Navy Department - Office of Research and Inventions

NAVAL RESEARCH LABORATORY
Washington, D. C.

* * *

DIVISION OF PHYSICAL METALLURGY - SPECIAL ALLOYS SECTION

June 1946

APPARATUS FOR MEASURING RAPID COOLING RATES

By

Ens. Walter T. Haswell, USNR

Report No. M-2454

* * *

Approved by:

S. L. Toleman - Acting Head, Special Alloys Section

F. M. Walters, Jr. Superintendent
Division of Physical Metallurgy

Commodore H. A. Schade, USN
Director, Naval Research Laboratory

Abstract
Numbered Pages 5
Parts List
Plates

NRL Problem No. M-55

ABSTRACT

An apparatus has been developed which, in conjunction with a Speedomax recorder, makes it possible to measure very rapid cooling rates. A rotating poteniometer disk is used to produce a varying potential which is applied to the thermocouple of the quenched specimen so that the drop in potential of the thermocouple is compensated for by the voltage from the rotating potentiometer disk. The Speedomax is then required to measure only the difference between the two changing potentials.

TABLE OF CONTENTS

INTRODUCTION

A. Authorization

1. This problem was authorized by Bureau of Ships letter JJ 461 (21)(350), 22 May 1942, under BuShips Project Order No. 2418/42.

B. Statement of the Problem

2. In the investigation of low hardenability steels conducted at this laboratory, it was necessary to measure the rapid cooling rates encountered when 3/4 to 1/4 inch rounds were water quenched. There was no apparatus commercially available which will satisfactorily measure these rapid cooling rates but it was possible to design and build an apparatus which, in conjunction with a Speedomax recorder, could satisfactorily follow cooling rates up to 2400°C per second. A Speedomax recorder was used in this work but a high speed millivoltmeter could have been substituted providing that the auxiliary apparatus was designed so that the rate of change of potential from the auxiliary apparatus and the specimen thermocouple did not exceed the rate of response of the measuring instrument. The Speedomax recorder was found capable of accurately recording cooling rates up to about 120°C per second.

GENERAL DISCUSSION

A. Considerations Bearing on the Problem

3. In order to use the Speedomax Recorder to measure cooling rates faster than those for which it was designed, an apparatus was built in which a varying potential from a rotating potentiometer disk was applied to a thermocouple connected to the quenched specimen, so that the drop in potential of the thermocouple was compensated for by the potential from the rotating disk. If the potential from the rotating disk changes in exactly the same manner as the thermocouple potential, the Speedomax will not be required to measure any change in potential with time.

4. However, in practice it is not possible to make the two changing potentials fully compensating, but the difference between the two changing potentials can be made small enough to be measured accurately by the Speedomax.

5. The cooling curve for the center of quenched rounds may be approximated by a series of straight lines having different slopes. The initial portion (Plate 6) (a) would indicate no change in temperature with time and would correspond to the lag between the time the surface of the specimen was immersed in the quenching medium and the time when the center of the specimen would begin to cool. The second segment would

correspond to the average change in slope of the cooling curve as the specimen begins to cool and the third section would roughly correspond to the maximum cooling rate of the specimen. For a series of rounds of different diameters the slope and length of these straight lines are roughly proportional to the total cooling time. Therefore, if these straight line approximations of a cooling curve are developed by the rotation of the potentiometer drum the cooling rate of different diameter rounds can be closely matched by varying the speed of rotation of the drum. The first straight line portion (a) Plate 6 corresponds to the time during which the roller (Plate 2) is riding on the copper plate covering the ends of the potentiometer coil. Because the resistance of this plate is small, there is no change of potential with displacement. The remainder of the potentiometer coil has been divided by the auxiliary shunt resistance (Plate 2) so that upon rotation of the potentiometer disk the segments b and c (Plate 6) are developed. Using this scheme, it would be possible to divide the resistance of the potentiometer coil into any number of segments so that the characteristic curve would be a closer approximation to the true cooling curve. A characteristic curve consisting of three straight lines was found satisfactory for the most rapid cooling rates encountered.

6. The slope and position of these three lines were obtained by recording on the Speedomax Chart the potential developed by the rotation of the potentiometer disk. A very slow speed of rotation of the disk was used so that the change of potential with time did not exceed the speed of response of the Speedomax.

7. The apparatus has been used to measure only the cooling rates of the center of rounds, but the characteristics of the potentiometer disk could be changed so that it would approximate any type of potential time curve.

8. The principle parts of this apparatus are:

a. A potentiometer disk made by mounting a potentiometer coil from a Micromax recorder on a bakelite disk (Plate 2).

b. A mechanism for turning the potentiometer disk at different rates of speeds consisting of a 1/4 H.P. D.C. shunt motor, a speed reductor and a set of three interchangeable gears (Plate 5).

c. A mechanism for starting the revolution of the potentiometer disk at the instant the specimen is quenched. This is done by means of a thyratron circuit (Plate 5) actuated by contact of the speciment with the quenching medium. The thyratron circuit operates a magnetic clutch (Plate 4) which couples the rotating motor to the potentiometer disk.

d. A timing circuit which makes it possible to determine accurately the time of the start of the quench and the time for revolution of the potentiometer disk. This is done by means of a magnetic coil (Part 8, Plate 3) which throws a pen against the recorder paper at the instant the thyratron tube fires.

9. When this equipment was tested, it was found necessary to use grounded metal-shielded wire for the wires running from the specimen and the quenching fixture to the thyratron circuit in order to avoid interference from stray magnetic fields encountered in the furnace room.

10. For the initial runs the speed of rotation of the potentiometer drum for each run is determined by trial and error methods. In general, two or three trial runs are sufficient since it is necessary only to adjust the speed of rotation of the potentiometer disk so that the Speedomax is not required to measure a rate of change greater than 120°C per second. Later as data are collected, they may be used to predict the time for rotation of the potentiometer drum.

11. In order to explain the purpose of each piece of equipment, the manner in which they are operated and the sequence of operations, the procedure for making a typical run is outlined below:

a. The speed of the potentiometer disk is first roughly adjusted with the interchangeable gears (Plate 4) and then more exactly by a variable resistance in series with the rotor of the D.C. motor.

b. The potentiometer disk is turned by hand to the point of maximum potential.

c. The thermocouple is shorted out so that the Speedomax measures only the potential from the potentiometer disk.

d. The maximum potential is adjusted approximately equal to the temperature from which the specimen is to be quenched.

e. The starting point of the potentiometer disk is then set by slowly turning the input shaft of the speed reductor by hand until the Speedomax registers a change from maximum to zero potential. This takes up all the mechanical play in the speed reductor and the interchangeable gears and permits a very accurate setting of the starting point because a relatively large movement of the input shaft of the speed reductor results in a very small movement of the potentiometer disk.

f. The short across the thermocouple is then broken and the Speedomax now measures specimen temperature.

g. The test potential of the Speedomax is changed by reversing the battery terminals. Then the test switch on the test dial is adjusted to give an offset of 300°C to center the pen of the Speedomax on the recorder paper.

h. With the clutch disengaged the motor is turned on and allowed to come up to constant speed. The apparatus is then ready to make a run.

i. The paper travel of the Speedomax is turned on just prior to quenching.

j. When the specimen enters the quenching bath, the water closes a circuit causing the thyratron tube to fire. This in turn actuates the magnetic clutch and turning pin.

k. After the run is completed, the time at which the run starts and stops is determined from the position at which the timing pen first strikes the paper. For this apparatus the distance between the timing pen and the recording pen is 2.08 inches.

1. From the constants of the potentiometer disk, the time per revolution and maximum potential, the curve of the bucking potential can be drawn on the recorder paper (Plate 6). A point on the true cooling curve may be obtained by the equation -

$$C = (A + 300) - B.$$

Where A = the temperature recorded by the Speedomax at time (t)
B = the temperature of the bucking potential at time (t)
C = the temperature of the specimen at time (t)
300°C is the off-set potential which is done by reversing the test potential on the Speedomax and ajusting to -300°C offset.

PARTS LIST

1. Thyratron Circuit (Electronic Relay)
2. Circuit to Adjust Maximum Potential on Potentiometer Disk
3. Potentiometer Disk
4. Auxiliary Resistance on Potentiometer Disk to Give a Curve of Three Straight Lines Instead of only Two as Shown in Plate 3
5. Stationary Roller to Pick off Contact from Potentiometer Coil
6. Brushes to Provide Contacts for Each End of Potentiometer Coil
7. Magnetic Clutch - coil of approximately 5300 turns of #32 B & S gauge enamel covered copper wire with soft iron yoke around it.
8. Timing Coil - coil taken from 19-5594 Meisner Air Core R.F. Choke.
9. 1/4 H.P. 1750 RPM, DC Shunt Motor with an External Variable Resistance Connected in Series with the Rotor to Provide a Gradual Variation of Speed over a Relatively Small Range.
10. Small Speed Reductor
11. Interchangeable Gears to Provide for Rough Adjustment of the Speed of Rotation of Potentiometer Disk.

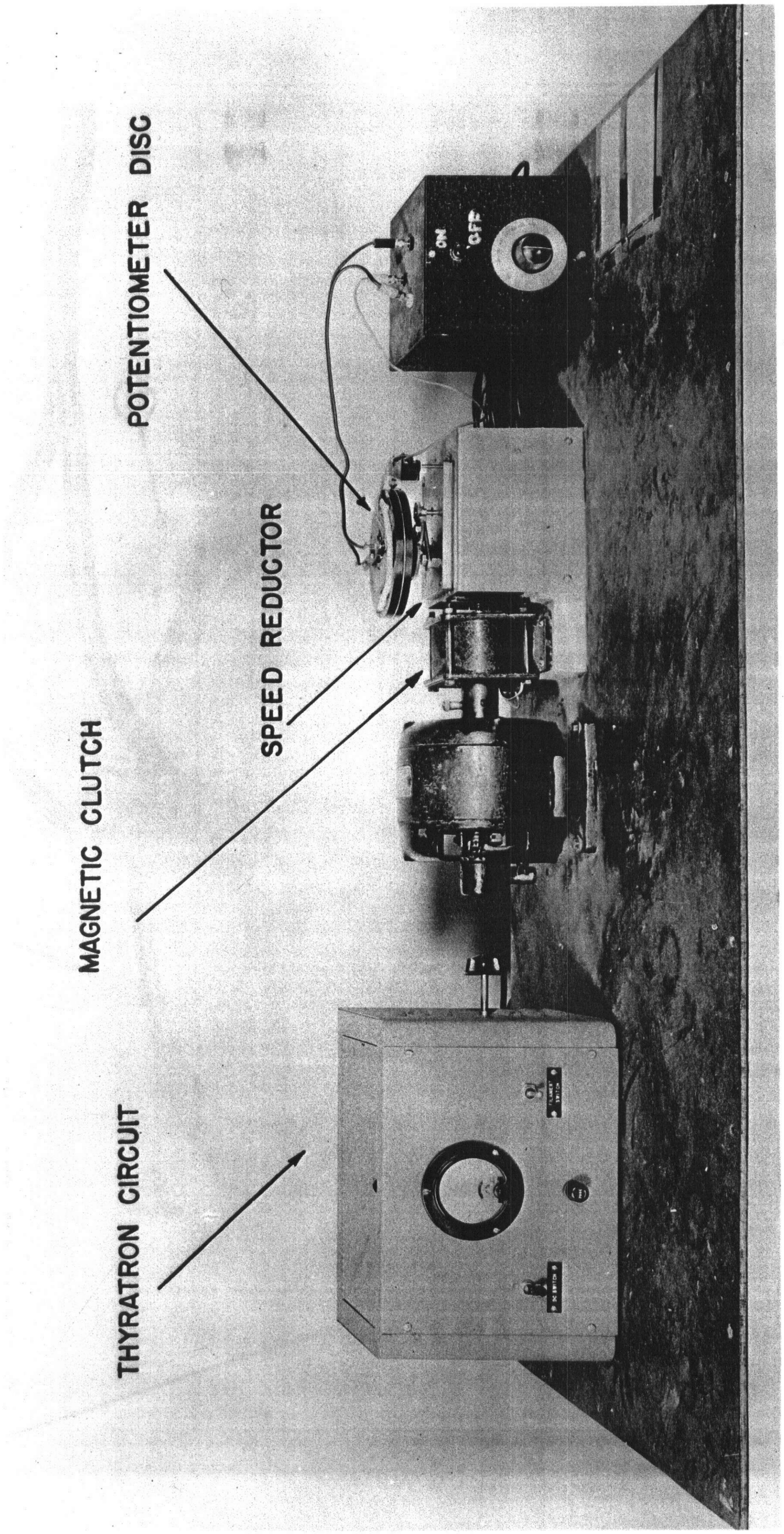

THYRATRON CIRCUIT
MAGNETIC CLUTCH
SPEED REDUCTOR
POTENTIOMETER DISC
ON
OFF

PLATE I

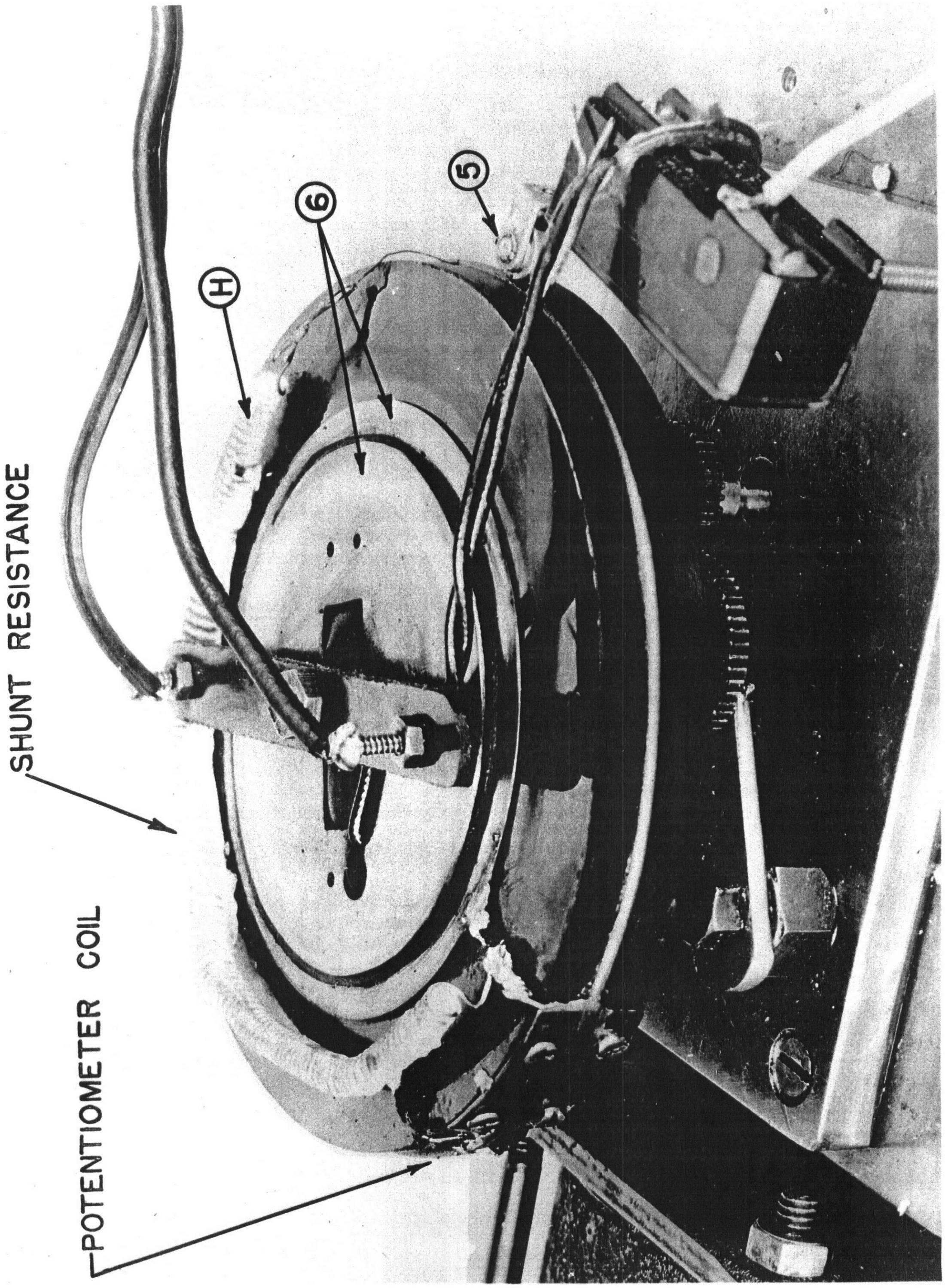


PLATE 2

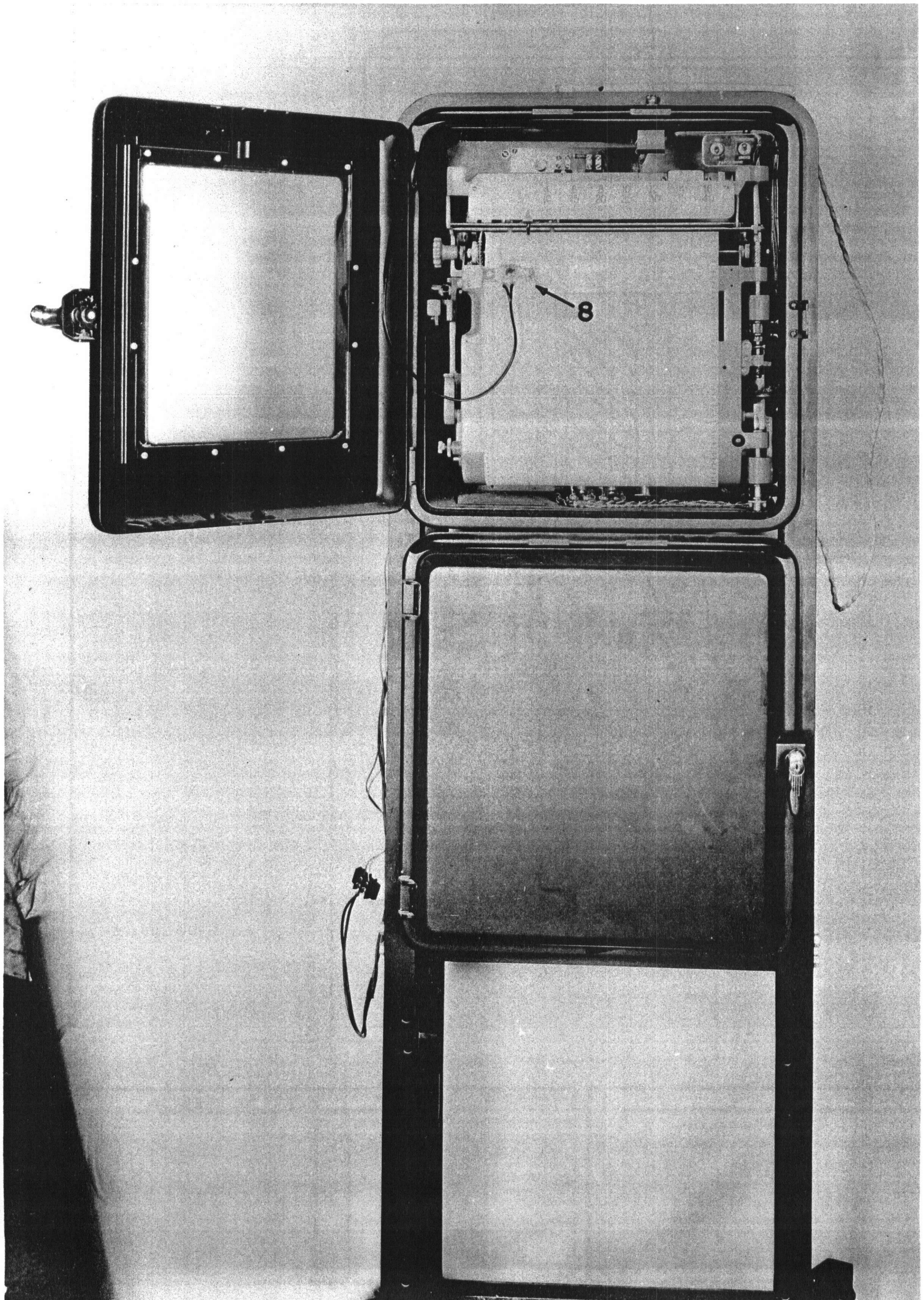
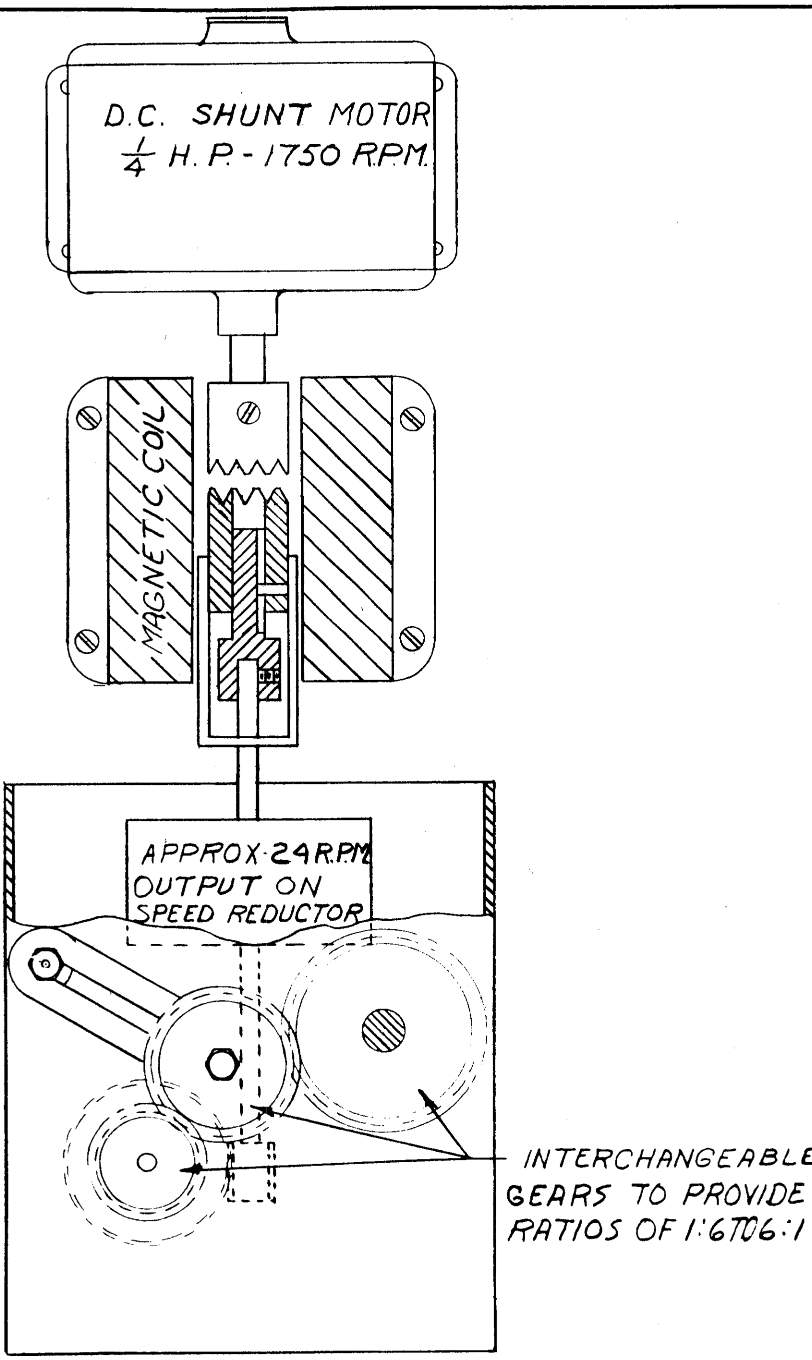


PLATE 3



ALTERATION TABLE		

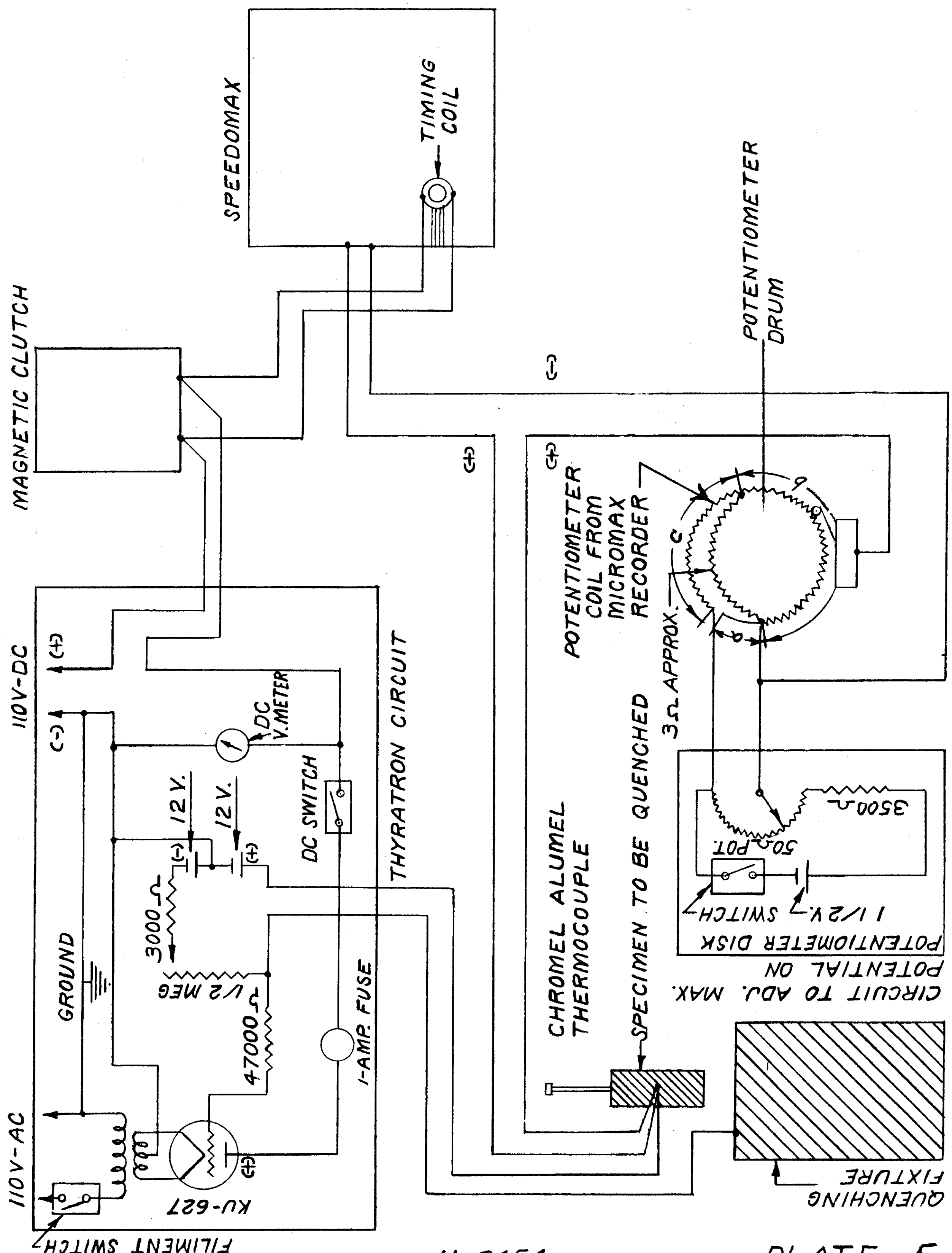
DRAWN	E. J. Graeber
TRACED	
CHECKED	
APPROVED	WTH
IN CHARGE OF DESIGN	SUPT. DESIGN & DRAFTING DIV.
FOR DIRECTOR	W. Carter, LT. U.S.N.R.

NAVAL RESEARCH LABORATORY
WASHINGTON 20, D. C.

COOLING RATE APPARATUS
(BLOCK DIAGRAM)

SCALE NO SCALE DATE NOV. 27, 1944

M-2454 PLATE 4 A 788A



M-2454

PLATE 5

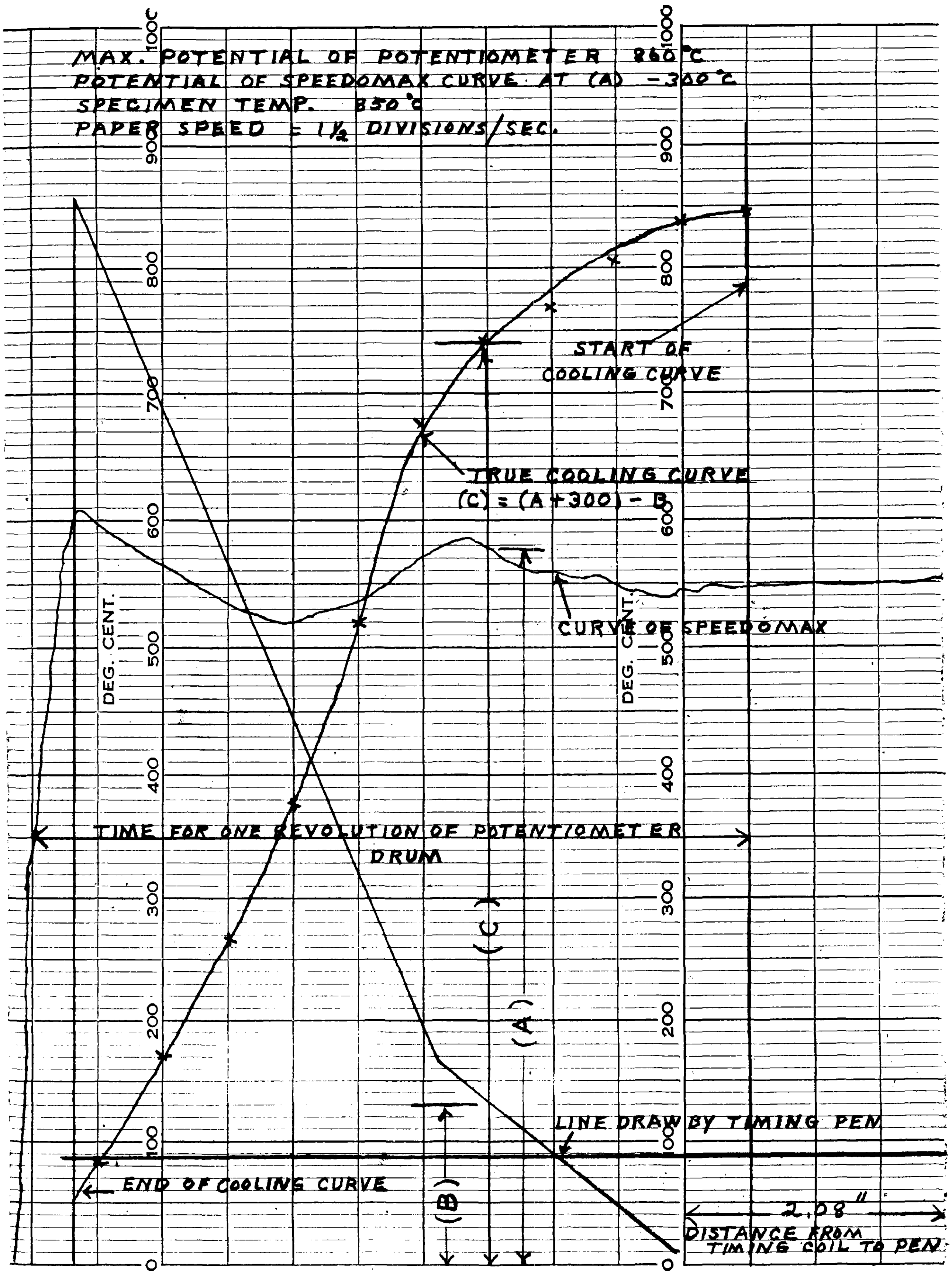

MAX. POTENTIAL OF POTENTIOMETER 860°C
POTENTIAL OF SPEEDOMAX CURVE AT (A) -300°C
SPECIMEN TEMP. 850°C
PAPER SPEED = 1½ DIVISIONS/SEC.
START OF COOLING CURVE
TRUE COOLING CURVE
(C) = (A+300) - B
CURVE OF SPEEDOMAX
DEG. CENT.
TIME FOR ONE REVOLUTION OF POTENTIOMETER DRUM
(C)
(A)
(B)
LINE DRAW BY TIMING PEN
END OF COOLING CURVE
2.08"
DISTANCE FROM TIMING COIL TO PEN
1000
900
800
700
600
500
400
300
200
100
0

PLATE 6