qualification testing, however, another series of development tests will be performed to verify design changes. The tests will consist of the following:

(a) The SBIRT will be operated with the operator wearing space gloves. The time for the operator to accomplish the task and the ease with which he accomplishes the task will be noted.

Three tests are proposed for this operation.

(b) The SBIRT will be operated in a 1.0×10^{-6} mm Hg vacuum at temperatures of -54°F (five minute soak) and 160°F (five minute soak). At each temperature, the tool shall be cycled for five minutes at no load and then cycled for 30 seconds at six minute intervals for one hour with a 100 in-lb load. Temperature rise measurements, brush arcing, and gear-box operation will be noted to determine that they meet design criteria. Four tests are proposed for this area.

(c) The SBIRT will be operated under water on a predetermined number of bolts, utilizing space gloves. The time and ease of accomplishing this operation will be compared with previous tests described in Paragraph (1). The tool will be waterproofed for the tests. Four tests are estimated in this area.

(d) The SBIRT will be operated in an airplane flying a zero "g" flight path. The tests will determine the effect of the tool reaction torque on an operator in a zero "g" environment. Two tests are proposed for this area, with six bolts to be removed during each test.

Recycling of any developmental tests will be required when modifications are made on the tool. Satisfactory completion of all tests to this point will complete the development tests for the SBIRT.

2. Qualification Test

The data obtained during development tests will be utilized to establish the final design criteria for the flight tool. Three Space Bolt Installation and Removal Tools will be fabricated. Each SBIRT will be complete with a power unit, an electrical control unit and five socket assemblies (1/4, 5/16, 3/8, 7/16 and 1/2 inch). One tool will be used for the qualification testing (Qualification Test Unit) and two tools for flight use (deliverable units). Containers should also be provided for environmental protection of the tools during transportation on the ground and in space.

The qualification tests should consist of those tests required to verify the ability of the Space Bolt Installation and Removal Tool to withstand the conditions which will occur in orbit, in transport to orbit, and in ground handling. The test parameters are in accordance with MSFC's Orbital Workshop Experimenter's Handbook, SAA-209. These tests should consist of the following:

<u>Test</u>	<u>Procedure</u>
Low Temperature	MIL-STD-810A, Method 502.1 shall apply except that the test temperature shall be -30°C instead of -62°C and duration shall be not less than four hours at stabilized temperatures.
Low Pressure	MIL-STD-810A, Method 500.1, Procedure II at 10^{-6} Torr.
High Temperature	MIL-STD-810A, Method 501.1 shall apply except that duration shall not be less than four hours at stabilized temperature.
Temperature Shock	MIL-STD-810A, Method 503.1.
Acceleration Longitudinal	MIL-STD-810A, Method 513.1, Procedure I. Acceleration level shall be 1.0 to 7.0 g increasing linearly in 60 seconds.
Lateral	MIL-STD-810A, Method 513.1, Procedure I. Acceleration level shall be 1.0 to 4.0 g increasing linearly in a total of one second.
Vibration	MIL-STD-810A, Method 514.1.
Shock	MIL-STD-810A, Method 516.1, Procedure III.
Low Pressure - Solar Energy	MIL-STD-810A, Method 517.1.
Humidity	MIL-STD-810A, Method 507.1.

3. Acceptance Test

Acceptance testing of the two deliverable units should be conducted to verify that they have been fabricated in accordance with the applicable specifications and drawings.

4. Flight Qualification Test

This plan covers those tests which must be accomplished to flight rate the Space Bolt Installation and Removal Tool (SBIRT).

a. The SBIRT must be capable of operating unprotected in a 100-300 nautical mile earth orbit. The tool must also operate in the 5 psi oxygen atmosphere of the Orbital Laboratory.

b. The SBIRT must be capable of operating under the conditions of a., above, after being transported into orbit, stored in the pressurized or unpressurized Orbital Laboratory.

5. Environmental Tests

Environmental tests will be accomplished to determine the ability of the SBIRT to withstand the conditions which will occur in orbit, in transport to orbit, and in ground handling. Where various requirements are not a limiting factor (e.g., fungus), or do not apply (e.g., explosive atmosphere) they have been eliminated.

The environmental tests consist of the vacuum 1.0×10^{-6} mm Hg temperature (-30°F to 160°F), low pressure, acceleration, vibration, shock, and humidity tests as outlined in MIL-STD-810A.

The specific tests described below will be performed in accordance with MIL-STD-810A as modified by the MSFC Orbital Workshop Experimenter's Handbook, SAA-209.

a. The low temperature tests shall be conducted in accordance with Method 502.1 of MIL-STD-810A. The low temperature

shall be -30°F . The tool will not be operated at this temperature. The tool shall be brought to room conditions and inspected and operated in accordance with Note 1.

b. The low pressure test shall be performed in accordance with Method 500.1 of MIL-STD-810A. The test chamber shall be reduced to a vacuum of 1.0×10^{-6} mm Hg and a temperature of -54°F . The tool shall be cycled in the 1.0×10^{-6} mm Hg vacuum for five minutes with no load. Observations shall be made and noted relative to the following acceptance criteria:

- o The tool drive system shall continue to rotate.
- o The motor running current shall not exceed 25 amps.
- o The motor case temperature shall not exceed 140°F .
- o The temperature of the gear box, and bolt grasping mechanism shall not exceed 140°F .

Upon completion of the test, the tool shall again be operated and inspected per Note 1. The change in altitude test requirement described in Method 500.1 will not be applicable.

c. The high temperature test shall be performed in accordance with Method 501.1 of MIL-STD-810A. The tool shall be cycled at no load at 160°F . The tool shall be brought to room conditions and inspected and operated in accordance with Note 1.

d. The temperature shock test shall be performed in accordance with Method 503.1 of MIL-STD-810A. The tool shall not be

operated during the test, but shall be operated and inspected at the conclusion of the test in accordance with Note 1.

e. The acceleration test shall be performed in accordance with Method 513.1 of MIL-STD-810A, Procedure I. Longitudinal acceleration levels shall be 1.0 to 7.0 g increasing linearly in 60 seconds. Lateral acceleration level shall be 1.0 to 4.0 g increasing linearly to a total of one second.

f. The vibration test shall be performed in accordance with Method 514.1 of MIL-STD-810A. The SBIRT shall be packaged in the shipment container and tested in accordance with Equipment Class 4, Mounting Type A category vibrational requirements. The tool will not be operated during the test, but will be operated and inspected per Note 1 upon completion of the test.

g. The shock test shall be performed in accordance with Method 516.1 of MIL-STD-810A. Procedure III is to be utilized with the tool packaged for shipment. The tool is to be operated at the conclusion of the test in accordance with Note 1.

h. The low pressure solar energy test shall be performed in accordance with Method 517.1 of MIL-STD-810A. The tool shall be cycled 30 seconds every six minutes for four hours with a load of 100 in-lb, and the test radiation set at 130 watts/sq ft with a spectrum distribution per referenced method. The 1800 to 2500 angstrom wavelength band will not be included.

i. The humidity test shall be performed in accordance with Method 507.1 of MIL-STD-810A. The tool shall be housed in its shipping container during the test. At the conclusion of the test, the tool shall be operated and inspected in accordance with Note 1.

Recycling of the above tests will be performed where modifications may affect the tool operation.

C. CONCLUSIONS

Upon successful completion of all the above tests, the Space Bolt Installation and Removal Tool will be considered capable of performing its intended function in an anticipated 100-300 nautical mile earth orbit environment, and will be considered flight qualified.

VIII. SUMMARY

The work conducted by the Aerojet-General Corporation on the Bolt Installation and Removal Tool has demonstrated that a tool to perform under adverse conditions can be and was developed. Two models or prototypes have been developed for underwater use and simulated space station use; with further refinement and development a space qualified tool can be realized to meet all of the environment conditions that will exist in an orbiting space platform or station. The design knowledge learned on the two prototypes will prove invaluable in the final design of a tool for use in space.

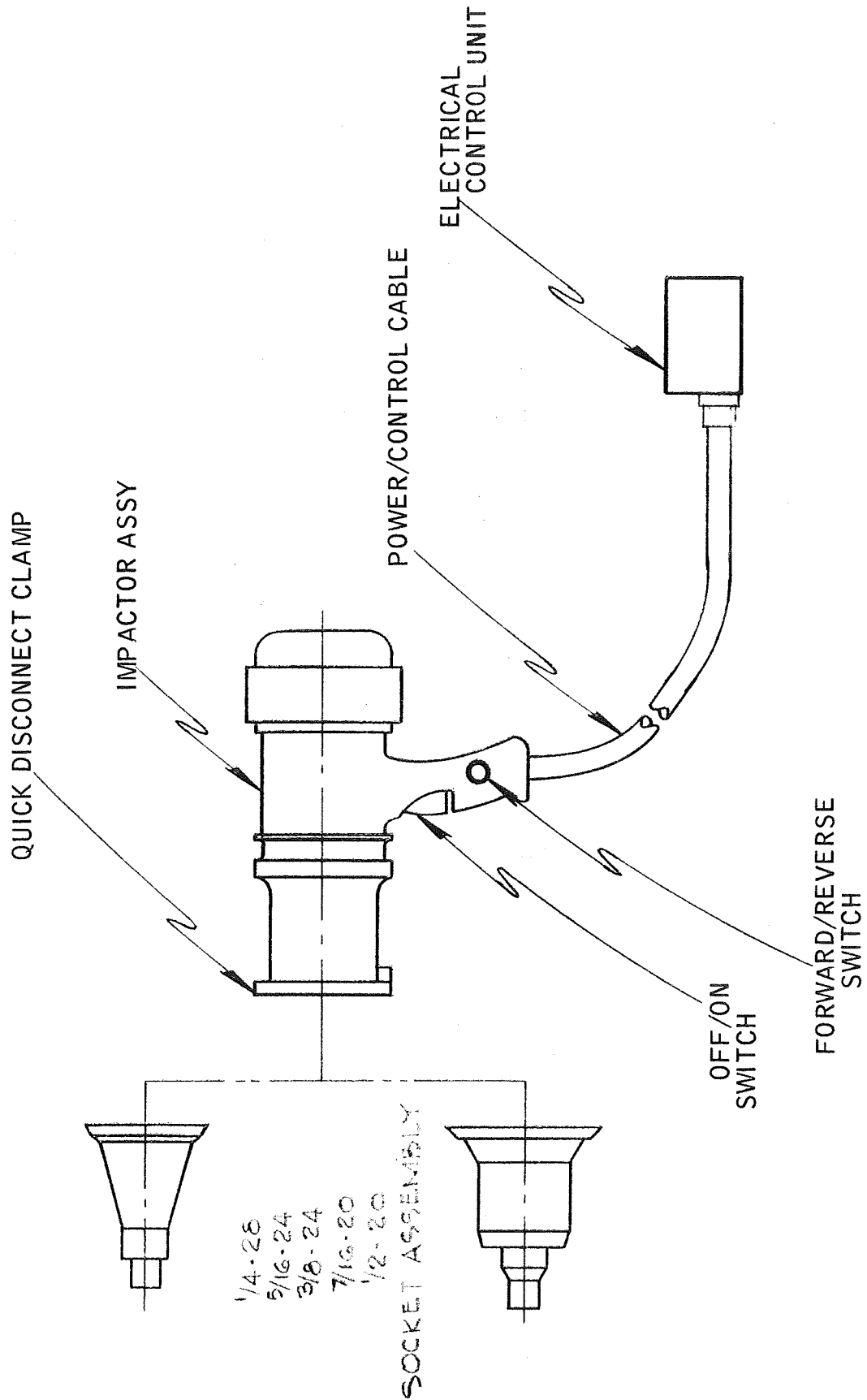


FIGURE 1.
TOOL, ASSEMBLY
BOLT INSTALLATION AND REMOVAL

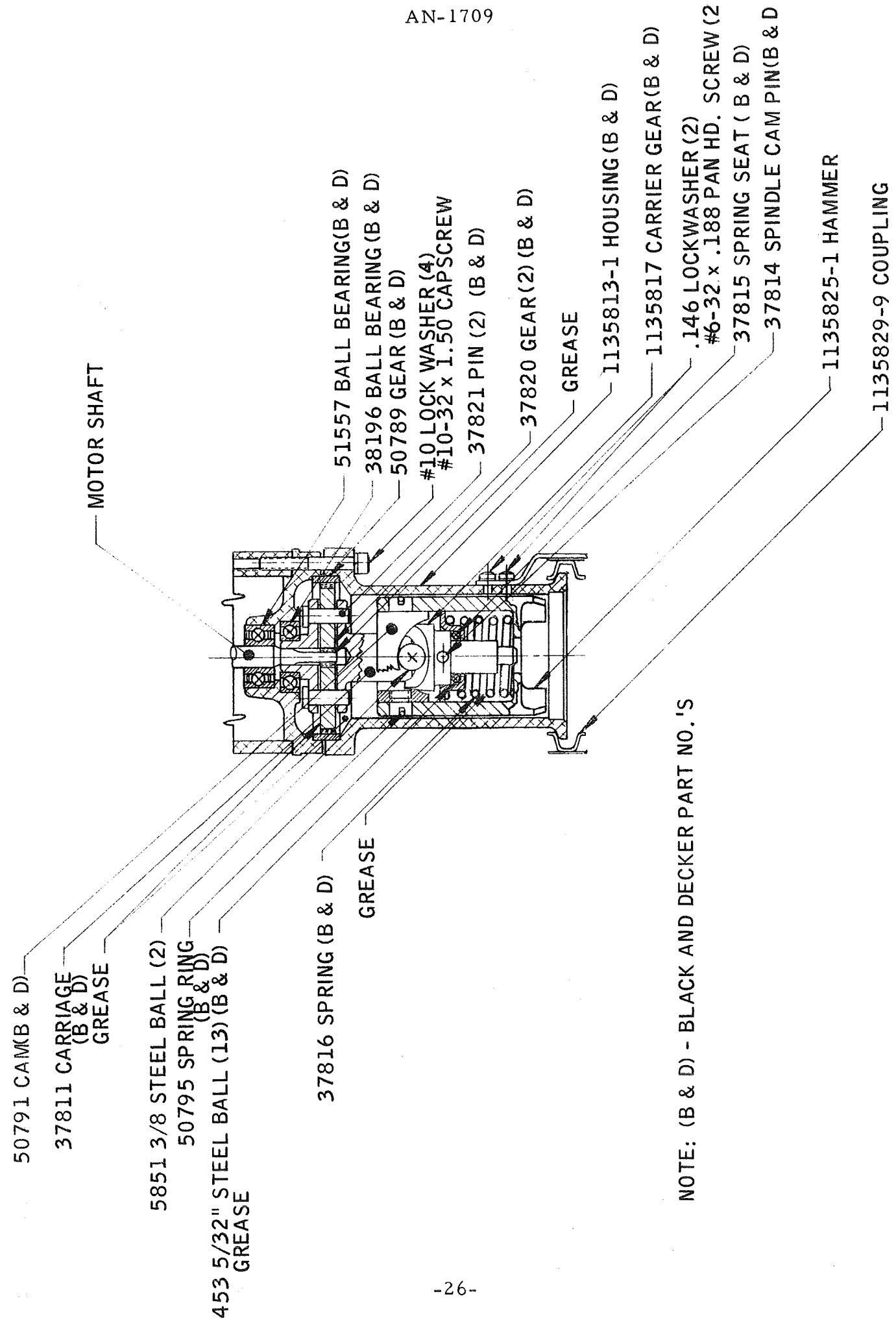


FIGURE 2. - IMPACTOR ASSEMBLY
BOLT INSTALLATION AND REMOVAL TOOL

- ① 38031-71 S.A. FIELD (1)
- ② 27765-71 FIELD (1)
- ③ 33315 TERM CLIP (2)
- ④ 37900-31 ARMATURE (1)
- ⑤ 37899 ARMATURE SHAFT (1)
- ⑥ 31675 SET SCREW (2)
- ⑦ 38167 INSULATING SHIELD (1)
- ⑧ 37907-04 END CAP (1)
- ⑨ 37913 S.A. CONT. BLOCK (1)
- ⑩ 37905 SWITCH CONT. (2)
- ⑪ 37915 CONT. BLOCK (1)
- ⑫ 4006-01 RIVET (2)
- ⑬ 37908 S.A. BRUSH LEAD (2)
- ⑭ 33311 TERM SPRING (2)
- ⑮ 33314 AMP CONN. (2)
- ⑯ 26119 TERMINAL CLIP (2)
- ⑰ 34524 BRUSH ASSY (2)
- ⑱ 32457 Be. HOLD (2)
- ⑲ 32594 BRUSH HOLDER INSERT (2)
- ⑳ 7441 BRUSH HOLDER PLUG (2)
- ㉑ 7442 BRUSH HOLDER PLUG INSERT (2)
- ㉒ 1135844 TRIGGER
- ㉓ LC-032C-4 MW SPRING
- ㉔ GATZ TOGGLE SWITCH
- ㉕ N-5030L BOOT
- ㉖ 6107 SWITCH
- ㉗ 82236 SPRING, LEAF

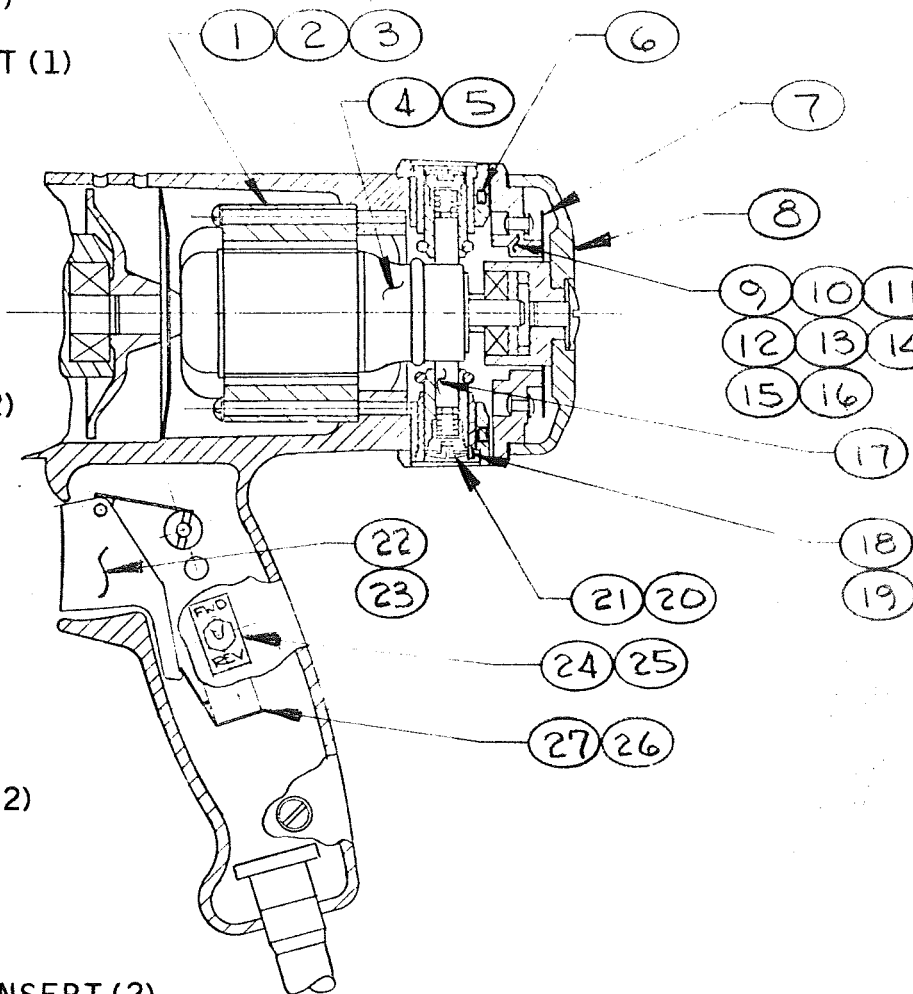


FIGURE 3.
ELECTRICAL AND CONTROL SWITCHES
BOLT INSTALLATION AND REMOVAL TOOL

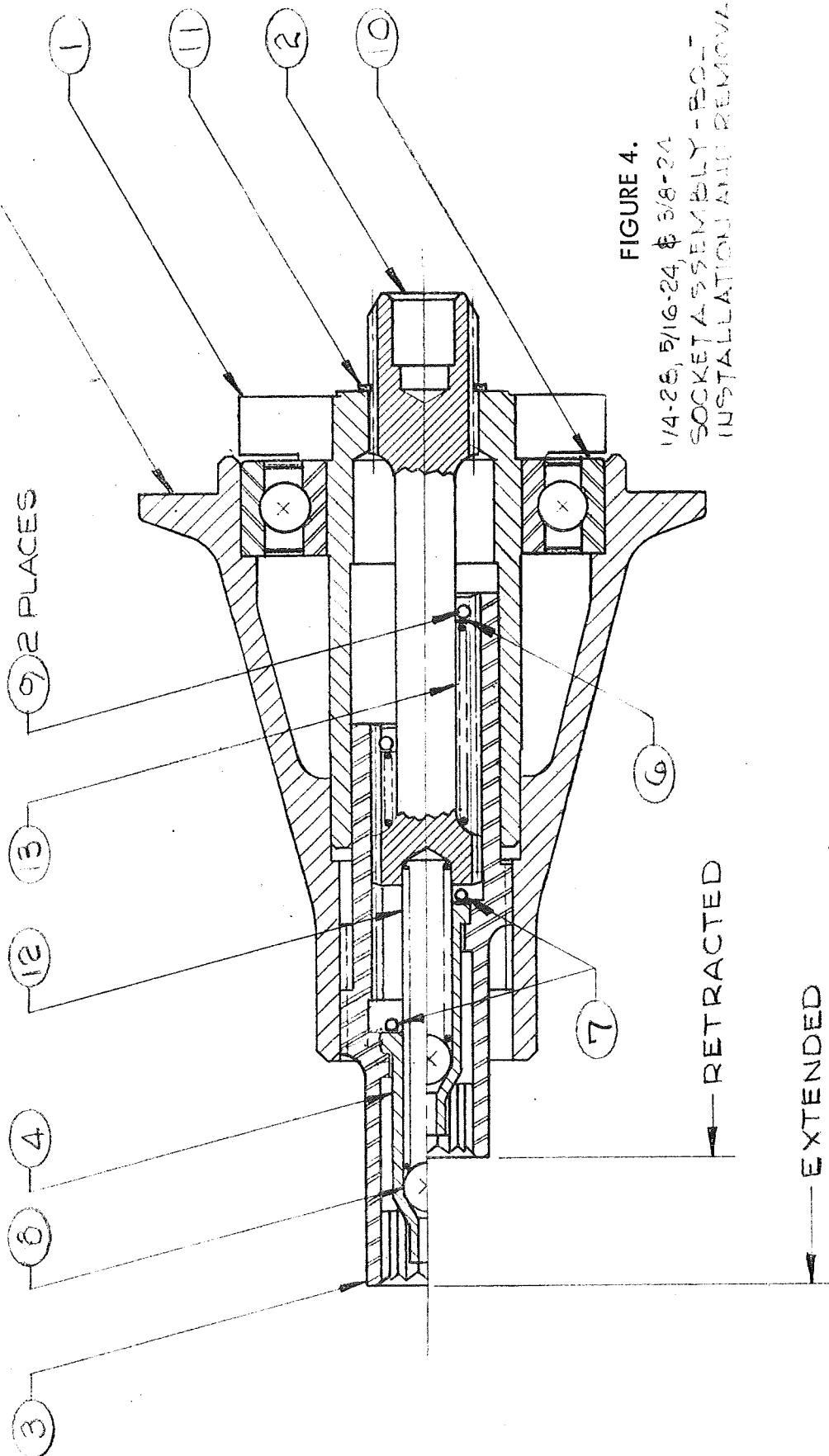


FIGURE 4.

1/4-26, 5/16-24, 3/8-24

SOCKET ASSEMBLY-BOLT
INSTALLATION AND REMOVAL TOOL

- | | | | |
|---|-----------------|----|---------|
| 1 | ANVIL | 8 | BALL |
| 2 | DRIVER | 9 | PIN |
| 3 | SOCKET | 10 | BEARING |
| 4 | COLLET | 11 | RING |
| 5 | HOUSING | 12 | SPRING |
| 6 | SPRING RETAINER | 13 | SPRING |
| 7 | ROLL PIN | | |

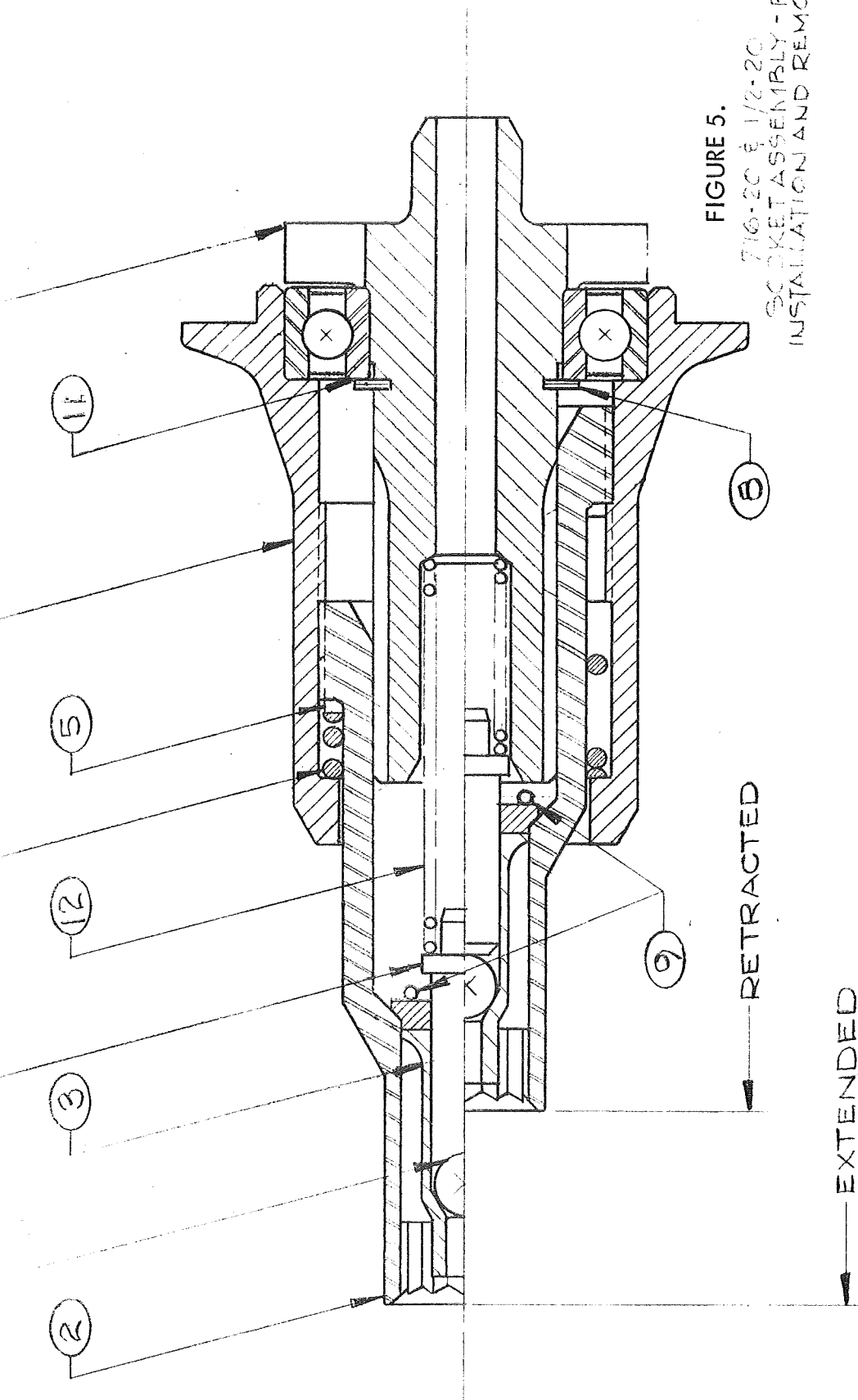


FIGURE 5.

716-20 & 1/2-20

SOCKET ASSEMBLY - BOLT
INSTALLATION AND REMOVAL TOOL

- | | |
|------------|------------|
| ① SPRING | ⑦ ANVIL |
| ② SOCKET | ⑧ RING |
| ③ COLLET | ⑨ ROLL PIN |
| ④ EXPANDER | ⑩ BALL |
| ⑤ RING | ⑪ BEARING |
| ⑥ HOUSING | ⑫ SPRING |

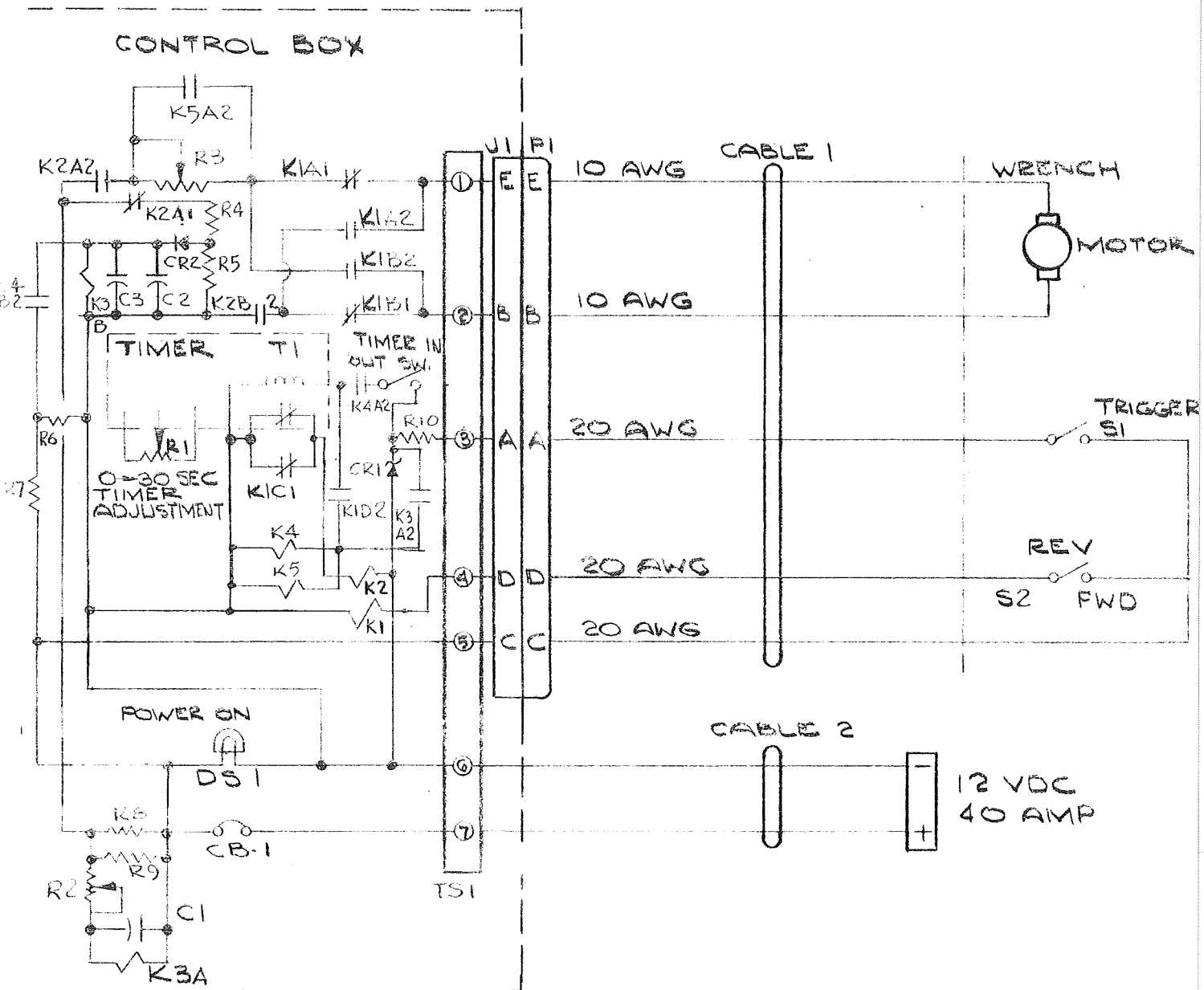
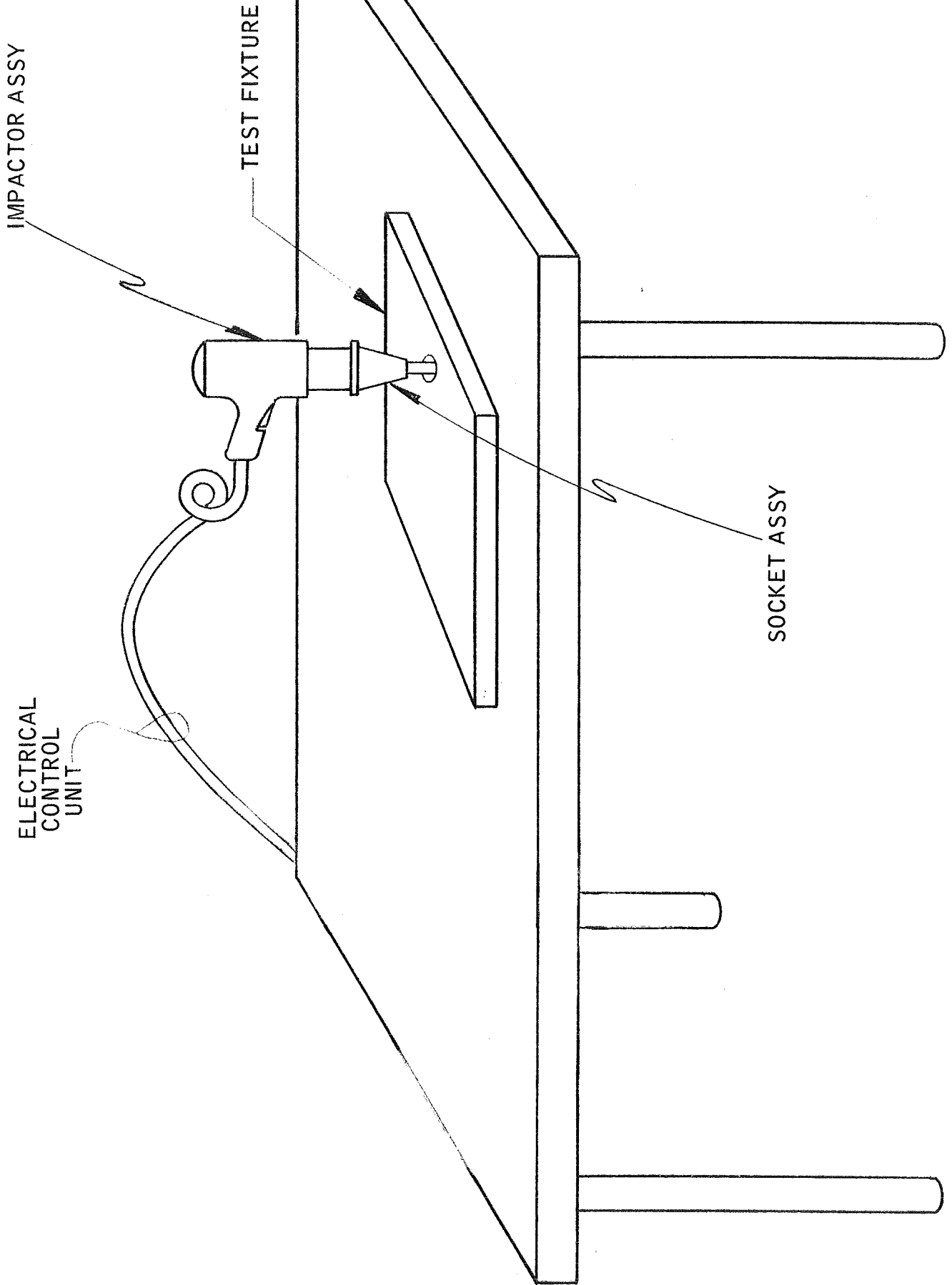


FIGURE 6.
ELECTRICAL SCHEMATIC OF CONTROL UNIT
BOLT INSTALLATION AND REMOVAL TOOL



GENERAL EQUIPMENT ARRANGEMENT BOLT INSTALLATION AND REMOVAL TOOL TEST

FIGURE 7.

BOLT INSTALLATION & REMOVAL TOOL

CONTRACT NAS-8-30026

PROOF TEST DATA SHEET

Engineer J.R. Brown

Date 9-9-69

MS21250H04	PROOF TEST PARAGRAPH NUMBER.												
	C-1	C-2	C-3	C-4	C-5	IMPACT TIME SEC.	C-6	C-7 _{IN-1b}	C-8 _{IN-1b}	C-9	C-10	C-11	C-12
1	✓	✓	✓	✓	✓	5.6	✓	90	60	✓	✓	✓	✓
2	✓	✓	✓	✓	✓	5.4	✓	85	80	✓	✓	✓	✓
3	✓	✓	✓	✓	✓	5.3	✓	95	70	✓	✓	✓	✓
4	✓	✓	✓	✓	✓	4.7	✓	85	55	✓	✓	✓	✓
5	✓	✓	✓	✓	✓	5.0	✓	90	55	✓	✓	✓	✓

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AN-1709

MS21250H05	PROOF TEST PARAGRAPH NUMBER.												
	C-1	C-2	C-3	C-4	C-5	IMPACT TIME SEC.	C-6	C-7 _{IN-1b}	C-8 _{IN-1b}	C-9	C-10	C-11	C-12
1	✓	✓	✓	✓	✓	5.1	✓	165	125	✓	✓	✓	✓
2	✓	✓	✓	✓	✓	5.1	✓	165	125	✓	✓	✓	✓
3	✓	✓	✓	✓	✓	5.0	✓	175	130	✓	✓	✓	✓
4	✓	✓	✓	✓	✓	5.0	✓	155	120	✓	✓	✓	✓
5	✓	✓	✓	✓	✓	5.0	✓	150	105	✓	✓	✓	✓

MS21250H06*	PROOF TEST PARAGRAPH NUMBER												
	C-1	C-2	C-3	C-4	C-5	IMPACT TIME SEC.	C-6	C-7 _{IN-1b}	C-8 _{IN-1b}	C-9	C-10	C-11	C-12
1	✓	✓	✓	✓	✓	5.3	✓	250	170	✓	✓	✓	✓
2	✓	✓	✓	✓	✓	5.1	✓	250	190	✓	✓	✓	✓
3	✓	✓	✓	✓	✓	5.0	✓	240	185	✓	✓	✓	✓
4	✓	✓	✓	✓	✓	5.2	✓	225	160	✓	✓	✓	✓
5	✓	✓	✓	✓	✓	5.4	✓	240	160	✓	✓	✓	✓

BOLT INSTALLATION & REMOVAL TOOL

CONTRACT NAS-8-30026

PROOF TEST DATA SHEET

Engineer J. R. Brown

Date 9-9-69

MS21250H07*	PROOF TEST PARAGRAPH NUMBER.												
	C-1	C-2	C-3	C-4	C-5	IMPACT TIME SEC.	C-6	C-7 _{IN-1b}	C-8 _{IN-1b}	C-9	C-10	C-11	C-12
1	✓	✓	✓	✓	✓	4.8	✓	540	375	✓	✓	✓	✓
2	✓	✓	✓	✓	✓	4.9	✓	590	475	✓	✓	✓	✓
3	✓	✓	✓	✓	✓	5.3	✓	580	400	✓	✓	✓	✓
4	✓	✓	✓	✓	✓	5.1	✓	590	460	✓	✓	✓	✓
5	✓	✓	✓	✓	✓	5.8	✓	615	525	✓	✓	✓	✓

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AN-1709

MS21250H08*	PROOF TEST PARAGRAPH NUMBER.												
	C-1	C-2	C-3	C-4	C-5	IMPACT TIME SEC.	C-6	C-7 _{IN-1b}	C-8 _{IN-1b}	C-9	C-10	C-11	C-12
1	✓	✓	✓	✓	✓	5.2	✓	925	750	✓ *	✓	✓	✓
2	✓	✓	✓	✓	✓	5.0	✓	850	625	✓	✓	✓	✓
3	✓	✓	✓	✓	✓	5.0	✓	775	610	✓	✓	✓	✓
4	✓	✓	✓	✓	✓	5.2	✓	915	615	✓	✓	✓	✓
5	✓	✓	✓	✓	✓	5.1	✓	940	750	✓	✓	✓	✓

MS21250H0	PROOF TEST PARAGRAPH NUMBER												
	C-1	C-2	C-3	C-4	C-5	IMPACT TIME	C-6	C-7	C-8	C-9	C-10	C-11	C-12
1													
2													
3													
4													
5													

* DISPOSITION ON #SR1589

Figure 9

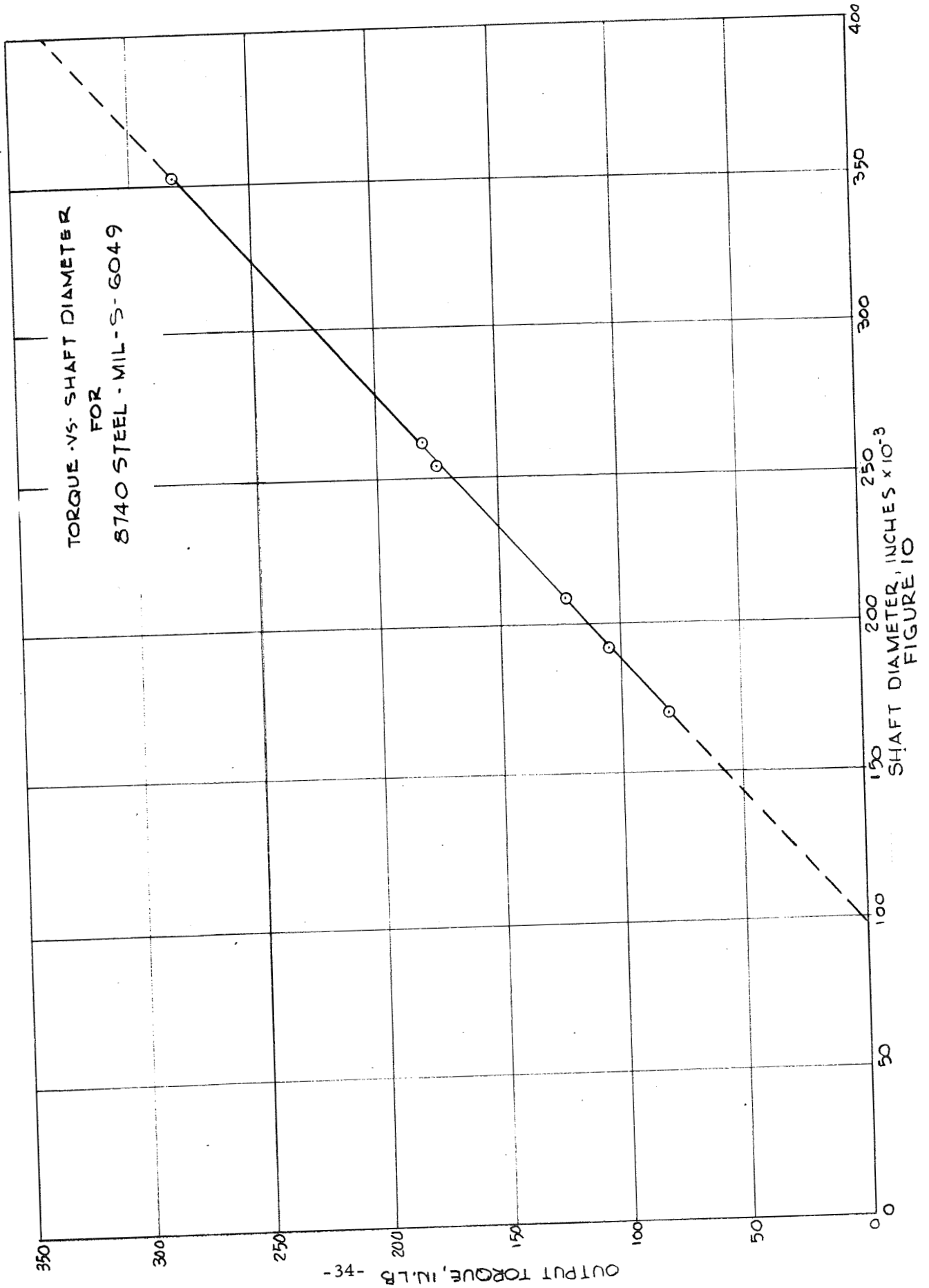




FIGURE 11. BOLT INSTALLATION AND REMOVAL TOOL WITH SOCKET ASSEMBLIES AND TIMER

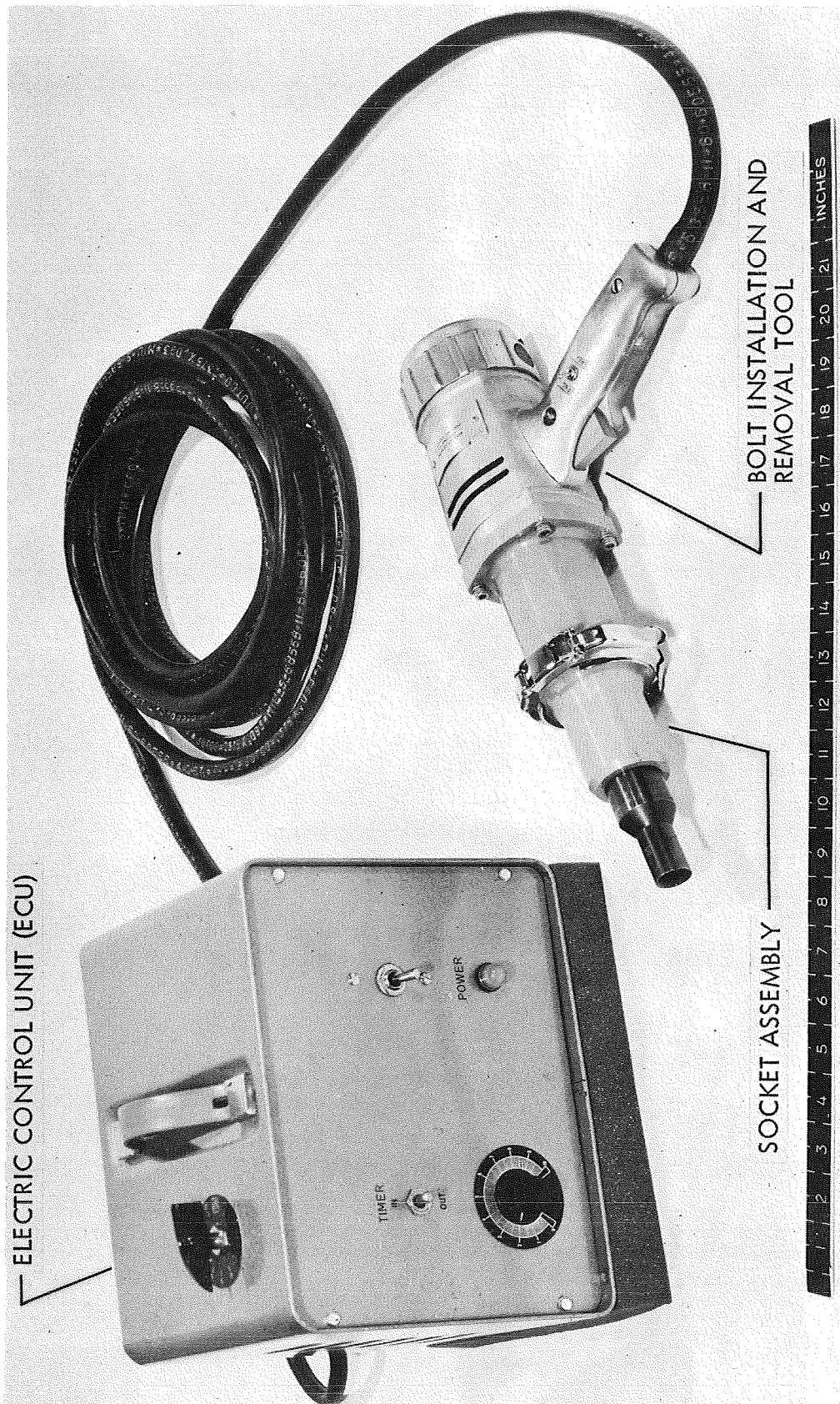


FIGURE 12. BOLT INSTALLATION AND REMOVAL TOOL WITH SOCKET ASSEMBLY



FIGURE 13. BOLT INSTALLATION AND REMOVAL TOOL WITH SOCKET ASSEMBLY AND TEST PLATE



AEROJET-GENERAL CORPORATION