by an angle, D. Suppose these two currents to be any neighboring currents in a simple rotary current system. Now, if these two currents be united into one, as shown in the lower part of the figure, the resulting current, I, will be about as shown by the dotted line; that is, it will lie between the other two and at its maximum point, and for a difference of phases equal

FIG. 9.

to 90 degrees it will be about 1.4 times as great as the maximum of either of the others; the important feature is that the phase of this current is midway between that of the other two. Fig. 5 shows the winding of a cylinder armature and Fig. 7 that of a Gramme armature for a simple three-phase current with three leads,

FIG. 10.

with which system we assume that the reader is familiar.

The two figures, 4 and 5 (or 7), correspond with each other in so far as the currents in the three leads, shown in heavy lines, have a phase between those of the two which compose them. Referring now to Fig. 6 (or 8), which is precisely like Fig. 5 (or 7), except that it

FIG. 11.

has an additional winding shown in heavy lines, it will be seen that each of the three leads, shown in heavy lines, is wound around the armature before leaving it, forming an additional coil lying between the two coils with which it is in series. The phase of the heavy line currents was shown in Fig. 4 to lie between the other two. Therefore, in the armature in Fig. 6 (or

FIG. 12.

8) there will be six phases, while in Fig. 5 there are only three, the number of leads (three) remaining the same as before. This is the fundamental principle of this ingenious invention. To have six phases in Fig. 5 would require six leads, but in Fig. 6 precisely the

same result is obtained with only three leads. In the same way the three leads in Fig. 6 might again be combined and passed around the armature again, and so on forming still more phases, without increasing the number of leads. Figs. 7 and 8 compound with 5 and 6 and show the same system for a Gramme ring instead of a cylinder armature.

FIG. 13.

As was stated in the early part of this description, the main object in a rotary current motor is to have a magnetic field which is as nearly constant in intensity as possible, and which changes only its position, that is, its axis. But in Fig. 4 it was shown that the current I (in dotted lines) is greater than the others (about as 1.4 to 1 for a phase difference of 90 degrees). If therefore the coils in Fig. 6 or 8 were all alike, the magnetism generated by the heavy line coils would be greater than that generated by the others, and would therefore produce very undesirable pulsations in the magnetic fields; but as the magnetism depends on the ampere turns, it is necessary merely to have correspondingly fewer turns on these coils, as compared with the others. This is shown diagrammatically in Figs. 6 and 8, in which the heavy line coils have less windings than the others. In practice it is not always possible to obtain the exact ratio of 1 to 1.4, for in-

FIG. 14.

stance, but even if this ratio is obtained only approximately, it nevertheless reduces the pulsations very materially below what they would be with half the number of phases. It is therefore not necessary in practice to have more than an approximation to the exact conditions.

Fig. 9 shows a multiple phase armature having double the number of phases as Fig. 1, and would according to the old system, therefore, require eight leads. Fig. 10 shows the new system with the same number of phases as in Fig. 9, but requiring only four leads instead of eight. Figs. 11 and 12 correspond with Figs. 7 and 8 and show the windings for a multipolar motor in the two systems.

These figures show how a motor may be wound so as to be a multiple phase motor, although the current entering the motor is a simple, elementary three or two phase current, which can be transformed by means of a simple three or two phase current transformer, before entering the motor, such transformers as are used

FIG. 15.

at present in the Lauffen-Frankfort transmission. But the same principle as that for the motor may also be applied to transformers themselves, as shown in Figs. 13 and 14. Fig. 13 shows a set of transformers which are fed by a simple three-phase current shown

in heavy lines, and which gives in its secondary circuit a multiple phase rotary current. The connections for the primary circuit of a transformer with six coils are shown diagrammatically in Fig. 15, the numbers 1 to 6 representing the succession of the phases. Fig. 14 shows a transformer for a two-phase current with four leads, transforming into a multiple phase current of 16 leads. The transformer in this figure is a single "interlocked" transformer in which the fields are magnetically connected and not independent of each other as in Fig. 13. This has advantages in the regulation of currents, which do not exist in Fig. 13, but which need not be entered into here. The transformers used in the Lauffen-Frankfort transmission are similar, magnetically, to Fig. 14, only that they are for a simple three-phase current in both primary and secondary circuits. Attention is also called to the difference in the connections of secondary circuits in Figs. 13 and 14; in the former they are connected in a closed circuit similarly to an ordinary closed circuit armature, while in Fig. 14 they are independent as far as the currents themselves are concerned, though magnetically their cores are connected. It is not the intention to enter into a discussion of the relative values of these various connections, but merely to draw attention to the wide range of the number of combinations which this system admits of.—*Electrical World*.

THE LONDON PARIS TELEPHONE.*

By W. H. PREECE, F. R. S.

1. I HAVE already on two occasions, at Newcastle and at Leeds, brought this subject before Section G, and have given the details of the length and construction of the proposed circuit.

I have now to report not only that the line has been constructed and opened to the public, but that its success, telephonic and commercial, has exceeded the most sanguine anticipations. Speech has been maintained with perfect clearness and accuracy. The line has proved to be much better than it ought to have been, and the purpose of this paper is to show the reason why.

The lengths of the different sections of the circuit are as follows:

London to St. Margaret's Bay.....	84.5 miles.
St. Margaret's Bay to Sangatte (cable).....	23 0 "
Sangatte to Paris.....	199 0 "
Paris underground.....	4 8 "
Total.....	311.3 "

The resistances are as follows:

Paris underground.....	70 ohms.
French line.....	294 "
Cable.....	143 "
English line.....	183 "
Total (R).....	693 "

The capacities are as follows:

Paris underground.....	0.43 microfarads.
French line.....	3.33 "
Cable.....	5.52 "
English line.....	1.32 "
Total (K).....	10.62 "

$$693 \times 10.62 = 7,359 = K R$$

a product which indicates that speech should be very good.

2. *Trials of Apparatus.*—The preliminary trials were made during the month of March between the chief telegraph offices of the two capitals, and the following microphone transmitters were compared:

Ader	Pencil form.
Berliner	Granular form.
D'Arsonval.....	Pencil "
De Jongh.....	" "
Gower Bell.....	" "
Post office switch	
instrument	Granules and lamp filaments.
Roulez.....	Lamp filaments.
Turnbull.....	Pencil form.
Western Electric....	Granular.

The receivers consisted of the latest form of double-pole Bell telephones with some Ader and D'Arsonval receivers for comparison. After repeated trials it was finally decided that the Ader, D'Arsonval, Gower-Bell (with double-pole receivers instead of tubes), Roulez, and Western Electric were the best, and were approximately equal.

These instruments were, therefore, selected for the further experiments, which consisted of using local extensions in Paris and London. The wires were in the first instance extended at the Paris end to the Observatory through an exchange at the Avenue des Gobelins. The length of this local line is 7 kms. The wires are guttapercha-covered, placed underground, and not suitable for giving the best results.

The results were, however, fairly satisfactory. The wires were extended to the Treasury in London by means of the ordinary underground system. The distance is about two miles, and although the volume of sound and clearness of articulation were perceptibly reduced by these additions to the circuit, conversation was quite practicable.

Further trials were also made from the Avenue des Gobelins on underground wires of five kilometers long, and also with some renters in Paris with fairly satisfactory results. The selected telephones were equally efficient in all cases, which proves that to maintain easy conversation when the trunk wires are extended to local points it is only necessary that the local lines shall be of a standard not lower than that of the trunk line. The experiments also confirm the conclusion that long-distance speaking is solely a question of the circuit and its environments, and not one of apparatus. The instruments finally selected for actual work were Gower-Bell for London and Roulez for Paris.

3. The results are certainly most satisfactory. There is no circuit in or out of London on which speech is more perfect than it is between London and Paris. In

* Paper read before the British Association.—*Elec. Engineer*.

fact, it is better than I anticipated, and better than calculation led me to expect. Speech has been possible not only to Paris but through Paris to Bruxelles, and even, with difficulty, through Paris to Marseilles, a distance of over 900 miles. The wires between Paris and Marseilles are massive copper wires specially erected for telephone business between those important places.

4. *Business Done.*—The charge for a conversation between London and Paris is 8 s. for three minutes' complete use of the wire. The demand for the wire is very considerable. The average number of talks per day, exclusive of Sunday, is 86. The maximum has been 108. We have had as many as 19 per hour—the average is 15 during the busy hours of the day. As an instance of what can be done, 150 words per minute have been dictated in Paris and transcribed in London by shorthand writing. Thus in three minutes 450 words were recorded, which at 8 s. cost five words for a penny.

5. *Difficulties.*—The difficulties met with in long-distance speaking are several, and they may be divided into (a) those due to external disturbances and (b) those due to internal opposition.

(a.) Every current rising and falling in the neighborhood of a telephone line within a region, say, of 100 yards, whether the wire conveying it be underground or overground, induces in the telephone circuit another current, producing in the telephone a sound which disturbs speech, and if the neighboring wires are numerous and busy, as they are on our roads and railways, these sounds become confusing, noisy, and ultimately entirely preventive of speech. This disturbance is, however, completely removed by forming the telephone circuit of two wires placed as near to each other as possible, and twisted around each other without touching, so as to maintain the mean average distance of each wire from surrounding conductors the same everywhere. Thus similar currents are induced in each of the two wires, but being opposite in direction, as far as the circuit is concerned, they neutralize each other, and the circuit, therefore, becomes quite silent.

In England we make the two wires revolve completely round each other in every four poles, but in France it is done in every six poles. The reason for the change is the fact that in the English plan the actual crossing of the wires takes place in the span between the poles, while in the French plan it takes place at the poles. This is supposed to reduce the liability of the wires to be thrown into contact with each other by the wind, but, on the other hand, it diminishes the geometrical symmetry of the wires—so very essential to insure silence. As a matter of fact, contacts do not occur on well constructed lines, and I think our English wires, being more symmetrical, are freer from external disturbance than those in France.

(b.) The internal opposition arises from the resistance, R, the capacity, K, and the electromagnetic inertia, L, of the circuit. A current of electricity takes time to rise to its maximum strength and time to fall back again to zero. Every circuit has what is called its time constant, t , Fig. 1, which regulates the number of current waves which can be transmitted through it per second.

FIG. 1.

rent waves which can be transmitted through it per second. This is the time the current takes to rise from zero to its working maximum, and the time it takes to fall from this maximum to zero again, shown by the shaded portions of the figure; the duration of the working current being immaterial, and shown by the unshaded portion.

The most rapid form of quick telegraphy requires about 150 currents per second, currents each of which must rise and fall in $\frac{1}{150}$ of a second, but for ordinary telephone speaking we must have about 1,500 currents per second, or the time which each current rises from zero to its maximum intensity must not exceed $\frac{1}{3000}$ part of a second. The time constant of a telephone circuit should therefore not be less than 0.0003 second.

Resistance alone does not affect the time constant. It diminishes the intensity or strength of the currents only; but resistance, combined with electromagnetic inertia and with capacity, has a serious retarding effect on the rate of rise and fall of the currents. They increase the time constant and introduce a slowness which may be called retardance, for they diminish the rate at which currents can be transmitted. Now the retardance due to electromagnetic inertia increases directly with the amount of electromagnetic inertia present, but it diminishes with the amount of resistance of the conductor. It is expressed by the ratio—

$\frac{L}{R}$ while that due to capacity increases directly, both with the capacity and with the resistance, and it is expressed by the product, $K R$. The whole retardance, and, therefore, the speed of working the circuit or the clearness of speech, is given by the equation

$$\frac{L}{R} + K R = t$$

or

$$L + K R^2 = R t$$

Now in telegraphy we are not able altogether to eliminate L, but we can counteract it, and if we can make $R t = 0$, then

$$L = -K R^2$$

which is the principle of the shunted condenser that has been introduced with such signal success in our post office service, and has virtually doubled the carrying capacity of our wires.

If, in the above equation, we make $L = 0$

$$K R = t$$

This is done in telephony, and hence we obtain the law of retardance, or the law by which we can calculate the distance to which speech is possible. All my calculations for the London and Paris line were based on this law, which experience has shown it to be true.

How is electromagnetic inertia practically eliminated? First, by the use of two massive copper wires, and secondly by symmetrically revolving them around each other. Now L depends on the geometry of the circuit, that is, on the relative form and position of the different parts of the circuit, which is invariable for the same circuit, and is represented by a coefficient, λ . It depends also on the magnetic qualities of the conductors employed and of the space embraced by the circuit. This specific magnetic capacity is a variable quantity, and is indicated by μ for the conductor and by μ_0 for air. It depends also on the rate at which currents rise and fall, and this is indicated by the differential coefficient $\frac{dC}{dt}$. It depends finally on the number of lines of force due to its own current which cut the conductor in the proper direction; this is indicated by β . Combining these together we can represent the electromagnetic inertia of a metallic telephone circuit as

$$L = \lambda (\mu + \mu_0) \frac{dC}{dt} \times \beta$$

Now, $\lambda = 2 \log \frac{d}{a}$ Hence the smaller we make the distance, d , between the wires, and the greater we make their diameter, a , the smaller becomes λ . It is customary to call the value of μ for air, and copper, 1, but this is purely artificial and certainly not true. It must be very much less than one in every medium, excepting the magnetic metals, so much so that in copper it may be neglected altogether, while in the air it does not matter what it is, for by the method of twisting one conductor round the other, the magnetization of the air space by the one current of the circuit rotating in one direction is exactly neutralized by that of the other element of the circuit rotating in the opposite direction.

Now, β , in two parallel conductors conveying currents of the same sense, that is flowing in the same direction, is a retarding, Fig. 2, and is therefore a positive quantity, but when the currents flow in opposite directions, as in a metallic loop, Fig. 3, they tend to assist each other and are of a negative character. Hence in a metallic telephone circuit we may neglect L in toto as I have done.

I have never yet succeeded in tracing any evidence of electromagnetic inertia in long single copper wires, while in iron wires the value of L may certainly be taken at 0.005 henry per mile.

FIG. 2.

I have never yet succeeded in tracing any evidence of electromagnetic inertia in long single copper wires, while in iron wires the value of L may certainly be taken at 0.005 henry per mile.

FIG. 3.

In short metallic circuits, say of lengths up to 100 miles, this negative quantity does not appear, but in the Paris-London circuit this helpful mutual action of opposite currents comes on in a peculiar way. The presence of the cable introduces a large capacity practically in the center of the circuit. The result is that we have in each branch of the circuit between the transmitter, say, at London and the cable at Dover, extra currents at the commencement of the operation, which, flowing in opposite directions, mutually react

FIG. 4.

on each other, and practically prepare the way for the working currents. The presence of these currents is proved by the fact that when the cable is disconnected at Calais, as shown in Fig. 5, and telephones are inserted in series, as shown at D and D', speech is as perfect between London and St. Margaret's Bay as if the wires were connected across, or as if the circuit were through to Paris. Their effect is precisely the same as though the capacity of the aerial section were reduced by a

FIG. 5.

quantity, M, which is of the same dimension or character as K. Hence, our retardance equation becomes

$$R (K - M) = t$$

Thus it happens that the London-Paris telephone works better than was expected. The nature of M is probably equivalent to about 0.0075 ϕ per mile, and therefore K should be also about 0.0075 ϕ instead of 0.0156 ϕ per mile. This helpful action of mutual induction is present in all long circuits, and it is the reason why we were able to speak to Brussels and even to Marseilles. It also appears in every metallic loop, and vitiates the measurements of electromagnetic inertia and of capacity of loops. Thus, if we measure the capacity of a loop as compared with a single wire, the amount per mile may be 50 per cent. greater than it ought to be; while if we measure the capacity of one branch of a circuit under the conditions of the London-Paris telephone line, it may be 50 per cent. less than it

ought to be. This effect of M is shown by the dotted line in Fig. 1.

Telephonic currents—that is, currents induced in the secondary wire of an induction coil due to the variation of microphonic currents in the primary wire—are not alternating currents. They do not follow the constant periodic law, and they are not true harmonic sine functions of the time. The microphonic currents are intermittent or pulsatory, and always flow in the same direction. The secondary currents are also always of the same sign, as are the currents in a Ruhmkorff coil, and as are the currents in high vacua with which Crookes has made us so familiar. Moreover, the frequency of these currents is a very variable quantity, not only due to the various tones of voices, but to the various styles of articulation. Hence the laws of periodic alternate currents following the sine function of the time fail when we come to consider microphones and telephones. It is important to bear this in mind, for nearly everything that has hitherto been written on the subject assumes that telegraphic currents follow the periodic sine law. The currents derived from Bell's original magneto-transmitters are alternate, and comply more nearly with the law. The difference between them and microphones is at once perceptible. Muffling and disturbance due to the presence of electromagnetic inertia become evident, which are absent with microphones. I tested this between London and St. Margaret's, and found the effect most marked.

7. *Lightning.*—A metallic telephone circuit may have a static charge induced upon it by a thunder cloud, as shown in Fig. 6. Such a charge is an electric

FIG. 6.

strain which is released when the charged cloud flashes into the earth or into a neighboring cloud. If there be electromagnetic inertia present, the charge will surge backward and forward through the circuit until it dies out. If there be no E.M.F. present it will cease suddenly, and neutrality will be attained at once. Telephone circuits indicate the operation by peculiar and characteristic sounds. An iron wire circuit produces a long swish or sigh, but a copper wire circuit like the Paris-London telephone emits a short, sharp report, like the crack of a pistol, which is sometimes startling, and has created fear, but there is no danger or liability to shock. Indeed, the start has more than once thrown the listener off his stool, and has led to the belief that he was knocked down by lightning.

8. The future of telephone working, especially in large cities, is one of underground wires, and the way to get over the difficulties of this kind of work is perfectly clear. We must have metallic circuits, twisted wires, low resistance, and low capacity. In Paris a remarkable cable, made by Fortin-Herman, gives an exceedingly low capacity—viz., only 0.069 ϕ per mile. In the United States they are using a wire insulated with paper which gives 0.08 ϕ per mile. We are using in London Fowler-Waring cable giving a capacity of 1.8 ϕ per mile, the capacity of gutta-covered wire being 3 ϕ per mile.

THE MANUFACTURE OF PHOSPHORUS BY ELECTRICITY.

ONE of the most interesting of the modern applications of electricity to the manufacture of chemicals is to be found in the recently perfected process known as the Readman-Parker process, after the inventors Dr. J. B. Readman, F.R.S.E., etc., of Edinburgh, and Mr. Thomas Parker, the well known practical electrician, of Wolverhampton.

Before giving an account of this process, which has advanced beyond the experimental to the industrial stage, it may be well to recall the fact that for several years past Dr. Readman has been devoting an enormous expenditure of labor, time and money to the perfection of a process which shall cheapen the production of phosphorus by dispensing altogether with the use of sulphuric acid for decomposing the phosphate of lime which forms the raw material of the phosphorus manufacturer, and also with the employment of fire clay retorts for distilling the desiccated mixture of phosphoric acid and carbon which usually forms the second stage of the operation.

The success of the recent applications of electricity in the production of certain metals and alloys led Dr. Readman to try this source of energy in the manufacture of phosphorus, and the results of the first series of experiments were so encouraging that he took out provisional protection on October 18, 1888, for preparing this valuable substance by its means.

The experiments were carried on at this time on a very small scale, the power at disposal being very limited in amount. Yet the elements of success appeared to be so great, and the decomposition of the raw material was so complete, that the process was very soon prosecuted on the large scale.

After a good deal of negotiation with several firms that were in a position to supply the electric energy required, Dr. Readman finally made arrangements with the directors of the Cowles Company, limited, of Milton, near Stoke-on-Trent, the well known manufacturers of alloys of aluminum, for a lease of a portion of their works and for the use of the entire electrical energy they produced for certain portions of the day.

The experiments on the large scale had not advanced very far before Dr. Readman became aware that another application for letters patent for producing phosphorus had been made by Mr. Thomas Parker, of Wolverhampton, and his chemist, Mr. A. E. Robinson. Their joint patent is dated December 5, 1888, and was thus applied for only seven weeks after Dr. Readman's application had been lodged.

It appeared that Mr. Parker had conducted a number of experiments simultaneously but quite independently of those carried on by Dr. Readman, and that he was quite unaware—as the latter was unaware