



XXVI. Short spark phenomena

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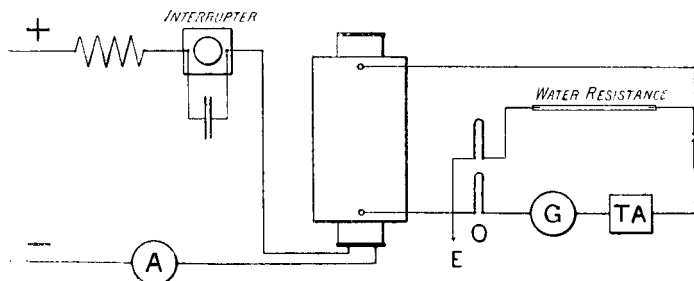
XXVI. *Short Spark Phenomena.**By W. DUDELL, F.R.S.**

[Plates XIII.-XV.]

IN connexion with some measurements of the current in the secondary circuit of an induction-coil, I have noticed two curious effects, which are probably well known but which I do not remember having seen described anywhere.

The apparatus in use consisted of a 12-inch Newton induction-coil which was supplied from the 200 volt direct-current mains. A large resistance was placed in series with the primary of the coil to limit the current, and the current was interrupted by means of a mercury-jet interrupter; the connexions are shown in fig. 1. The secondary circuit

Fig. 1.



contained a galvanometer *G* to measure the mean current and thermo-ammeter *T. A.* to measure the root-mean-squared current.

The galvanometer was specially constructed for the purpose so as to have a sufficiently low sensibility without using a shunt. It was of the moving-coil type and was well insulated from earth by means of porcelain insulators. The sensibility was such that 1 milliampere gave a scale-deflexion of 200 divisions (1 division equals $1/40$ in.). The thermo-ammeter had a resistance of about 101.5 ohms and gave its full scale-deflexion for about 70 milliamperes R.M.S. value.

By breaking the current through the primary by means of a switch, the direction of the deflexion of the galvanometer corresponding to breaking the primary current was determined. A deflexion, in this direction I will call, in what follows, a positive deflexion, and a deflexion in the opposite direction, that is corresponding to the make of the primary current, I will call a negative deflexion.

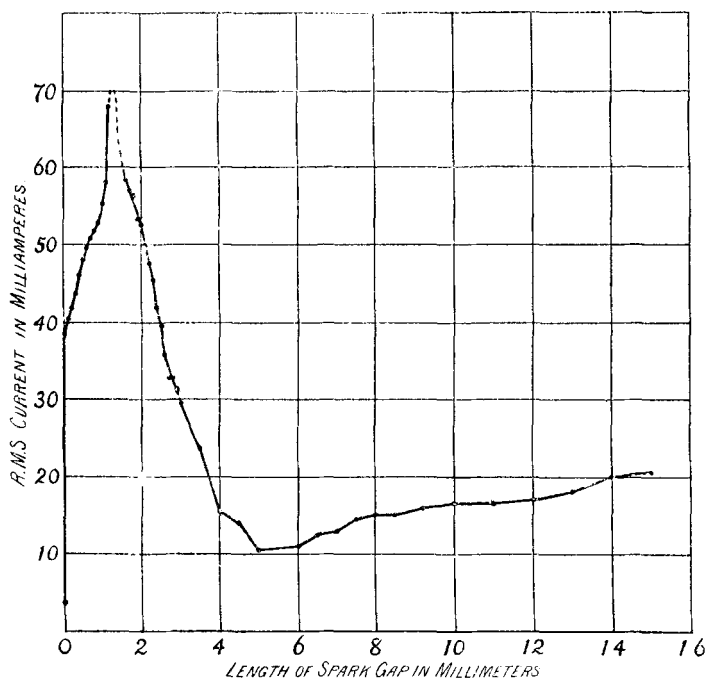
* Communicated by the Physical Society: read April 10, 1908.

When there was no spark-gap in the secondary circuit and the coil was in action, the mean current, as read by the galvanometer, was zero, as it should be, and the root-mean-squared current had a value of about 3.8 milliamperes.

If now a microscopic spark-gap, say between two aluminium points, is introduced into the secondary circuit two curious effects take place. Firstly, the R.M.S. current enormously increases in value; and secondly, a very large deflexion is produced on the galvanometer, reading the mean current, and this deflexion is in the *negative* direction, that is to say, in the direction corresponding to making the primary circuit. I will consider these two effects separately.

In order to give an idea of the magnitude of the increase in the R.M.S. current produced by introducing a very small spark-gap into the secondary circuit of the coil, I have plotted in fig. 2 the R.M.S. current corresponding to various

Fig. 2.



lengths of spark between 0 and 15 mm. In making these observations the resistance in the primary circuit of the coil and the frequency of the interrupter of the primary current

were kept constant, the resistance being 137 ohms and the frequency 75 interruptions per second. The current through the primary of the coil was about $1/4$ ampere.

A large number of points were taken and are plotted on the curve. They do not give very consistent results, so it is difficult to draw a smooth curve through them; but the general appearance of the phenomenon can be seen. On introducing a spark-gap $1/10$ mm long the root-mean-squared current instantly rose from 3.8 to 38.5 milliamperes, and continued to increase with increasing spark-length until it reached a maximum at a spark-length somewhere in the neighbourhood of 1.4 mm. The exact point is slightly uncertain owing to the R.M.S. current just exceeding the range of the instrument that was in use. From 1.6 to 5 mm. spark-length the R.M.S. current gradually fell in value and attained a minimum value of $10\frac{1}{2}$ milliamperes. Further increase in spark-length produced a gradual increase in the R.M.S. current up to the maximum length of 15 mm. that was used in the experiments.

There is no doubt in my mind as to the cause of this effect. It is due to very high frequency oscillations being set up in the wires connected to the secondary circuit of the coil when a spark-gap is introduced. The magnitude of the oscillations will depend on the voltage between the terminals of the spark-gap just before the spark passes and on the resistance that the spark-gap offers. Now the P.D. between the terminals of the spark-gap will increase with increasing length and so will the resistance, so that on increasing the spark-length we have two conflicting agencies at work, one tending to increase the magnitude of the oscillatory current, and the second tending to decrease the magnitude. I think that it is due to this differential action that the curve is such a curious shape.

The presence of the oscillations in the secondary circuit can easily be made evident by taking a well insulated metal plate and touching various points in the secondary circuit with it. The effect of this plate will be to largely increase or decrease, generally increase, the value of the R.M.S. current. The practical aspect of this question from my point of view was that, owing to the unexpectedly large value of the R.M.S. current, I burnt up several thermo-ammeters before I discovered the cause of the trouble.

I have obtained the effect with brass, iron, zinc, and aluminium electrodes and it probably takes place with all other metals. I think that, so far, the best metal to show the effect has been aluminium.

The large deflexion in the negative direction observed on the galvanometer was investigated by recording the wave-forms of the P. D. and the current by means of an oscillograph. The sensibility of the oscillograph was adjusted so that 1 mm. deflexion equals 1 milliampere for the current wave-forms. To obtain the P.D. wave-forms a water resistance of about 1 megohm was placed in series with the second moving system of the oscillograph so that 1 mm. equals about 1000 volts. The speed of the plate on which the records were taken was 1500 mm. per second. For this series of tests, the frequency of interruption was 75 per second and the resistance in series with primary of the induction-coil was 37 ohms.

Records were made for a series of spark-lengths between aluminium-point electrodes. I have selected from these some typical results which are shown in Plates XIII.-XV. figs. 3, 4, 5, 6, 7, 8.

Fig. 3 is the current wave-form when the spark-gap is short-circuited, length 0. The straight line across the centre of the figure is the true zero line. Deflexions above this zero line represent current in the positive direction and below the zero line represent current in the negative direction. It will be noticed that the maximum current in the positive direction (14.5 milliamperes) is much less than the maximum current in the negative direction (35 milliamperes), but the length of time that the negative current lasts is much shorter than that which the positive current lasts; so that the areas of the two sides of the zero line are equal and the mean current zero.

The smallest gap that I could make in this circuit between the aluminium electrodes, at once changed the wave-form to the type shown in fig. 4, which is for spark-length 1 mm. In this figure, the straight parts of the curve along the centre of the figure are in the position of zero current. This was carefully checked by taking records with a fixed datum-line at the zero of the curve. The line was afterwards moved to the lower part of the figure in order not to hide small details of the curve near the zero. The effect of introducing the spark-gap of 1 mm. is, while leaving the maximum current on the two sides of the zero at practically the same value, to reduce the area of the curve on the positive side of the zero line nearly to zero, so that instead of the areas on the two sides being equal there is a large excess of area on the negative side causing a large mean current in the negative direction.

On increasing the length of the gap a small area on the opposite side of the zero line again begins to form, which

increases with increasing length of gap, until the condition shown in fig. 6 is reached. In this figure, the spark is sometimes rectifying or stopping the current flowing round the circuit in the negative direction altogether. We have in this figure the large triangular current wave-form which corresponds to the current flowing in only one direction round the circuit, and the smaller triangular current pulses accompanied by a large current in the negative direction at make.

Further lengthening the spark-gap brings it into the normal condition of long sparks; the current wave of this is shown in fig. 7. The datum-line across the centre of the plate, in this case, is true zero line.

It was necessary in order to obtain the wave-form of these longer lengths to disconnect the circuit for recording the P.D. wave-form, as the leak which it formed, having a resistance of only 1 megohm, prevented the sparks passing across the gap.

Fig. 8 shows the P.D. wave-form with so long a spark-gap that the spark could not jump across it. This is the normal wave-form given on the secondary of the induction-coil when supplied from a high voltage direct-current circuit.

It will be noted that the voltage induced in the circuit at the break is about 23,000 volts and at make about 13,500, so that the make voltage exceeds one half of the break voltage. Also, the voltage induced at the make dies away less rapidly than that induced at the break. It may be enquired how it is possible, if the make voltage is less than the break voltage, for the current to be larger at make than at break. I think that this question must be answered by noting that during the make period the primary of the induction-coil is connected to the supply mains so that the energy may be directly transferred from the primary to the secondary circuit by magnetic induction; that is to say, as long as we maintain a steadily increasing flow of current into the primary, we can continue to take energy from the secondary. During the break period, however, things are very different. The whole of the energy that we can get out of the secondary is that stored up in the magnetic field which is linked with the secondary winding. The greater part of this magnetic field will pass through the core. The magnetization of the core will depend upon the resultant magnetizing ampere-turns which is equal to the primary ampere-turns less the secondary ampere-turns. At the moment of break the current in the secondary is at a value of say 35 milliamperes, and the current in the primary cannot have exceeded $\frac{200 \text{ v.}}{37 \text{ ohms}}$ or 5.4 amperes.

I do not know the exact ratio between the numbers of turns on the primary and on the secondary of this induction-coil, but it is probably of the order of 100, so that the 35 milliamperes flowing in the negative direction in the secondary would correspond to a demagnetizing current of about $3\frac{1}{2}$ amperes in the primary, which would leave a comparatively small margin of resultant magnetizing ampere-turns.

If this is the case, the energy that can be got out of the secondary on break is very limited, which would account for the rapid dying away of the current to zero when even a very small spark-gap is introduced in the circuit. Directly the length of the spark-gap is sufficient to prevent the current flowing in the negative direction round the secondary circuit, the whole of the demagnetizing effect of the secondary current is done away with, and under the conditions of the experiment the magnetizing current in the primary is mainly limited by the large resistance in the circuit; hence, we get a very much larger amount of energy available directly the secondary current is prevented from flowing in the negative direction. This I think accounts for the large difference in the size of the current waves in fig. 6, and shows the great importance of preventing any current from flowing round the secondary circuit in the negative direction at make when using the induction-coil on a high voltage supply.

I made certain that the phenomenon was not due to any want of symmetry in the points of the spark-gap by reversing the electrodes of the gap and also by interchanging the connexions to it. The material of the electrodes did not seem to appreciably affect the results, but the shape of the electrodes was important in so far that the spark-length at which the galvanometer deflexion changed sign depended on the shape. Thus with two spheres the galvanometer deflexion changed sign at a shorter length than with points.

I have brought these two observations forward in the hope that in the discussion either my views as to the explanations may be confirmed or that better ones may be suggested.

XXVII. *On some Physical Relations affecting Matter in Diverse Stages of Subdivision.* By Dr. S. TOLVER PRESTON*.

THE phrase "Continuity" is employed here in respect to certain physical qualities, in actual practice as efficacious as *if* continuity in an absolute sense existed. We refer, for instance, to the capacity to maintain a sensibly equable

* Communicated by the Author.

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2 A

P.D. and Current Wave-Forms of Short Sparks.

FIG. 3.—Spark-length equals zero.

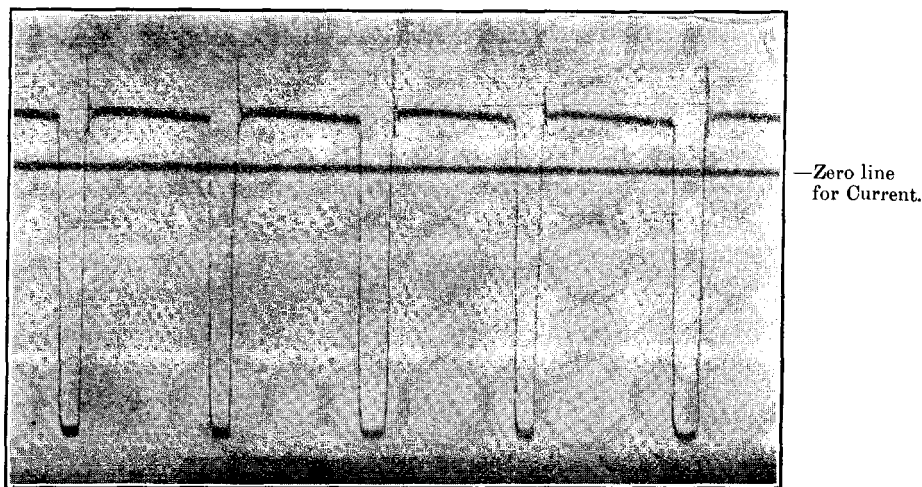
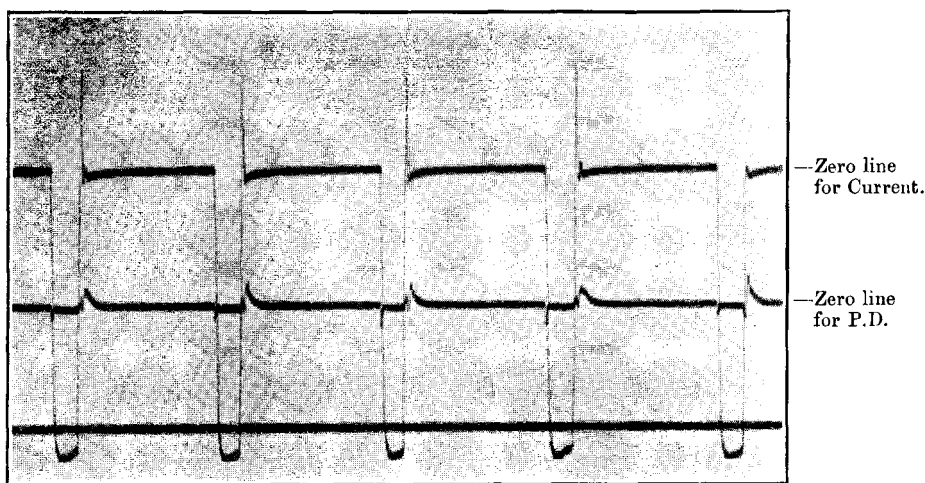


FIG. 4.—Spark-length 1 mm.



P.D. and Current Wave-Forms of Short Sparks.

FIG. 5.—Spark-length 5 mm.

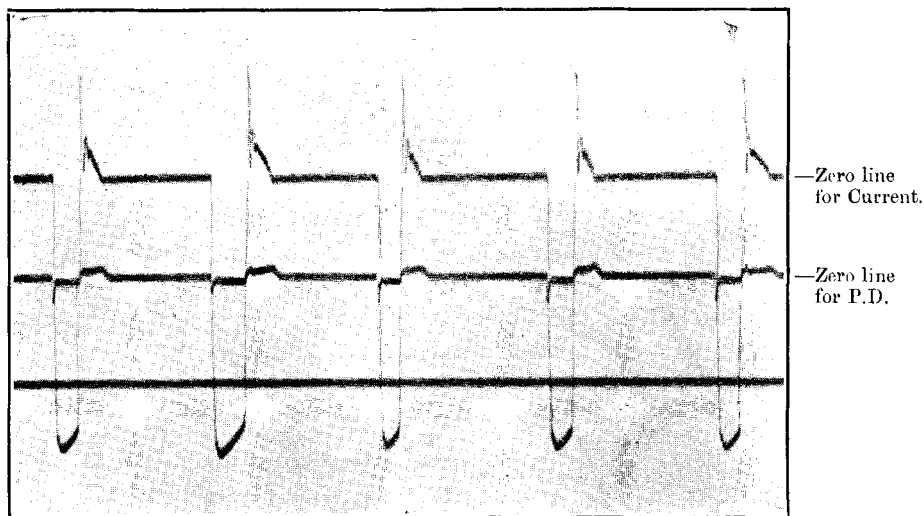
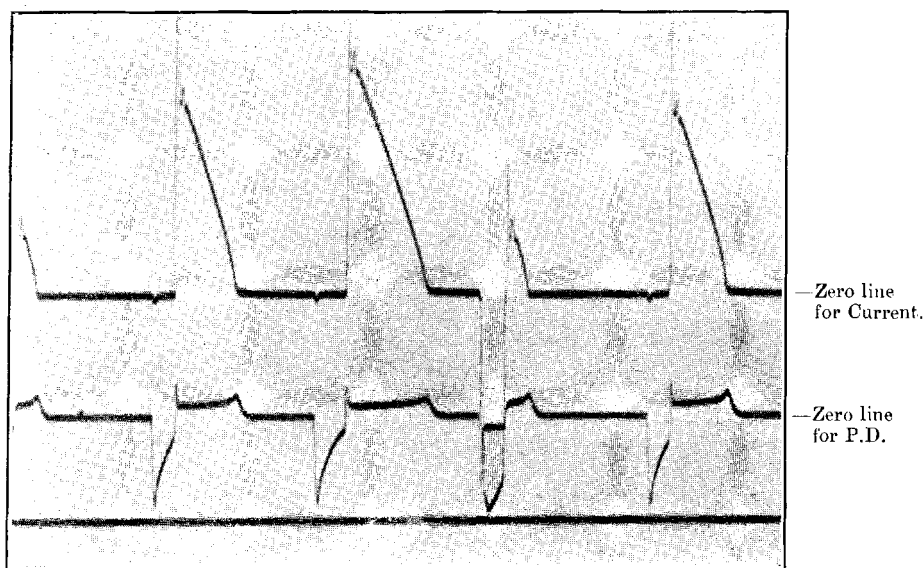
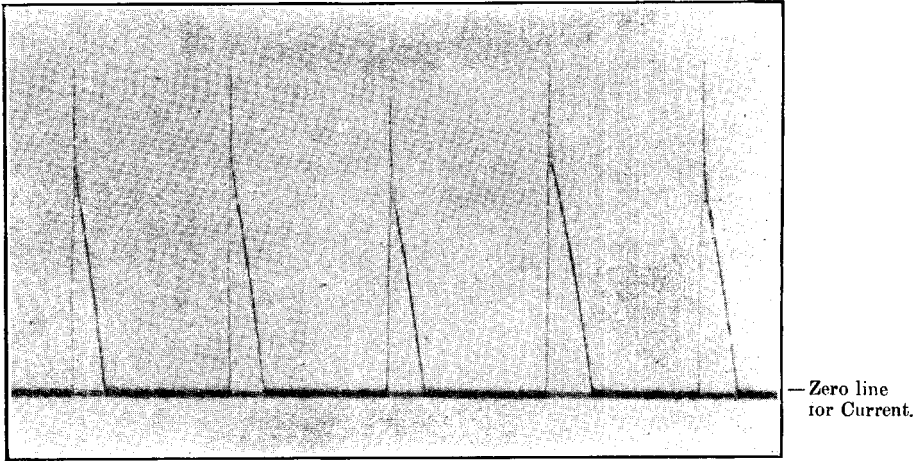


FIG. 6.—Spark-length 15 mm.



P.D. and Current Wave-Forms of Short Sparks.

FIG. 7.—Spark-length 30 mm.



P.D. Wave-Form not recorded.

FIG. 8.—Distance between electrodes too great for sparking to take place.

