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veins, some of which have a gouge selvage and brecciation indicating movement, are thought to correspond to the second set of shear faults noted by Dr. Mead in his experiment. The N20W segments of the veins are thought to be due to the filling of the early openings along the direction of maximum shear, while the post-mineral faults, notably those striking N20W, and to lesser degree some of the N70E structures, are thought to be due to the continued application of the same stress. The low-dipping N60W group of faults evident in the district as a whole probably are of the compression type mentioned by Dr. Mead as being approximately perpendicular in strike to the tension cracks. It seems likely that the faults of the district and the fractures filled by the veins in the tin deposit were both caused by the same progressive shearing stress acting in an almost horizontal plane.

♦ ♦ ♦

PERIOD OF OSCILLATION OF A THYRATRON CIRCUIT

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In the course of a series of experiments requiring a constant rate of interruption of continuous radio signals, considerable trouble was experienced with strays generated by mechanical methods of interruption. At the suggestion of Dr. H. E. Hartig of the University of Minnesota, a circuit was used in which a thyatron tube with a

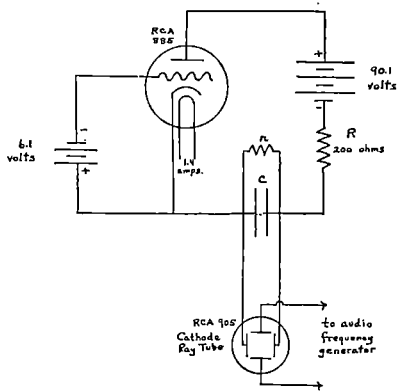


FIGURE 1

condenser-resistance unit in its plate circuit produced periodic discharges across the condenser. The present paper deals with the theory of the interrupting circuit which is shown in detail in Figure 1. To use this circuit for interrupting an oscillator, the resistor in the plate circuit of the thyatron is connected to the grid circuit of the oscillator.

The 885 thyatron is similar to an ordinary triode in structure but is filled with neon gas under low pressure. The gas ionizes when the plate voltage becomes

sufficiently great. By actual measurement it was found that with a grid bias of -6.1 volts and a heater current of 1.4 amperes, ionization would occur when the plate voltage reached 54 volts and deionization when the voltage dropped to 17 volts. When ionized, the

tube offers very little resistance to the flow of current through it, and a rapid flow of current takes place, charging the condenser, *c*, which exerts a back E. M. F. proportional to the charge upon it. (See Figure 1). Eventually this becomes sufficient to make the plate voltage drop below 17 volts, and deionization takes place. When the gas is not ionized, the tube acts like an ordinary triode—i. e. a rectifier. The condenser, *c*, discharges across the resistor, *r*, exactly as if the rest of the circuit did not exist. The truth of this statement is easily seen when it is recalled that the flow of current due to the condenser discharge is directed oppositely to the current which charged the condenser, and thus could not pass through the tube. As the condenser discharges it opposes the battery less and less and the plate voltage rises. When it reaches 54 volts, ionization occurs and the cycle is repeated.

From the preceding remarks it was concluded that the circuit used is electrically equivalent to Figure 2 in which the thyatron

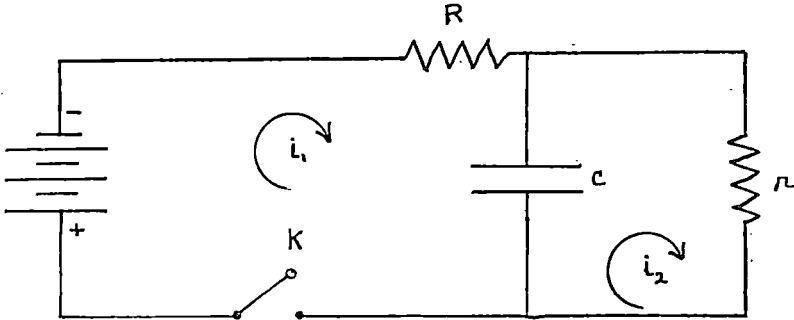


FIGURE 2

is replaced by a key, *k*. The closed position of the key corresponds to the thyatron when the gas is ionized; the open position to the case when the gas is not ionized and the condenser is discharging across *r*.

To obtain the period of the cycle, the above network was solved. With the key closed (gas ionized), the condenser is charged; with the key open (gas deionized), the condenser discharges across *r*. (A) Key closed—Solution obtained by Maxwell's Law. Let x_1 equal the charge on the condenser associated with i_1 and x_2 the charge on the condenser associated with i_2 . In each branch, the sum of the E.M.F.'s equals the sum of the ir drop less the ir drop of the linking unit. In the case of the condenser, $ir = \frac{x}{c}$.

Therefore:

$$E = i_1 R + \frac{x_1 - x_2}{c} \quad \text{and} \quad 0 = i_2 r + \frac{x_2 - x_1}{c}$$

Since $i = \frac{dx}{dt}$ these can be written:

$$(1) \quad R \frac{dx_1}{dt} + \frac{x_1 - x_2}{c} = E \quad \text{or} \quad \frac{dx_1}{dt} + \frac{x_1 - x_2}{Rc} = \frac{E}{R}$$

$$(2) \quad r \frac{dx_2}{dt} + \frac{x_2 - x_1}{c} = 0 \quad \text{or} \quad \frac{dx_2}{dt} + \frac{x_2 - x_1}{rc} = 0$$

The resistance R is unnecessary to the operation of the circuit since there is a small amount of resistance in the wires, the tube (even when the gas is ionized) and the battery. But since these are not easily determinable, a resistance R of 200 ohms was used and the other small resistances became negligible by comparison. If no resistance R is used, it would not be correct to set R equal to zero in equation (1) above unless it could be shown that $\frac{dx_1}{dt}$ remained finite. The equation $e = ir$ suggests that i becomes infinite as r approaches zero and $i = \frac{dx}{dt}$.

The simultaneous differential equations (1) and (2) can be solved by any convenient method.

For example, multiply the second equation by l and add:

$$\frac{dx_1}{dt} + l \frac{dx_2}{dt} + \frac{x_1 - x_2}{Rc} + l \frac{x_2 - x_1}{rc} = \frac{E}{R}$$

$$\frac{d}{dt}(x_1 + lx_2) + \left(\frac{1}{Rc} - \frac{l}{rc}\right)x_1 + \left(\frac{l}{rc} - \frac{1}{Rc}\right)x_2 = \frac{E}{R}$$

Choose K $\left(\frac{1}{Rc} - \frac{l}{rc}\right)x_1 + \left(\frac{l}{rc} - \frac{1}{Rc}\right)x_2 = k(x_1 + lx_2) = kx_1 + klx_2$

$$\text{Then } \frac{1}{Rc} - \frac{l}{rc} = k \quad \text{or} \quad \frac{l}{rc} - \frac{1}{Rc} = kl \quad \text{and } l = -1.$$

$$\text{This gives: } k = \frac{1}{Rc} + \frac{1}{rc} = \frac{R+r}{cRr}$$

$$\text{Therefore: } \frac{d}{dt}(x_1 - x_2) + k(x_1 - x_2) = \frac{E}{R}$$

$$\text{Let } y = x_1 - x_2. \text{ Then } \frac{dy}{dt} + ky = \frac{E}{R}$$

Using the general solution,

$$y = e^{-kt} \left(\int e^{kt} \frac{E dt}{R} + a \right) = \frac{E}{Rk} + ae^{-kt} \quad (a \text{ is arbitrary})$$

$$\text{We get } y = x_1 - x_2 = \frac{Ecr}{R+r} + ae^{-\frac{r+r}{cRr}t} \quad (3)$$

Now $x_1 - x_2$ is actually the charge on the condenser which opposes the battery. This is seen upon inspection of the circuit, in which the currents are taken positive in the clockwise direction. We begin counting time at the instant the gas ionizes; i. e., when the plate voltage is 54 volts.

Let v_1 be the voltage due to the charge on the condenser at this time. Then: $cv_1 = x_1 - x_2$ where c is the capacity of the condenser. Therefore when $t = 0$, $x_1 - x_2 = cv_1$. Substituting these values in equation (3); we find the value of a : $a = cv_1 - \frac{Ecr}{R+r}$. Therefore

$$x_1 - x_2 = \frac{Ecr}{R+r} + \left(cv_1 - \frac{Ecr}{R+r} \right) e^{-\frac{r+r}{cRr}t}$$

When the plate voltage drops to 17 volts, the gas deionizes. Let the charge on the condenser at this time be cv_2 . Thus, while the thyratron is ionized, the charge on the condenser changes from cv_1 to cv_2 . The time, t , goes from $t = 0$ to $t = T_2$.

$$cv_2 = \frac{Ecr}{R+r} + \left(cv_1 - \frac{Ecr}{R+r} \right) e^{-\frac{r+r}{cRr}T_2}$$

Solving this for T_2 :

$$T_2 = \frac{cRr}{r+R} \log_e \frac{\left(cv_1 - \frac{Ecr}{R+r} \right)}{\left(cv_2 - \frac{Ecr}{R+r} \right)}$$

Since the battery is opposed by the condenser, the plate voltage is the difference between the E.M.F. of the battery, and the E.M.F. due to the charge on the condenser.

$E - v_1 = 54$ volts and $E - v_2 = 17$ volts.

$$\text{Therefore: } T_2 = \frac{cRr}{r+R} \log_e \frac{\left(c(E - 54) - \frac{Ecr}{R+r} \right)}{\left(c(E - 17) - \frac{Ecr}{R+r} \right)}$$

(B) Key open — condenser discharges across r . The equation for the discharge is obtained as follows. Let q be the charge on the condenser at any time t . Then $\frac{dq}{c} = -ri = -r \frac{dq}{dt}$, the solution for which is $q = ke^{-\frac{t}{rc}}$

For this part of the cycle we begin counting time at the instant the gas deionizes. At this time $q = cv_2$. When $t = 0$, $q = cv_2$ and so $k = cv_2$. Then $q = cv_2 e^{-\frac{t}{rc}}$

When the charge falls to cv_1 , the gas ionizes again.

$$\text{Then } cv_1 = cv_2 e^{-\frac{t}{rc}} \text{ and } t = rc \log_e \frac{V_2}{V_1} = T_1.$$

According to data from the RCA Company, ten microseconds are required for ionization or deionization of the gas. Thus the total period of the thyatron cycle in this circuit is $T_1 + T_2 + 20 \times 10^{-6}$ seconds.

In order to check the theoretical value for the period of interruption, the oscillations of the thyatron circuit were fed into the vertical deflecting plates of a cathode ray oscillograph, and the frequency generator oscillations were fed into the horizontal deflecting plates. The frequency generator available was accurate to 1%. The following table shows fair agreement between the theoretical and experimental values of the period.

TABLE OF RESULTS

c in Farads	r in Ohms	Experimental Period	Computed Period
.01155 x 10 ⁻⁶	9,391	.00010 seconds	.00009 seconds
.01155 x 10 ⁻⁶	66,000	.00048	.00048
.01155 x 10 ⁻⁶	104,490	.00079	.00075
.01155 x 10 ⁻⁶	660,000	.00455	.00464
.01155 x 10 ⁻⁶	2,070,000	.01666	.01451

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