THE "HYTONE" RADIO TELEGRAPH TRANSMITTER.*

By

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In this paper a description of some of the radio transmitting sets manufactured by the Clapp-Eastham Company will be given, and also a description of some other apparatus and instruments used in connection with them. The method used in these transmitting sets is to charge a condenser by a low frequency alternating voltage about 30,000 times per second; the discharges being divided, by means of a rotary sectored gap, into definite groups recurring at a rate of about 1,200 per second. The group frequency determines the tone in the receiver. The tone due to the frequency of the supply circuit is not very prominent, particularly with weak signals; and the spark frequency, due to its very high frequency is not noticeable in the telephones.

The supply circuit may be of any commercial frequency; but where direct current only is available, a rotary converter is used to obtain alternating current. A closed core transformer, with high magnetic leakage, raises the potential to several thousand volts, and its design is such as to give approximately constant current with a somewhat flat topped electromotive force wave in the secondary.

The glass condenser which it charges is discharged across a rotary quenched gap and thru the primary of an inductive coupler, the secondary of which is connected between the aerial and ground, as usual. The coupling of the oscillating circuits varies, of course, with the radiation resistance of the secondary circuit or antenna; but is somewhat higher than is the case for the usual stationary quenched gap set because of the very short gap used, and the cooling effect of the rotation of the copper electrodes.

THE TRANSFORMER.

The transformer is designed to be used directly on the line, and the primary (A) is tapped at different points to allow the

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power to be varied by varying the inductance. It is shown in Figure 1. The closed core (B) has the secondary (C) wound on the leg opposite the primary, and a plug of magnetic material (D) is placed as shown, to increase the leakage. The core is worked at a magnetic flux density of about 12,000 lines per square millimeter.; so that the leakage across the leakage plug will cause the secondary discharges to occur more regularly, this effect being due to the flat topped current wave caused by working the transformer iron near saturation.

The other sketch "B," Figure 2, shows another design of transformer, to allow the magnetic leakage to be easily and continuously varied.

As the transformer voltage is low (about 4,000 volts in a 5 kilowatt set), there is no difficulty in properly insulating the transformer without sacrificing mechanical strength. The end turns on the secondary are spaced and well insulated, thus protecting them against the sudden drop of potential at the transformer terminals which occurs when the condenser discharge begins. This decrease of potential does not penetrate far into the windings because of its short duration, and consequently it produces a high potential across the outer turns.

METHOD OF OPERATION.

Figure 3 shows the way in which the discharges occur during one cycle of the supply circuit; the discharge frequency shown, being at a rate of about 4,000 per second, this value being assumed for the sake of clearness. The full line is the voltage curve obtained with the gap open, and the dotted line shows the voltage at which a spark will occur across the gap. It will be seen that the voltage rises from O to the point at which discharges begin in such a way that several sparks occur before the rotation of the gap has opened the circuit.

The first spark in the next group, which occurs when the gap surfaces approach each other again, is somewhat higher in potential than the succeeding ones, because the voltage across the condenser and the gap rises during the time between groups. This discharge was experimentally removed from each group of radiated waves by connecting a spark gap across the secondary of the oscillation transformer set, this gap being just long enough to allow only those wave trains to spark across which were of higher potential than most of the others. The adjustment is easily made by watching the effects produced in a rotating vacuum tube; and it is found that about 6 per cent of the total

FIGURE 1

FIGURE 2

FIGURE 3

FIGURE 4

radiated energy is in the first spark, which is not so well quenched as the succeeding sparks. As the secondary electromotive force wave is not perfectly flat topped, more sparks per group will occur near the peak of the wave than at either end; and of course there is a time, when the voltage is passing thru zero, when no sparks occur. The groups average about thirty sparks each, the maximum number per group being about 45.

THE SPARK GAP.

The spark gap is of the rotary quenched type, several units being used in series, the number depending on the power rating of the set. The construction of a "Type K" gap is shown in the photographs and drawing, the latter giving constructional details of one rated at 3 kilowatt (Figure 4).

A small motor ($\frac{1}{8}$ horse power) is direct connected to the shaft "L," which rotates inside of the cast iron housing "A C B." Bakelite discs "I" are screwed at their centre to hubs "D" and at the outside to copper rings "E." Opposite each copper ring "E" are two copper half rings "F," supported on bakelite pieces "J."

The gaps are connected in series, and terminals are brought out from each thru insulating bushings. The air tight casing is made up of two ends "A," and "B," and three sections "C," so accurately fitted together that gaskets are unnecessary. Both

inside and outside of the casings are ribbed, to give additional heat radiating surface; and the rotary copper "E" has milled radial grooves next to the disc "I" which grooves act as centrifugal fan blades. The heat losses in the gap are not sufficient to require a fan to keep the gap casing cool. A double thrust ball bearing "N" is mounted in a nut "G," so that the distance between the rotary and stationary electrodes may be adjusted. The coupling, not shown in the photograph has a safety stop to prevent running the two electrodes together. The 5 kilowatt gap is similar, five units being used instead of the three shown in the drawing. These gaps are made very accurately, as a spark length at each gap of only about 0.003 inch (0.075 mm.) is used, and it is desirable to have the sparking distances constant and alike. The sparking surfaces of the copper on both stationary and rotary elements are milled with 36 radial slots, so that when rotated at 1,800 R. P. M., the tone corresponds to that of a 540 cycle alternator. It is necessary that the width of the sparking segments be so proportioned that sparks occur during not more than one-half of the total time, as otherwise the telephone diafram is retarded on its excursion away from the magnet, thereby resulting in a decreased sound intensity. This retardation may occur when a "tone circuit" is used instead of the segmented gap, and the same effect would be produced by exciting a radio frequency alternator with a sinusoidal alternating current for tone purposes.

The photographs show the construction of the parts of the gap, the left half being that of one complete rotary element with its insulating disc and hub. The right half shows a stationary unit with the insulating disc and copper electrodes in place (Figure 5). The next drawing shows a 1 kilowatt gap of somewhat similar construction (Figure 6). The two stationary elements are of different outside diameters, so that they may both be placed in position with the back of "B" removed.

TRANSMITTING SETS.

A 5 kilowatt switchboard set, for use on a 120 volt 60 cycle circuit, is shown in Figure 7. In the upper panel are the ammeter, voltmeter, wattmeter, main switch, circuit breaker, gap motor switch, and a switch to short circuit the ammeter and current terminals of the watt meter while sending. The four point switch is connected to taps on the primary of the transformer, for varying the power input.

FIGURE 5

FIGURE 6

The lower panel has the radiation meter, oscillation transformer, and clips for short circuiting series inductances in the aerial and gap circuits. The oscillation transformer (Figure 8) has its secondary of edgewise wound copper fastened to the switchboard, while the primary is hinged, at the right side, for variation of the coupling. A sliding contact on the primary allows it to be adjusted by means of the insulating handle, when the current is on.

The gap and motor can be seen, with the condenser case underneath. The condenser is made up of thin glass plates, covered with tinfoil, and impregnated in a non-hygroscopic wax which reduces leakage.

Figure 7

Figure 8

Figure 9

FIGURE 10

FIGURE 11

The next photograph of the back of the set (Figure 9) shows the transformer, protective condenser and load coils. One inch by 0.125 inch (2.54 cm. by 0.32 cm.) copper strip is used for the oscillating circuit connections, and the high tension circuit is insulated from the marble by Bakelite bushings.

Figures 10 and 11 show a 1 kilowatt set for use on 110 volt direct current, a rotary converter for changing it to alternating current as well as for driving the spark gap. The meters are D. C. ammeter, D. C. voltmeter, A. C. ammeter, A. C. voltmeter, A. C. watt meter, and radiation meter. The four round handles are for the starting box, the power variation switch, the antenna switch, and the primary of the oscillation transformer. This set is supposed to be placed within reach of the operator, to avoid extra complications and wiring. A double throw switch throws the set from the D. C. line to a 90 volt battery, giving about 0.6 kilowatt for emergency service. The efficiency of these sets, from A. C. supply to a 10 ohm phantom antenna is usually about 58 or 60 per cent, one set having shown 67 per cent.

In Figure 12 is shown a relay key for use on high power sets, where a hand key is not desirable. The large silver contacts cool the spark so rapidly that there is very little difficulty in breaking heavy currents, particularly as the armature gives a hammer blow to open the circuit quickly.

The next Figure 13 shows a sectional view of the relay, in which "D" is the core, "F" the winding, "I" the armature, "N" the moving contact, and "L" "L" the two stationary contacts. The moving contact slowly rotates and so keeps the stationary contacts from wearing unevenly.

A portable set of $\frac{1}{4}$ kilowatt capacity is shown in Figure 14. It is for sending and receiving, to be operated in connection with a small A. C. generator, not shown. A similar set designed to operate on a 24 volt storage battery with an independent interrupter, is shown in Figure 15.

Altho we believe the closed core transformer is better adapted to radio work, we build some open core transformers, the one shown in Figure 16 being of 3 kilowatt capacity at 120 cycles. It is shown on top of its case. The next one is 10 kilowatt capacity, of similar construction, but larger. (Figure 17.)

The next drawing, Figure 18 gives the constructional details of the 3 kilowatt open core transformer, one-half showing a front view, while the other half is a sectional view from the top. This construction allows any secondary coil to be removed without disturbing the others; as the primary slides out in a unit.

It is arranged to have a large surface for heat radiation. These resonance transformers, in common with most others of the open core type, have an $I^2 R$ loss about four times that of a closed core transformer of the same output.

FIGURE 12

FIGURE 13

Instead of using an alternating current for charging the condenser, a high voltage direct current can be used with extremely satisfactory results. Either a segmented disc or a "tone circuit" across the gap may be used for telegraph work, or a smooth gap

for telephone work. The telephone results are limited in power by the available transmitters, this being the principal difficulty in most telephone methods.

FIGURE 14

FIGURE 15

SUSTAINED WAVES.

The experimental work on direct current transmitters developed some very interesting, as well as practical, results. It was found that by using a very high coupling (about 65 per cent), and a well cooled rotary gap, single impulses could be produced in the gap circuit which would transmit their energy to the oscillating circuit with a very good efficiency. These

impacts occur so rapidly that the antenna receives new energy before its energy absorption has practically damped out its oscillations, and so there is a sustained wave. After the first impulse, the reaction of the secondary on the primary produces an oscillating voltage across the gap, and when that voltage, plus the condenser voltage, reaches a sufficiently high point, a second impulse will occur. Because of the secondary reaction, the impulse will always occur at that part of the secondary oscillation at which its tendency will be to increase the amplitude of the oscillating current. This is the same effect Dr. Chaffee has shown in his admirable oscillograms when working with his rectifying gap. The rate at which these impacts occur depends upon the supply of current to the condenser, the length of gap, and the damping of the oscillating circuit; but it is usually about one fifth the oscillation frequency. Altho the primary circuit does not oscillate, it is necessary approximately to adjust its natural period to that of the secondary, so that it will transfer its energy during a half oscillation of the secondary. Without changing the primary adjustment, the wave length may be varied over a range of about 50 per cent with no material variation in the radiated energy; and the coupling also is not critical.

Large inductances are placed in the supply leads to assist in maintaining a constant current, and to stop any tendency to arc when the discharges occur, but they have no effect on the impact frequency.

For telegraph work a tone circuit is preferable to a sectored gap, as the former allows a continuous current to flow from the generator thru the steadying inductance, while the latter interrupts the supply current at each tone impulse.

A wave meter coupled to the primary circuit does not show any one prominent frequency, as it is set into oscillation whenever its frequency is a multiple of the impact frequency. This fact gives a simple method, suggested by Dr. Chaffee for determining the rate at which the impacts occur.

The efficiency of this arrangement, from generator to a 10 ohm phantom antenna, at 600 meters, is about 65 per cent, and I believe it can be raised to a still higher value.

AUDIBILITY METER.

During the earlier work with high spark frequencies, we used a resistance shunt across the telephone receivers for measuring audibility, the instrument having resistance steps varying in a constant ratio for convenience in quick adjustment. This was

FIGURE 16

FIGURE 17

FIGURE 18

found to be very inaccurate, however, as every variation of the spark frequency (as well as of the tone frequency) varied the ratio of the currents in the telephones and shunt. We found that we could get more reliable results from a small iron core telephone transformer, the coupling of which could be varied from a maximum to zero. The primary was connected to the detector and the secondary to the telephones, and, using a

FIGURE 19

winding of proper inductance and a resistance low compared to the telephones, the losses are very slight. The instrument is calibrated with two sensitive alternating current meters, one in the primary, the other in the secondary in series with the telephones. If the transformer is properly designed, the ratio of currents at any certain coupling will be practically constant, even with large frequency variations. This may be roughly proved by testing it on a telephone conversation when it will be found not to produce distortion.

Figure 19 shows one type of construction used in which the primary "P" is wound on the lower stationary core, and the secondary, "S," on a similar core, which can be rotated thru 90 degrees, a pointer indicating the audibility. The inductance and resistance of the telephone may be varied over quite a range without affecting the accuracy of calibration within the audible limits (which latter are not very close). By proper design, this

could probably be given an audibility scale of constant ratios, tho the experimental instruments had irregular intensity calibration curves.

RADIO FREQUENCY WATTMETERS.

During the development of these transmitting sets, it was thought desirable to have a more satisfactory method of measuring the radio frequency energy than that provided by the use of an absorbing phantom circuit and hot wire meter, and therefore a number of experimental wattmeters for radio frequencies were built, the construction of which may be of interest to some of the readers. The first wattmeter tried (shown in Figure 20) was of the electrostatic type, as used by several English and German experimenters, at lower frequencies. The moving vane was connected to the high potential side of the helix, and the two stationary sets of vanes across a resistance in the ground circuit. This instrument was unreliable, because of the low torque resulting from the necessity for high insulation. The same difficulty was found in the next instrument which was built like a "string electrometer" and so the later instruments were all made on the electrodynamicometer plan. In this type, the current in the ground lead is conducted thru the stationary coils, and the moving coil is connected in series with a high non-inductive resistance between the ground and the aerial. It was at first thought necessary to reduce the inductance of the potential circuit to the lowest possible value; and the moving coil was made like the movement of a Duddell Oscillograph, using two parallel phosphor bronze galvanometer suspension ribbons with a mirror at their center. The photograph of Figure 21 shows an instrument built this way, but the sensitiveness was not great enough, so that others were built with longer wires. This change resulted in considerable improvement, giving fair results with high power factors, and at radio frequencies. The instrument is shown in Figure 22. The power factor in an antenna is only a few per cent; and consequently greater sensitiveness was required, so that moving coils were made having six or eight round turns about 1 inch (2.5 cm.) in diameter, wound astatically on a mica frame. Some difficulty was experienced with electrostatic charges which collected on the mica and exerted a torque comparable to that produced by the winding, but this was eliminated by using very thin wood frames. As the mutual induction between the moving and stationary coils introduces some complications, an instrument of the torsion head type was built, which was the most successful of all. This instrument.

shown in the photograph of Figure 23, had eight turns in the stationary coils wound with thirty strands of Number 29 double-cotton-covered wire,* and would carry seven amperes. The

FIGURE 20

FIGURE 21

FIGURE 22

FIGURE 23

* Diameter of wire, 0.0113 inch (0.287 mm.)

moving coil had six and one-half active turns, and was suspended on a phosphor bronze strip about 4 inches long. With seven amperes in the current coils about 2 milliamperes was required to give a full scale deflection of 300 degrees at unity power factor. As the potential circuit was capable of carrying 80 milliamperes without a serious temperature rise, full scale deflection could be obtained on a circuit having a power factor of 1.5 per cent. The difficulty at low power factors, however, was in the inductance, and to a smaller extent the capacity, of the series resistance in the potential circuits. These effects could probably be compensated for, or at least a correcting factor used in the readings. The range of the instrument can be greatly increased by the use of air core current transformers, which can be constructed with a current ratio which is constant over large ranges of frequency variation, and with small phase angle error. By the use of proper transformers, potential and current may also be measured on the same instrument.

SUMMARY: A transmitting radiotelegraphic set using a very short, rapidly rotating, quenching gap is described. It is shown that by using properly sectorized sparking surfaces the partial discharges can be regularly spaced, and a higher note obtained in the receiver than corresponds to the frequency of the alternating current supplied. The construction of the set is given in detail. The generation of sustained radio frequency energy by similar means is explained.

An audibility meter, which is a modified audio frequency telephone transformer with variable and measurable coupling between primary and secondary, is discussed. The author also outlines the development of a radio frequency wattmeter. The successful instrument, which is of the electro-dynamometer type, is shown.