PROGRESS REPORT

MONOCHROME PRODUCT ENGINEERING

HEATER DESIGN

By: E. M. Krackhardt
Date: February 1, 1960

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PROGRESS REPORT NO. 1

TITLE: Heater Design

PERSONNEL ASSIGNED: E. M. Krackhardt

PROGRESS TO: January 25, 1960

OBJECT: Design heaters having the desired values of parameters for use in any immersion structure, including especially the low wattage structures.

INTRODUCTION

With battery operation of television sets has come the necessity for cathode ray tube heater voltages which are either higher or lower than normal. There are three modes of operation considered for the heater; (1) connected directly across the battery, (2) in series with the battery or (3) supplied at 15 KC from the fly back transformer. For supplying the heater directly from the battery, voltages from 8.4 to 12 volts have been considered. A 12 volt battery is required for the present battery-portable TV development. For series string operation, about 1.35 amperes at less than 1 volt would be required. If the heater is supplied from the horizontal fly back transformer, 0.6 volts per turn is available or 2.4 volts for 4 turns looping the transformer core.

Since March 1959, we have been working toward the design of a reliable high voltage heater. In cooperation with Electronic Tube Coil in New Jersey and the Special Products Engineering Section of the General Electric Receiving Tube Department, we have made and tested many coiled coil, folded coil, and folded heaters to be used in the 90 mil cylindrical and the tubular cathode of the mica design.

This report presents an evaluation of 12 volt heaters in the current cathode structures. Also discussed in this report is the design of low voltage heaters which satisfy the second and third modes of operation.

SUMMARY

Due to failures incurred in tests and information from the Receiving Tube Department on reliability, it is my opinion that no heater (folded coil or folded heater) will operate reliably at 12 volts in the standard tubular cathode of the mica structure. This is true at all wattages that might be built into this design. However, using a coiled coil heater in a 90 mil diameter cathode (1.89 watts) is a possibility since the greater length of wire permits a larger and more reliable wire size. Low voltage heaters are reliable and can be designed in a straight forward manner.

DISCUSSION

High Voltage Heaters

The heater voltage may be increased by increasing either the wattage or the hot resistance of the heater, as seen by equation 5 of the appendix,

$$E = \sqrt{WR_t}.$$

We are primarily interested in low wattage heater-cathode structures because of the drain on the battery imposed by the cathode ray tube. However, increased wattage as a means of raising the voltage rating is being investigated and will be discussed. First, the case of higher hot resistance will be considered. Equation 6 of the appendix gives the relationship,

$$R_t = \frac{4\rho_t \; l}{\pi d^2} \quad .$$

The resistance depends on (1) the restivity of the wire at operating temperature, (2) the total heated length and (3) the inverse of the diameter squared. Cleveland Wire has made heater wire with 10% increased resistivity[1], but this results in only a 5% gain in voltage. Essentially 100% over the present heater voltage is required, 6 to 12 volts. For the most reliable heater design, the maximum length of wire which will fit in a given cathode is used. This allows the largest wire size at a given voltage. The maximum wire length in a particular cathode is practically fixed, for in a tubular cathode of the mica design 3.7 inches of wire is used in a folded coil heater and 3.9 inches in an 8 strand folded heater. In the 90 mil cylindrical cathode, 10.2 inches of wire are used in a coiled coil heater. Although this is actually a coil wound into a double helix, I shall refer to this configuration as a "coiled coil" in this report. The remaining parameter, wire diameter, may be reduced to increase heater voltage. The limit on wire size is established by heater reliability throughout the tube life. In correspondence from J. G. Tucker of the Receiving Tube Department, the minimum practical wire weight has been set at 4 mg./200 mm.

Folded Coil Heaters

Folded coil heaters for the tubular cathode patterened after the first heater used in the 9QP4 tube (Drwg. No. N16000FU) were wound by Electronic Tube Coil, varying only the wire weight. See Table I under identification numbers XC1464 for the heater descriptions. Twenty-five tubes were made using heater no. XC1464A (2.75 mg/200 mm); these heaters were wound for 12 volt operation. So called window tubes were used to provide optical temperature measurements of the cathode, heater power information and heater life test data. Of these 25 heaters, 18 failed in testing. Some failed when taking routing temperature curves, others on the cycling test for heater reliability and still others under hot shot conditions of 1200°C for 2 minutes. Two out of three XC1464B heaters (3.80 mg/200 mm) failed in less than 1000 hours at rated voltage (10.2V.) on heater cycling test.

(1) Trip Report, Lamp Metals and Components Department, August 1959

TABLE I

LIST OF AVAILABLE HEATERS

IDENTIFICATION NO.	HEATER TYPE	CATHODE TYPE	WIRE WT. MG./200MM.	WIRE DIA. MIL.	VOLTAGE DESIGNED FOR	HOT RESISTANCE OHMS
21EAP4	Folded Coil	Tubular		3.2	2.34	3.9
17DAP4	" "	"		2.6	2.68	6.0
XC1181	" "	.020"x.040" 1.41W.	10.0	2.25	4.7	15.7
XC1464D	" "		6.20	1.78	8.4	
XC1464C	" "		4.50	1.52	9.6	
XC1464B	" "		3.80	1.39	10.8	
XC1464A	" "		2.75	1.19	12.0	118.0
2EP4	" "			1.3	6.0	
Telefunken	M-Coil		4.8	1.57	10.2	61.8
2AF4	Folded Coil	Tubular	18.5	3.07	2.34	
N16000FU	" "	.020"x.040" 1.41X.	9.53	2.2	4.7	
6AF4	" "		5.4	1.68	6.3	
12AF4(special)	" "		3.23	1.28	12.0	
XC1415A	Coiled Coil	Cylindrical	10.0	2.25	8.4	43.1
XC1415D	" "	.090" Dia. 1.89 W.	6.22	1.78	9.6	
XC1415C	" "		4.51	1.52	10.8	
XC1415B	" "		3.80	1.39	12.0	
XC397D	" "		25.0	3.57		
MCH 8026-1	Double Helix		15.2	2.8	6.3	14.0

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No failures have occurred in heater types XC1464C or D (4.50 and 6.20 mg/200 mm) which were wound for 9.6 and 8.4 volts respectively. In the present cycling test, 20% over rated voltage is applied for 2 minutes, then the power is turned off for 4 minutes. This is the schedule used on receiving tubes at Owensboro. It accents the surge current due to the long cooling period. From the foregoing tests, it is apparent that folded coil heaters of 3.8 mg./200 mm wire and smaller are not reliable in the standard tubular cathode.

Folded Heaters

Special heaters designed and wound at the Receiving Tube Department by J. G. Tucker were made for 12 volt operation in the 6AF4 cathode. One-hundred of these heaters were inserted in 6AF4 tubes and sent to us for evaluation. Comparing this special heater with the 6.3 volt - 6AF4 heater, 12 strands of wire instead of 8 is employed and the body length is increased from 12 1/2 mm. to 14 mm. This adds 78% to the total wire length. At the same time the wire diameter was reduced 24% to 1.28 mils (3.23 mg/200 mm.). An overhang of .100" on each end of the cathode throws away heat raising the wattage from 1.4 to 2.1 watts, which also contributes to the increased voltage. An operating voltage of 11.0 volts was obtained. This heater is .560 inches long excluding the legs, which would be bent downward since it must fit into a .600 inch I.D. neck. With this extreme length and very fine wire size, the heater still operates below the 12 volts required. Note that the 12.6 volt folded heaters in receiving tubes are 1 1/4 inches long. Finally, this heater is extremely fragile and insertion into the cathode is difficult. This points up that it is impractical to consider high voltages for a folded heater in the space restrictions of the 3/4" neck tube.

Nevertheless, some heaters will be life tested to further substantiate the above conclusion.

Coiled Coil Heaters

The coiled coil heater has more wire in the same volume and can thus be made with large wire (approximately 4.5 mg/200 mm); it therefore promises to be a more reliable heater. The smallest coiled coil heater is used in a .090 inch diameter cathode and requires 1.89 watts. Tests on 30 heaters operating at 12 volts are now under way.

Higher Voltage Due to Higher Wattage

It is my contention that if we elect to increase wattage as a means of increasing heater voltage, this should be done external to the tube through a dropping resistor. From our present knowledge, it appears that an 8.4 volt filament is feasible in the mica structure, therefore, 3.6 volts would be dropped across a resistor. At 1.41 watts to the heater, 0.6 watts is dissipated in the dropping resistor, a total of 2.01 watts. If a 1.0 watt heater at 7 volts is considered (the wire required for 8.4V and 1.0W. is too fine), the voltage drop across a resistor would be 5 volts. The power dissipated in the resistor would be 0.7 watts making a total dissipation of 1.7 watts.

Low Voltage Heaters

The design of a reliable low voltage heater is relatively simple since the wire size will be large. Figure 1 shows the relation between wire size and the number of strands of a folded heater for 2 volt operation. Curve 2 is for a heater having one-half the body length which requires input power of approximately 1.0 watt. The actual and the calculated wire diameter of the 2AF4 heater is shown to be very close. See the appendix for the method of calculation.

There are heaters for the tubular cathode of the mica design which operate at 2.34 volts and 1.41 watts. We have 1000 - 2AF4 folded heaters and 1000 - Philco folded coil heaters on hand. Both are reliable from a breakage standpoint, however, the Philco heater has a change in power consumption with life.

FUTURE PLANS

Since it is a tentative decision of TVRD to supply the heater from the horizontal flyback transformer (at 15KC), preparation is being made to life test tubes with the heater supplied by this mode. Five 17"-110° tubes with Philco's 2.34 volt heater and five with the 2AF4 heater are being built for test. These tubes employ TPF guns, mica cage, .395 in. O.D. parts, with anode, and mounted with ceramic rods. By February 15th, ten life rack positions will be converted to supply 2.34 volts at .600 amperes from the horizontal transformer.

I am confident that the voltage can be pin-pointed at any given low voltage without difficulty, therefore, my efforts are being concentrated on developing a low wattage heater-cathode structure requiring 1.0 watt or less.

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CATHODE RAY TUBE DEPARTMENT

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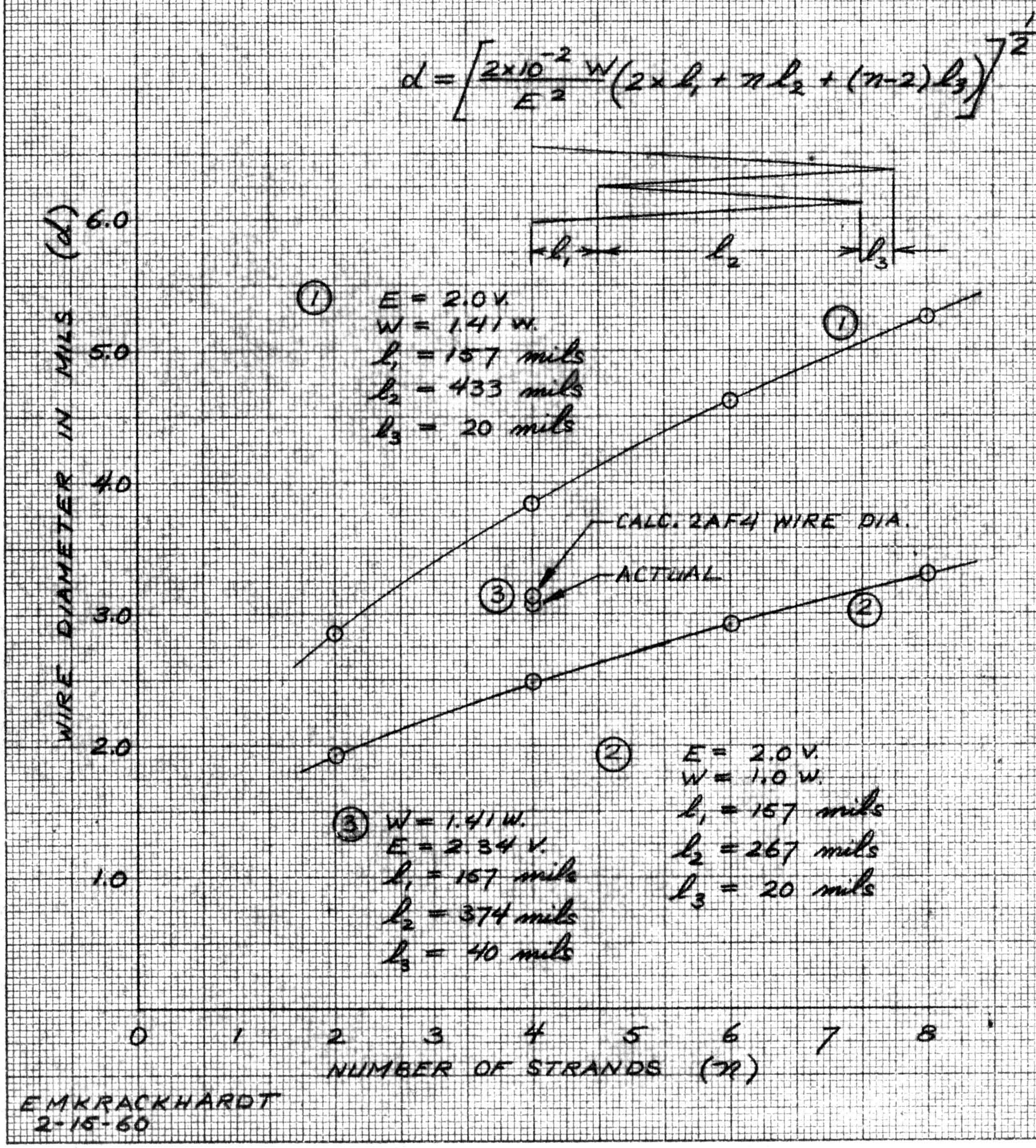
FIGURE 1

WIRE DIAMETER OF A FOLDED HEATER AS A FUNCTION OF THE NUMBER OF STRANDS



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APPENDIX

Heater Design

1. $T_k = C = 825^oC$
2. $T_k = f\ (T_f)$
3. $T_f = f\ (Q_{in})$
4. $Q_{in} = KW$

(1–4: heat transfer equations)

Given an immersion structure, it is usual to assume as a first approximation that the input power (W) to the heater is a constant. That is to say the power requirement is not a function of the heater design itself. The input power must be known either thru experiment or prior experience.

Given the desired heater rating in current or voltage, the heater geometry can be calculated.

5. $W = \frac{E^2}{R_t} = I^2 R_t$

6. $R_t = \frac{\rho_t\, l}{A} = \frac{4 \rho_t\, l}{\pi\, d^2}$

$$\frac{l}{d^2} = \frac{\pi\, W}{4 \rho_t\ I^2} = \frac{\pi E^2}{4 \rho_t\, W}$$

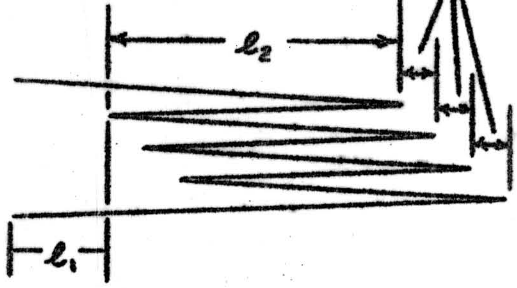
$\rho_t = (T_f)$ for a given material.

The resistivity (ρ_t) may vary since the heater temperature (T_f) is to some degree dependent upon the heater design. It therefore should be checked against experimental evidence. For heater designs similar to the 9QP4 heater, $\rho_t = 15.75 \times 10^{-6}\ \Omega$-in.

The length (l) of the heater is the total heated length and can be calculated for each type of heater.

For folded heaters:

$$l = 2l_1 + n\ l_2 + (n-2)\ l_3$$



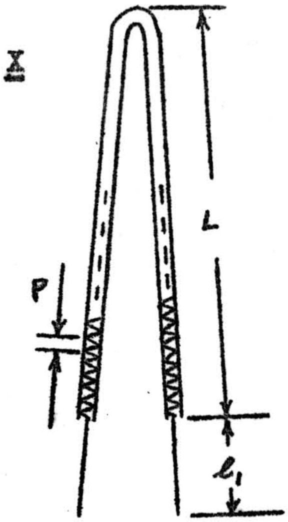
A P P E N D I X

Folded Coil Heater or Double Helical Coil

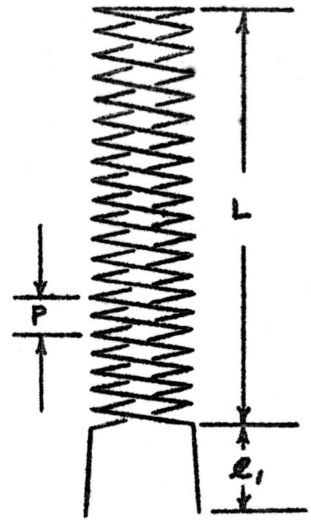
$$l = 2\, l_1 + \frac{2L}{P} \sqrt{\pi^2 D^2 + P^2}$$

$$\frac{l}{P} = TPI$$

D = uncoated coil O.D. minus wire dia.

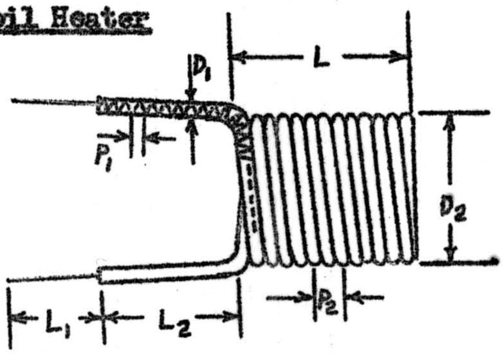


FOLDED COIL



HELICAL COIL

Coiled Coil Heater



$$l = 2L_1 + \frac{2}{P_1} \sqrt{\pi^2 D_1^2 + P_1^2} \quad \left(\frac{L}{P_2} \sqrt{D_2^2 + P_2^2} + L_2 \right)$$

Altho the formula is theoretically exact, small deviations in the coil dimensions will produce cumulative errors in the calculated length.

T_k	Cathode temperature
T_f	Heater temperature
Q_{in}	Heat flow to the heater
W	Heater wattage
E	Heater voltage
I	Heater current
R_t	Heater resistance at operating temperature
t	Resistivity at operating temperature
A	Cross sectional area of heater wire
d	Diameter of heater wire
l	Total heater wire length