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By

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CONTACT POTENTIAL MEASUREMENTS OF CONVENTIONAL TRIODES

Electronic Tube Engineering Department May 14, 1945

Abstract:

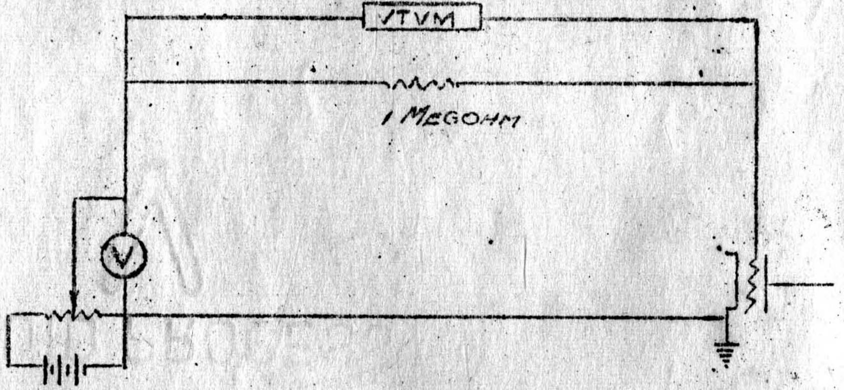
Three circuits used for the experimental measurements of the contact potential of 6J5 vacuum tubes are described. This experiment was to investigate the proposed addition to I.R.E. standards on electronics, and to establish limits of the contact potential of triodes operating at low voltages. The modified T.I.B. No. 7 circuit was accepted as the most satisfactory circuit for the measurement of contact potential.

Purpose:

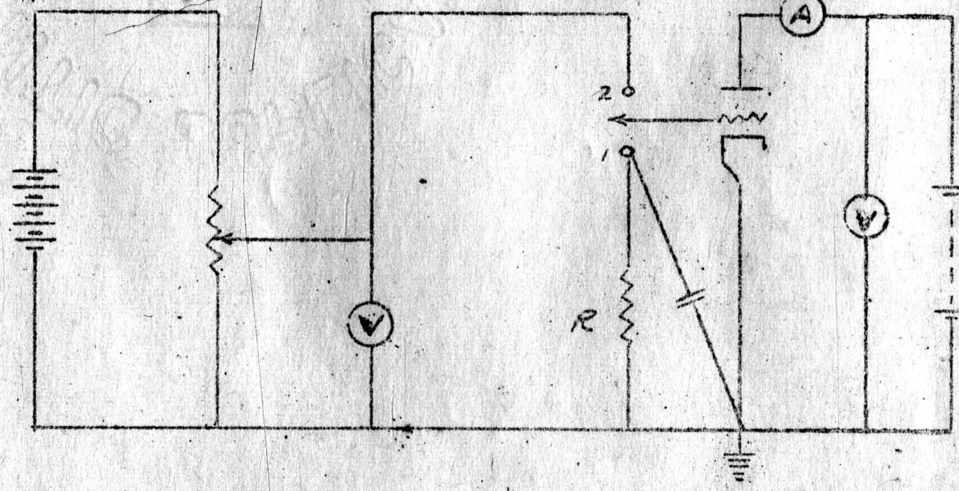
The purpose of these investigations was to check Raytheon's circuits and methods used in establishing the proposed additions to I.R.E. standards. Limits of contact potential were also desired for conventional triodes operating at low voltages. Raytheon's Technical Information Bulletin No. 7 on "Contact Potential" will be found in Appendix A at the end of this data folder.

Discussion:

A number of ideas and methods of measuring contact potential have been advanced. Raytheon has used the circuit shown below and the method is described in the Technical Information Bulletin No. 7.



Another method, known as O'Neil's method, uses the following circuit:



R = 10 MEGOHMS

The O'Neil method was tried first with the relationship resulting shown on page 4. Difficulty was found in trying to recheck the various 6J5 tubes at particular plate voltage values, so as a possible solution to this, data was taken for the warm-up time versus contact potential while the plate voltage was held constant at 90 volts and at 28 volts. The next procedure was to vary the filament voltage while the plate voltage was constant at 90 volts and 28 volts. The warm-up time and filament voltage data is in Appendix B.

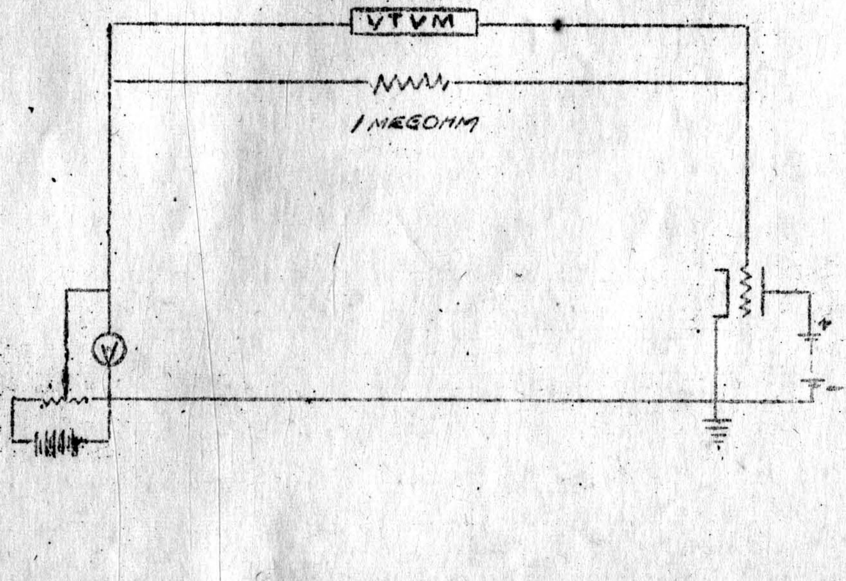
Following this, Bulletin #7 method was used, and readings were recorded for both floating and grounded plate circuits. The contact potential was found to be different for the two conditions. Immediately a reason was sought to explain the difference, and it was found that 0.15 microamperes of current were flowing in the grounded plate circuit. When the plate was floating, it took on a negative charge thus tending to repel any electrons coming into the region of the plate, while at ground potential some of the electrons reached the plate and therefore the contact potential increased.

The last of the experiments used the Raytheon circuit with a plate voltage applied. Rated filament voltage was used, and at a plate potential of 90 and 28 volts, contact potential values were recorded. Enough negative plate voltage was also applied to produce zero contact potential.

The curve on page 5 was obtained by using the O'Neil method for all positive plate voltages, and the modified T.I.B. #7 circuit was used to determine the contact potential at various negative plate potentials. The data used for plotting the curve was computed as an average at the various points for ten 6J5 vacuum tubes.

Results:

At a plate potential of +28 volts the average contact potential obtained was 0.78 volts by the modified Bulletin #7 circuit shown below.



For the above circuit with the plate open or floating, the average contact potential was 1.174 volts, and with the plate grounded the average contact potential was 1.285 volts.

The average contact potential at a filament voltage of 6.3 volts was 1.135 volts using the O'Neil circuit.

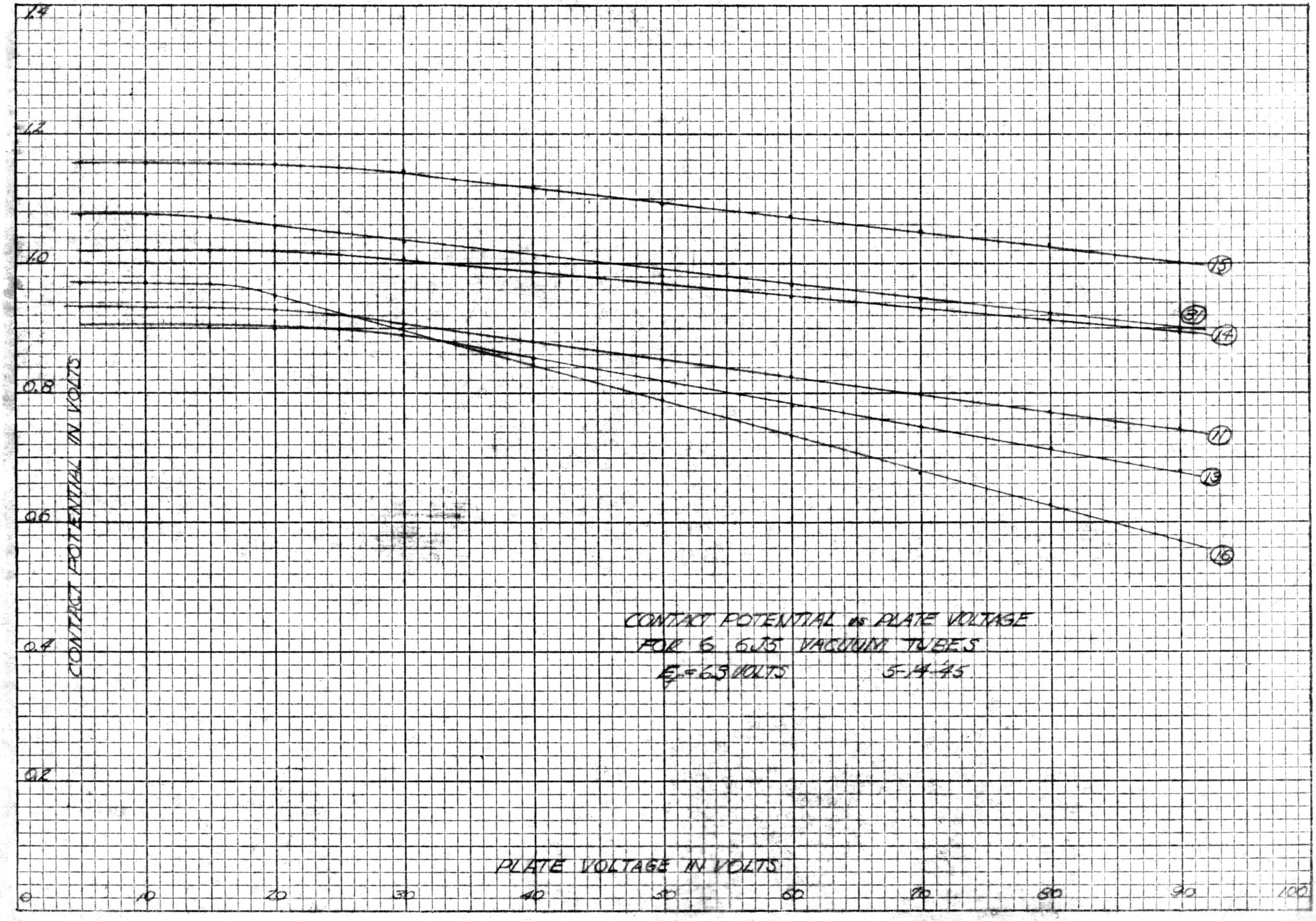
From the various experiments with the two circuits, it can be said that the measurement of contact potential varies with the circuit used, with the Modified Bulletin #7 circuit giving the lowest average value.

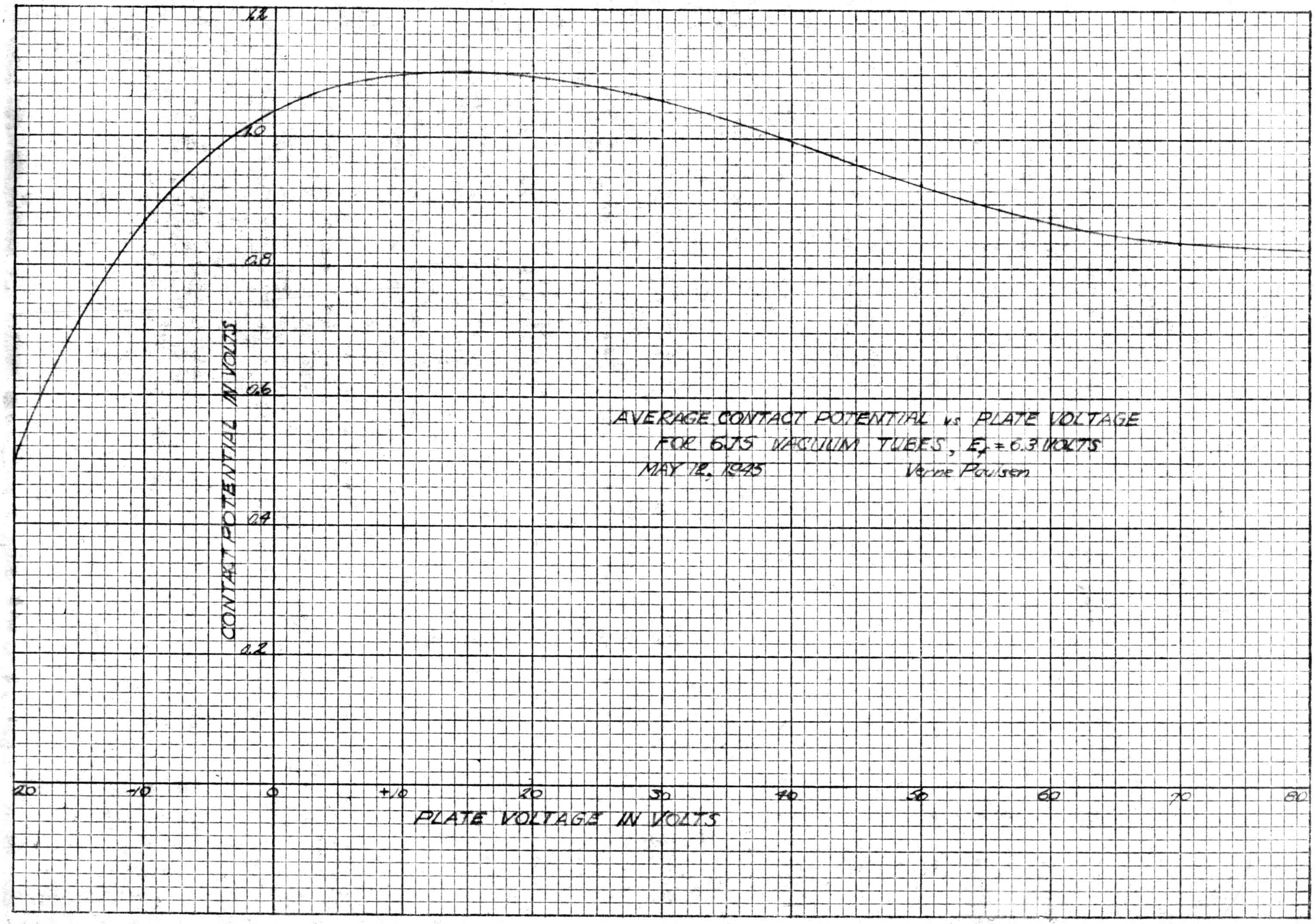
L. B. PAULSEN

L. B. Paulsen

COUNTERSIGNED BY:

E H Peterson


CONTACT POTENTIAL vs PLATE VOLTAGE
FOR 6 6J5 VACUUM TUBES
E_f = 6.3 VOLTS 5-14-45



AVERAGE CONTACT POTENTIAL vs PLATE VOLTAGE
FOR 6J5 VACUUM TUBES, E_f = 6.3 VOLTS
MAY 12, 1945 Verne Poulsen

APPENDIX A

PROPOSED ADDITIONS TO I. R. E. STANDARDS ON ELECTRONICS

A. Contact Potential (Definition)

The contact potential of an electrode in a vacuum tube is its potential with respect to the potential minimum of the virtual cathode when the electrode is shorted externally to the cathode.

Numerically, this is equal to the algebraic sum of (a), $\Phi k - \Phi e$ where Φk and Φe are the work functions respectively of the cathode and the other electrode (b), the Peltier or thermal emf's in the connecting circuit, and (c), the effect of the initial velocity of the electrons emitted by the cathode, measured as the potential difference between the virtual cathode and the cathode.

Note: The above definition is intended to define a characteristic of specific importance in vacuum tube engineering; a distinction should be made between this and true contact potential difference as understood by the physicist, which does not include the effect of initial electron velocity.

B. Test Method

Contact Potential (IE--). The contact potential of a vacuum tube electrode, as defined in the section, "Definitions and Symbols", is usually found to be positive. In such case, its value is conveniently measured in a circuit typified by Fig. (to be assigned) which shows the connections and equipment for a triode, using the tube under test as a vacuum tube voltmeter to measure its own grid contact potential.

It will be recognized that if the potential of the grid is positive with respect to the virtual cathode, a current will flow in the grid circuit. If the resistance in the external circuit is increased, the current in the grid circuit will decrease and the potential of the grid will approach that of the virtual cathode. The limiting condition will be that the potential difference between grid and virtual cathode approaches zero and the IR drop in the resistor approached the contact potential difference.

Referring to Fig. (to be assigned), normal voltage is applied to the filament or heater, and the anode voltage is set at a value appropriate to the operation of the tube at zero grid bias. The resistance R is normally 10 megohms, while the potentiometer, P, should have a resistance high enough to avoid running down the battery too rapidly, but low enough to supply current to the grid voltmeter.

In carrying out the test, the switch Sw is set in position 1, and the anode current noted. The switch is then thrown to position 2, and the anode current adjusted downward to its original value by the potentiometer.

The voltmeter in the grid circuit then reads the grid contact potential directly in volts.

In applying this method to the measure of the contact potential of a diode anode, the same principle is employed, a vacuum tube voltmeter being connected between anode and cathode of the diode as shown in Fig. (to be assigned). When the reading of the milliameter is the same for the switch in positions 1 and 2, the voltmeter in the potentiometer circuit reads the contact potential of the diode anode. The use of a triode having a high ratio of amplification factor to plate current is recommended for use in the indicating part of the circuit.

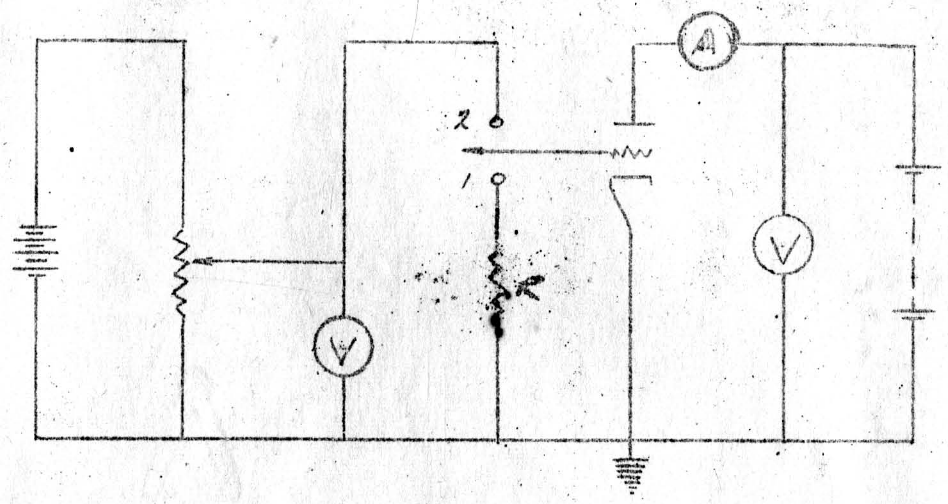
C. Symbol

The symbol E' is here proposed, the reasons being as follows:

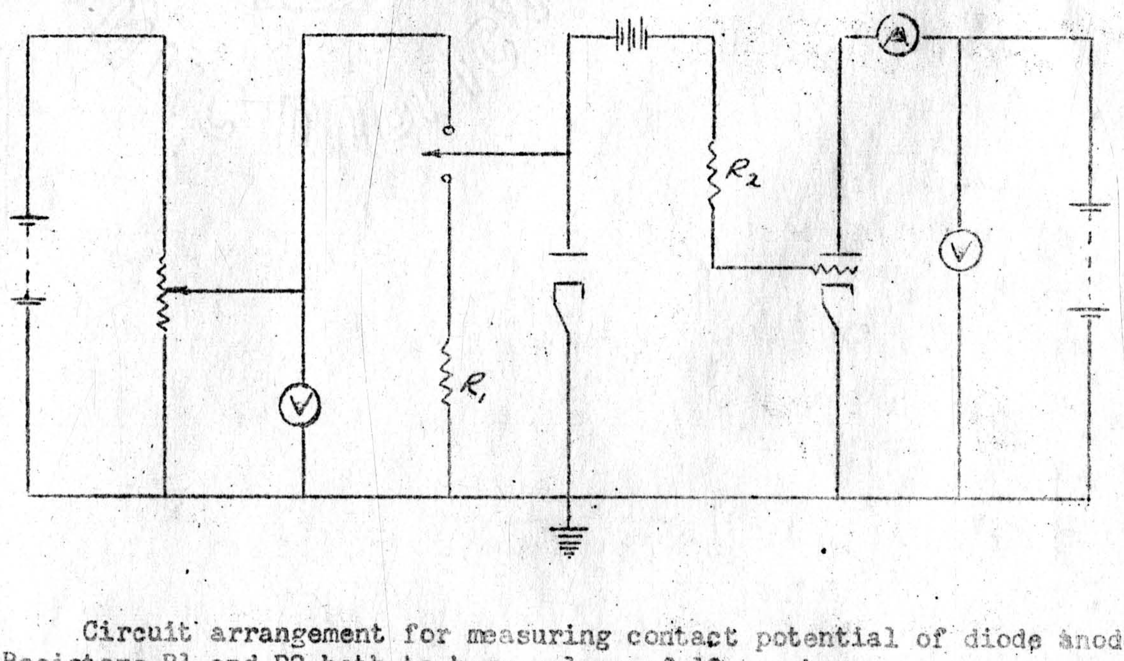
The capital letter E is used because it refers to a steady state voltage.

The prime is used because it has a precedent - Chafee used e' in his book. Capitals are ordinarily used for dc values.

The use of a subscript is not recommended because it is apt to be confused with a voltage impressed between an electrode and the cathode by an external source. The use of two subscript letters such as E_{ct} might be interpreted as the voltage between two points, c and t.



Circuit arrangement for measuring positive values of grid contact potential of triodes. Resistor R has a value of 10 megohms.



Circuit arrangement for measuring contact potential of diode anode. Resistors R1 and R2 both to have values of 10 megohms.

Technical Information Bulletin No. 7 TIB Sheet 1
Rev. 0 RLM, RW
3/20/44

RAYTHEON PRODUCTION CORPORATION

NEWTON, MASS.

Subject: CONTACT POTENTIAL

The following excerpt is taken from R. M. Bowie's article entitled, "This Matter of Contact Potential" which appeared in the "Proceedings of the Institute of Radio Engineers," November 1936. Only the introductory paragraphs are quoted here - the remainder of this article is well worth reading. This discussion of "contact potential" is presented to give a clearer picture of what is meant by "contact potentials" at Raytheon.

"The term "contact potential," in connection with thermionic vacuum tubes, has come to include a combination of several spurious voltages which affect the operation of the tube. The so-called contact potential between the cathode and grid in a triode, for instance, may be made up of effects due to velocity of emission of electrons from the cathode, grid emission, grid leakage current, gas ions and true contact potential. A similar combination of spurious voltages show themselves in the case of diodes.

The reasons for grouping several such voltages together are the difficulty of measuring each separately and the fact that their total is usually less than one volt. Although some combination of spurious voltages exists between every element and its cathode, only the combinations which apply to elements at low potential with respect to their cathode and which exert a large control upon the electron stream need be considered. Thus, in multielement tubes or polyodes, the control grid or a diode plate is usually the only critical element. In what follows, the word element will be used to mean any critical element other than the cathode.

The combination effective is not only a constant of the element's position and material but is a function also of the applied voltages and the method of measurement. The quantities commonly measured may be divided into four groups: (1) floating element potential, (2) floating, shunted element potential, (3) effective element current cutoff, and (4) calculated correction potential."

Floating element potential is the voltage the element assumes when disconnected, all other elements having normal applied voltages.

Floating shunted element potential is the potential which the element assumes when connected externally to the cathode through a high resistance, all other elements having normal applied voltage.

Effective element cutoff is the negative potential at which the element current becomes less than some predetermined small value such as 0.1 ua.

Calculated correction potential is the small quantity added to the voltage term of the polyode current equations as E in the triode plate current equation:

$$I_p = K\left(E_g + \frac{E_p}{u} + E\right)^{3/2}$$

At Raytheon, "contact potential" (E_{ct}) means the Floating, shunted element potential described in the preceding paragraph. It may be visualized as a small battery connected between grid and cathode as shown below:

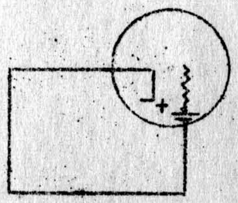


FIG. 1

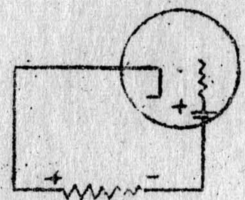


FIG. 2

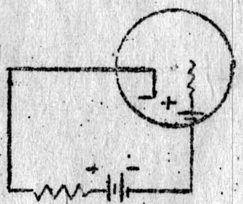


FIG. 3A

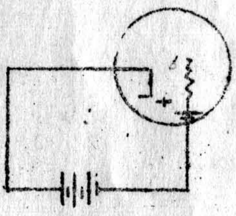


FIG. 3B

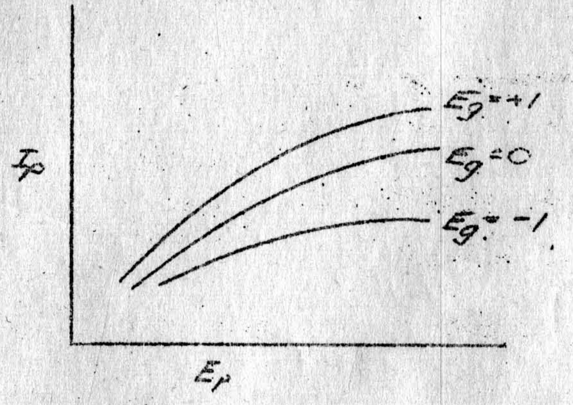


FIG. 4

In each of the above cases $+E_{ct}$ may be visualized as a small battery inside the tube with its positive terminal connected to the grid.

In Fig. 1 where the grid is returned directly to the cathode with no intervening resistance, the grid from its external connection to the cathode may be said to be at zero bias. It is under this condition of zero <u>external</u> bias that readings are taken on tubes rated for "zero bias" operation. A tube having $E_{ct} = +1.0$ volt with the grid returned directly to the cathode will thus act the same as a similar tube having Ect = 0 but with a bias of + 1.0 volt applied to the grid externally. It should be emphasized that "zero bias" readings would be made on each of these tubes with <u>zero external</u> bias, and the resulting plate current would be lower for the tube having Ect = 0.

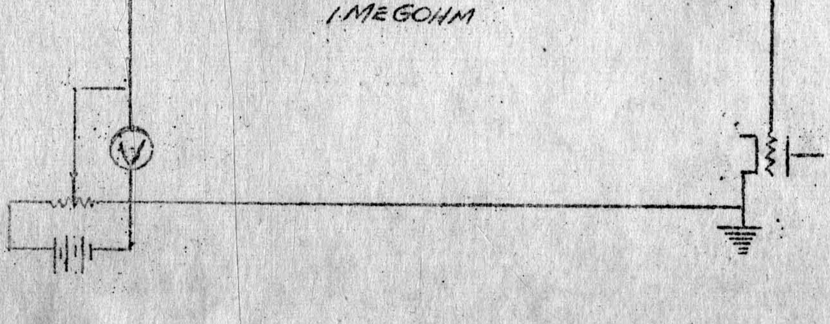
In Fig. 2 where the grid is returned to the cathode through a high resistance, the voltage developed in the high resistance by the electron current to the grid due to Ect will be of the reverse polarity to Ect and thus will tend to nullify the effect of Ect on the tubes Ep - Ip characteristic. Thus a tube having Ect = + 1 volt, and connected as in Fig. 2 would act practically the same as a similar tube having Ect = 0 but connected as in Fig. 1. In other words, compared to its own "zero bias" operation (Fig. 1), such a tube with Ect = + 1 when connected as in Fig. 2 will operate on the Eg = -1 volt curve of its Ep-Ip family since the <u>external bias</u> of -1.0 volt is actually applied externally by virtue of the voltage drop across the high resistance due to the electron current collected by the grid. (For resistor values of several megohms the voltage developed across the resistor will be essentially of the same value as Ect, while for lower resistor values, eg., 100,000 ohms, the voltage developed across the resistor will be substantially less than Ect.)

In Fig. 3A, where a negative external bias greater than Ect, is applied to the grid, a tube having Ect = + 1.0 volt will act the same as a tube with Ect = 0 but with 1.0 volt less negative bias applied externally. That is a tube having Ect = + 1.0 and an external bias of Eg = 3.0 volt will act the same as a similar tube having Ect = 0 and an external bias of -2.0 volt. Compared to its own "zero bias" operation (Fig. 1), a tube having Ect = + 1 with an external bias of Eg = -3.0 volts will operate on the Eg = -3.0 volt curve of its <u>own</u> Ep-Ip family, and likewise a tube having Ect = 0 with an external bias of Eg = -3.0 volt will operate on the Eg = -3.0 volt curve of <u>its own</u> Ep-Ip family.

In Fig. 3B where a negative external bias, greater than Ect, is applied to the grid through a high resistance the operation will be identical with that of Fig. 3A since there will be no electron current collected by the grid and hence no current through the resistor and no drop across the resistor.

For the more or less rare cases when the polarity of Ect is opposite from that discussed above (e.g., Ect = -1.0 volt) the signs of the small batteries shown in the tubes in the figures can be reversed and the same line of reasoning applied.

The elemental circuit used for measuring "contact potential" at Raytheon is shown below:

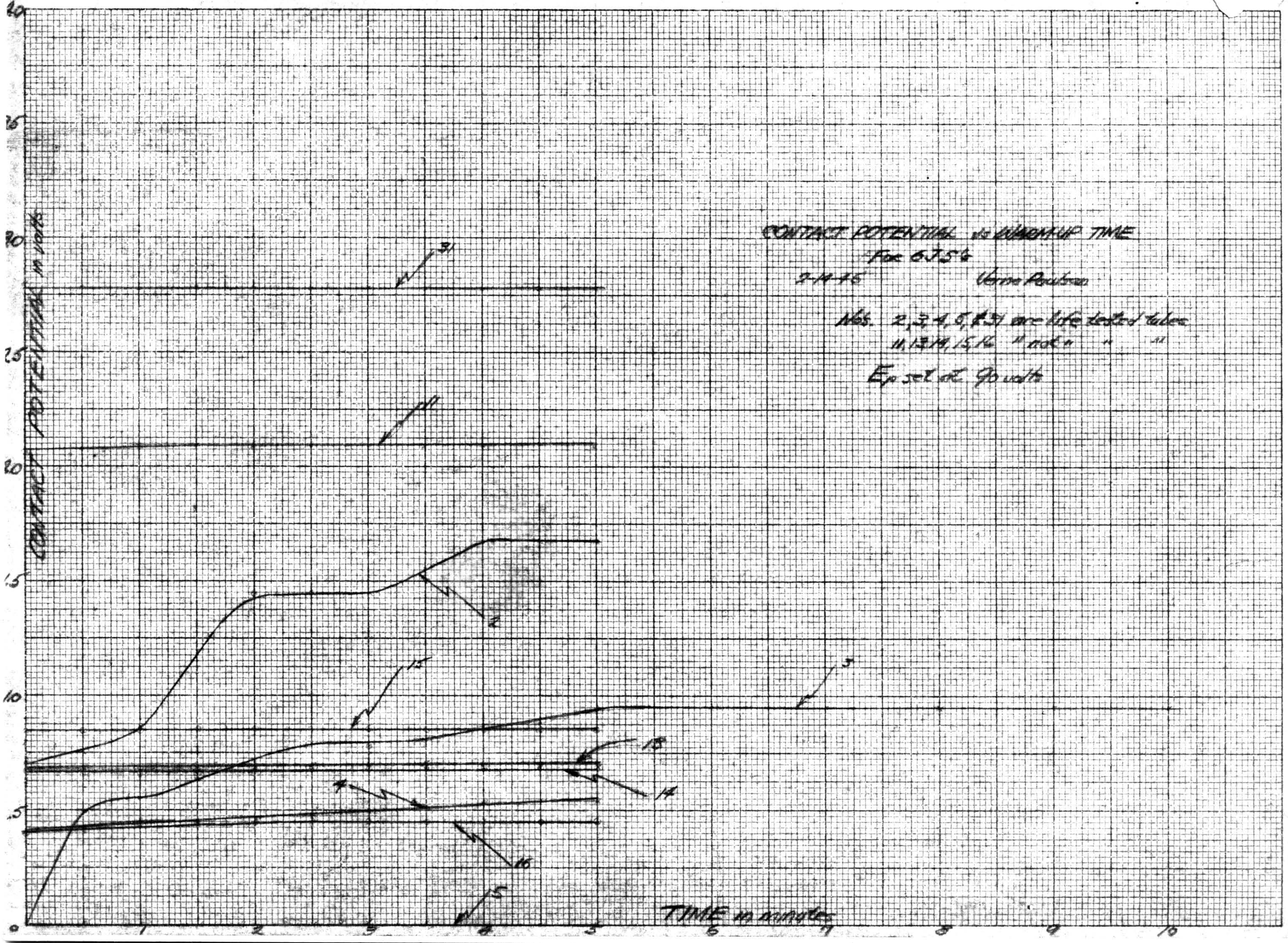


With the potentiometer P set at zero the "contact potential" difference between cathode and grid of the tube is normally such as to cause electrons to flow from cathode to grid and through the 1 meg. resistor in the direction indicated by the arrow. The voltage developed by this current on the 1 meg. resistor may be read by the vacuum tube voltmeter. If now, by adjustment of potentiometer some portion of the battery voltage is inserted into the external circuit with such polarity that it tends to force electrons to flow through the circuit in the reverse direction, the voltage drop across the 1 meg. resistor will be lowered. When the bucking voltage is so adjusted as to give 0.1 ua through the 1 meg. resistor, the voltage read by the Ect meter plus the 0.1 volt drop in the 1 meg. resistor is called the "contact potential" (Ect). Note that the 0.1 volt drop in the resistor is added to the Ect reading only when Ect is positive.

The actual schematic circuit used in the Life Test Department for this measurement is shown in Appendix A.

The "spurious voltages" due to the effects of true contact potential, initial velocity of electrons, primary emission, secondary emission, gas and photoelectric emission are to a large extent determined by the condition of the surfaces of the grid and cathode. In the commercial manufacture of radio tubes, the surfaces of these elements undergo considerable change during processing and during normal tube operation - for this reason, it is very difficult to produce tubes with uniform "contact potential" characteristics. However, the "contact potential" does tend to stabilize at some characteristic value when a tube is burned under one set of conditions for a long period of time and this stabilization occurs assymptotically - that is most of the change occurs during the first few hours operation. Since radio tubes are made to operate under certain rated conditions, it is desirable, during the processing of the tubes, particularly during the aging cycle, to stabilize its "contact potential" for the conditions under which the tube is expected to operate. For this reason, every aging schedule should have as a last step, and for as long a period of time as possible, the rated life test conditions. Although these conditions cannot always be duplicated exactly on the production aging racks, they can usually be approximated to a satisfactory degree. Particularly to be avoided as last steps on aging schedules are grid or cathode "hot shots" as these generally produce unstable surface conditions which may result in large changes in characteristics during life. Characteristic averages should be judged only on characteristic readings taken after 24 hours rated life test operation particularly if these averages are to be used for design changes.

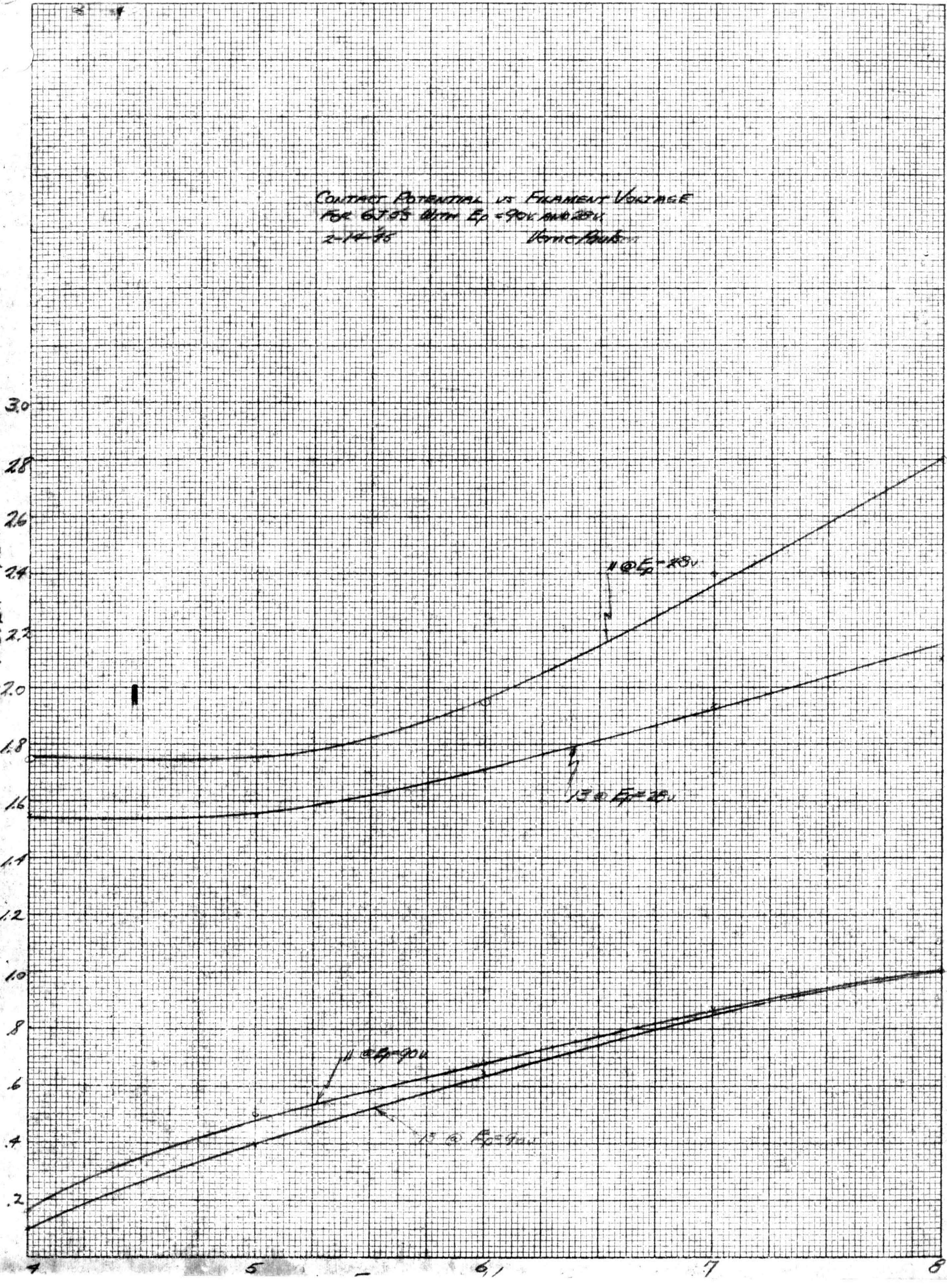
APPENDIX B



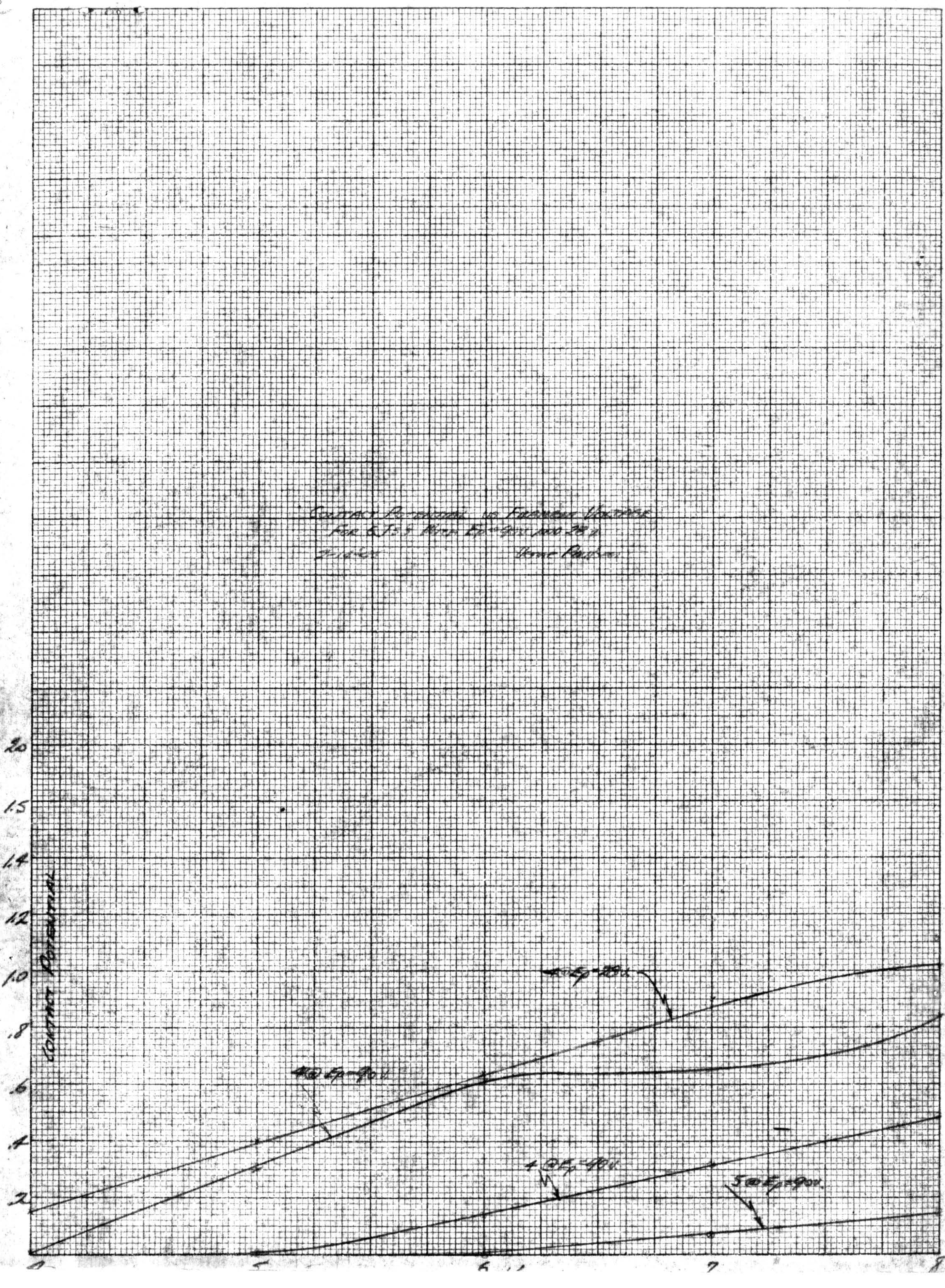
CONTACT POTENTIAL vs WARMUP TIME
For 6J5G
2-14-45
Verne Paulsen

Nos. 2, 3, 4, 5, & 31 are life tested tubes
11, 13, 14, 15, 16 " not " " "

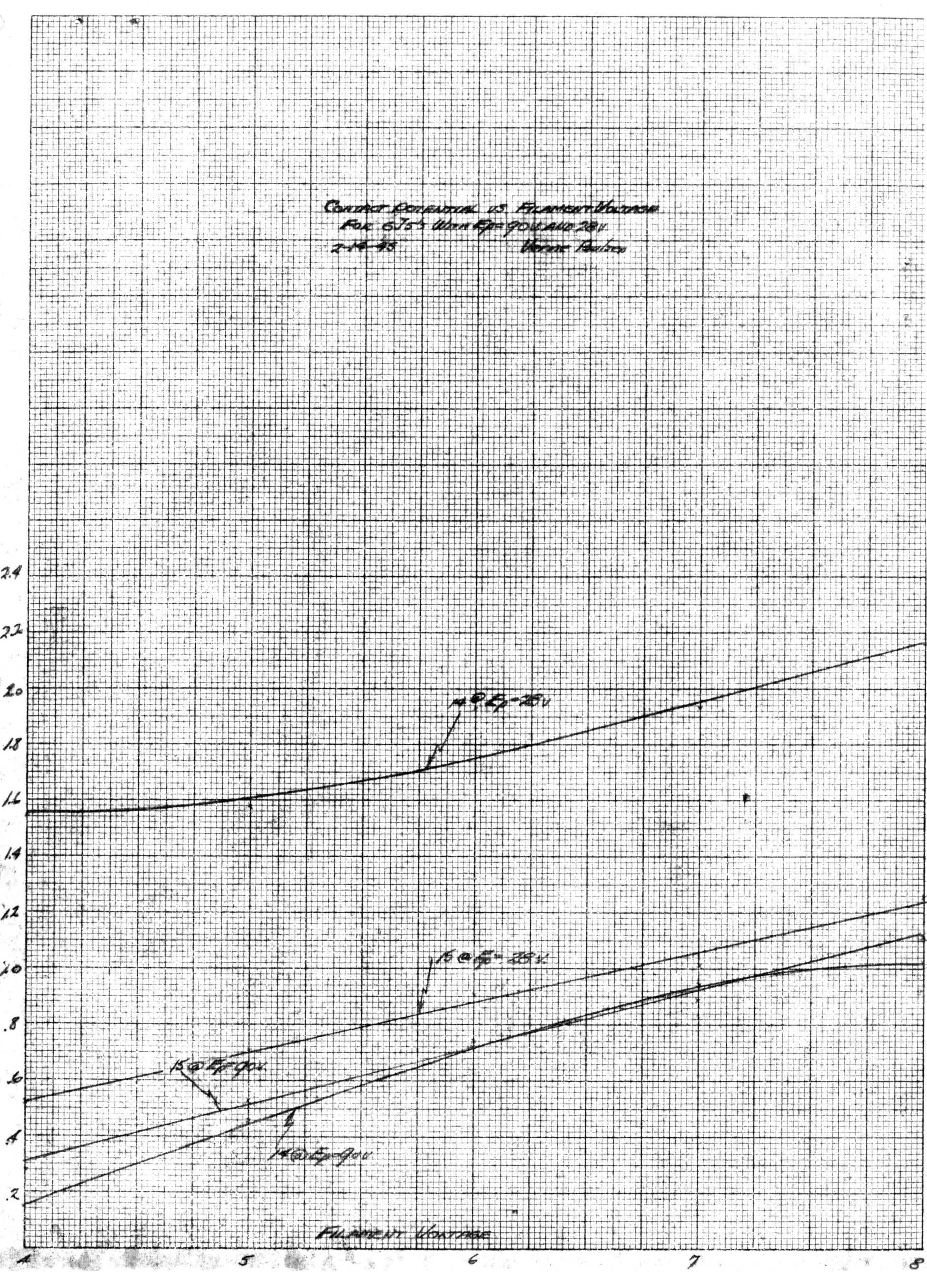
E_p set at 90 volts



CONTACT POTENTIAL VS FILAMENT VOLTAGE
FOR 6J5S WITH Ep = 90v AND 28v.
2-14-45



Contact Potential vs Filament Voltage
For 6J5 [illegible] Ep = 90v. and 28v.
2-16-[illegible] [illegible]


Contact Potential vs. Filament Voltage
For 6J5's With Ep=90v and 28v
2-14-45
Verne Paulsen

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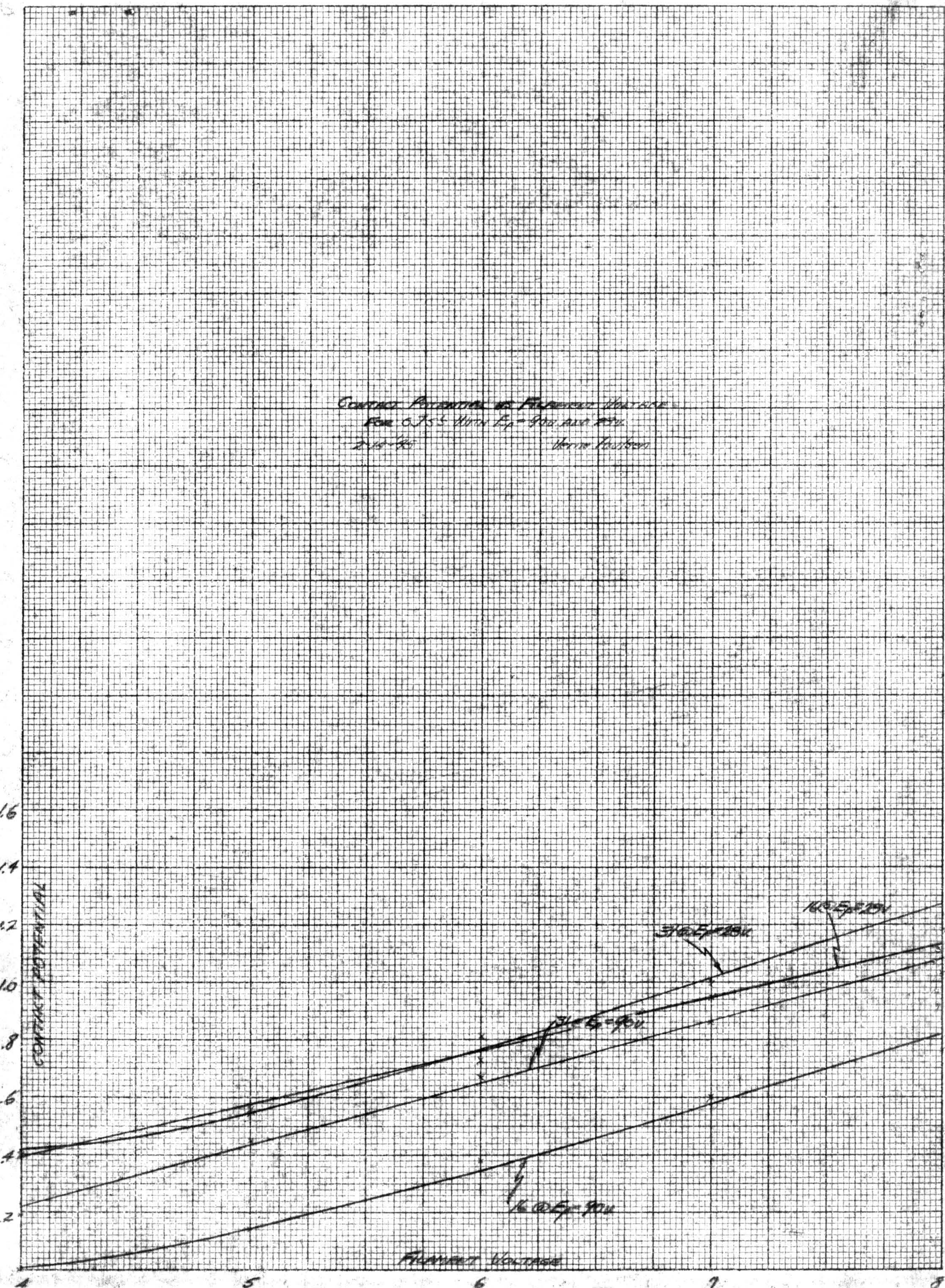
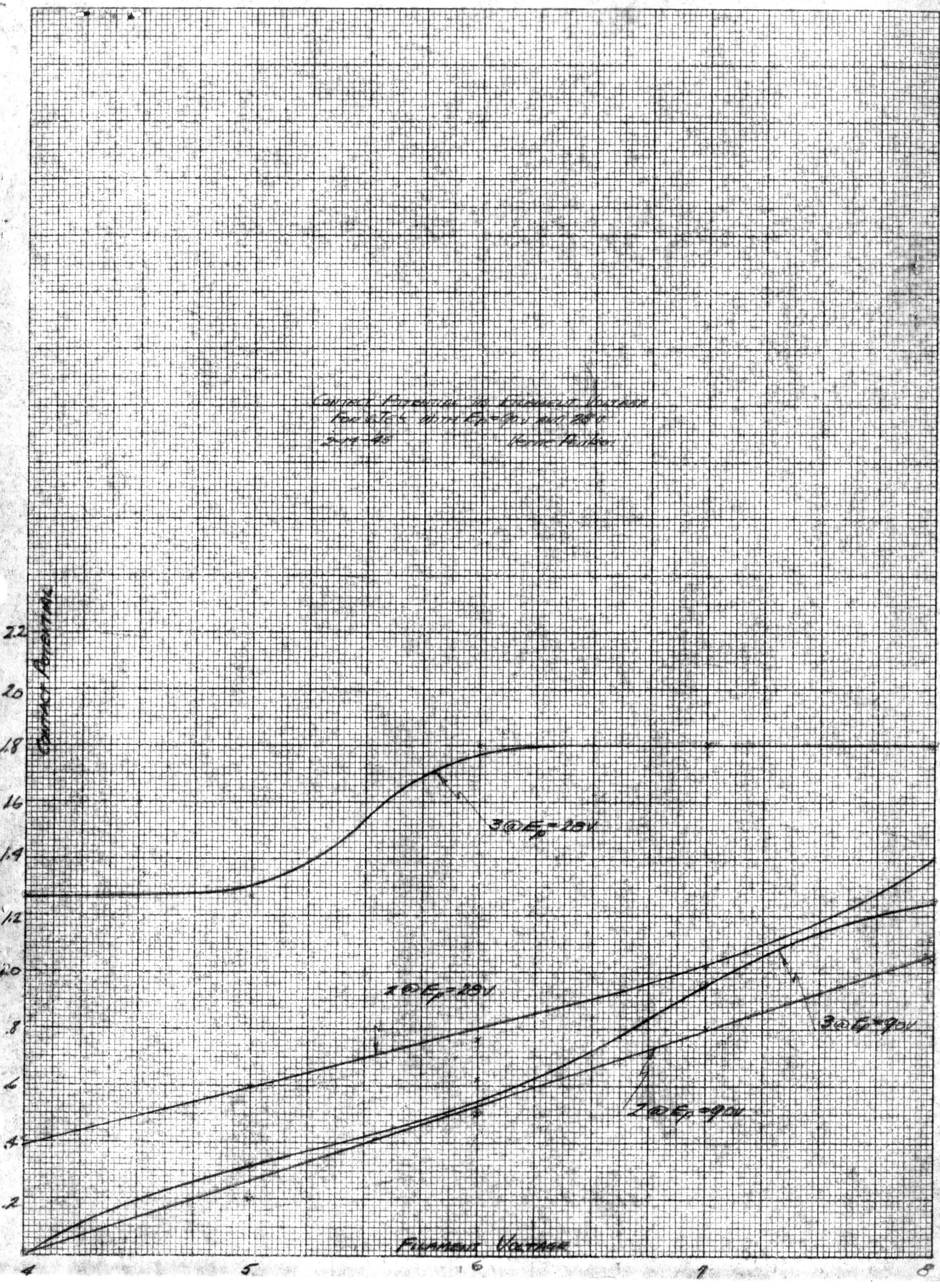


Contact Potential vs Filament Voltage
For 6J5's With E_p=90v and 28v
2-10-45
Verne Paulsen


Contact Potential vs Filament Voltage
For 6 TC's with Ep = 90V and 28V
2-14-45
Verne Parker
Contact Potential
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.8
.6
.4
.2
3 @ Ep = 28V
1 @ Ep = 28V
3 @ Ep = 90V
2 @ Ep = 90V
Filament Voltage
4
5
6
7
8

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