

# ON THE POULSEN ARC IN COUPLED CIRCUITS\*

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## 1. INTRODUCTION

The Poulsen arc generator in connection with coupled circuits has been used by V. Poulsen<sup>1</sup> at a comparatively early date. Rather close coupling was often used by him in his radio telegraphic tests,<sup>2</sup> whereas he usually employed comparatively loose coupling in the series of tests by which long distance radio telephony<sup>3</sup> was, for the first time, shown to be feasible.

Arc oscillations in coupled circuits have been the subject of a number of laboratory investigations as well as of theoretical studies. In this connection may be mentioned the investigations on musical (audio frequency) arcs by E. Taylor Jones,<sup>4</sup> E. Taylor Jones and M. Owen,<sup>5</sup> E. Taylor Jones and D. E. Roberts,<sup>6</sup> and S. Subkis,<sup>7</sup> and on radio frequency arcs by P. O. Pedersen<sup>8</sup> and Hidetsugu Yagi.<sup>9</sup>

The author himself carried out a series of investigations on the Poulsen arc in coupled circuits in the autumn of 1918. He employed for these investigations, among other arrangements, the one shown in Figure 1 where  $L_1$  is considerably larger than

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<sup>1</sup> See U. S. Patents, numbers 789, 449 and 793, 608; filed June, 1903.

<sup>2</sup> V. Poulsen: "Ein Verfahren zur Erzeugung ungedämpfter Schwingungen und seine Anwendung in der drahtlosen Telegraphie," "Elektrotech. Zeitschrift," pages 1040-1044, 1906 (Figure 8).

<sup>3</sup> V. Poulsen: "La téléphonie sans fil." "Rapport officiel au Congrès international des applications électriques," Turin, 1911.

<sup>4</sup> E. Taylor Jones: "Electrical Oscillations in Coupled Circuits," "Phil. Mag.," (6), volume 17, pages 28-43, 1909.

<sup>5</sup> E. Taylor Jones and M. Owen: "Musical Arc Oscillations in Coupled Circuits," "Phil. Mag.," (6), volume 18, pages 713-722, 1909.

<sup>6</sup> E. Taylor Jones and D. E. Roberts: "Phil. Mag.," (6), volume 20, pages 660-663, 1910.

<sup>7</sup> S. Subkis: "Der Einfluss der Koppelung bei langsamen ungedämpften Schwingungen," "Jahrbuch d. drahtlosen Telegraphie," volume 5, pages 507-513, 545-563, 1912.

<sup>8</sup> P. O. Pedersen: "Beiträge zur Theorie der drahtlosen Telephonie," "Jahrbuch d. Drahtlosen Telegraphie," volume 5, pages 449-498, 1912.

<sup>9</sup> Hidetsugu Yagi: "Arc Oscillations in Coupled Circuits," PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, volume 4, pages 371-388, 1916.

$L_2'$ , and he obtained a current  $I_2$  in the secondary circuit 2 to 3 times larger than the current  $I_1$  in the primary circuit (arc-circuit), whereas  $I_1$  at the same time kept its normal value  $\sqrt{\frac{1}{2}} I_o$ , where  $I_o$  is the supply current.<sup>10</sup> (During these tests the wave-length was  $\lambda=7,700$  m., the resistance  $R_2=3$  to 4 ohms, and the capacity  $C_2=32,000$  cm. or 0.036 microfarad.) These tests were discontinued in order that some investigations on the arc generator proper might be carried out, and it is hoped to get the opportunity later on of publishing, in another paper, the results thereof. Before discontinuing the above-mentioned

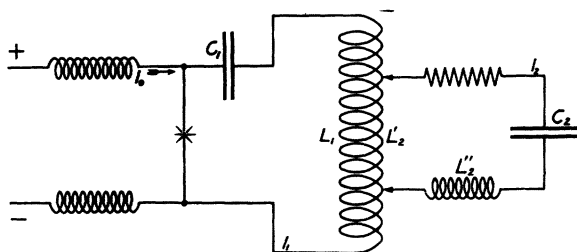


FIGURE 1

tests, there had, however, been carried out a series of investigations on a special arrangement of coupled circuits which is shown in Figure 2 and which, as far as I am aware, has been introduced by L. F. Fuller<sup>11</sup> and by Hartenstein<sup>12</sup> independently of each other.

## 2. INVESTIGATION OF THE CIRCUIT SHOWN IN FIGURE 2

The distinctive feature of this diagram is that a condenser  $C_2$  is inserted next to the arc, in series therewith and with the aerial, and further that the arc and  $C_2$  are shunted by another condenser  $C_1$ . In the following treatment,  $C_1$  is at times called the "shunt condenser" and  $C_2$  "series condenser." If  $C_1$  be disconnected, the diagram is reduced to the usual and simple

<sup>10</sup> P. O. Pedersen, (a) "On the Poulsen Arc and Its Theory," PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, volume 5, pages 255-316, 1917. (b) "Supplementary Note," volume 7, pages 293-297, 1919.

<sup>11</sup> L. F. Fuller, U. S. Patent, number 1,179,353, filed April, 1913.

<sup>12</sup> H. Rein, "Lehrbuch der drahtlosen Telegraphie," second edition, pages 182-183, 1917.

$$\lambda_o = 6 \pi \cdot 10^8 \sqrt{LC} \cdot \sqrt{\frac{C_2}{C_1 + C_2}} \quad (1)$$

We will use the following symbols:  $n \cdot \lambda = 3 \times 10^8$ ;  $2\pi n = \omega$ ;  $\sqrt{-1} = j$ ; the antenna capacity  $= C$ ; the impedance of the radio frequency circuit between  $A$  and  $B = Z$ ; the admittance of the circuit  $aLCc = Y_a$ ; the admittance of the circuit  $aC_1c = Y_b$ .

$$Z=j\frac{C+C_1+C_2-\omega^2 L \cdot C \cdot (C_1+C_2)}{\omega C_2 \cdot (\omega^2 L C C_1-C-C_1)} \quad (2)$$
$$\omega = \sqrt{\frac{C + C_1 + C_2}{LC(C_1 + C_2)}} \quad (3)$$

The length of the radiated wave in meters is, therefore, determined by

$$\lambda = 6\pi \cdot 10^8 \cdot \sqrt{LC} \cdot \sqrt{\frac{C_1 + C_2}{C + C_1 + C_2}} \quad (4)$$

which, in combination with (1), gives

$$\frac{\lambda}{\lambda_0} = \sqrt{1 + \frac{C \cdot C_1}{C_2(C + C_1 + C_2)}} \quad (5)$$

It is evident that  $\lambda$  is always larger than  $\lambda_0$ , which, it seems, has not always been taken fully into consideration.

In the above calculations no regard is paid to the resistances in the radio frequency circuits, because these resistances are of very small importance in the determination of the wave-length; furthermore, the calculations would be very much complicated if the resistances were taken into account.

We have carried out a series of measurements of sets of  $\lambda$  and  $\lambda_0$  in order to make sure that the above considerations hold good. The results of these measurements are shown in Table 1 below.

TABLE 1

C cm.	C <sub>1</sub> cm.	C <sub>2</sub> cm.	$\lambda_0$ m.	$\lambda$		$100 \frac{\lambda - \lambda_0}{\lambda}$	
				measured m.	calculated m.	measured	calculated
7,300	1,250	14,600	3,440	3,490	3,487	1.45	1.35
7,300	14,600	14,600	3,810	4,200	4,225	10.3	10.9
6,400	7,400	12,500	3,800	4,060	4,066	6.85	7.0
13,800	13,050	39,600	5,870	7,080	7,090	3.2	3.3
13,800	600	14,600	5,400	5,500	5,455	1.8	1.0
13,800	1,200	14,600	5,400	5,560	5,503	3.0	1.9
13,800	2,000	14,600	5,400	5,620	5,567	4.1	3.1
13,800	2,400	14,600	5,400	5,660	5,594	4.8	3.6
13,800	4,400	14,600	5,400	5,800	5,735	7.4	6.2
13,800	5,600	14,600	5,400	5,900	5,805	9.3	7.5
13,800	7,600	14,600	5,400	5,980	5,913	10.8	9.5
13,800	10,350	14,600	5,400	6,100	6,048	13.0	12.0
13,800	13,250	14,600	5,400	6,120	6,160	13.3	14.1

Taking into account that the values given above for the capacities of the condensers may be wrong by about 0.5 per cent., the measured values of  $\lambda$  may be considered to agree quite satisfactorily with the values as calculated from equation (5). There can, consequently, be no doubt that the above calculations are correct, and that it therefore is possible to calculate in the

usual way how the radio frequency arc current (wave-length  $\lambda$ ) divides itself between the two circuits (a)  $I_a$  in  $aLc$  and (b)  $I_b$  in  $aC_1c$ . If, as before, the resistances are not taken into account we obtain by means of (3)

$$Y_a = \frac{j \omega C}{1 - \omega^2 LC} = -j \frac{1}{\omega L} \frac{C + C_1 + C_2}{C} \quad (6)$$

and

$$Y_b = j \omega C_1 = j \frac{1}{\omega L} \frac{C + C_1 + C_2}{C} \frac{C_1}{C_1 + C_2} \quad (7)$$

Furthermore,

$$Y_a + Y_b = -j \frac{1}{\omega L} \frac{C + C_1 + C_2}{C} \frac{C_2}{C_1 + C_2} \quad (8)$$

From the above, we derive

$$\frac{I_a}{I} = \frac{Y_a}{Y_a + Y_b} = 1 + \frac{C_1}{C_2} \quad (9)$$

$$\frac{I_b}{I} = -\frac{Y_b}{Y_a + Y_b} = \frac{C_1}{C_2} \quad (10)$$

and

$$\frac{I_b}{I_a} = -\frac{Y_b}{Y_a} = \frac{C_1}{C_1 + C_2} \quad (11)$$

We note that  $I$  and  $I_a$  are in phase, whereas  $I_b$  is of opposite phase to  $I$  and  $I_a$ .

It may not appear to be correct to disregard the resistances when the calculation deals with the distribution of the currents between the two circuits. The resulting error is, however, small; which may be shown as follows:

In the above calculations the impedance  $Z_a$  of the circuit  $aLc$  has been taken as

$$Z_a = j \omega L \frac{C}{C + C_1 + C_2}$$

whereas the real value is

$$Z_a' = R + j \omega L \frac{C}{C + C_1 + C_2}$$

If, in these equations, we take  $\omega = 400,000$ ,  $L = 10^{-3}$  henry, and  $\frac{C}{C + C_1 + C_2} = \frac{1}{4}$ , we have

$$Z_a = j \cdot 100 \quad \text{and} \quad Z_a' = R + j \cdot 100$$

Assuming  $R = 5$  ohms (which is a comparatively high value) we obtain the ratio of the absolute values of the impedances

$$\left| \frac{Z_a'}{Z_a} \right| = \frac{100.1}{100} = 1.001$$

The difference between the true value of  $Z$  and the value used in the calculations is therefore only 0.1 per cent.

If, therefore, the total radio frequency current is of the wave-length  $\lambda$ , that is, if no harmonics or other oscillations of a wave-length differing from  $\lambda$  are present, it must be expected that the current will distribute itself according to equation (11).

In Figure 3 are plotted the results of a series of measurements of the simultaneous values of the currents. Curve A

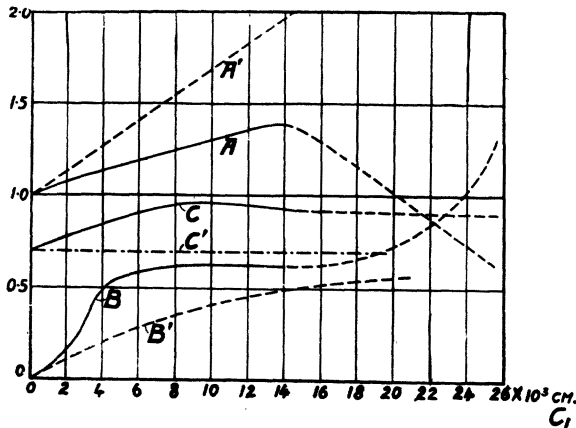


FIGURE 3

shows the ratio  $\frac{I_a}{I}$  between the antenna current and the arc radio frequency current; curve B shows the ratio  $\frac{I_b}{I_a}$  between the shunt current and the antenna current, and curve C shows the ratio  $\frac{I}{I_o}$  between the arc radio frequency current and the arc direct current. The curves are plotted as functions of the capacity of the shunt condenser. (The other constants were:  $\lambda_o = 5,400$  m.;  $C = 13,800$  cm.;  $C_2 = 14,600$  cm.; and  $R = \text{about } 3$  ohms.) The corresponding theoretical curves, as based upon the equations (9) to (11), are indicated by the curves A', B', and C'.

It will be seen that the measured curves differ to a considerable extent from the theoretical curves, the antenna currents being much less and the shunt currents comparatively much greater than what they should be. The reason for this is, that in addition to the fundamental oscillation of wave-length  $\lambda$ , a series of oscillations with shorter wave-lengths are created, these latter being partly the higher harmonics of the fundamental

oscillation and partly the fundamental of the circuit arc— $AaC_1c-C_2B$ —arc. We have hitherto not taken the inductance of this circuit into our calculation; this omission is permissible only to a certain extent. The circuit will always contain some inductance and will, consequently, always have a definite fundamental oscillation. The wave-length of this oscillation was about 420 m. in the tests from which the curves in Figure 3 are plotted.

The proof of the presence of these superfluous and, consequently detrimental oscillations of wave-lengths smaller than  $\lambda$  is:

(1) That the ratio  $\frac{I}{I_o}$  between the arc radio frequency current and the arc direct current is larger than  $\sqrt{\frac{1}{2}}=0.7$ , this being the value of the ratio when only one oscillation is present.<sup>13</sup> Figure 3 shows values of  $\frac{I}{I_o}$  up to 0.9 and more; the arc radio frequency current  $I$  is therefore far from being a sine curve.

(2) The existence of oscillations of shorter wave-lengths than  $\lambda$  is evident also from the following observation:

During certain tests, a safety arrangement was inserted across the leads connecting the choke coils with the switchboard, the safety arrangement consisting of two sets of carbon filament lamps, each set in series with a condenser, the two condensers being connected to each other and to earth. When the capacity of  $C_1$  was diminished, the lamps ceased glowing, or at any rate glowed very dimly, whereas the brilliancy increased with increasing  $C_1$ .

(3) A further proof is that  $\frac{I_b}{I_a}$  is very much larger than what would be expected from formula (11); and this fact indicates especially that the fundamental oscillation of the shunt circuit, as mentioned above, is of great importance in this connection.

(4) That the statement in the latter part of (3) is correct is finally proven by the oscillographic analysis of the voltage of the arc as set forth below.

Oscillograms of the arc tension  $e_1$  have been taken by means of the method previously employed by the author.<sup>14</sup> The oscillograms thus obtained showed the features indicated in Figure 4. Besides the normal peaks  $A$  (the extinction voltage)

<sup>13</sup> P. O. Pedersen, previous citation, (a).

<sup>14</sup> P. O. Pedersen, previous citation, (a), page 285.

and  $B$  (the ignition voltage), a third peak  $C$  appeared, which latter, no doubt, is due to the arc current again decreasing to zero shortly after the ignition has taken place, or in any case decreasing to a very small value. That this is so is without doubt due to the free oscillations in the shunt circuit of the short wave-length  $\lambda_2$ , these oscillations being set up at the moment the discharge thru the arc commences anew. The correspond-

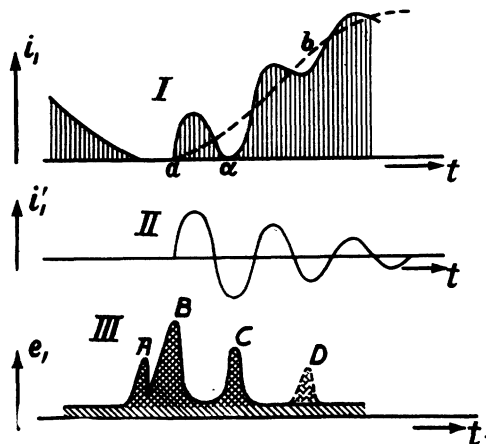


FIGURE 4

ing current  $i'_1$  is also plotted in Figure 4. The arc current is composed of the direct current (supply current)  $I_0$  + the radio frequency current of wave-length  $\lambda$  and of the corresponding higher harmonics (the sum of these latter is shown as the dotted line  $ab$  in Figure 4) + the current  $i'_1$  of wave-length  $\lambda_2$ . The arc current  $i_1$  resulting from all these currents is shown in Figure 4 and fully explains the reason for the appearance of the extra peak  $C$ .

The above described course of the arc tension is the simplest one of those observed. Several peaks may appear as shown by  $D$  in Figure 4, III; also  $C$  may divide itself in two by analogy to  $A$  and  $B$ . This latter condition takes place if the current at  $\alpha$  (Figure 4, I) remains zero for some time, because in this case another separate extinction voltage and ignition voltage are created.

Figure 5 shows one of the arc voltage oscillograms obtained.

We have now in the main explained the action of the diagram (Figure 2). This diagram may evidently be considered as a



transformer arrangement, because the two circuits  
 (1) arc— $Aa C_1 C_2$ —arc and (2) arc— $Aa L C c C_2$ —arc are coupled  
 together by means of the arc and the series condenser  $C_2$ .

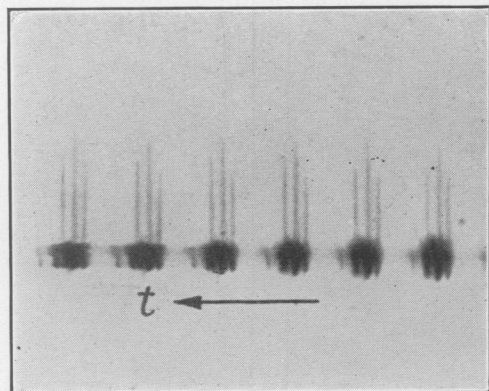


FIGURE 5

### 3. COMPARISON OF FIGURE 2 WITH THE SIMPLE DIAGRAM (WITHOUT THE SHUNT CONDENSER $C_1$ )

It is evident from Figure 3 that the ratio  $\frac{I_a}{I}$  between the antenna current and the arc radio frequency current may become somewhat larger than 1 by applying the arrangement shown in Figure 2. Some other effects, however, are introduced in connection therewith, which, at any rate, partly counteract the advantage in question. We will consider especially that:

1. The necessary direct current voltage across the arc increases very considerably.
2. The wave-length increases.

Tables 2, 3, and 4 below show this clearly.

TABLE 2

(Diagram and indications refer to Figure 2.)  $C_1=13,800$  cm. ( $0.0153 \mu\text{f.}$ ),  $C_2=14,600$  cm. ( $0.0162 \mu\text{f.}$ ), wave-length for  $C_1=0$  is equal to 5,400 m.;  $R$ =about 3 ohms;  $P_o=I_o V_o$  is the energy supplied to the arc;  $C_1$  is variable; and ( $C_1=0$ ) attached to any of the symbols means that the value of the latter is measured when  $C_1=0$ , that is, when the simple circuit connection, without the shunt condenser, is used.

1	2	3	4	5	6	7	8	9	10
$C_1$	$\frac{I_o}{I_o(C_1=0)}$	$\frac{V_o}{V_o(C_1=0)}$	$I$	$I_a$	$I_b$	$\lambda$	$\frac{I_a}{I}$	$\frac{I}{I_o}$	$\frac{I_a^2}{P_o} \frac{P_o}{I_a^2}$ $P_o(C_1=0)$
cm.			amps.	amps.	amps.	m.			
0	1.0	1.0	9.8	9.8	0	5,400	1.00	0.70	1.0
600	0.964	1.0	9.2	9.6	Small	5,500	1.033	0.68	1.03
2,400	0.857	1.29	9.2	10.2	2	5,660	1.11	0.767	0.982
5,600	0.714	1.61	9.4	10.8	6.5	5,900	1.15	0.94	1.06
7,600	0.750	1.61	9.3	11.6	7	5,980	1.245	0.885	1.17
10,350	0.672	1.73	9.4	12.2	8	6,100	1.298	1.00	1.33
13,250	0.693	1.77	9.2	12.7	8.6	6,160	1.38	0.95	1.37
25,750	0.571	2.03	7.1	4.5	6		0.635	0.89	0.187

The results of these measurements are partly represented by Figure 6. Curve *A* shows the figures of column 10 of Table 2; that is, the ratio  $\frac{\gamma}{\gamma_0}$  between the apparent efficiency with shunt condenser and without the same. The curve shows that this ratio is a maximum for a value of  $C_1$  between 12,000 and 14,000 cm. (0.0133 and 0.0156  $\mu$ f.), further that the maximum  $\gamma$  is about 1.37  $\gamma_0$ . It must, however, be noted that the wavelength increases simultaneously, as previously mentioned, and as shown by curve *D* in Figure 6. The increase of the wave-

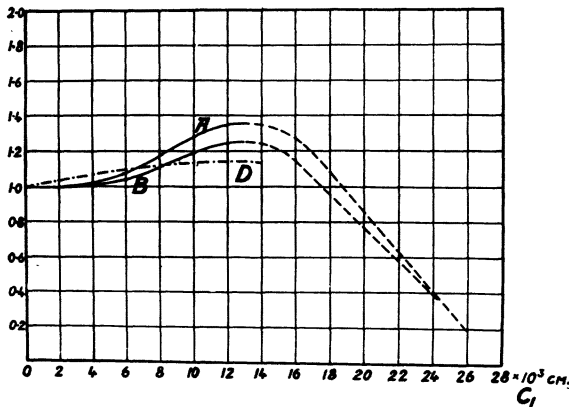


FIGURE 6

length in itself produces a higher efficiency; this increase amounts to about  $1.12\gamma$ , according to tests. The antenna current is, as previously mentioned, not quite a sine curve when the condenser  $C_1$  is inserted, and this is especially the case for values of  $C_1$  as large as 12,000 to 14,000 cm. (0.0133 to 0.0156  $\mu$ f.) The antenna current in the ordinary arc circuit, for which  $C_1 = 0$ , is practically a sine curve when everything is properly adjusted. It is impossible to indicate definitely what fraction of the antenna current is due to "harmonics" of various kind. Three per cent. is very likely much too small a figure when  $C_1 = 12,000$  cm. (0.0133  $\mu$ f.). Curve *B*, Figure 5, is based upon the above corrections. It will be seen from this curve that the effective increased value of the efficiency  $\gamma$  cannot be reckoned to be more than about  $1.2\gamma_0$ .

It might be that a more advantageous result could be obtained

by choosing another ratio between the inductance and the capacity. In order to ascertain whether this be so or not, a series of tests were carried out (Table 3) in which the capacity of the condenser was kept constant, whereas the inductance was varied in such a way that the corresponding wave-lengths covered the range from 6,430 m. to 3,120 m. In no case were better results obtained than those shown in Table 2.

TABLE 3

(Data refer to Figure 2).

$C_1 = 13,800$  cm. (0.0153  $\mu$ f.),  $C_2 = 14,600$  cm. (0.0162  $\mu$ f.),  $R =$  about 3 ohms;  $P_o = I_o V_o =$  energy supplied to the arc. The inductance  $L$  is variable;  $L$  has the same value in each two related tests.

Tests were also carried out by varying the series condenser  $C_2$ , and a few of these tests are tabulated in Table 4. But none of these tests gave better results than the ones in Table 2.

TABLE 4

(Data refer to Figure 2)

$C_1 = 13,800$  cm. (0.0153  $\mu$ f);  $R = 1.6$  ohms;  $P_o = I_o V_o$ . The inductance in the first two tests was about 30 per cent. larger than in the two last tests.

We have thus, by applying the shunt circuit, been unable to increase  $\gamma_o$  to more than about 1.25  $\gamma_o$ . This increase in efficiency was, however, in all our tests accompanied by a considerable unsteadiness of the arc. It proved very difficult to keep the arc burning as steadily as desirable when  $C_1$  has the large capacity necessary for increasing the efficiency by the above-mentioned value. Furthermore, a good many frequencies are created—as set forth above—which are of no use at all, and might cause interference. We are, therefore, of the opinion that the advantages obtained by applying the shunt circuit are, as a whole, not of any great value. This, of course, does not exclude the possibility that the shunt circuit may be of advantage under certain other conditions of a special nature.

I wish to acknowledge my indebtedness to Messrs. J. P. Christensen, H. Erichsen, and A. Teglbjerg for the valuable assistance rendered during the above investigations.

Royal Technical College,  
Copenhagen, February, 1920.

1	2	3	4	5	6	7	8	9	10
$C_2$	$\frac{I_o}{I_o(C_1=0)}$	$\frac{V_o}{V_o(C_1=0)}$	$I$	$I_a$	$I_b$	$\lambda$	$\frac{I_a}{I}$	$\frac{I}{I_o}$	$\frac{I_a^2}{P_o} \frac{P_o}{I_a^2} \frac{1}{P_o(C_1=0)}$
cm.			amps.	amps.	amps.	m.			
12,000 0	0.674 1.0	2.15 1.0	9.6 10.0	12.2 10.0	8 0	6,430 5,610	1.27 1.00	1.01 0.709	1.03 1.0
12,000 0	0.738 1.0	1.89 1.0	9.5 10.0	13.9 10.0	8.2 0	6,140 5,360	1.465 1.00	0.913 0.709	1.39 1.0
12,000 0	0.686 1.0	2.04 1.0	9.6 10.2	14.0 10.2	8 0	5,840 5,140	1.46 1.00	0.99 0.714	1.35 1.0
12,000 0	0.653 1.0	2.29 1.0	10.1 10.5	14.0 10.5	9.2 0	5,160 4,730	1.385 1.00	1.03 0.70	1.19 1.0
12,000 0	0.715 1.0	2.09 1.0	9.7 10.5	13.8 10.5	8.2 0	4,430 3,890	1.425 1.00	0.898 0.696	1.16 1.0
12,000 0	0.734 1.0	1.88 1.0	10.0 10.2	12.6 10.2	9 0	3,610 3,120	1.26 1.00	0.95 0.713	1.11 1.0
12,000 0	0.662 1.0	2.29 1.0	9.9 10.3	14.1 10.3	7.8 0	6,400 5,640	1.425 1.60	1.03 0.71	1.23 1.0
12,000 0	0.667 1.0	2.04 1.0	10.7 10.5	14.0 10.5	15 0	3,620 3,180	1.31 1.00	1.07 0.70	1.31 1.0

1	2	3	4	5	6	7	8	9	10	11
$C_2$	$C_1$	$\frac{I_o}{I_o(C_1=0)}$	$\frac{V_o}{V_o(C_1=0)}$	$I$	$I_a$	$I_b$	$\lambda$	$\frac{I_a}{I}$	$\frac{I}{I_o}$	$\frac{I_a^2}{P_o} \frac{P_o}{I_a^2}$ $P_o(C_1=0)$
cm.	cm.			amps.	amps.	amps.	m.			
14,600	12,000	0.731	2.12	10.0	13.8	8.4	6,400	1.38	0.943	1.21
14,600	0	1.0	1.0	10.1	10.1	0	5,640	1.00	0.702	1.0
39,600	12,000	0.798	1.68	13.2	11.2	9.8	5,820	0.85	1.15	0.899
39,600	0	1.0	1.0	10.2	10.2	0	5,600	1.00	0.709	1.0

**SUMMARY:** A bibliography of oscillating arc investigations with coupled circuits is given. A special form of circuit, wherein the arc and the antenna circuit are coupled electrostatically thru an arc "series condenser," and a "shunt condenser," is studied analytically. Experimental results on the same circuit are given, and the practical usefulness of the circuit discussed.

## DISCUSSION

**Leonard F. Fuller** (by letter): A preferred form of circuit in which  $C_2$  of Professor Pedersen's Figure 2 is omitted and  $C_1$ , shunted directly across the arc terminals, is the only local condenser used, is shown in United States Patent 14,760, of November 25, 1919. This is a re-issue of my original patent number 1,179,353, and was used at Arlington and Tuckerton for some time. It increases antenna current about as effectively as the connection shown in Figure 2, and saves considerable equipment in a large station. Both circuits are only a means of improving an arc which is not operating under the best conditions and will cause no appreciable increase in the antenna current delivered by a well-designed arc operating with "tuned fields" in the proper atmosphere. For these reasons they have fallen into disuse in recent years.

It seems likely that the arc Professor Pedersen used in his experiments was operating with the air gap flux density,  $B_g$ , below the tuned value, for he states that "the increase of the wave length itself produces a higher efficiency." Such a change in efficiency is the natural consequence of operating an arc "underfield."

It would have been very helpful if the observations had been made with tuned fields, as arc performance data rarely permit of quantitative comparison if they are taken with untuned fields. A great amount of experimental work has had its value very seriously reduced by failure to appreciate this fact.

I heartily agree with the conclusion that circuits such as these are hardly worth while, but this is because of our present knowledge of tuned fields and the other factors effecting arc performance which enable us to accomplish the same desirable results in better ways and without fostering the harmonics mentioned by Professor Pedersen.