SHORT LENGTH WIRE AS AN ELECTRICAL FUSE

[a] Maral Hasheminasab, [b] Mahan Fallahpour,
a) Farzanegan 7 High School , Tehran ; b) Alghadir High School, Kish, Iran

ARTICLE INFO

a) Participated in PYPT 2022 ,

b) participated in PYPT- IYPT 2022, Georgia

Accepted in country selection by Ariaian Young Innovative Minds Institute , AYIMI

http://www.ayimi.org ,info@ayimi.org

ABSTRACT

A short length of wire can act as an electrical fuse. A fuse is an electrical safety device that consists of a conductive wire or strip that is designed to melt and separate in the event of excessive current. We aim to determine and investigate the parameters that effect the time it takes for this fuse to blow. The two defining parameters are the current passing through the wire and the wire's melting point. The indirect parameter, resistance is also investigated as well as physical characteristics of the wire such as length and width also by assuming that a known current is passing through the wire and thus eliminating resistance as a direct defining parameter.

Key Words : *Fuse, Blow, Wire, Resistance*

1. Introduction

A fuse is an electrical safety device that operates to provide overcurrent protection of an electrical circuit. There are a myriad of different fuse designs which have specific current and voltage ratings, breaking capacity, and response times, depending on the application. The time and current operating characteristics of fuses are chosen to provide adequate protection without needless interruption. An important characteristic of a fuse in our work is the rated current, which is the maximum current that the fuse can continuously conduct without breaking and interrupting the circuit.

When the electric current passes from a short length of a wire, the wire produces heat. The heat is produced by ambience and crocodile clip by convection, conduction and a small part by radiation is wasted but in the special situation can be seen the wire blow.

2. Theory

Since in order for the fuse to blow the conducting part must melt this will happen if the heat generated in the wire because of the passage of the current is sufficient, making this current produced heat of paramount importance, with the reasonable assumption that the wire is an ohmic conductor, the heat generated in the wire while a current I is passing through it will be RI^2t, with t being the time has passed since the current was flowing through the wire.

The speed at which a fuse blows depends on how much current flows through it and the material of which the fuse is made, since wires made of different material have different melting points even if they have the same resistance. With this in mind that we are assuming a certain given current is flowing through the wire and thus resistance is no longer directly involved in the time it takes for the fuse to blow we will begin looking at the relevant parameters. Aside from this fuses usually have small resistance so as not to interfere with circuit.

2.1. Current

As seen in the generated heat relationship with current I passing through the wire, the current plays a crucial role in the heat generated and thus the time it takes for the fuse to blow. Moreover the current is squared so for instance if a fuse has the rated current of 1 A, it will blow much faster if a current of 10 A is passing through it than when a 2 A current is passing through it, since in the first case the heat produced is 25 times that of the second case (Fig. 1) (Eq. 1-2).

$$V = RI \tag{1}$$

$$P = \frac{W}{t} = \frac{q.\Delta V}{t} = I\Delta V = IV = \frac{V^2}{R} \tag{2}$$

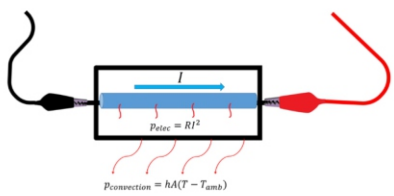

Fig. 1: When electrical current passes through a wire

It produces Heat (p_{elec})*Part of this heat is absorbed by the ambience (p_{conv})*Another part of the heat is lost by conduction, which will be shown in the fourth section of Theory.

2.2. Melting Point

Clearly this parameter dictates when the wire is going to melt. For instance imagine we have two fuses with wires made from aluminum and tin, the wires have the same resistance and the rated currents are the same. Since tin's melting point is less than aluminum's the tin wire is going to melt sooner.

2.3. Physical Characteristics of Wires: Length And Width

It is pretty clear that with the same current a thicker a wire takes longer to melt and fall of and vice versa, a thin wire will fall apart faster. This is the case regardless of other parameters.

It is known that a wire that is fixed in the two ends and suspended will form a catenary shape, the tension in different parts of the wire will vary. Again with the assumption that the passing current and the resistance are the same a longer wire will break faster since the bigger inner tension will aid gravity.

2.4. Other Parameters

Surface tension of the molten can have a minimal effect in the time it takes for the fuse to blow since it can cause the molten metal to form spheres and disconnect from the wire and thus cutting the current.

Orientation of the fuse can also play a role since it is ultimately the reason that the molten segment of the wire falls of.

3. Basic Theory

The temperature, heat transfer and its relation with blowing are as equations (3-11):

$$P_{elec} - P_{conv} = \mathrm{mc}.\frac{dT}{dt} \quad (3)$$

$$\int_0^Q dQ = \int_{T_i}^{T_f} mc \Longrightarrow Q\Big|_0^Q = mcT\Big|_{T_i}^{T_f} \Longrightarrow Q = mc(T_f - T_i) \quad (4)$$

$$p_{elec} = p_{conv}$$

$$RI^2 = hA(T_F - T_{amb} \quad (5)$$

$$T_F = T_{Amb} + \frac{RI^2}{hA} \quad (6)$$

$IF\ T_F < T_L$ (dose't blow)

h =Convectional coefficient

e=2.71828, A=cross sectional area (7)

$IF(T_F > T_L$:It blows $I = 0$

3.1. Instantaneous Temperature

Heat produced by current:

$$Q = RI^2t \quad (8)$$

Heat dissipated by the convection:

$$-hA(T - T_{amb}).dt \quad (9)$$

$$RI^2.dt - hA(T - T_{amb}).dt = mc.dT \quad (10)$$

$$T = \frac{RI^2}{hA}.e^{-\frac{h}{m\times c}t} + \frac{RI^2}{hA} + \mathrm{T_{amb}} \quad (11)$$

3.2 Time of Blowing

It is supposed (T) in equation (11) is melting temperature so time of blowing is (Eq. 12):

$$t_{blow} = \frac{mc}{hA} \times \ln\left(\frac{RI^2}{RI^2 - hA(T_l - T_{amb})}\right) \quad (12)$$

3.3 Place of Melting

Because of conduction it seems that temperature of part 3 is higher than another part and it is the place of melting point, but it is not correct (Eq. 13)(Figs. 2 and 3).

$$R''I^2.\mathrm{t} > R'I^2.\mathrm{t} > RI^2.t$$

$$Q_{R''} > Q_{R'} > Q_R \quad (13)$$

Wire impurities is the reason of this phenomenon because the impurity of the wire in the R″ part produces more heat, although it is close to the crocodile wire, the conduction does not have much effect. That's why Low impact is considered as conduction in theory (Figs. 2-4).

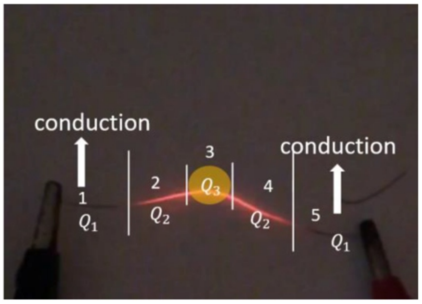

Fig 2:

Conductin 1 ≈ Conductin 5 > Conductin 2 ≈ Conductin 4 > Conductin 3

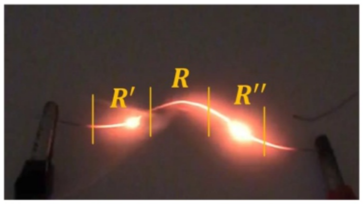

Fig. 3:

$$R'' > R' > \mathrm{R}$$

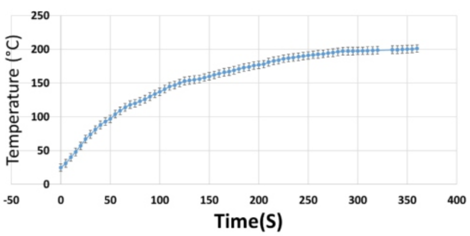

Fig. 4: Temperature vs time in the wire as Fuse

4. Experimental Setup

Experimental setup consists of (Fig. 5):

1. Multimeter
2. Short length wire as Fuse

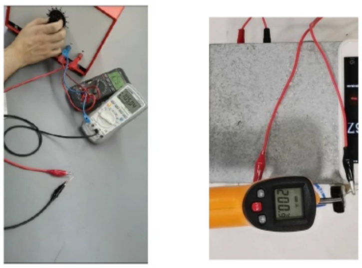

Fig.5: Experimental setup

5. Finding the Range of Current or Voltage Before Melting

The rang of (V),(I) for blowing are found (Eqs. 14- 21).

$$V < \sqrt{h_{(Laboratory)} A_{(WIRE)} R (T_L - T_{amb})} \quad (14)$$

$$\longrightarrow \begin{cases} (T_L - T_{amb})_{cu} = 1060 \\ h_{(Lab)} = 28 \end{cases}$$

$$I < \sqrt{\frac{h_{(Laboratory)} A_{(WIRE)} (T_L - T_{amb})}{R}} \quad (15)$$

$$\begin{cases} V < \sqrt{AhR(T_L - T_{amb})} & (16) \\ I < \sqrt{\frac{Ah(T_L - T_{amb})}{R}} & (17) \end{cases}$$

$$h = \frac{\frac{V^2}{(T_{max} - T_{amb})R}}{A} \approx 28 \quad (18)$$

$$Ah = \frac{V^2}{(T_{max} - T_{amb})R} \approx 0.028, \quad A \approx 1 \times 10^{-3} \quad (19)$$

$$V < \sqrt{29680\, A_{(WIRE)}\, R} \quad (20)$$

$$I < \sqrt{\frac{29680\, A_{(WIRE)}}{R}} \quad (21)$$

6. Conclusions

By experiments the range of V(v) and I(A) are calculated. By increasing the length of the wire the time of blow is increased and also by increasing the voltage the time of blow for any length is increasing (Fig. 6).

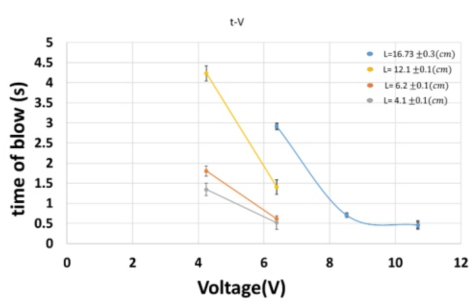

Fig. 6: Time of blowing vs voltage in Fuse

References

[1] Lessons in Electric Circuits by Tony R. Kuphaldt

[2] Arthur Wright, P. Gordon Newbery Electric fuses 3rd edition, Institution of Electrical Engineers (IET), 2004, ISBN 0-86341-379-X,