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MECHANICS & ELECTRICITY DIVISION - INSTRUMENT AND PHYSICAL TESTING SECTION

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ELECTRIC CONTROL FOR THE LIMITING OF MAXIMUM TORQUE, SPECIFIC APPLICATION TO ROLLING-IN OF SMALL CONDENSER TUBES

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ABSTRACT

An electronic relay for opening the circuit to a universal motor at the time the current reaches a pre-selected value is described. This device serves as a control method for the rolling-in of tubes in the process of fabrication and repair of condensers. Because the current to a universal motor depends almost entirely upon the motor load, providing line voltage remains constant, this device permits rolling of the tube until the torque required to rotate the expander reaches a prescribed value, and in this manner produces uniform tube to tube sheet joints. The electronic control consists of a sampling transformer, arranged so that the voltage across its secondary is proportional to the current to the motor. This voltage is applied to a biased diode which becomes conducting only if the positive peaks of the voltage exceeds the diode bias. The signal thus passed by the diode is applied to the grid of a gas tube, which upon becoming conducting, is instrumental in operating a relay to open the circuit to the motor. Means are provided for automatically resetting the circuit for subsequent operations. Means are also provided for making adjustments to compensate for differences in tube characteristics when tube replacements are made. The device can be useful in any application where it is desired to limit the maximum torque to be applied.

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INTRODUCTION

A. Authorization and References

1. This work is authorized by reference (a).

(a) Bureau of Ships letter NP14/N32(335C) of 23 June 1945 establishing Project Order No 550/45

(b) Fisher, F. F. and Cope, E. T. Automatic Rolling-In of Small Tubes. Trans. of the ASME. Vol. 65 p 53-60

(c) Norfolk Navy Yard letter to Bureau of Ships N5(56-87); N5(38-36); N5(31-145-MSP2) dated 3 May 1945

B. Statement of Problem

2. The purpose of this problem is to design and build a working model of an electronic device which has as its function the stopping of an electric motor when the output torque of the motor has reached a preselected value. Such a device will serve as a control method for the rolling-in of condenser tubes, and thus insure the proper degree of rolling of each tube. The device shall provide a simple method of selecting the desired torque, and shall incorporate means for automatically resetting the device for each subsequent operation.

C. Known Facts Bearing on the Problem

3. In the manufacture and repair of surface condensers, air coolers and air heaters it is necessary to provide a water tight joint between the tube and tube sheet. This is quite commonly accomplished by means of an expanding tool similar to the one shown in Plate 1. Three tapered rollers, R, are supported by the cage, C, and are placed at intervals of 120° in the cage. A tapered mandrel, M, extends through the cage and contacts the rollers. The large end of the mandrel is attached to a motor, driven either by air or electricity, which revolves the mandrel about its axis. The revolving mandrel revolves the individual rollers in the opposite direction to that of the mandrel, thus carrying the cage at a reduced rate in the same direction as the mandrel. The rollers are usually set in the cage with the axis of each roller at an angle of 1° to 3° with a plane passing through the axis of the mandrel. This angle (feed angle) causes the expander to tend to pull itself into the tube, T, as the expander revolves. The taper of each roller is 1/2 the taper of the mandrel so that the finished joint is cylindrical. The thrust coller, K, contacts the tube sheet, S, and prevents the cage from entering the tube beyond the desired distance.

4. For a satisfactory tube to tube sheet joint, the correct degree of rolling is required. If the joint is under rolled, it will leak upon the application of a hydro-static test. If the joint is over-rolled the joint may not leak when subjected to a hydro-static test but will subsequently fail under operating conditions.

5. The methods for control of the degree of rolling that are found in practice are quite varied. In many instances the amount of rolling depends entirely upon the experience of the operator, who after much experience is purported to "feel" when the tube has been sufficiently rolled. Under such conditions it is not uncommon for as many as 10% of the joints to leak when placed under test, which necessitates rerolling of the leaky joints.

6. One method of control is known as the uniform-entrance method. By this method the degree of rolling is determined by the distance the mandrel is permitted to enter the expander. This method produces tube ends of uniform diameter but the joints can be assumed to be uniform only if the tube holes are of identical diameter and the tubes have the same inside diameter and wall thickness. Commercial tolerances of tubing do not permit uniform rolling by such a method. Condensers which are being repaired present additional objections to this method in that the diameter of the holes may vary over a wide range as a result of previous rolling.

7. Another method of control that has been advanced is that of stopping the rolling operation when the torque being applied to the expander has reached a given value. During the first part of a rolling operation, the tube is expanded until contact is made with the tube sheet. After contact is made between tube and tube sheet, continued rolling causes the tube to flow axially and also causes expansion of the hole in the tube sheet with an attendant cold working of tube and tube sheet. The torque required to revolve the expander steadily increases as the cold working of tube and expansion of tube sheet hole proceeds. If the rolling of all the joints is stopped at some given value of the torque, it is assumed that the same degree of cold working of tube and expansion of the tube sheet hole has been attained for all joints. This method is not therefore critically dependent upon the tolerances of tube diameter and wall thickness and the diameter of the hole in the tube sheet. Various mechanical torque limiting devices can be devised, such as friction clutches etc., but they do not appear satisfactory for this application because of lack of flexibility and dependability.

8. In reference (b) it has been purposed to limit the torque applied to the expander by use of an electromagnetic relay which will open the circuit to the electric motor driving the expander when the current to the motor reaches a given value. This method offers a simple and convenient means for limiting the torque applied to the expander. However, the use of electromagnetic relays offer the following objections in this particular application.

(a) Non-flexible, that is, difficulty in readily setting the relay to operate at the desired torque.

(b) Non-dependable, that is, the value of the current which operates the relay is subject to wear of mechanical parts and to temperature changes.

(c) Chatter of relay. Because the current slowly approaches the operating value of the relay, there is a region of uncertainty in which the relay may have a tendency to chatter.

9. The use of an electronic device makes it possible to overcome all of the above objections to the electromagnetic relay.

10. The use of a current limiting device to limit the torque of a motor assumes that the relation between torque and current to the motor is independent of other factors. Plate 2 gives curves which show the relation between output torque and input current for several different line voltages. The curves are for a universal motor operating on alternating current. It can be seen that the torque output for a given current depends upon the input voltage, therefore it is necessary to insure a constant input voltage to the motor in order to maintain a simple relation between current and torque. Conceivably, it is possible to use electronic means for compensating for line voltage changes so that the device would operate to stop the motor at a given torque regardless of the line voltage, but in this particular application only fractional horse-power motors are used, therefore it is more expedient to use a constant voltage transformer to insure constant input voltage to the motor.

DESCRIPTION OF APPARATUS

A. Motor

11. The motor, M, is a fractional horsepower universal motor which will operate on either a.c. or d.c. power. The particular electronic control device to be described requires that the motor be operated on a.c. The motor is housed in the conventional pistol grip housing, commonly used as a tap gun for the tapping of threads. A gear reduction transmission attached to the motor normally rotates the expander in a counter-clockwise direction. As the expander is pushed into the tube end there is a limited axial movement of the drive spindle which causes a change in the gear transmission so that the spindle is made to rotate in a clockwise direction. The micro-switch, S_4, is mounted on the motor so that the switch is open when the motor is rotating in a counter-clock-wise direction, but the axial motion of the spindle necessary to reverse the direction of rotation causes the switch to be closed. The function of this switch is explained in paragraph 13.

12. It is desirable that the motor be designed to operate with as low a no-load current as possible, and the value of the torque at which it is desired to stop the motor should be near the maximum rated torque of the motor. If the motor is so designed, the curves shown in Plate 2, will have the greatest slope permissible over the range the motor is to be used and thus present the optimum conditions for good control by the current limiting method.

B. Electronic Control

13. Plate 3 shows a schematic diagram of the circuit. The transformer, T_1 serves as a sampling transformer which provides a voltage across its secondary that is proportional to the current through its primary. The resistances R_1 and R_2 serve as shunts on the primary, preventing core saturation of the transformer. It is essential that these resistances

be made of material having a low temperature coefficient of resistivity. The output voltage of T_1 is applied across the biased diode V_1. The negative bias on V_1 prevents V_1 from being conducting until the positive peak value of the voltage from T_1 is greater than the negative bias. As the current to the motor increases, the amplitude of the a.c. voltage appearing across the secondary of T_1 eventually becomes great enough so that the positive peak voltage is large enough to permit conduction by V_1, thus causing a signal to appear across R_7. The signal across R_7 is applied to the grid of the gas tube, V_2, through the filter composed of H_1 and C_2. This filter removes all high frequency "noise" arising in the motor commutator. As the positive peak value of this signal increases and reaches a given value, it causes V_2 to become conducting, and the resulting plate current energizes the relay, Y, thereby opening the circuit to motor, M. V_2 will continue to be conducting until the micro-switch, S_4, is opened. The opening of S_4 opens the plate circuit of V_2 and thus de-energizes the relay and restores the closed circuit to the motor.

14. The sequence of events in the process of rolling a tube will illustrate the operation of the device. S_1 is closed and the apparatus is permitted to warm up. Closing the trigger switch, S_5, starts the motor and rotates the expander in a counter-clock-wise direction. Due to the fact that S_4 is now open, it is impossible for the starting surge of current to energize the relay. The expander is inserted into the tube end and a force is applied to the motor tending to push the motor toward the tube sheet. This force causes a limited axial movement of the drive spindle which in turn changes the direction of rotation of the expander to a clockwise rotation and simultaneously closes the micro-switch S_4. As the rolling-in process progresses the current drawn by the motor gradually increases. At a given value of the current, as described in paragraph 13, the relay, Y, is energized and the motor stopped. After the motor stops, the operator pulls the motor away from the tube sheet. This motion causes axial translation of the drive spindle, which in turn opens switch S_4. The opening of S_4 de-energizes the relay, Y, and restores operation of the motor which now rotates the expander in a counter-clockwise direction permitting easy withdrawal of the expander.

15. The current to the motor which will cause the device to open the circuit is made to depend upon the negative bias on V_1, this bias being determined by the setting of R_5. The setting of R_5 is made by means of the "Calibration Control" C, shown on the photograph of Plate 4 and thus permits a very flexible method of setting the device to operate at the desired torque. The negative voltage, D, is maintained very constant by means of the voltage regulating tube V_5. The amplitude of the positive voltage peaks passed by V_1 necessary to ignite the gas tube V_2, can be adjusted by means of the bias control R_9. The circuit constants are such that a peak voltage of approximately 3 volts is required on the grid of V_2 to cause the tube to become conducting. It is to be pointed out that the characteristics of grid controlled gas tubes may differ considerably from one another, e.i., it is not uncommon to find as much as 20% difference in the positive grid voltage required to ignite similar tubes under the same

operating conditions. The advantage of using the biased diode, V_2, to clip the positive peaks of the a.c. voltage derived from the transformer, T_1, is now apparent, for the peak voltage applied to the grid of V_2 is only a fraction of the total voltage across the secondary of T_1. Because of this fact the responsibility of stable calibration is placed largely upon the regulated voltage D, rather than the characteristics of the gas tube V_2.

16. To further minimize the dependence of the calibration upon the characterisitics of V_2, means are provided for adjussting the negative bias on the grid of V_2 and thus compensate for a change in tube characteristics whenever a replacement of V_2 is made. This adjustment is made by throwing the switch, S_3, from "operate" to the "check" position which alters the circuit in the following ways:

(1) The plate of the diode, V_1, is removed from the transformer T_1 and connection is made to one side of the filament heater supply through resistor, R_4. This places an a.c. voltage of several volts across V_1, irrespective of the setting of R_5. The positive peaks of this a.c. signal appearing across R_7 are applied to the grid of V_2.

(2) The plate circuit involving V_2 is changed so that the micro-switch, S_4, is removed from the plate circuit and one of the normally closed contacts of the relay, Y, is substituted in its place.

(3) The condenser, C_3, is placed in the circuit. As a result of the above three changes the circuit in effect become s a relaxation oscillator which behaves as follows:

When the value of R_9 is adjusted so that the negative bias between grid and cathode of V_2 is of such a value as to permit the positive peak of the signal being applied to the grid of V_2 to just ignite the tube, the condenser, C_3, will be discharged through the tube and the relay winding. This surge of current through the winding of Y will open the contacts of the relay and thereby remove the B voltage supply from V_2 which in turn causes the plate current to cease, permitting the relay to return to its normal closed position. The closing of the contacts permit the condenser C_3 to again charge through R_8 and R_9 to a potential approximately that of B, causing the tube V_2 to again ignite and thus repeat the above described sequence of event. It is seen that the adjustment of R_9 to the point where the relay is just on the verge of chattering, places a bias on the gas tube, V_2, such that it will be ignited by a given positive voltage on the grid.

17. The closing of switch, S_2, changes the range over which the control will operate. When the switch is open the maximum cut-off current is approximately 2.5 amperes. Closing S_2 places an additional shunt on T_1 thus changing the value of total current necessary to operate the control so that the maximum cut-off value is 5 amperes. Closing S_2 also places a shunt on the ammeter, A, so that the meter indicates one half the current to the motor.

DETERMINING THE PROPER VALUE OF CUT-OFF CURRENT.

18. The method of determining the proper setting of the "Calibration Control" to produce joints of the desired strength, requires the rolling-in of sample tubes into a sample tube sheet using various settings of the "Calibration Control." The push out strength of the joints are subsequently determined and that setting of the "Calibration Control" is chosen which produced joints having the desired push out strength. The push-out strength is defined as the maximum axial force required to push the tube out of the tube sheet. The optimum value for the push-out strength is dependent upon the following factors:

(a) Composition of tubes and tube sheets

(b) Thickness of tube sheet

(c) Diameter and wall thickness of tubes

(d) Condition of surface inside the hole in tube sheet and the outside of the tube end.

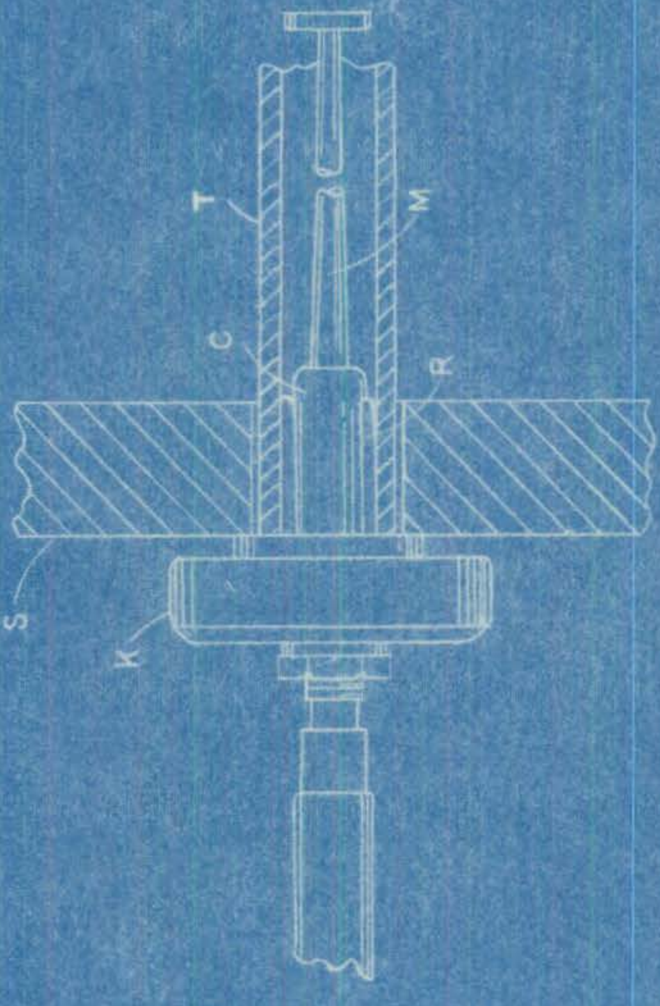
The optimum value for the push-out strength for a given set of conditions is not as yet definitely defined but experience has indicated the approximate range in which the push-out strength must be in order to produce satisfactory joints.

TEST OPERATION

19. The initial test operation of the device was made at the Norfolk Navy Yard in April 1945 and is reported in reference (c). A condenser unit consisting of 2358 Cu Ni 5/8" gage tubes were rolled into a tube sheet 1" in thickness. The tubes were rolled at both ends making a total of 4716 joints. A subsequent hydrostatic test at 15 pounds per square inch showed three leaks, these three joints having been missed during the rolling operation.

REMARKS

20. Although this report has neen prepared with the specific application of the rolling-in of condenser tubes in mind, the device which has been described may well find use in other applications where it is desired to limit the maximum torque that is to be applied. Such applications may include tapping of threads and tightening of screws and nuts.



EXPANDER

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PLATE I

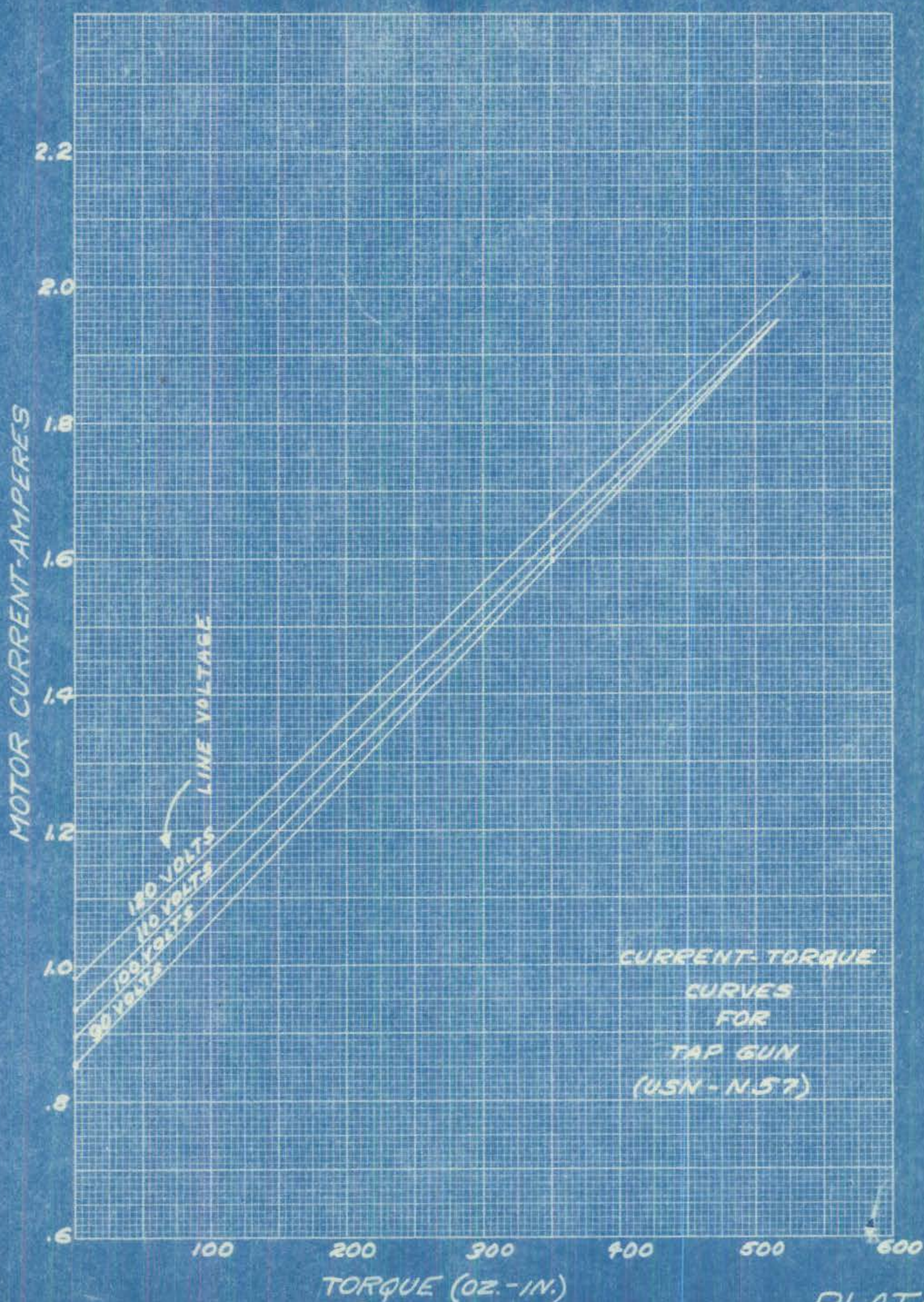

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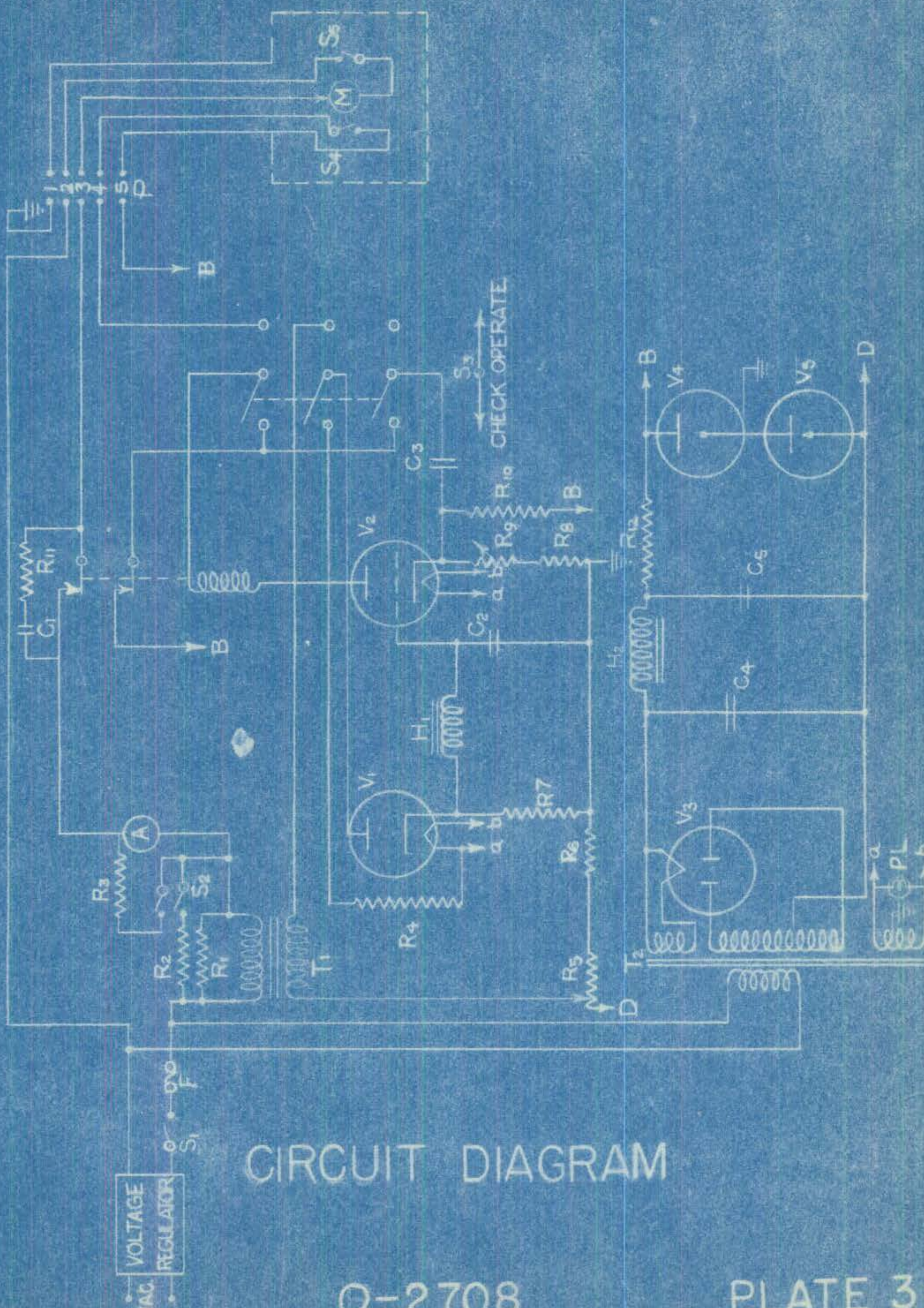
PLATE 2



CIRCUIT DIAGRAM

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PLATE 3

R_1 = 1 ohm

R_2 = 1 ohm

R_3 = Fraction of ohm determi ed by trial

R_4 = 27,000 ohms

R_5 = 100,000 ohms Wire Wound G.R. Potentiometer

R_6 = 50,000 ohms

R_7 = 120,000 ohms

R_8 = 27,000 ohms

R_9 = 2,000 ohms Wire Wound Clarostat

R_{10} = 27,000 ohms

R_{11} = 10,000 ohms

R_{12} = 47,000 ohms, 5 watt

C_1 = .1 mfd

C_2 = .05 mfd

C_3 = 2.5 mfd

C_4 = 8/450 electrolytic

C_5 = 8/450 electrolytic

V_1 = 6H6

V_2 = 884

V_3 = 5Y3G

V_4 = OC3/VR105

V_5 = OA3/VR75

T_1 = Thordarson T-19F80

T_2 = Thordarson T-13R11

H_1 = Thordarson T-13C27

H_2 = Thordarson T-57C51

S_1 = Power Switch

S_2 = Range switch

S_3 = Triple pole double throw switch

S_4 = Microswitch (normally open)

S_5 = Trigger switch on Motor

Y = Relay

A = Ammeter 2.5 amps full scale

M = Universal Motor

VALUE OF CIRCUIT CONSTANTS FOR DIAGRAM ON PLATE 3

PLATE 4

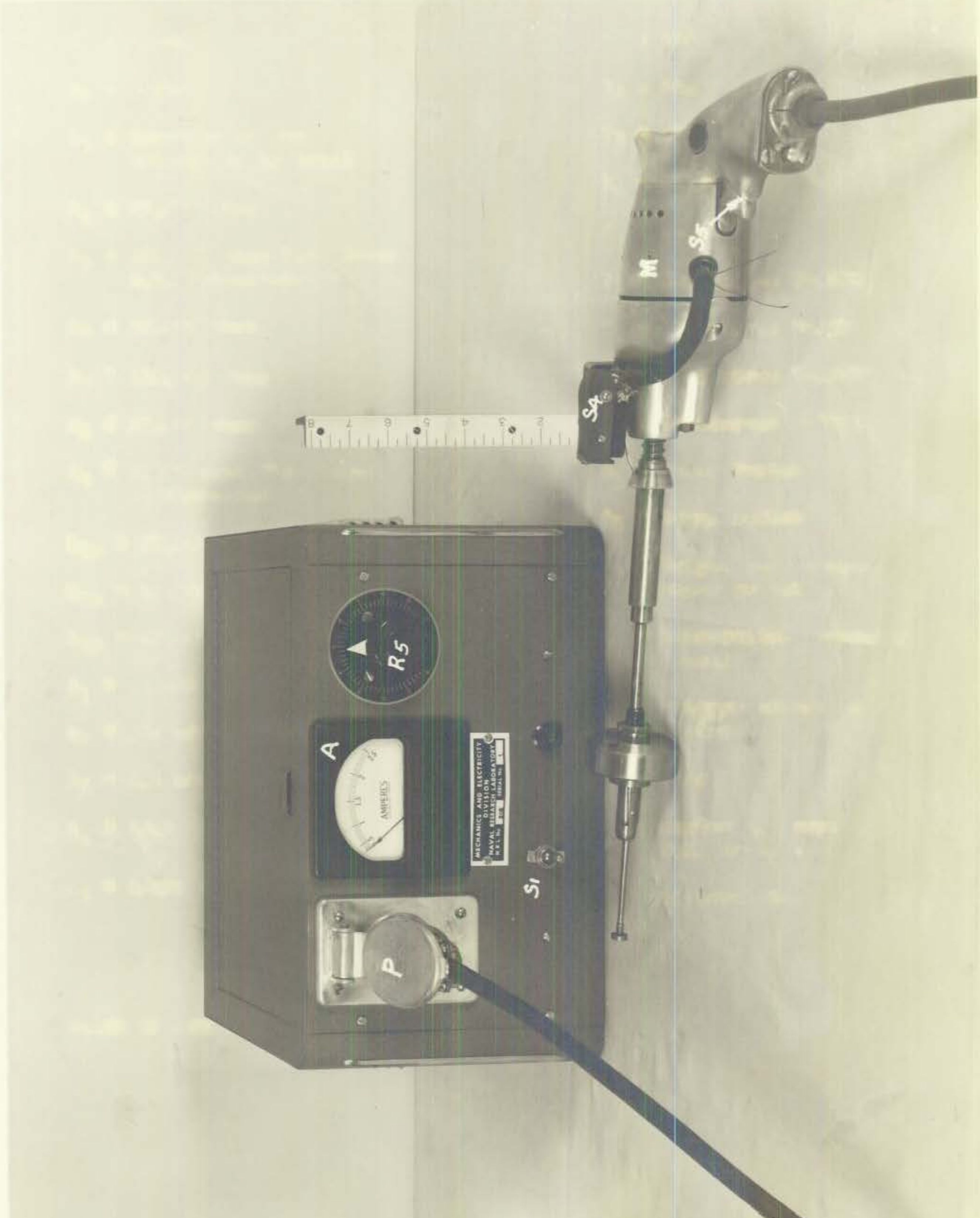
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PLATE 5