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CONTACT TRANSIENTS IN SIMPLE ELECTRICAL CIRCUITS

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ABSTRACT

An oscilloscopic study has been made of transient types occurring over a range of inductance and capacity values in direct-current circuits. This work is an extension of that of Curtis and his associates, who worked with circuits containing a relay and a line of variable length. The results reported here are similar to those obtained by the earlier experimenters, but amplify them and broaden their validity.

PROBLEM STATUS

This is an interim report on the problem; work is continuing.

AUTHORIZATION

NRL Problem M01-25R
NR 441-250

CONTACT TRANSIENTS IN SIMPLE ELECTRICAL CIRCUITS

STATEMENT OF PROBLEM

The proper functioning of electrical contacts is of great importance to the armed forces. Much work has been done on electrical contacts, but comparatively little has been done on types of electrical transients obtained at circuit break and their relation to contact erosion. A study of these transients, their variation with contact alloys and the contact erosions associated with them, should result in better understanding of contact performance and make possible better selection of contact materials for specific purposes. The first step was to ascertain how the transients varied with circuit conditions for a contact pair of fixed composition.

KNOWN FACTS

In 1940, Curtis and his associates at the Bell Telephone Laboratories published a study of contact operation in telephone relay circuits at circuit break.[1] Reference to the A.S.T.M. Bibliography[2] and other sources on electrical contacts indicate that this was pioneer work and that apparently it has not been followed up. The work of Curtis and his associates was done in an effort to discover what types of voltage and current transients were generated at the break of telephone relay circuits. It dealt with transients in d-c circuits embracing the fixed inductance of a relay winding and the small distributed capacity of a line wire. The effect of changing the length of the line wire on transient phenomena was investigated. It was found that the transients fell into a few types and some of the conditions leading to these were discussed.

PROCEDURE

The investigation reported here covered the case of simple d-c circuits embracing lumped inductance and lumped capacity. It was intended to develop an understanding of the transients occurring at circuit break with such inductance and capacity when the voltage was less than 100 volts and the current less than one-half ampere.

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[1] *Curtis, A. M., Contact Phenomena in Telephone Switching Circuits, The Bell System Technical Journal, Vol. 19, pp. 40-62, January 1940.*

[2] *(a) Bibliography and Abstracts on Electrical Contacts, American Society for Testing Materials, 1944.*

(b) 1944 Supplement to the Bibliography and Abstracts on Electrical Contacts, American Society for Testing Materials, 1945

The circuit shown in Figure 1 was used for this study. Shunt condensers were used either in position I directly across the contacts or in position II across the coil. A potential divider across storage cells was the source of emf. When the current was interrupted, the total potential drop in the circuit was the sum of the applied voltage and the induced emf; the latter usually greatly exceeded the former.

Figure 2 shows the equivalent circuits for the two shunt positions. A battery cell, B, replaces the potential divider. It will be noted that the induced current charges the condenser in the second case without flowing through the principal circuit resistance and that, in both cases, the contact current from the coil passed through this resistance.

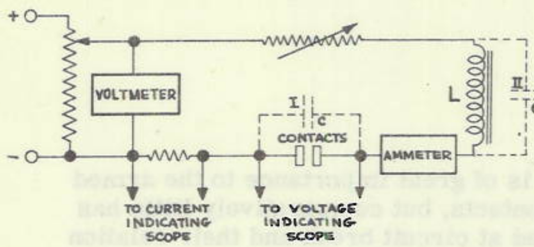

Figure 1 - Contact circuit

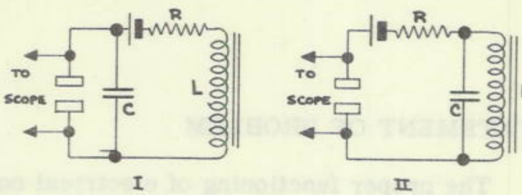

Figure 2 - Equivalent circuits for the two shunt positions

Voltage transients were observed by means of an oscilloscope. Properly synchronized single sweeps were obtained by using a separate triggering circuit combined with a synchronizer employing delay circuits. With the voltage transients, no amplifier was necessary. Leads from the contacts were shorted through a 10-megohm potential divider and the voltage obtained from the divider was impressed directly on the deflecting plates of the oscilloscope. Another 10-megohm variable resistor was shunted across the line from the contacts and adjusted to eliminate 60-cycle ripple. The input circuit comprised of these two resistors provided the d-c return necessary for unbalanced signals. A high value in the recommended range of return resistance was chosen to minimize the effect of the measuring equipment on the circuit under study. Transients were photographed directly from the oscilloscope. Timing oscillograms of oscillator signals were interspersed between those of the transients. Measurements of the durations of transient components were restricted to regions of the oscillograms in which the sweep voltage was sufficiently linear with time for accurate relations to be established. When it was necessary to observe current transients, this was done with a conventional oscilloscope.

For production of an interrupted current, an ordinary telegraph key with silver-alloy contacts was used. To obtain a transient the key was depressed rapidly and released immediately. Effects of varying capacity, inductance, current and voltage were studied.

DISCUSSION OF EXPERIMENTAL RESULTS

Curtis identified two distinct types of transients, which he designated "A" and "B," and a mixed type. The classification was based on voltage characteristics.

Transients corresponding to the "A" type are shown in Figures 3 and 6 (page 5). These were characterized by a voltage plateau at about 300 volts, which was accompanied by a bluish-violet discharge at the contacts. Such plateaus were frequently preceded for very short periods by complex phenomena which for convenience are called the strikeovers.

For steady-state currents[3] above about 0.15 ampere, the plateaus were frequently preceded by arcs striking at about 12 volts. Such an arc is shown in Figure 11 and, if both impressed voltage and steady-state current were high, as was the case here, voltage alternations between arc and plateau levels were observed. An arc-like discharge at about 70-130 volts, observed several times under similar conditions, is also shown in Figure 11.

"B" transients are shown in Figures 7 to 9. These consisted of a series of strikeovers on relaxation oscillations with high maximum voltages beginning at about 300 volts. Frequently, low-voltage arcs occurred during each strikeover, as shown in Figures 8 and 9. A greenish discharge was observed between the contacts in these cases. The maximum voltages of succeeding strikeovers showed a gradual increase, presumably because increased gap length led to increased breakdown voltage. This transient varied in frequency and maximum voltage with the capacity shunted across the coil or the contacts.

Mixed plateau and strikeover transients were found in both this investigation and in that of Curtis. In the present work plateau fragments were observed interspersed between strikeover series and initial plateaus often gave way to strikeovers. An example of the latter transition, interesting because of the high strikeover voltage, reaching about 2200 volts, is shown clearly in the original negative. Figure 12 is a retouch of print.

A comparison of Figures 3 to 10 with Figures 18 to 24 in the earlier work shows that the sequence of transients obtained by shunting increased capacity across the coil was very similar to that obtained by lengthening the line wire. The greater transient duration in the present series is accounted for by the presence of greater inductance (nominal value 5 henries) and capacities in the circuit.[4]

The transition series of Figures 3 to 10 was obtained for an impressed emf of 90 volts and a steady-state current of 0.30 ampere. However, a similar transition sequence with increasing shunt capacity was observed for impressed voltages from 30 to 90 volts and steady currents from 0.05 to 0.50 ampere, and for an inductance as low as 520 millihenries. Apparently the following relations are true for any values of impressed voltage, steady-state current, and inductance for which plateau transients may be observed:

(1) For low shunt capacities, plateau transients predominate.

(2) As the shunt capacity is increased, plateau transients give way to strikeover and mixed transients, with the former predominating.

(3) These in turn give way, for high capacities, to phenomena similar to those terminating other transients.

Damped sinusoidal waves are shown terminating all of the voltage transients in this report and, when the shunt capacity was sufficiently great, the transient phenomena consisted entirely of these waves, as in Figure 10. No discharge was seen at the gap under the conditions of Figure 10, nor was any distortion of the type accompanying gaseous discharge observed in any of the damped sinusoidal wave series. No contact current could be detected with the oscilloscope during the terminal voltage waves except for a very small damped sinusoidal current, flowing presumably by virtue of the capacity of the contacts and associated structures. In the absence of evidence of gap discharge, it has been assumed that the

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[3] *Reference is made to the current immediately preceding circuit break as the steady-state current.*

[4] *For measured values of inductance and capacity, see Appendix.*

transient period destructive to contacts ended with the initiation of these waves. Apparently the waves were initiated when, as the gap lengthened, the voltage was not adequate to induce or sustain gap discharge.

The sinusoidal waves appeared to indicate merely an oscillatory transfer of energy between coil and condenser of the type to be expected in RLC circuits for certain ranges of the constants.[5] The analogous highly damped terminal phenomena of the earlier study[6] would be expected for other RLC values. When low shunt capacities were employed, damped terminal phenomena similar to those of the earlier work were observed if a potential divider of lower resistance was used across the deflecting plates of the oscilloscope and hence across the contacts.

For low values of inductance, an interesting sequence was observed. For very low values, low-voltage damped sinusoidal transients were obtained. As the inductance was increased, the initial voltage peak of the transient approached the plateau level (i.e., a level of approximately 300 volts) and, when it reached this level, a dark spot formed on it. At still higher inductance values, the spot broadened into a typical plateau.

Some of the current changes observed to accompany voltage transients are shown in the remaining oscillograms.

For the plateau transient, some changes in contact and coil currents are shown in Figures 13 and 14. These figures show the slow rise in current following the make of the inductive circuit and indicate that the current had attained an almost steady state at the time of circuit break. At circuit break, initial current strikeovers of short duration occurred. Evidences of current strikeovers can be seen below the base line in Figure 13. The almost steady fall in current in both figures corresponded with the nearly steady plateau voltage ($e = -L\,(di/dt)$). Terminal sinusoidal waves, masked by the base line in Figure 13, may be seen in Figure 14.

For the strikeover transient, some changes in contact, coil and condenser currents are shown in Figures 15, 16, and 17. Again, in Figures 15 and 16, the slow rise of current in the inductive branch of the circuit following the make is shown. Evidences of current strikeovers are shown in Figure 15 and much more clearly in Figure 16. Figure 17 shows the high surge current charging the condenser at circuit make. Subsequent small condenser current changes while the current through the coil was building up were masked by the base line. The broken line below the base line, immediately preceding the sinusoidal trace, corresponds with the voltage minima observed for current strikeovers. This oscillogram was taken for large shunt capacity across the coil, and terminal sinusoidal waves, masked by the base line for smaller capacities, (as shown in Figures 15 and 16), are prominent here. In the strikeover transient, a sharp voltage drop followed each gap breakdown, and observation of transients consisting of single strikeovers showed that this drop was accompanied by a high current surge from the shunt condenser through the contacts. High surge currents were also observed for multiple strikeovers.

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[5] *Windred, G., Electrical Contacts, MacMillan and Co., Ltd. London 1940, pp. 165-168.*

[6] *Curtis, op. cit.*

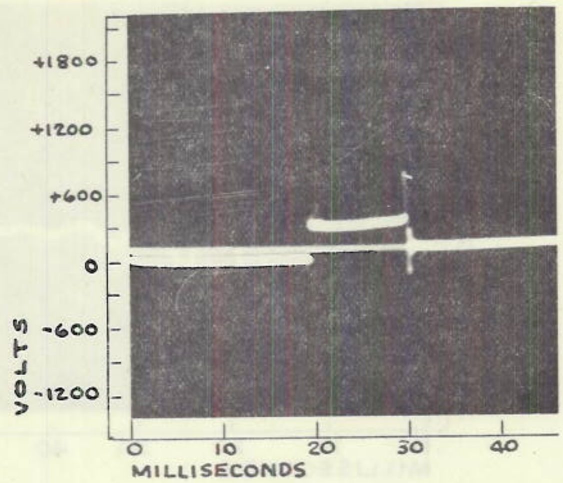

Figure 3 - Plateau transient, no shunt capacity

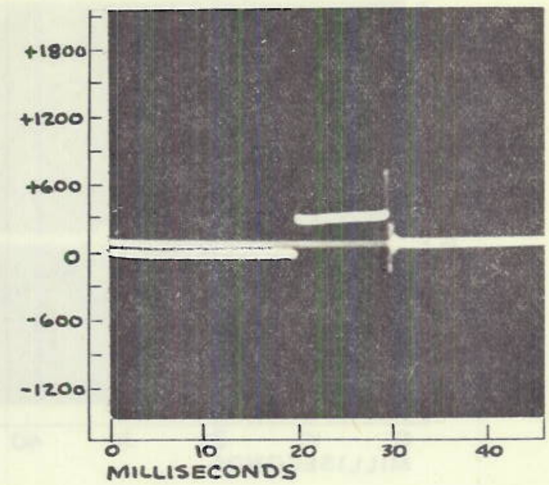

Figure 4 - Plateau transient, shunt capacity - 160 μμfd

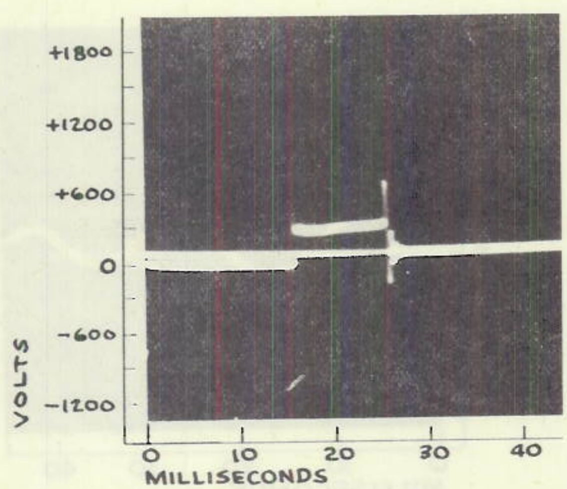

Figure 5 - Plateau transient, shunt capacity - 500 μμfd

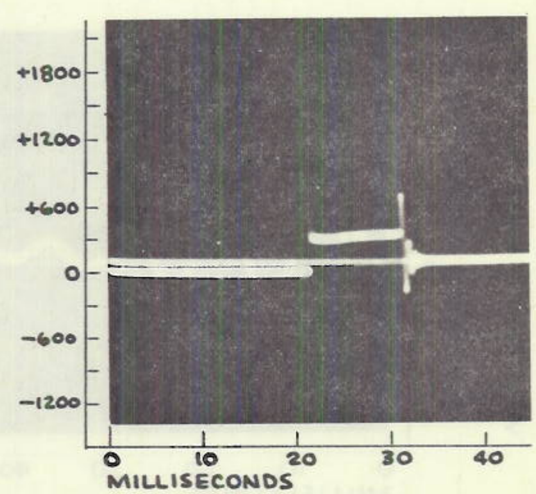

Figure 6 - Plateau transient, shunt capacity - 1,000 μμfd

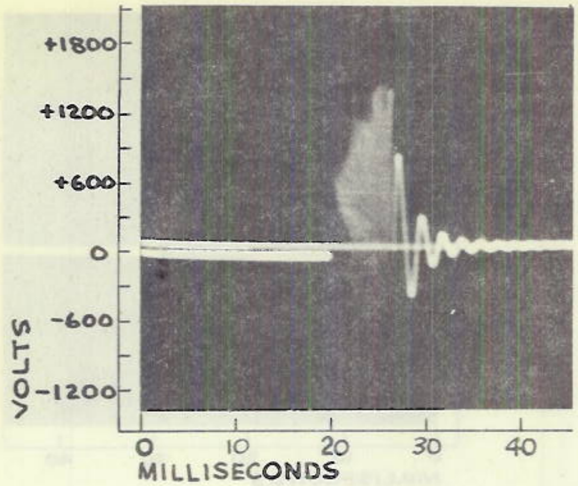

Figure 7 - Strikeover transient, shunt capacity - 10,000 μμfd

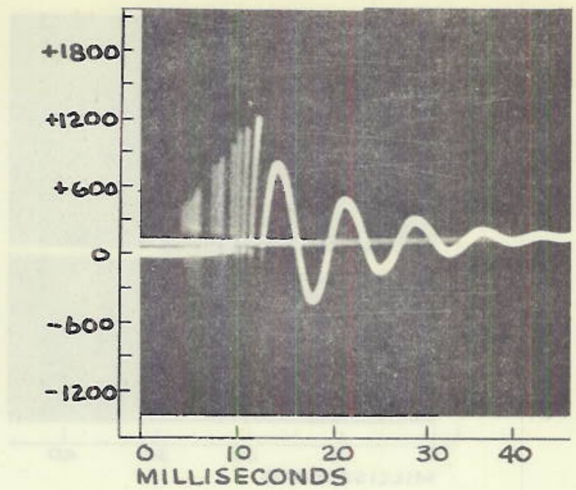

Figure 8 - Strikeover transient, shunt capacity - 0.10 μfd

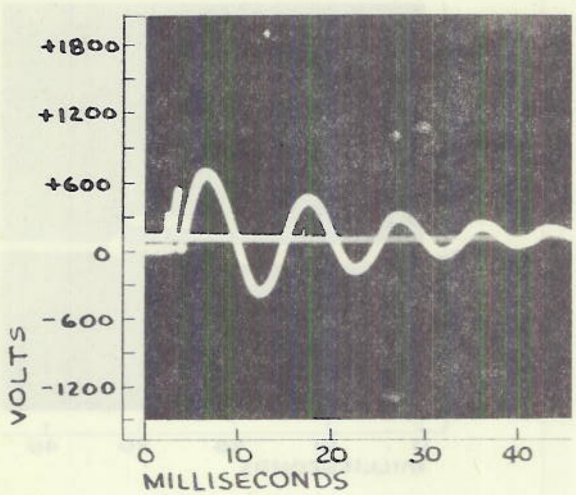

Figure 9 - Strikeover transient, shunt capacity 1.0 μfd

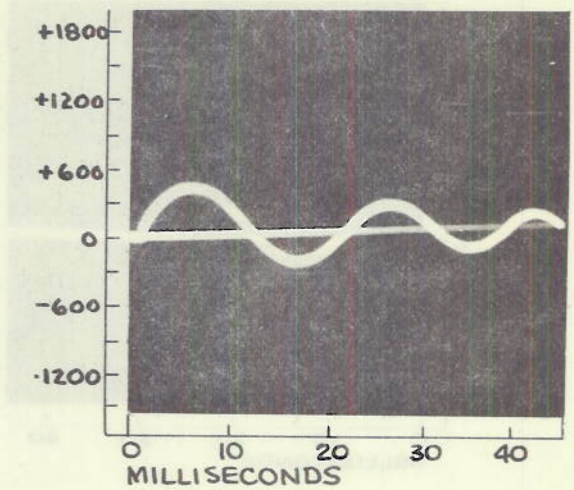

Figure 10 - Sinusoidal transient, shunt capacity - 5.0 μfd

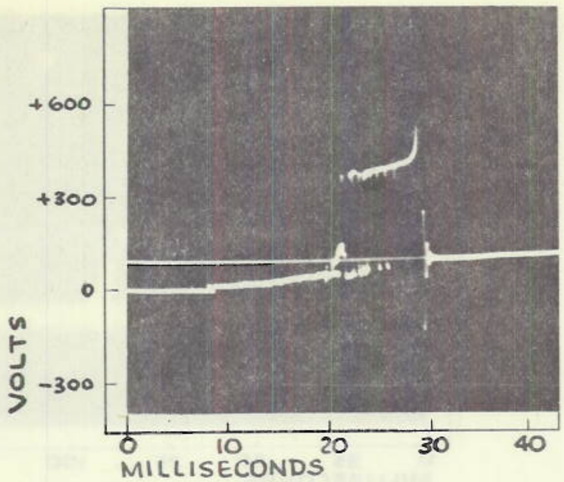

Figure 11 - Plateau interrupted by arcs

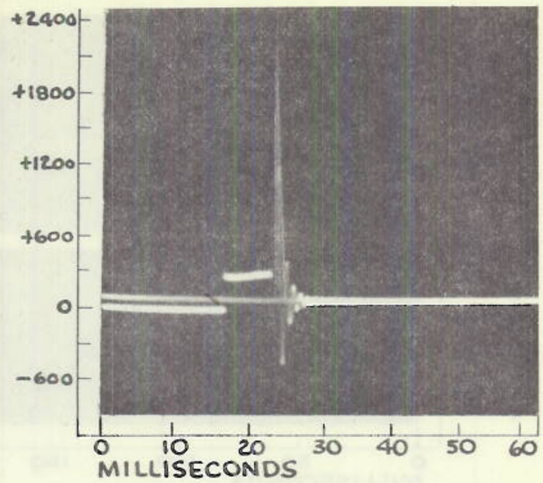

Figure 12 - Mixed transient

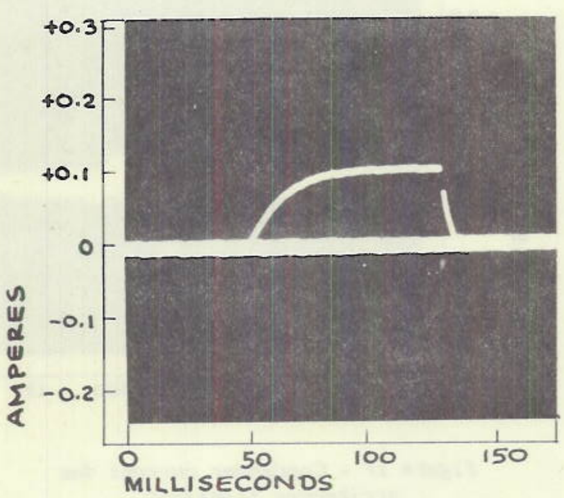

Figure 13 - Contact current for plateau transient

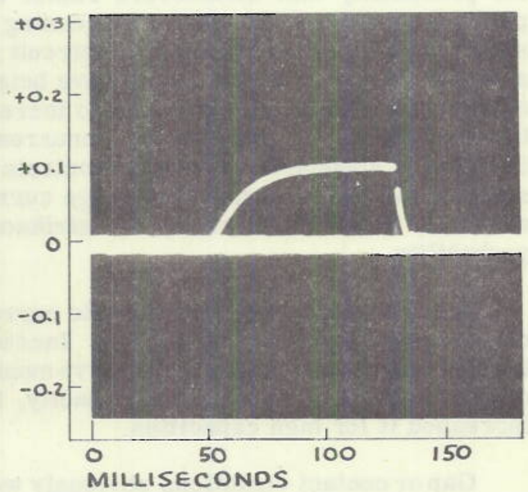

Figure 14 - Coil current for plateau transient

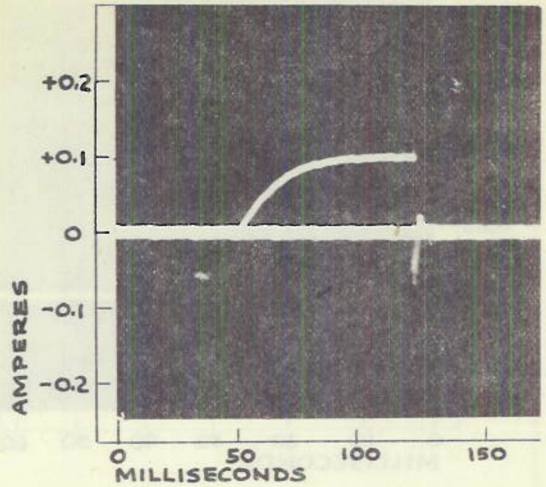

Figure 15 - Contact current for strikeover transient

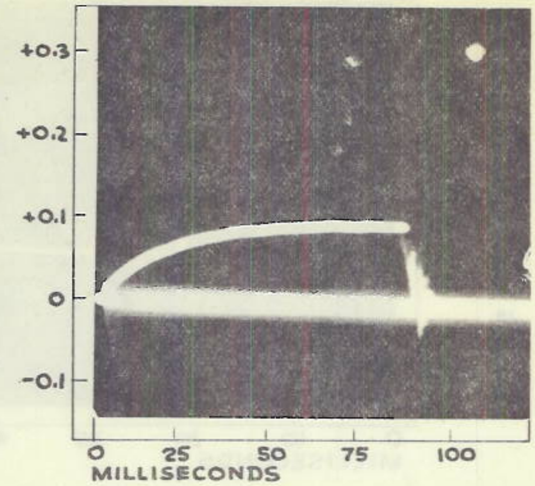

Figure 16 - Coil current for strikeover transient

Circuit conditions which favored high surge occurrence on gap breakdown increased the probability that strikeovers rather than plateaus would occur. Thus, increasing the shunt capacity or decreasing the circuit resistance, either of which should have heightened the current surge, were found to increase the probability of strikeover occurrence. Shunting a condenser across the contacts instead of the coil increased the surge current and was found to increase the strikeover probability.

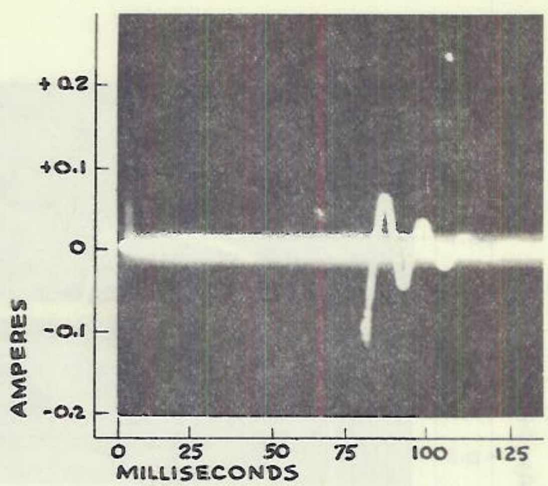

Figure 17 - Condenser current for strikeover transient

A curious effect of steady-state current on strikeover probability was noted. Increasing this current decreased the relative number of strikeovers for low shunt capacity, but increased it for high capacities.

Gap or contact conditions obviously were influencing the probability of strikeover occurrence because, under identical circuit conditions, plateau discharges were sometimes, but not always, preceded by initial strikeovers. At times plateau discharges were found for very high shunt capacities when strikeovers were to be expected; at times strikeovers were found for low capacities (even for a capacity comprised only of that of the key, coaxial cable, etc., and of the distributed capacity of the coil) when plateaus were to be expected. Blowing the breath directly on the contacts increased the relative number of strikeovers and placing a drop of water between the contacts led to a long series of breaks showing only strikeovers for circuit conditions which otherwise would have produced plateaus.

In protective circuits, condensers are shunted across contacts to minimize arcing. In the present study it was found that shunting a condenser across the contacts instead of the coil resulted in better protection from arcing, an increase in the number of strikeover transients and their duration, and in plateaus of longer duration when they occurred. With the condenser across the coil, energy appeared to be dissipated in arcing that, in the other case, would have been expended in strikeovers or in plateau discharges of longer duration.

Data were obtained on the variation of some transient components with changes in steady-state current. For constant impressed voltage, initial-plateau voltage increased slightly with increasing steady current. Two sets of data on this effect are given in the accompanying table and are represented graphically in Figure 18. Oscillograms for Trial 1 were taken over a four day period, those for Trial 2, over a period of a few hours. Data also are given on the variation with steady-state current of plateau, arc, and terminal oscillation durations for an impressed emf of 90 volts.

TABLE 1
Variation of Transient Characteristics With Current

Steady-State Current (ampere)	Initial Plateau Voltage Trial 1	Initial Plateau Voltage Trial 2	Plateau Duration (milli-seconds)	Arc Duration (milli-seconds)	Plateau Duration + Arc Duration (milli-seconds)	Terminal Oscillation Duration (milliseconds)
0.05	270*	290*	2.5	0.00	2.5	2.3
0.10	280	290	4.7	0.00	4.7	2.4
0.20	280	300	7.3	0.34	7.6	2.9
0.30	290	310	9.3	1.1	10.4	3.4
0.40	290	310	9.3	3.9	13.2	3.4
0.50	320	330	9.6	4.9	14.5	3.4

* The progressive change in each trial is more significant than the differences between the trials.

The graphs of Figure 19 bring out the relations observed. Arcing for the silver-alloy contacts began at currents between 0.10 and 0.20 ampere. Arc duration increased slowly with currents less than 0.30 ampere and more rapidly for larger values. Plateau duration increased until a current of 0.30 ampere was attained and thereafter remained almost constant. These two increases complemented each other with the effect that the total (overall plateau plus arc) duration increased fairly uniformly throughout the entire range. Terminal oscillation durations showed a very gradual increase with currents below 0.30 ampere and remained constant for higher values.

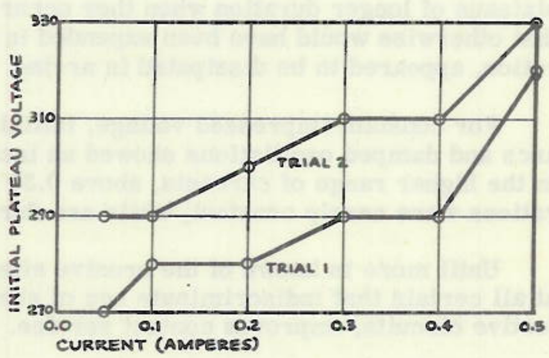

Figure 18 - Variation of initial plateau voltage with current

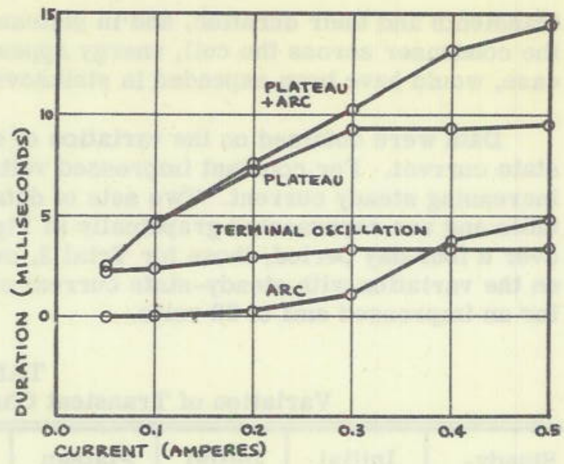

Figure 19 - Variation of transient durations with current

SUMMARY AND CONCLUSIONS

Plateau, strikeover and mixed transients, observed over a range of lumped-constant values in a contact circuit, were similar to those found by Curtis in telephone relay circuits. Increase in lumped capacity shunted across the coil was found equivalent to increase in line length in Curtis's work.

For all values of voltage, steady-state current and inductance yielding clearly defined transients, the following transition sequence was observed:

(1) Plateau transients (with the plateau at about a 300 volt level) predominated for low shunt capacities across the coil or the contacts. Strikeovers of short duration frequently preceded plateaus.

(2) With increase in shunt capacity, plateau transients gave way to strikeover and mixed transients, with the former predominating.

(3) A further increase in capacity led to damped phenomena similar to those terminating other transients.

Arcs often preceded any type of transient, especially under conditions of high impressed voltage and steady-state current.

Circuit conditions that favored high current surges on gap breakdown increased the number of strikeover transients at the expense of plateau transients.

Shunting a condenser across the contacts instead of the coil resulted in arcs of shorter duration, an increase in the number of strikeover transients and in their duration, and plateaus of longer duration when they occurred. With the condenser across the coil, energy that otherwise would have been expended in strikeover or plateau discharges of longer duration, appeared to be dissipated in arcing.

For constant impressed voltage, initial plateau voltages, and the durations of plateaus, arcs and damped oscillations showed an increase with increase in steady-state current. In the higher range of currents, above 0.30 ampere, plateau and terminal oscillation durations were nearly constant, while arc duration increased.

Until more is known of the erosive effects of various transient types, it will not be at all certain that indiscriminate use of shunt condensers, or of resistance-capacity protective circuits, improves contact service.

RECOMMENDATIONS

Work should be done on the erosive effects of various transient types and the effects of contact materials and atmospheres on these types.

* * *

APPENDIX I
Nominal vs. Measured Values of Circuit Constants

Nominal Values		Measured Values
	Inductance	
5 henries		6.63 henries
	Capacity	
160μμ fd		150μμfd
500 "		455 "
1,000 "		970 "
10,000 "		10,200 "
0.1 μfd		0.100μfd
1 "		0.96 "
5 "		4.78 "

* * *

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