(*Stated meeting held Wednesday, March 20, 1907.*)

# The Secondary Current of the Induction Coil.

By H. Clyde Snook, A.M.

The purpose of this paper is to give a discussion of the currents flowing in the secondary of an Induction Coil, as observed by means of a Duddell High Frequency Oscillograph.

The principal apparatus used in this investigation consisted of a Duddell High Frequency Oscillograph and a twenty-inch Rühmkorff Induction Coil, equipped with an electrolytic interrupter, a mercury jet interrupter, and a mechanically vibrating platinum contact break. A general view of the apparatus appears in Figure 1.

The Oscillograph is provided with a falling plate apparatus in the usual manner. The arc lamp which furnished the light for the moving beam that traced the curves is in the foreground near the falling plate arrangement. The mercury jet interrupter, a lead glass shield enclosing an X-Ray tube, and a milliampere meter for measuring the secondary current are in the left foreground.

Curves No. 12 to No. 20, inclusive, are of the current at the middle of the Induction Coil secondary, and were taken by inserting the oscillograph loop directly in series with the two halves of the secondary. The method of connecting up the apparatus was such that the only difference of potential between the oscillograph parts was due to the I. R. drop through the resistance of the oscillograph loop.

This was effected by connecting the permanent magnet of the oscillograph to one side of the loop and making a ground connection to earth at this point. It is true that the loop has a very slight self-induction and that there would be a very slight $L\frac{di}{dt}$ drop through it, and this would be added to the I. R. drop, but their sum is very small, so that the entire oscillograph is subjected to very low differences of potential. By making the middle of the secondary a neutral point at zero potential, the induction coil secondary was permitted to develop its usual high potentials without endangering the recording apparatus.

No. 12 is of the current at the middle of the secondary, obtained in the manner just indicated, when there is no sparking at the terminals of the secondary coil. It is seen that current is

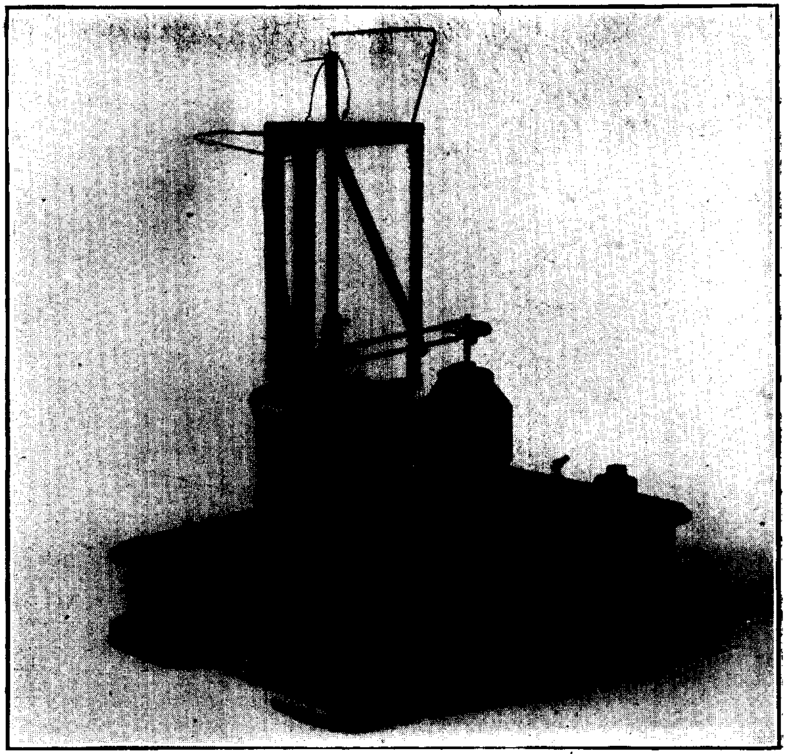


Fig. 1

flowing at the middle of the secondary winding even though no current is passing at the terminals. This is evidently due to the fact that the secondary is oscillating through its own self-induction and electro static capacity as an open-circuited Hertz resonator, the natural period of the thus self-constituted resonator being indicated by the shorter waves in each of the wave trains.

In this curve, as in a number of others, the zero line has been shifted away from the true zero in order that the minute wave forms may be more clearly distinguished.

Curve No. 13 was taken under the same conditions as No. 12, with the exception that a bright snappy sparking was occurring at the secondary terminals of the induction coil. The effect of the sparking is seen in the extra tiny wiggles and the slight change in the contour of the larger waves, which latter effect is due to a change in the leakage inductance between the secondary and primary coils of the induction coil. One of the wave trains in this curve is seen not to have the tiny wiggles which are due to

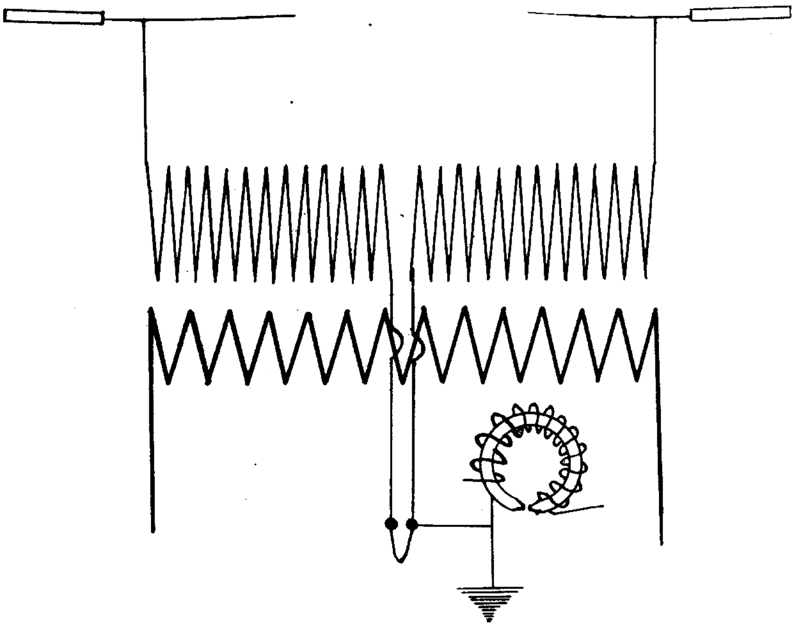


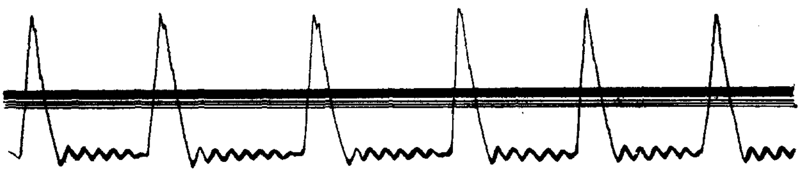
Fig. 2

the spark and its very high frequency oscillation which penetrates entirely through the secondary winding, but which has a still higher frequency than that of the natural period of the secondary winding when oscillating entire as an open-circuited resonator. On one of the wave trains it is seen that the spark failed to occur, and that the shape of the waves in this train is just the same as that in curve 12, where sparking did not occur.

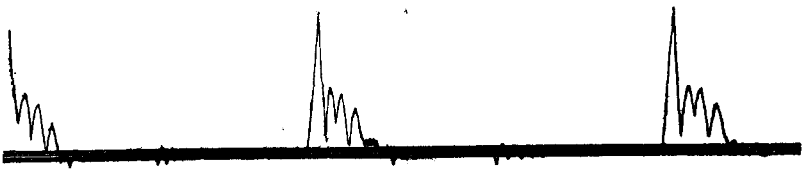
The previous curves, as well as this one, were obtained when the electrolytic interrupter was being used in the primary circuit

CURVE NO. 12.

CURVE NO. 13.

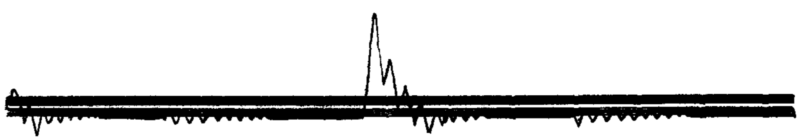


CURVE NO. 14.

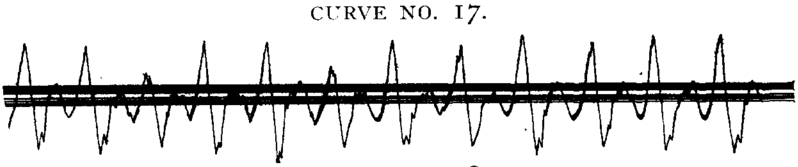


CURVE NO. 15.

CURVE NO. 16.



CURVE NO. 17.



CURVE NO. 18.

of the coil. This curve was obtained by permitting the secondary terminals to be only a few inches apart, and causing a heavy yellow flaming discharge to pass between them. The high wave peaks correspond to the "breaks" of the interrupter, and the tiny wavelets are again the oscillations of the same secondary but their time period is less than in curve No. 12 because in this instance the time period has been reduced by the lessening of the effective capacity of the ends of the secondary winding due to the low resistance of the flaming discharge.

When bright heavy sparking takes place at the secondary terminals, and the primary coil is operated by a platinum hammer break which is bridged with a moderate amount of condenser, we obtain a curve like No. 15. The self induction in the primary winding, when this curve was taken, was of medium value, and it, oscillating with the condenser bridged around the interrupter, caused the serrations in the main wave which occurs at "break." The regular and steady oscillations of the secondary are seen in a low wave train immediately preceding the large wave occurring at break.

No. 16 is quite similar to No. 15, but the electrolytic interrupter was employed. The saw teeth following the large wave occurring at "break" indicate very nicely the prolonged oscillation of the secondary. In this curve four milliamperes of current were being passed through an X-Ray tube having a parallel resistance of about two inches.

No. 17 is identical with No. 15, all adjustments being exactly the same excepting that the discharge was passed through a harder X-Ray tube, and it is seen that the current does not rise to so high an instantaneous value because of the increased tube resistance. The condenser oscillations are seen to serrate the wave form of the current at break, and when the latter has fallen to a low enough value they produce current of a negative sign.

By employing a low value of self induction in the primary coil, a high frequency of interruption by an electrolytic interrupter, and a soft X-Ray tube in series with the secondary, the current curve at the middle of the secondary is as in No. 18. The soft tube offers a low resistance to current of both positive and negative sign and a great deal of inverse current or current of negative value is seen in this curve.

Remembering that this curve is of current at the middle of the secondary winding, we find a most interesting thing due to the superimposition of the high frequency secondary oscillations upon the low frequency oscillations of the primary condenser and self induction which assert themselves in the secondary through the mutual induction between the primary and secondary windings. This is seen immediately following the large positive waves which occur at break. Midway between the large waves at break can be seen the oscillations of the secondary occurring at "make" while the secondary oscillates as an open-circuited resonator, being maintained open circuited in this particular time by the high resistance of the X-Ray tube, which at this instant does not permit the passage of any current through it from the secondary winding. The conditions in the primary when this curve was taken were, a large primary self induction, a mechanical platinum interrupter shunted by a large mica condenser, and a period of interruption of about twenty-five cycles per second; while the secondary had in series with it a soft X-Ray tube, and a small spark gap.

No. 20 was taken under exactly the same conditions as was No. 19 excepting that the electrolytic interrupter was used in the primary. The wave form is profoundly altered and is characteristic of the wave forms produced with this type of interrupter.

We now proceed to examine the current not at the middle of the secondary winding but at one end of it, in order that we may obtain a true record of the current which actually passes through the X-Ray tube and thus eliminate the oscillatory current which occurs only in the secondary winding, and which moves under the stimulus of comparatively small electro-motive forces. It will be seen in the subsequent curves that in the majority of cases these secondary oscillations never pass through the X-Ray tube because their maximum potentials are insufficient to equal the ionization potentials of the X-Ray tubes.

This diagram indicates how the oscillograph was maintained at a zero potential as in the previous curves, but instead of having the current connection at the middle of the secondary it is placed at one end of it. The electrode of the tube which is connected to the oscillograph has of course a low resistance connection to it, and there is maintained at practically zero potential, one end of the secondary winding, the oscillograph, and one of the electrodes of the X-Ray tube.

In this connection it is interesting to note that some of these succeeding curves are taken with the Kathode of the X-Ray tube maintained at zero potential, and some of them with the target maintained at zero potential. This was done in order to determine whether or not it is necessary to raise a kathode to a high *absolute* potential in order to cause it to emit kathode rays. It was found that the X-Ray tube behaved exactly the same in each case, no matter which way about the electrodes were placed with reference to the zero point, and the charactristics of the tube as to

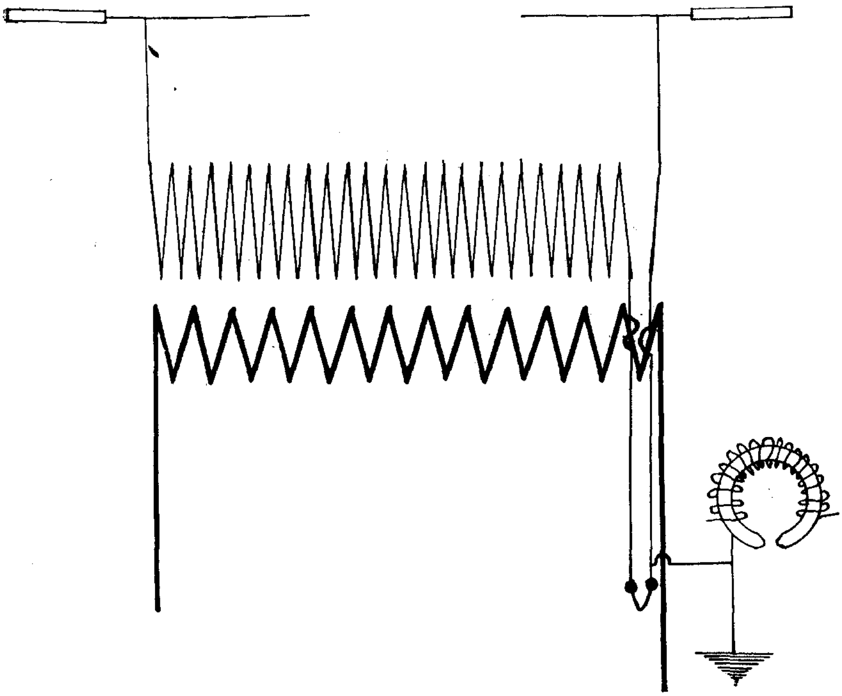
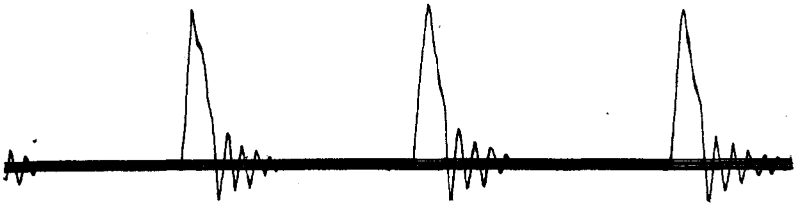


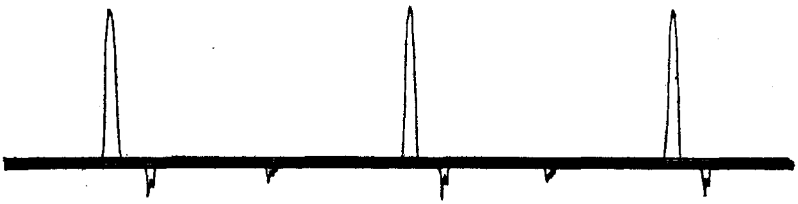
Fig. 3

resistance and emission of X-Rays remained absolutely the same in either position. It was therefore concluded that since no change in the tube characteristics was observed by making the kathode be at zero potential from the behavior of the tube when the kathode was made the high potential electrode, that the production of the kathode rays can take place at the surface of a kathode maintained at zero potential but between which and any other electrode in a Crooke's tube a sufficient difference of potential is maintained.

CURVE NO. 19.

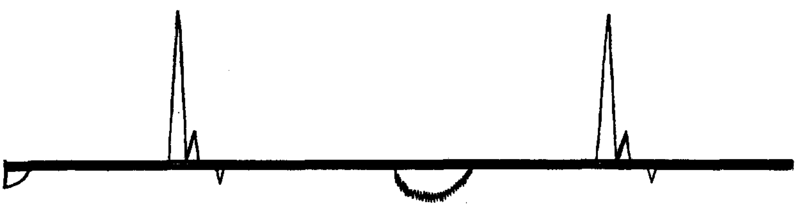


CURVE NO. 20.

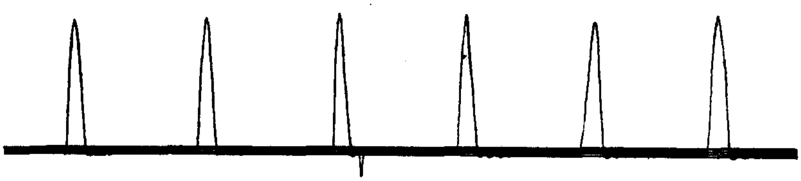


CURVE NO. 21.

CURVE NO. 22.



CURVE NO. 23.



CURVE NO. 24.

In this curve No. 21 we have the curve of current which actually passes through the X-Ray tube. It is seen that the maximum instantaneous value of the current is at times quite high but that the current lasts for very short intervals of time. If we take as land marks the tall peaks of positive current which comes at "break," we notice the negative current at "make," midway between these tall waves at "break." Immediately following the tall waves we see a negative wave of very short duration which is caused by the first semi-oscillation of the primary condenser which produced negative E. M. F. in the secondary, and it is to be noted that the succeeding condenser oscillations fail to produce sufficient potential to equal the ionization potential of the tube. The abruptness with which the current in the tube begins and ends at this semi-oscillation of the condenser, in spite of the fact that the current through the primary due to the condenser oscillation is a damped sine wave, proves the existence of a definite ionization potential for the tube. The oscillation due to the capacity of the tube electrodes, the wires leading to it and the secondary coil, are seen in small wavelets between the tall peaks of positive current and the negative wave caused by the primary condenser.

In No. 22 we have all the conditions the same as in No. 21, but the condenser and primary inductance have been adjusted so as to prevent the production of negative secondary potential of sufficiently high value to equal the negative ionization potential of the X-Ray tube. The curve is entirely above the line, which is as it should be, and is often exceedingly difficult to obtain.

If the X-Ray tube be very soft, its negative ionization potential is correspondingly low, and the negative voltage produced at "make" easily passes current through the tube in the wrong direction. In curve No. 23 midway between the tall peaks of current at the time of "break" we find a wave of current at "make" which lasts for a comparatively great length of time. In this curve can be seen a peak of positive and negative value due to the primary condenser oscillations. Serrating the negative curve at "make" can be seen the high frequency oscillations of the induction coil secondary.

This curve No. 24 is of current in an X-Ray tube when the current is passed through the tube in the proper direction, and there is none in the wrong direction. In this particular curve the induction coil was excited by an electrolytic interrupter, the adjustment of which together with the adjustment of the number of turns on the primary and the rheostat in series with both and the source of current was such as to prevent the negative voltage from equaling the negative ionization potential of the tube.

We have here a mercury jet interrupter directly connected to the shaft of which is a hard rubber rod which has mounted at its upper end a metal rod which rotates around with it. This metal

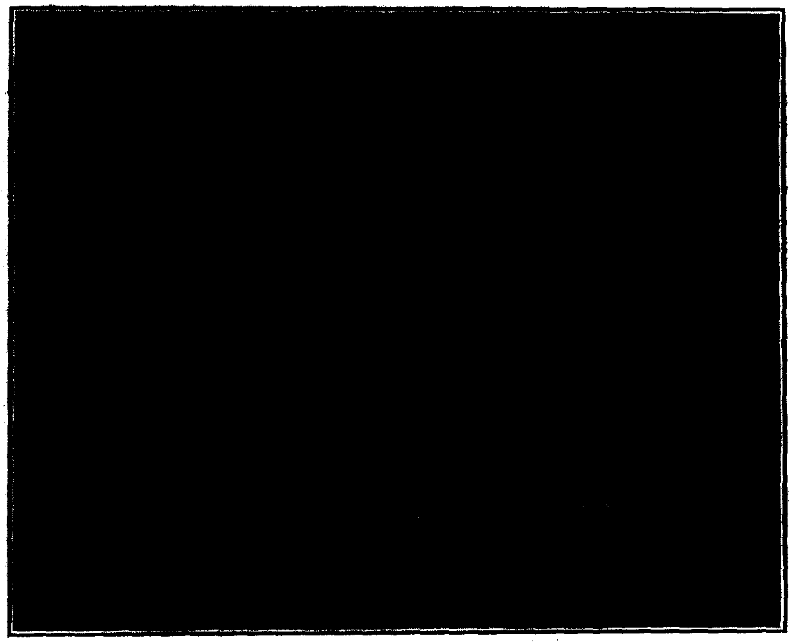


Fig. 4

arm or rod in its rotation bears a definite phase relation to the "make" and "break" of the interrupter, and is so arranged that when the interrupter is at "break" this metal arm closes the secondary circuit of the induction coil through a very small air gap. When, however, the mercury interrupter is at "make" this rotating arm is at such a position that it has introduced into the secondary circuit a large spark gap, which is so great that the negative voltage produced in the secondary winding by the "make" of the interrupter will not bridge across this gap. This constitutes a synchronous series spark gap maintained in series with the secondary winding of the induction coil in such a way that it has a minimum resistance at the time of "break" and a maximum resistance at the time of "make," thus enabling us to prevent the passage into the external secondary circuit any current induced in the secondary at the time of "make." The speaker has used this apparatus in the manner indicated, and has taken oscillographic records of the curves obtained by it, and as would be expected they are the same as previously obtained without the use of such a synchronous series spark gap, excepting that there is not present in the curves any indication of current in the external secondary circuit at the time of "make."

This investigation of the currents flowing in the secondary of this particular induction coil was a part of a general investigation of various kinds of induction coils which was undertaken by the speaker under Dr. Arthur W. Goodspeed, Professor of Physics at the Randal Morgan Laboratory of the University of Pennsylvania. The speaker is greatly indebted to Dr. Goodspeed for his encouragement and his placing the use of the oscillograph and other apparatus at the speaker's disposal.

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## STRAWBOARD WASTE.

A recent publication of the United States Geological Survey that should have wide circulation in the States where strawboard is manufactured is a paper entitled "The Prevention of Stream Pollution by Strawboard Waste." The author is Mr. Earle Bernard Phelps.

The total waste discharged into the streams in 1900 amounted to 10,239,710,000 gallons of liquor, containing 184,777,382 pounds of straw and mineral matter and 77,191,660 pounds of lime. This enormous waste was discharged by fifty-nine plants or various sizes, but as most of these mills are along small streams the resulting pollution is very apparent.

Experiments conducted in the Sanitary Research Laboratory and Sewage Experiment Station of the Massachusetts Institute of Technology show that 93 per cent. of the suspended organic solids and 98 per cent. of the total suspended matter determined as turbidity can be removed, after a short period of sedimentation, by filtration of the liquor through sand, without coagulants. The present method, that of sedimentation in large fields, is pronounced unsatisfactory, expensive, and based on a wrong principle. The sludge resulting from the sedimentation tanks is declared inocuous after being pressed. It is said to make good soil and to have some value as a fertilizer.