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Studies on commutation Sparks (II)

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Abstract

To obtain the fundamental understanding of the commutation sparks, voltage and current wave forms of the sliding contact are photographed by means of a three element Braun-tube oscilloscope. Some inherent characteristics of the positive and negative brush sparks are made clear, which will make possible more accurately the detection as well as the quantitative representation of sparks. Electronic peak voltmeter method for judging the commutation ability of brushes is also described.

The spark number which indicates the sparking intensity now under use varies considerably with differernt observers and with different light conditions. In view of this fact, one method of indicating commutation sparks was described in this Proceedings,[1] and was proved to be fairly well in accord with the actual conditions. However, the method is not accurate, becausc it neglected the inherent sparking characteristics of the brush polarity. To acquire the fundamental knowledge of this polarity effect, studies were first made with a high speed Braun-tube oscilloscope and then with an electronic peak voltmeter. As this high speed Braun-tube oscilloscope has three elements, it is possible to take the photographs of three phenomena at a time. This oscilloscope is designed and assembled in our laboratory, the character of which is reported in this Proceedings.[2]

As a sliding contact, we used the commutation tester devised by one of the authors, is shown schematically in Fig. 1. This commutation tester consists of a

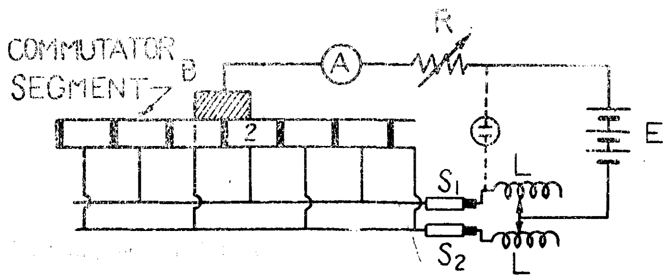

Fig. 1. Connection diagram of commutation tester

commutator and two slip rings mounted on the same shaft. The commutator has an even number segments in which alternate bars are connected to one ring S_1, and the remaining bars are connected to another slip ring S_2. The shaft is

1) This Journal, (4) **23** 1949

2) This Journal, (4) **23** 1949

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** Student in Graduate Course of Keio University supported in bearings and is driven by a variable speed motor. Two silver graphite brushes are mounted on each slip ring so that the contact drop of these places is made negligibly small. Coils are connected to each slip ring S_1 and S_2 and are so constructed as to obtain the same amount of inductance value on each side, when the finger attached to it slides. In Fig. 1, R is noninductive resistance, E low voltage direct current source and B the brush. To simplify the testing conditions, brush B spans only one bar.

Assuming the contact resistance being independent of the instantaneous current density, the contact resistance of the brush varies inversely with its contact area on the commutator segment, so long as the brush makes perfect contact. Under this ideal case, we can consider the simplified equivalent circuit as shown in Fig. 2.

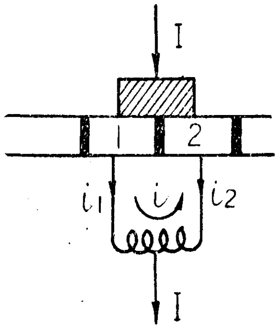


Fig. 2. Simplified equivalent circuit of tester

Let I = total current through the brush.
i_1 = instantaneous current through the segment 1.
i_2 = instantaneous current through the segment 2.
L = inductance.
R_c = total coil resistance.
R_b = brush contact resistance for full one segment contact area.
i = virtual current in the coil.
T = time required from full contact to the end of contact between a brush and a segment.

we obtain the following equations:

$$i_1 + i_2 = I$$

$$i_1 = \frac{I}{2} + i \; (t = 0 \; i_1 = I, \; t = T \; i_1 = 0)$$

$$i_2 = \frac{I}{2} - i \; (t = 0 \; i_2 = 0, \; t = T \; i_2 = I)$$

$$L \frac{di}{dt} + iR_c + \left(\frac{I}{2}+i\right) R_b \frac{T}{T-t} - \left(\frac{I}{2} - i\right) R_b \frac{T}{t} = 0 \qquad \text{......(a)}$$

At the end of the contact between the brush and the segment, i.e. at opening instant.

$$t \to T \quad i \to -\frac{I}{2}$$

$$\lim_{t\to T} \left(\frac{I}{2} - i\right) R_g \frac{T}{t} = I R_b$$

$$\lim_{t\to T} \left(\frac{I}{2} + i\right) R_b \frac{T}{T-t} = - R_b T \frac{di}{dt}$$

Therefore (a) becomes

$$L \frac{di}{dt} - \frac{I}{2} R_c - R_b T \frac{di}{dt} - I R_b = 0$$

$$\therefore \left| -L\frac{di}{dt} \right|_{t \to T} = \frac{I/2\,(R_c + 2R_b)}{\frac{R_b T}{L} - 1} \qquad \cdots\cdots \text{(b)}$$

Equation (b) is the same as the reactance voltage of the ordinary direct current machine, as is written in the text books.

Voltage and Current Wave Forms

Voltage and current wave forms are photographed by the above mentioned B.T. oscilloscope. During this experiment, the commutation tester is connected as shown in Eig. 3. In Fig. 3, B_1 records the voltage wave, while another element B_2 records

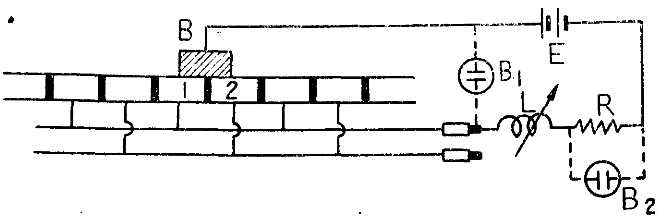


Fig. 3. Connection of commutation tester and the positions of B.T. oscilloscopes

the current set up in the external circuit. In order to understand easily the oscillograms shown later, the typical wave form reduced in a linear scale is described in Fig. 4, where (A) is voltage wave form (B) is current wave form.

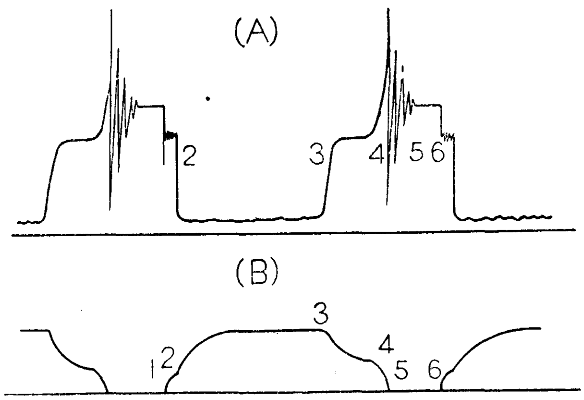


Fig. 4. Typical votage (A) and current (B) wave forms

At point 1, the brush touches the segment and sparks, arcs are sometimes observed from point 1 to point 2.

During the period from point 2 to point 3, current flows conductively from brush to segment (positive brush) or from segment to brush (negative brush) and the voltage wave indicates the contact drop.

During this period, the current will be governed by the general equation

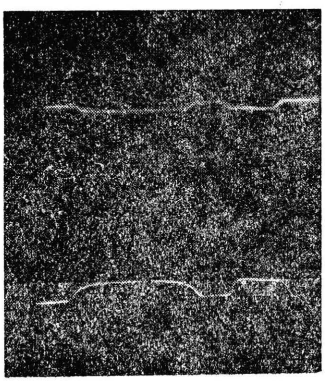
$$E = ir + L\frac{di}{dt}$$

where r is the sum of the contact resistance and the external resistance R. If we assume that E, r and L are constant, then the solution may be written as:

$$i = \frac{E}{r}\left(1 - e^{-\frac{r}{L}t}\right)$$

Current variation as indicated by this equation agrees very well with the oscillograms taken in our experiment, as long as the direct voltage E is large enough. If E is small, resistace varies greatly during the period of T. At the instant of circuit opening between the brush and the segment i.e. at point 3 sparking results. This spark develops into an arc when the dissipated energy at the contact is large. The wave form from point 3 to point 4 indicates this arc drop.

When the inserted inductance is large, an electric oscillation is observed at the end of an arc. This oscillation frequency perhaps depends largely upon the stray and the commutator segment capacity and the inductance inserted in the external circuit. By utilizing this oscillation phenomena, it might be possible that a very simply spark detection method would be devised. Wave form from point 5 to point 6 is line voltage, because in this part segment is open. Typical oscillograms taken in this experiment are next shown. The oscillogram of Fig. 5 shows that the voltage and current gradually increase at start and also gradually decrease at end and no sparks result. The oscillogram of Fig. 6 is similar but

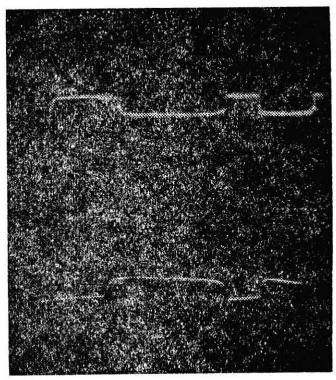


↑ V

↑ I

→ time

Fig. 5. positive polariry
$E = 4V$, $L = 0$
mean current 2.87A



↑ V

↑ I

→ time

Fig. 6. positive polarity
$E = 12V$, $L = 0$
mean current 2.85A

was taken with an impressed voltage of 12V, while Fig. 5 was taken with 4V. The difference is striking. The 4V case shows that the variation of contact resistance under a brush agrees somewhat with the classical idea, that is the contact resistance inversely varies with the contact area. In Fig. 6, the contact resistance does not obey the classical idea. This may be due to the existense of the copper oxide film formed on the commutator. Judging from the many oscillograms, this critical voltage exists between 4V and 3V in positive brush and less than 3V in negative brush. According to R.M.Baker; this critical voltage is 3.7V. Raising the input voltage, the voltage wave takes the form as shown in the oscillogram of

Fig. 7. In this Fig. 7, after the arc is extinguished, there appears the line voltage and then the leading edg arcs are observed. If we insert the inductance in the circuit, an electric oscillation occurs at the opening instant. The oscillogram of

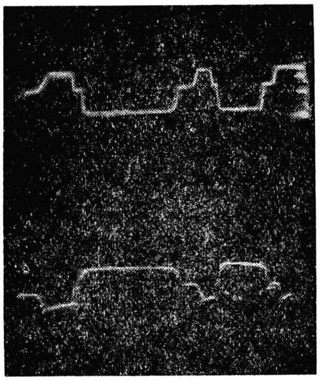


Fig. 7. positive polarity
$E = 24V, L = 0$
mean current 6.25A

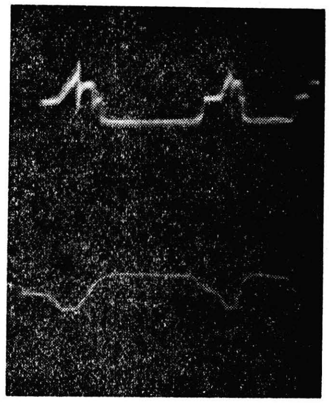


Fig. 8. positive polarity
$E = 24V, L = 105\mu H$
mean current 5.90A

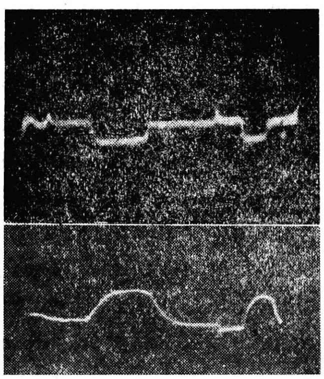


Fig. 9. negative polarity
$E = 24V \quad L = 105\mu H$
mean current 4.80A

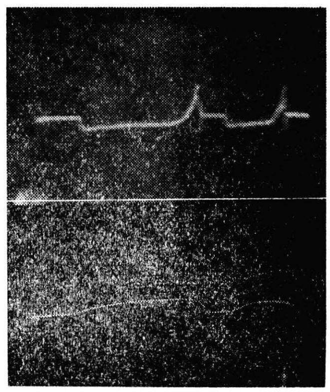


Fig. 10. positive polarity
$E = 2V \quad L = 203\mu H$
mean current 0.85A

Fig. 8 is this case. The oscillogram of Fig. 9 is similar to the oscillogram of Fig. 8 but this is the case of negative polarity. Quite a distinct difference in arcing region can be recognised between these two oscillograms. The arcing period of the negative brush is longer than that of positive brush. This is just what would be expected, because the cathode spot in the brush is more steady than in copper due to the fact that the thermal conductivity of the brush is much lower than that of copper. The arc voltage of the negative brush seems to have not so much difference from the line voltage 24V in Fig. 9, while the arc voltage of the positive brush is much less than the line voltage 24V, in Fig. 8.

Another interesting facts are found is Fig. 10 and in Fig. 11. In Fig. 11 (case of negative polarity), the current is suddenly broken and the voltage rises momentarily high, while in Fig. 10 (case of postive polarity) the current is gradually broken and the voltage rises gradually accompanying an electric oscillation. More intensive study is needed to find the reason why such phenomena occur.

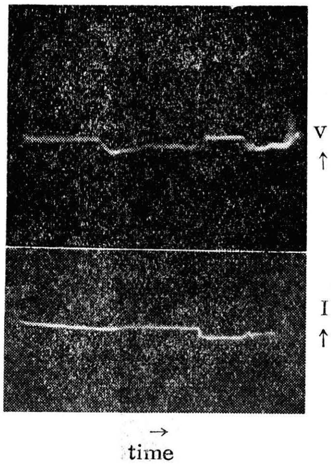


Fig. 11. negative polarity
$E = 2V$ $L = 203\mu H$
mean current 0.62A

Spark Detection

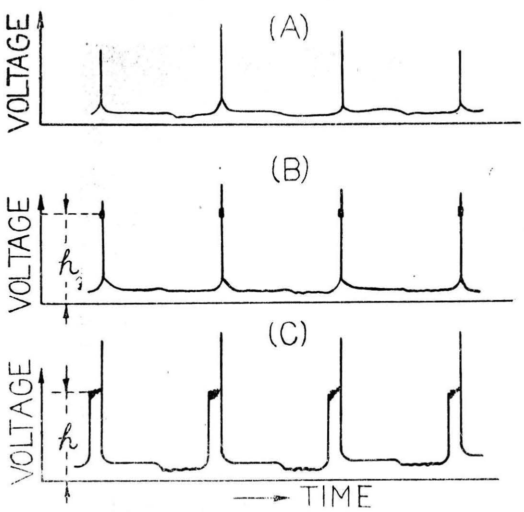


Fig. 12.
Voltage wave form of increasing inductance

Increasing the value of the inductance introduced in the external circuit of the commutation tester, the voltage wave between the brush and the commutator takes the form as shown in Fig. 12 successively. In Fig. 12, (A) is the case of small inductance and the peak value of the voltage is not definite, (B) is the case of medium inductance, the peak value becomes constant and there appears a brilliant point, (C) is the case of large inductance, the peak value becomes higher and the brilliant point wider. In view of this phenomena, electronic peak voltmeter method of comparing commutation and brush performance was devised by one of the authors and is published in this Proceeding.[3] Peak voltmeter method is also

3) This Journal, **2** (4) **23** (1949)
4) G.E.Review (6) **52** (1949)

published by Lundy in G.E.Review.[4] The former measured the peak value of the induced voltage in the coil placed near the sparking brush, and the latter measured the peak voltage connecting this instrument across the positive and negative studs. Here we used also the commutation tester and the peak voltmeter is inserted across the brush and the slip ring. Peak voltmeter used is schematically shown in Fig. 13. In Fig. 14, a family of curves of peak voltage against inductance are plotted, keeping current constant.

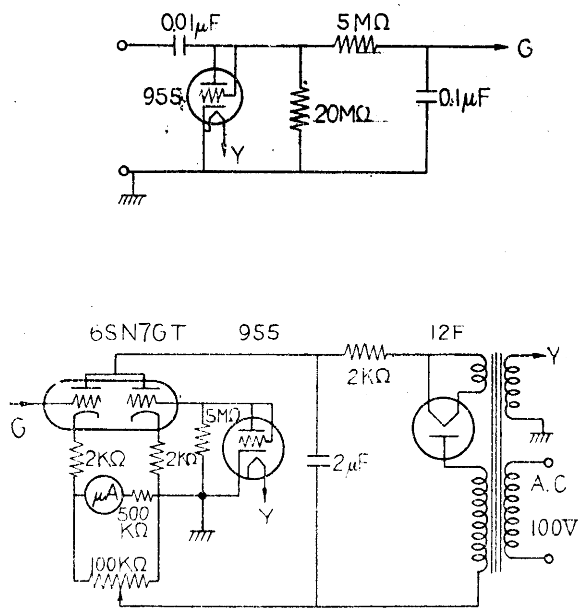


Fig. 13.
Connection diagram of peak voltmeter

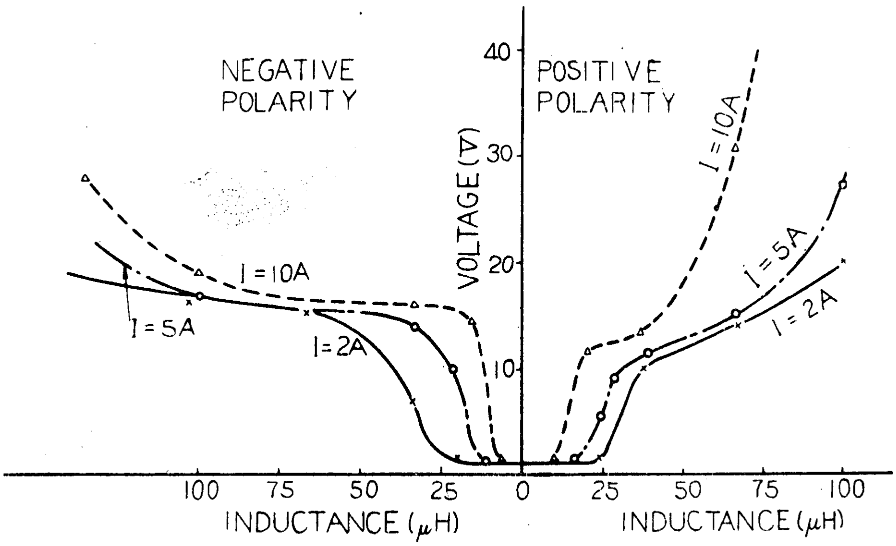


Fig. 14. Peak voltage inductance curves of positive and negative polarity

During the interval where the peak value remains nearly constant, the voltage is the contact drop. At a certain value of inductance, the peak value increases suddenly and here the voltage wave takes the form as shown in Fig. 12 (A).

Passing this range, the peak voltage again becomes nearly constant, the voltage wave form being the same as Fig. (B). The value of the peak voltage in this region shows lower in positive polarity than in negative polarity. Increasing L more and more, the wave form becomes Fig. 12 (C). Before each test with a new brush is started, the film was removed from the commutator with a fine sand paper, brush being carefully sanded to fit the commutator. So long as no damages occurred due to bad sparkings, the test results were approximately reproducible. Of course, as there are many variables which affect the commutation—humidity, contamination in atmosphere, vibration, brush fitness, commutator surface—careful precautions are necessary to obtain consistent results.

For the comparison of results obtained by the electronic peak voltmeter with the visual observation, Fig. 15 is drawn. There are also peak voltage inductance

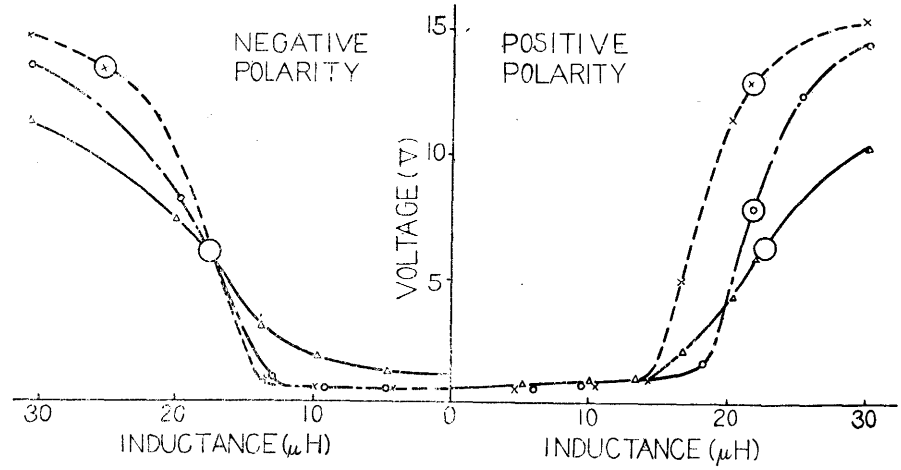


Fig. 15. comparison of results by the peak voltmeter with the visual obesvation.

curves, and at the marked positions on these curves, the first sparks were observed. This method is not only fairly sensitive to detect the first sparks, but also it detects the sparking under the brush where visual observation is impossible.

It is interesting to note how the speed affects the peakvoltage inductance curves of various brushes. The characteristics of the brushes used is listed in Table 1. In both cases of Fig. 16 and Fig. 17, the current is 5A and brush pressure 300 g/cm^2, the revolution being 1000 r.p.m. in the former, 1600 r.p.m. in the latter.

So long as the r.p.m. is 1000, no difference can be observed among these three brushes. But if the r.p.m. is raised to 1600, difference appears and *C* marked brush shows the superior quality. From this experiment, it is seen that a certain high speed is necessary to distinguish a brush of good commutating ability. The fact

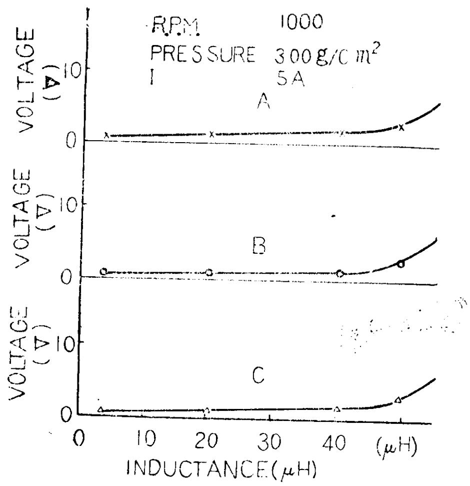


Fig. 16.
Peak inductance curves

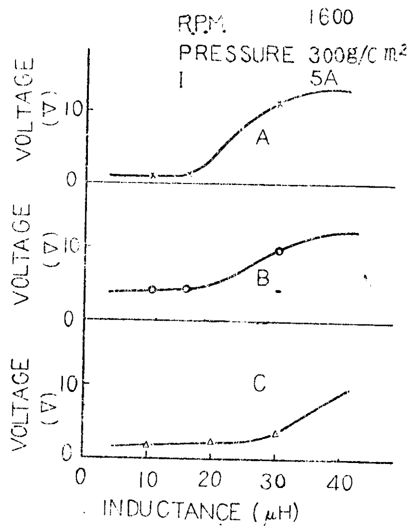


Fig. 17.
Peak inductane curves

Table. 1

Name / character	A	B	C
Hardness (Shore)	40	40	43
Sp. Resistance (Ω cm)	0.0015	0.0060	0.0080
Young's Modulus kg/mm²	900	500	350
True density	2.15	1.25	

that C marked brush is best, can be understood by noticing the brush character especially the smallest value of the Young's Modulus.

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