VOLUME 2 MARCH, 1914 NUMBER 1

PROCEEDINGS
of
THE INSTITUTE OF RADIO ENGINEERS

(INCORPORATED)

OFFICERS, COMMITTEES AND SUPPLEMENTARY LISTS OF MEMBERS AND ASSOCIATES OF THE INSTITUTE

THE AUDION—DETECTOR AND AMPLIFIER

DR. LEE DE FOREST

RADIO RANGE VARIATION

ROBERT H. MARRIOTT

THE INFLUENCE OF ALTERNATING CURRENTS ON CERTAIN MELTED METALLIC SALTS

C. TISSOT

THE GOLDSCHMIDT SYSTEM OF RADIO TELEGRAPHY

EMIL E. MAYER

EDITED BY
ALFRED N. GOLDSMITH, Ph.D.

PUBLISHED QUARTERLY BY
THE INSTITUTE OF RADIO ENGINEERS
SEVENTY-ONE BROADWAY
NEW YORK

THE GOLDSCHMIDT SYSTEM OF RADIO TELEGRAPHY*

By Emil E. Mayer

The problem of producing very high frequency energy by electrical machinery has aroused great interest ever since the beginning of the development of radio telegraphy. To its solution have been contributed much inventive thought and engineering skill. I need only recall to you the names of Nikola Tesla, Reginald Fessenden, and E. F. W. Alexanderson.

So far as obtaining large amounts of energy is concerned, the first to arrive at a practical solution of the difficulties was Professor Rudolph Goldschmidt, former Chief Electrician of the English Westinghouse Company, and Professor of Electrical Engineering at the Technical College of Darmstadt. Some of his large generators, which furnish an antenna output of 150 kilowatts, have now been in operation for almost a year, and the results obtained are quite unusual.

Principles of the Goldschmidt Alternator.

The principles used by Goldschmidt are as ingenious as they are simple.

1. The non-rotating part of an alternator may be excited by an alternating current. Since the time of Ferrari, it is well known that the magnetic field produced by an alternating current may be resolved or split into two separate fields, each of half the amplitude. These component fields are to be regarded as rotating in opposite directions with the same frequency as that ot the exciting current. To understand this, we need merely consider that every north pole changes into a south pole (with a sinusoidal variation); and that at the middle of this variation the magnetic field is equal to zero.

2. If a rotor revolves in the field of the exciting alternating current, two electromotive forces are produced in its windings. Calling the initial frequency n, and the frequency of the rotor n_1 it is obvious that the frequencies of the electromotive forces produced in the rotor are $(n+n_1)$ and $(n-n_1)$. If the revolving parts rotate synchronously, that is, if $(n-n_1)=0$, the frequencies produced are $2n$ and 0. We can thus explain the well known fact that by

* Delivered before a joint meeting of The American Institute of Electrical Engineers and The Institute of Radio Engineers, March 13, 1913.

simply adding a number of such machines on the same shaft, the field of each being excited by the current produced by the preceding one, the frequencies of the currents produced will increase in arithmetical progression.

3. The ingenious process of producing this continuous increase of frequency in *one* machine was the invention of Goldschmidt. If a current of frequency n is permitted to flow in the rotor, it will produce a magnetic field of the same frequency. If the stator is appropriately wound, there will be produced in it, in turn, the frequencies $(2n+n)$ and $(2n-n)$ that is $3n$ and n. Obviously, so far as the mutual induction between them is concerned, it makes no difference which of the parts is the exciter, or which the rotating portion. The current of frequency $3n$ in the stator will produce a magnetic field, which will excite electromotive forces of frequencies $4n$ and $2n$ in the rotor windings. If the process is continued for five frequency transformations, or "reflections," electromotive forces of the following frequencies will be produced:

Stator	*Rotor*
n	$2n$ and 0
$3n$ and n	$4n$ and $2n$
$5n$ and $3n$	$6n$ and $4n$

4. It is not necessary to provide separate windings for the currents of different frequencies, for they will all flow in the same stator or rotor windings provided they find an appropriate closed circuit.

As an example of this effect, the well-known fact may be cited that in the direct current exciter circuit of an ordinary single phase alternator there is an alternating current of double the fundamental frequency superposed on the direct current. This double frequency current has been produced in the way described, and had found its way over the commutator of the direct current exciter.

5. In dealing with the frequencies used in radio telegraphy, a simple short circuit is not the circuit of least impedance, for even a small piece of cable has considerable inductance and a very small capacity, which, when added to the inductance of the winding itself will make the reactance of the circuit

$$\left(2\pi nL-\frac{1}{2\pi nC}\right)$$

high even if the ohmic resistance is neglected. To have minimum impendance, particularly at such very high frequencies, the circuits must be so tuned that the effects of inductance and capacity balance each other, that is,

$$2\pi nL = \frac{1}{2\pi nC}$$

In this case, only the ohmic resistance, which is naturally made as small as possible, remains.

By properly tuning the circuits containing the inductance of the armature, currents lagging behind e. m. f. are avoided; and the only limits to the growth of current are the ohmic resistance of the circuit and the losses due to hysteresis and eddy current as well as losses in the insulating material. These latter losses may be summed up in a single resistance factor, properly calculated.

If in all the circuits electromotive force and current are in phase, the frequencies of the *same* magnitude produced by rotation in two *different* magnetic fields must be in *opposite* phase, and therefore cancel each other to a certain extent. They may be simply considered as action and reaction. For example, there is obtained by rotation in the field of the rotor current of frequency $2n$ another current of frequency n; that is, of the same frequency as the fundamental current. But the frequency $2n$ has been produced by rotation in the field of the original current of frequency $2n$. So that the current of frequency n produced by rotation in the field of frequency $2n$ will be in exactly opposite phase to the original current of frequency n, and will therefore reduce its magnitude. Experiments shows that if all the circuits are properly tuned and connected, only a very small margin of the intermediate frequencies will remain. The intermediate frequencies will exist in only sufficient amount to cover the losses in the tuning circuits and that portion of the loss in the machine which is necessarily due to the definite frequency considered.

The process of increasing the frequency can be stopped at any point merely by not adding any further tuned circuits to those already present, for no currents of the higher frequencies will flow without tuning.

As regards the magnetic fields, a similar phenomenon occurs. Only the magnetic field of the highest frequency will exist in its full intensity, for all the intermediate frequency fields will be partially neutralized. Therefore only the last field will add noticeably to the hysteresis and eddy current losses.

The Goldschmidt alternator, built as described, is a combined generator and frequency transformer. It is remarkable that theoretically the process of energy transformation to the higher frequencies takes place in such a way that all of the generated energy is transformed. The limit of the "reflection" is determined solely by the copper losses, and the losses in the iron and insulation of the machine; if we consider efficiency only. If actual output for a given amount of exciting energy is considered, the limit is reached when the magnetic leakage between the rotor and stator becomes excessive. Since the influence of the leakance will be to decrease the output per unit of exciting current at each reflection, it is of the highest importance to keep it small.

The diagram of connections (Figure 1) shows a Goldschmidt alternator with four frequency-transforming circuits. For each

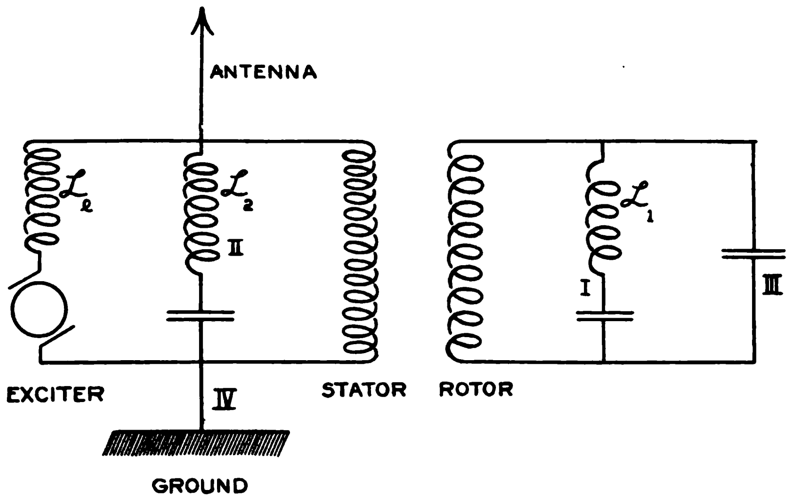

FIGURE 1—Connections of Goldschmidt Alternator.

frequency there is a tuned circuit. The exciter circuit, and also the circuit of the lowest frequency are protected against the higher frequency currents by additional inductances, or choke coils. As can be readily seen, this measure is necessary to render tuning feasible.

It is necessary that there shall be a certain relation between the inductances in the tuning circuits for, say, the third and fifth frequency currents produced in the stator. If this relation is not obtained the addition of a further circuit in the tuning process would detune the other circuits so considerably that it would be exceedingly difficult to tune again. It is clear that, however, we adjust the tuning circuits, a certain detuning will occur under the conditions. But if the inductances are properly chosen, this detuning can be easily calculated and allowed for.

It has already been stated that every process of reflection involves certain losses which are due to losses in the tuning circuits and also in the machine itself; and further, that the obtainable energy becomes less at each process of reflection because of magnetic leakage between the circuits. This fact makes it desirable to reach the highest frequency (which is to be used for radio telegraphy) without having more than, say four or five reflections in the machine. Consequently the designer is forced to use an unusually high fundamental frequency. For example, the wave length of 6,000 meters, which is frequently used for trans-Atlantic work, corresponds to a frequency of 50,000 cycles per second. (These quantities are connected by the equation $\lambda = v/n$ where λ is the wave length, v the velocity of light, and n the frequency.) If not more than five reflections are to be permitted, the initial frequency must be 10,000 cycles. Consequently a high speed and a large number of poles are necessary. Let us assume a maximum speed of rotation of 3,000 revolutions per minute. Then, as the following equations show, we must have 400 poles.

$$\frac{P\,U}{120} = n$$

where P is the number of poles, U the revolutions per minute, and n the frequency.

Using the best materials and the highest engineering skill, the maximum speed which can be safely maintained is 200 meters per second at the periphery. This is already rather unusual, but, as experience shows, it is permissible, if proper precautions are taken. We find therefore, that for 3,000 revolutions per minute, the greatest diameter of the rotating portion of the machine must not exceed 1.25 meters (4 feet 1 inch). This gives a circumference of 400 centimeters (12 feet 10 inches). Consequently, the width of each pole is 1 centimeter (0.4 inch). If account is taken of the necessary iron and insulation, it will be seen that we are limited as to the current which can be carried by the conductor in each slot.

To save room and to avoid capacity and inductance between parts of the winding, the safest and most economical method is to place only one conductor in each slot; that is, one winding per pole. To make it possible to adapt the voltage produced to the resistance of the antenna which is employed, the winding is arranged so that it can be divided into groups which can be arranged in series or parallel. The wire itself must be stranded, and the strands must be the finest the manufacturers will consent to use. For example, a number of Number 40 B. & S. gauge wires, each separately insulated and properly stranded, will prevent undue losses due to the skin effect. In addition, the outside insulation of this wire must be very reliable. In Figure 2 is shown a simple diagram of the winding of the rotor and stator.

Iron which is in a magnetic field of frequency of 30,000 or 40,000 cycles must be of the best quality and very well laminated. In addition to high mechanical strength it must have a large

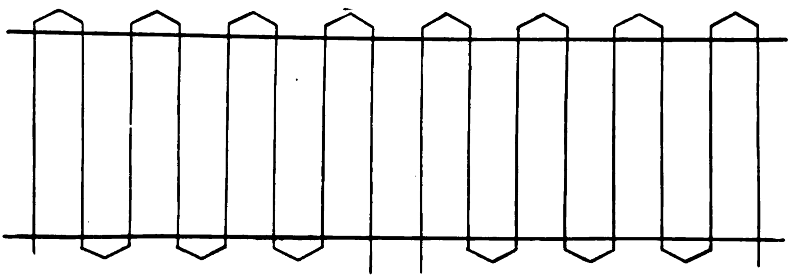

FIGURE 2—Winding Diagram of Rotor and Stator.

ohmic resistance to keep the eddy currents small. Eddy currents not only produce heat losses, but also weaken the magnetic fields by the reaction of their own fields. They will, therefore, decrease the output of the machine. In our machines we use steel of a thickness of 0.05 millimeters (or 2 mils = 0.002 inch) insulated by paper about 0.03 millimeter thick (1.2 mils). It will be seen that the body of the rotor and of the stator are more than one-third made up of paper, and the combination is a rare one to be used as a construction material of high quality. It is needless to say that an enormous amount of detail work and experimenting were necessary before it became possible to subject a rotor made of such materials to the strains arising at a speed of 200 meters per second. Great credit must be given the manufacturers, Messrs. Bergmann, of Berlin, for the ingenious manner in which they worked out every detail of this machine.

I feel that I am not speaking too strongly if I state that I believe that we shall consider the construction of these very high frequency machines as marking the beginning of a new era in engineering exactitude. For we have here an extremely large and heavy machine, which must be built with the precision of a watch. Consider, for instance, the air gap. We have seen the great importance of a low stray factor. This stray factor will depend almost entirely on the size of the air gap, for this is practically the only region of any marked reluctance to the magnetic flux. Therefore this air gap is made 0.8 millimeter wide; that is, a trifle more than 1-32 of an inch. This clearance, in combination with a peripheral speed of 200 meters per second for a rotor weighing about five tons, forces the manufacturer to adopt absolutely new engineering methods.

Another example of the unusual precision required is the following. In any electrical machine the slots must be approximately parallel, but in this particular case a divergence from parallelism of 1 millimeter in 1 meter's length causes 20 per cent. of the total output to disappear.

All of these effects could be foreseen, and were guarded against. We shall consider an unforeseen special difficulty which arises when handling such a large current at very high frequencies in a machine. This trouble arose at the slip rings. It is necessary to connect the ends of the rotor windings to slip rings in order to make it possible to attach the tuning circuits. In order to avoid having an excessively high voltage in the rotor, Goldschmidt placed a number of the rotor windings in parallel. Consequently the current flowing in the rotor was very high. A large number of brushes were put on to handle this current, but the current would not distribute itself equally between the various brushes. As soon as full load was put on, some of the brushes would heat and spark, while others would not. We soon found that because of the additional resistance of the particular circuit in which it was placed the impedance of that path would be considerably increased, and the brush in question would not take its share of the total current. Furthermore, if because of some unavoidable unevenness in the surface of the slip ring, one of the brushes was raised slightly, the current flow would not be interrupted, because the inductance of the circuit prevented a sudden change of current, the time constant, L/R, being large. As a result of this effect the slip ring would be burnt. A long time was required to find the necessary materials and design whereby these disadvantages were eliminated.

In addition, it was rather difficult to handle the currents outside of the machine. In usual power engineering the capacity of the windings of the machine to ground is of importance only in connection with certain transient phenomena such as occur when closing circuits or at a short circuit. This capacity plays a very important part in high frequency machines. A portion of the current which has been produced will escape to the ground thru this capacity without being usefully employed in producing the higher frequencies or being sent into the antenna. Under the worst conditions, the capacity to ground of the windings and the inductance of the iron paths from winding to winding or from windings to ground will combine to produce a resonant effect for currents of some one of the frequencies produced, with the result that the current itself will pass partly through the iron of the machine. In such a case it would be impossible to get the expected output even if the excitation be abnormally increased.

Excitation of the Alternator.

Because of the ease of handling it, direct current proved most suitable for use in excitation.

In radio telegraphy, it is necessary to vary the energy sent into the antenna rapidly in accordance with the signals (dots and

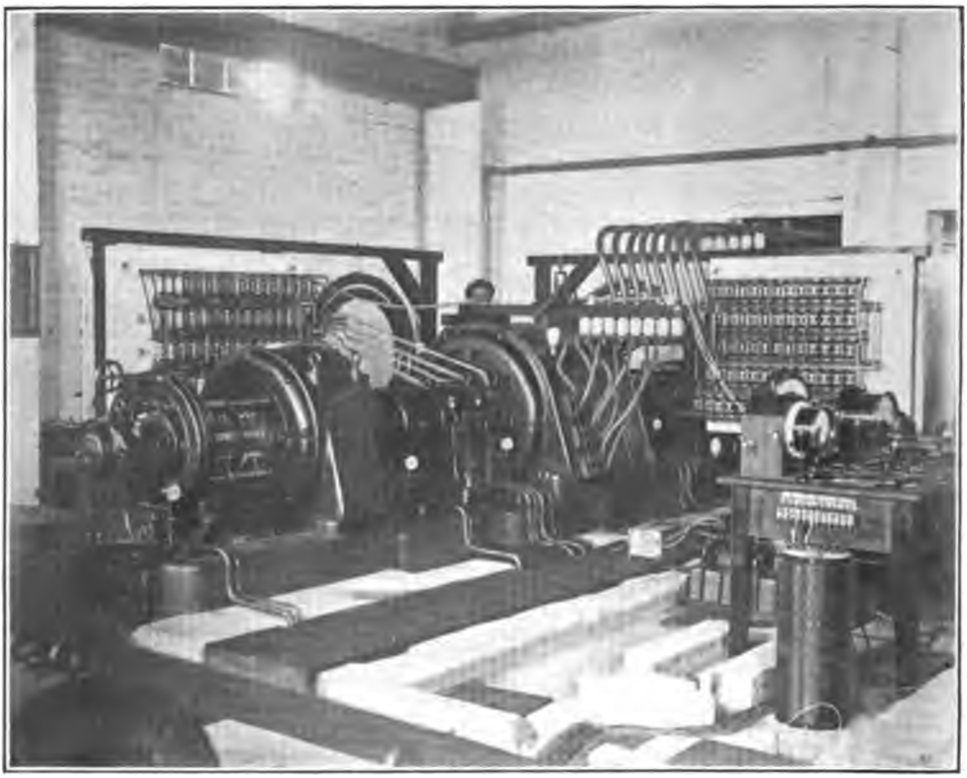

Figure 3—Goldschmidt 100 K. W. Radio Frequency Alternator.

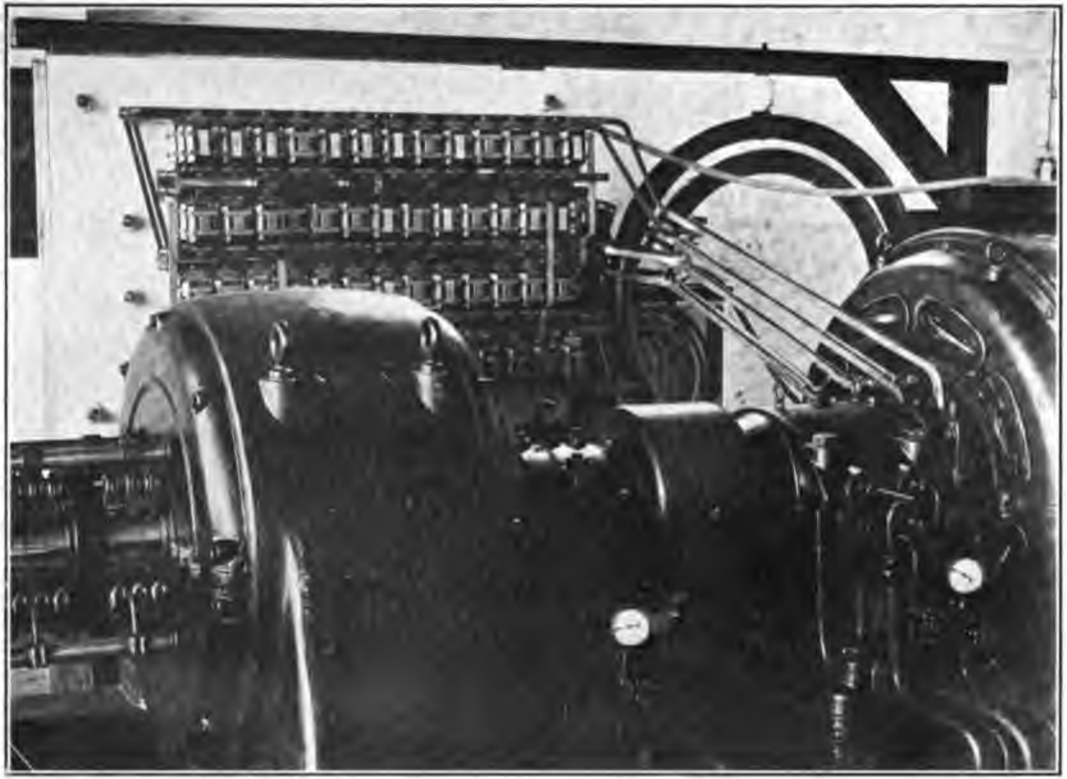

FIGURE 4—Driving Motor and Condenser Boards.

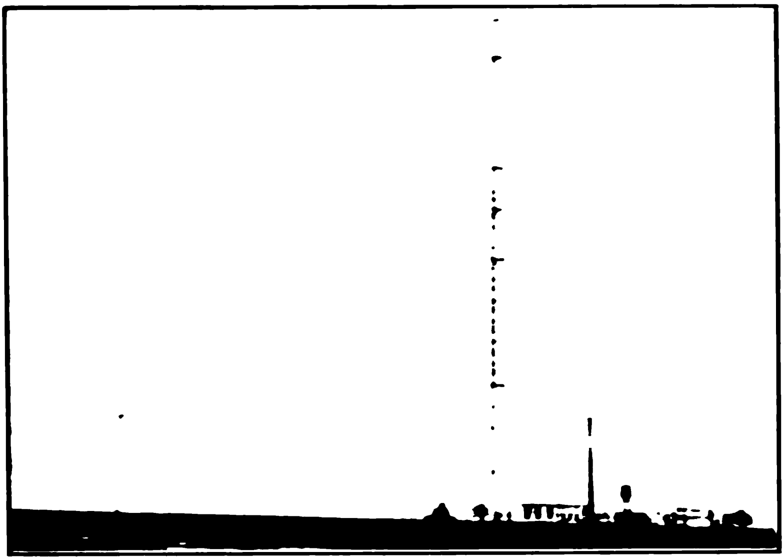

FIGURE 5—Tuckerton Radio Station. Showing 825 foot Steel Tower.

FIGURE 6—Tuckerton Radio Station Power House.

dashes) which are being sent. Assume, for example, an average speed of transmission of 30 words per minute, each word consisting of five letters of two signals each. We have, then, 300 signals, or 300 makes and breaks per minute. It is therefore vastly preferable to govern this energy flow in the exciter circuit, where the amount of energy to be controlled is so much smaller. The exciting energy is between 5 and 10 kilowatts for an output of from 100 to 200 kilowatts from the machine.

The phenomena which occur when the exciter circuit is closed are of interest. It is obvious that before reaching the final state, there will be damped oscillations having a time constant L/R.

FIGURE 7—Eilvese Radio Station Power House.

These free alternating currents are represented by an equation of the following kind:

$$i = I_m\left(1 - \epsilon^{-\frac{R}{L}t}\right)$$

We see that it is desirable to choose large capacities and small inductances for the tuning circuits, and that it might be advisable to insert additional resistance in the exciting circuit, or perhaps even in some of the other circuits to make the signals very distinct.

This might be the case for automatic transmission and automatic reception at high speed. With automatic transmission and

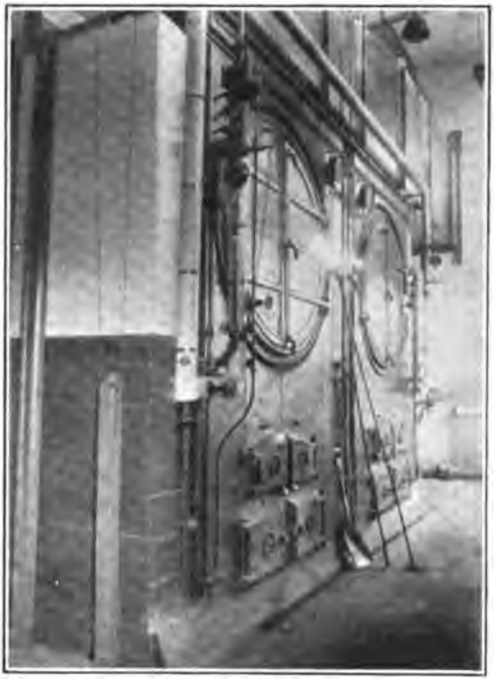

FIGURE 8—Tuckerton Radio Station Boiler Room.

FIGURE 9—Tuckerton Radio Station Dynamo Room.

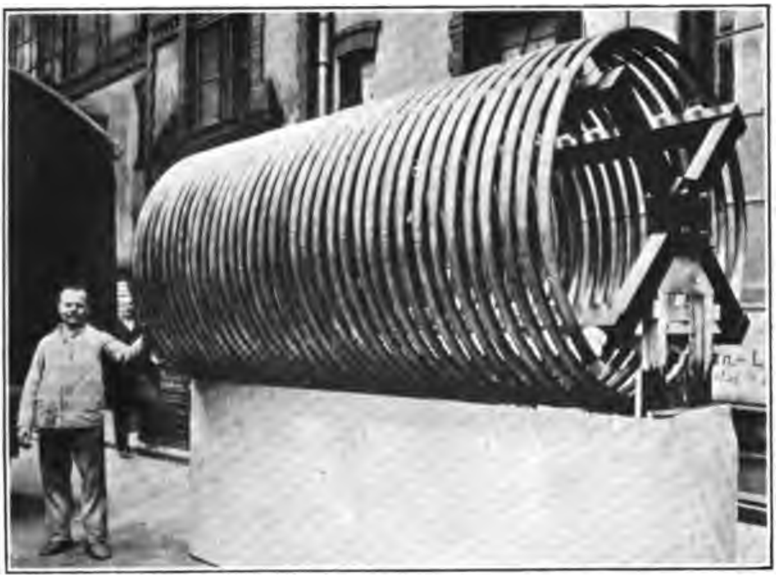

FIGURE 10—Antenna Loading Coil.

FIGURE 11—Base of Steel Tower Supported on Columns of Glass Insulators.

FIGURE 12—View Looking Up Steel Tower.

reception the number of makes and breaks per minute may be three times as great as in the case just described, and if the final state is not rapidly attained, the signals would not be distinct.

Trans-Atlantic Radio Communication.

Since April of last year, a Goldschmidt machine of maximum output of 200 kilowatts (normal output 100 kilowatts) has been in use at the German radio station at Neustadt-am-Ruebenbergen near Hanover, Germany. A point of interest in connection with this station, and also the nearly completed station at Tuckerton, New Jersey, is that they resemble a medium size power plant of the usual kind more than a typical station for radio telegraphy. The following illustrations of the machine and of the power house show this. (Figures 3 thru 9).

The antenna, with a loading coil of large dimensions, (Figure 10) is connected to the last tuned circuit of the alternator. The antenna output can therefore be readily measured by simply connecting a volt-meter across the antenna and ground, and placing an ammeter in the antenna. As an antenna, (Figures 5, 11, 12) we use a double cone wire system, consisting of thirty-six wires attached to the top of a steel tower 825 feet (250 meters) high. The outer ends of these wires are fastened to poles 40 feet (12 meters) high, which poles are placed in a circle around the tower, the radius of the circle being 1,500 feet (450 meters). The antenna itself is only about one-third of the length from the top of the tower to the surrounding circle of poles, and is supported by a chain of heavy saddle insulators. The tower is insulated from the ground, (Figure 11) and there is also an insulating joint in its middle. These separating insulators consist of a number of columns of glass insulators. Glass is used as an insulating material because it is satisfactory when used, as here, only under compression. The ends of the guy ropes which support the tower are fastened to reinforced steel beams which are sunk in heavy concrete foundations. They are shown in Figure 5.

It is unnecessary to describe the prime mover in detail. It may be of some interest to know that in Germany we use a 400 horse power "Wolf" engine which contains boiler and engine together. This engine meets the requirements of economical operation, small space required, and reliability of operation very satisfactorily.

The radio frequency machine is connected by means of a flexible coupling to a direct current motor, which draws its energy from two direct current generators in Ward-Leonard connection. By

Figure 13—Photographic Printer for High Speed Reception.

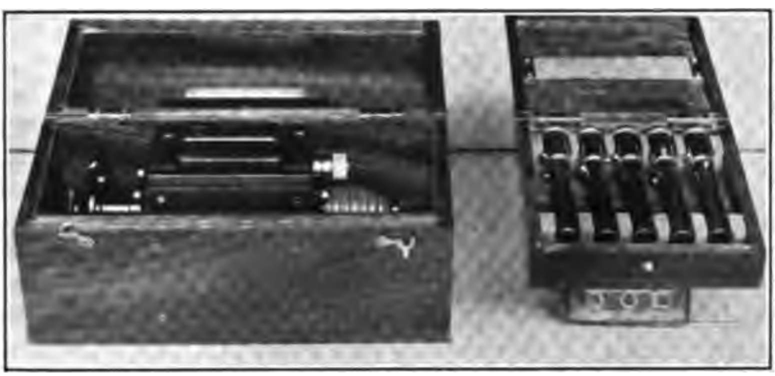

Figure 14—Vibrating Thread Cases and Holders for Photographic Printer.

FIGURE 15—Twenty-five Microhenry Inductance Coil Unit, 200 Amperes.

regulating the voltage of the two Ward-Leonard dynamos, ease in starting and convenience in speed regulation are obtained.

The motor, which was built by Messrs. Bergmann of Berlin, is somewhat out of the ordinary. It is a 4,000 revolutions per minute, 250 horse power, 220 volt direct current motor.

The inductances of the tuning circuits, which must carry currents of about 200 amperes, are made of tubing, and are partly of the cylindrical and partly of the spiral pan cake type. Experiment and theory agree, however in pointing to properly made cylindrical coils are preferable.

Quite a discussion has arisen concerning the possibility of satisfactory speed regulation for such machines employed for radio telegraphy under conditions of continuous and rapid variation from no load to full load. Certain individuals have feared that the inconstancy of speed might prove a serious drawback to the use of

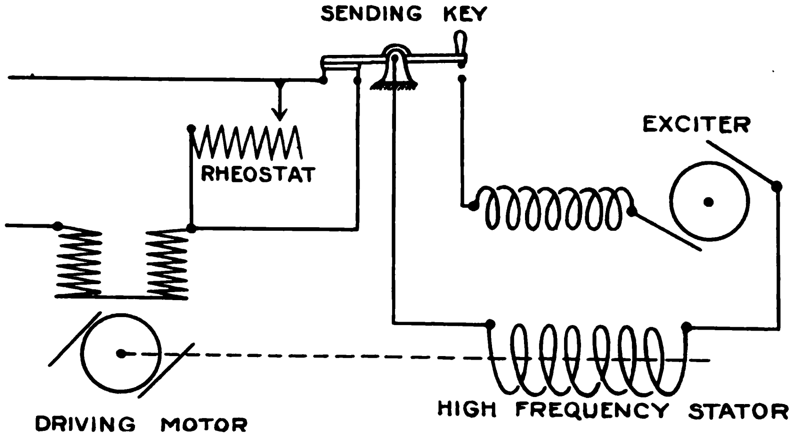

FIGURE 16—Speed Regulation Device for Driving Motor.

such alternators. Practice, however, has shown that speed regulation is really a very simple matter because of the influence of the enormous rotating masses which, thru their inertia, oppose any changes in speed. As an additional method of obtaining speed constancy, Professor Goldschmidt originated the design shown in Figure 16. While the sending key is open, a part of the field resistance of the driving motor is short circuited. This short circuit is broken when the key is pressed.

Theory shows that a slight variation in speed would, so far as transmission is concerned, have the effect of making the sustained waves equivalent to slightly damped waves. That is, the sharpness of tuning would be slightly impaired. However, we were unable to find any such effect in our tests.

RECEIVING APPARATUS.

An important portion of the Goldschmidt system of radio telegraphy is the receiving apparatus, of which the most novel and important portion is the tone wheel. This is the simplest form of frequency transformer that can be imagined, and yet has an exceedingly high efficiency. For normal telephone reception, the problem is the following. The incoming waves, of a frequency of about 50,000 cycles, are to have their energy so transformed as to give rise to alternating currents of audible frequencies, say between 250 and 3,000 cycles per second.

FIGURE 17—Sending Key.

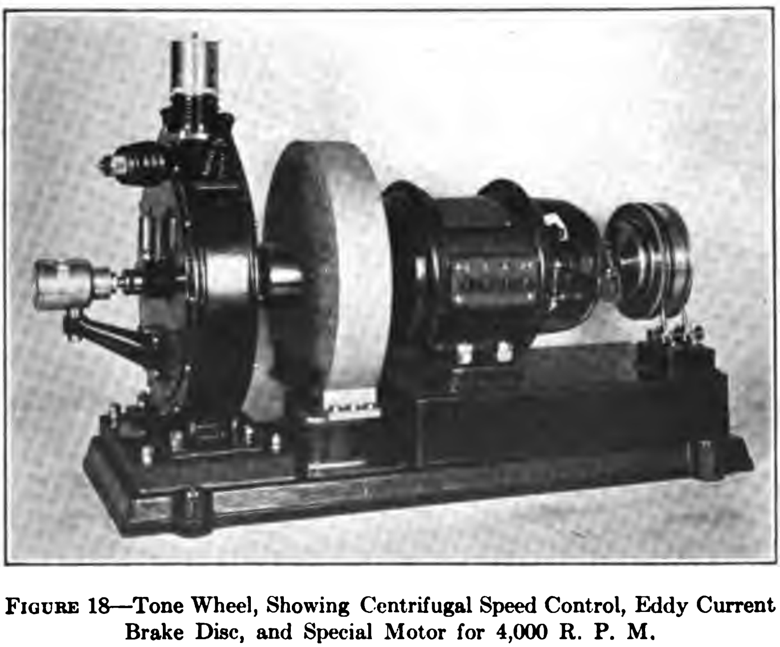

FIGURE 18—Tone Wheel, Showing Centrifugal Speed Control, Eddy Current Brake Disc, and Special Motor for 4,000 R. P. M.

The usual crystal, electrolytic, and magnetic detectors are capable of making only damped wave trains audible. For sustained waves, they react by giving a sort of click in the telephone receivers at the beginning and end of each incoming signal. The so-called "Tikker" of Waldemar Poulsen, a very sensitive detector for sustained waves, does not give a musical note in the receivers but only a sort of buzzing noise. Furthermore, it uses only a fraction of the incoming energy. The buzz produced is very similar to the sounds produced by atmospheric disturbances, (static) and make it very difficult to receive with the tikker if atmospheric conditions are unfavorable. The Goldschmidt frequency transformer transforms the incoming frequencies to a note of well defined frequency, and therefore gives a pure and musical tone. The principle of its operation is the following. A simple toothed wheel, acting as a make-and-break commutator, has such a number of teeth or poles that, at a reasonable speed its interruptions are synchronous with the incoming frequency. For example, 800 teeth on the wheel, and a speed of 3,750 revolutions per minute, would produce a frequency of interruption of 50,000 cycles per second.

The width of the teeth may be made equal to the width of the spaces between them. For the sake of simplicity in explanation, let us assume that the contact which slides on these teeth is merely a point (or line). If this device, running synchronously, is connected in any way to the receiving antenna, it will produce a pulsating direct current, for it will always make contact for just the length of a positive or negative half-period. The telephone diaphragm will not be displaced under the influence of this rapid succession of unidirectional impulses because of its mechanical inertia. Conse-

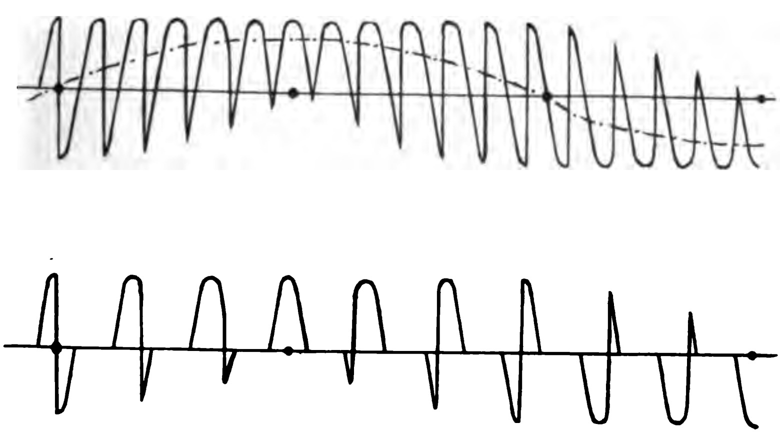

FIGURE 19—Current in Tone Wheel.

FIGURE 20—Ten K. W. Goldschmidt Alternator.

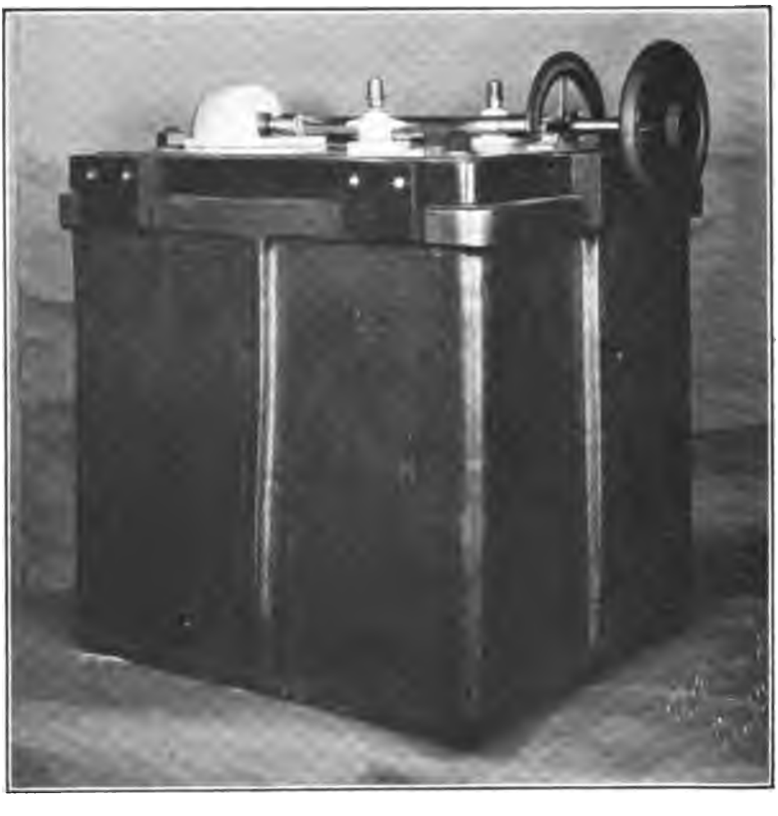

FIGURE 21—Antenna Variometer.

quently no sound will be heard. If now the speed be altered, so that the wheel runs slightly above or below synchronism, the full amount of energy of the positive half-period will be admitted to the receiver for only *one half period*, while for the next half period a smaller portion of the energy of the positive half period will be admitted. For each successive half period a smaller amount of the positive energy and a larger amount of the negative energy will be admitted, until, when the amounts of positive and negative energy admitted are equal, the telephone diaphragm will receive no net impulse at all. The amount of negative energy admitted will gradually increase from this time on, until finally all the energy of the negative half periods will be admitted to the telephone circuit. In other words, the telephone diaphragm is subjected to recurrent forces of the beat frequency, which latter may be easily adjusted to the sound of maximum audibility by altering the speed of the tone wheel. The current in the tone wheel circuit is shown in Figure 19. Higher harmonics, which will be superposed on the fundamental frequency, will be of small amplitude because of the large inductance in circuit, and will not affect the clearness of the note in any way.

It is not necessary to run the tone wheel at approximately its synchronous speed. The same effects will be produced if we run it at near one-half, one-third, etc., of its synchronous speed, with the only difference that a smaller portion of the incoming energy is transformed. The apparatus is very compact and convenient when used as a wave meter, for when synchronism is attained all sound disappears, and the wave length can be readily calculated from the number of teeth in the wheel and the speed of rotation.

Since this apparatus does not add to the losses of the telephone circuit, its energy efficiency is high and it permits very sharp tuning. It may be coupled electrically, inductively or capacitively to either the primary or secondary of the receiver, the choice being determined by the amount of interference to be avoided.

This type of receiving apparatus makes it possible to use a musical note which can be read through static, and also frees us from interference to a very large extent. A very slight difference in the wave length sent from an interfering station will be sufficient to produce an entirely differently pitched sound in the telephones when the tone wheel is used. Thus the interfering station can be readily distinguished from the desired one. An alternative method of procedure in avoiding interference is to alter the speed of the tone wheel to a point at which it is in syn-

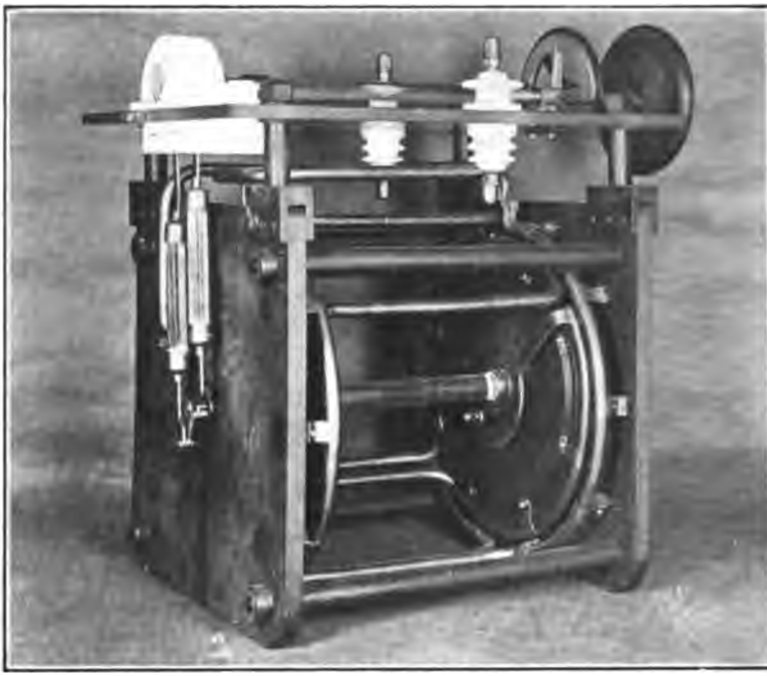

FIGURE 22—Antenna Variometer.

FIGURE 23—Receiving Room.

chronism with the undesired signals, which latter, as explained above, will then not be heard. The desired signals will however remain audible.

As an example of the application of this latter method, suppose we are receiving a wave length of 6,000 meters (corresponding to a frequency of 50,000 cycles). The tone wheel having 800 teeth will be at synchronous speed at 3,750 revolutions per minute. In order to get a high note in the telephones, we employ a slip of 1.5 per cent. thus running the wheel at 3,694 revo-

FIGURE 24—Receiving Set.

lutions. The note will therefore have a frequency of 750 cycles. Suppose that another radio station, working at a wave length of 6,100 meters should interfere. If the strength of the incoming signals in both cases is the same, it would be extremely difficult for operators using ordinary receiving sets to avoid this interference. They would be forced to use a very loose coupling, with the accompanying faint and doubtful signals. But with the tone wheel, there is no possibility of any interference at all. For the wave length of 6,100 meters, which corresponds to a frequency of 49,200, the synchronous speed of the tone wheel is 3,690. So that the tone wheel, which is running at 3,694, is just slightly above synchronism for the incoming interfering signals, and will therefore produce a current in the telephones of frequency of 50 cycles (0.1 per cent slip). This latter tone is below the limit of audibility.

Using the devices described above, we have been able to telegraph from Eilvese to Tuckerton, a distance of nearly 4,000 miles (6,500 km.) beginning in July of last year. Since that time we have been in communication, and have transmitted messages at different times of day and night, except for a few weeks, when, because of a break down in the antenna, we were not able to transmit. We found the same difference between day and night transmission which has already been remarked by others.

While it is not so large with the long waves as with short waves, the difference is still considerable. There is also a large difference in the strength of the signals received on different days, which leads naturally to the idea that there are reflection and refraction effects which sometimes aid and sometimes hinder communication.

But it may be confidently said that, whatever the conditions, the problem of reliable commercial communication between our stations is practically solved.

The Possibility of Radio Telephony.

In radio telephony, we find an interesting possibility of future development of the Goldschmidt system. Without discussing the question of the commercial value of radio telephony over long distances, I may say that we feel sure that the problem will meet an early solution. It is possible now to produce sufficient energy in an appropriate form. It is possible to control it, and it is very easy to receive it. A machine invented by Professor Goldschmidt, which, with very slight excitation, gives an extremely large output and so may be considered an amplifying or "trigger-control" generator, will certainly help to solve the problem. Its theory, together with some data obtained in tests, may be given in a future paper.

Tuckerton, New Jersey,
January 14, 1914.

DISCUSSION.

Robert H. Marriott: Transoceanic means of communication in addition to the cables are certainly desirable, and the radio station described evidently was designed with a view to approaching as nearly as possible to cable utility. I presume duplication of parts is contemplated to insure continuous service.

The development of high power generators for radio frequency, equal amplitude alternating current has been spoken of for some time as the solution of the problem of long distance radio communication and this paper describes stations which are believed to be beyond anything which has been done in this line.

The radiation of high power in the form of equal amplitude waves, as is accomplished by this machine, may take the place of the ordinary method of sending groups of waves of decreasing amplitude, because the ordinary method insuring high powers where the station is located near the track of vessels may interfere with communication with ships. And ship communication is not to be interfered with because it is relied upon for the saving of life.

The tone wheel is an unexpected instrument in that it apparently provides an efficient detector and an interference preventer in one.

I believe you will all admit that these stations are an engineering proposition. What would have been said twenty years ago if a man had stated he could connect one end of a conductor to earth, hold the insulated end 800 feet in the air, put 100 K. W. in that conductor, and use that arrangement for telegraphing 4,000 miles? I have prepared a chart which, I believe, will illustrate that these stations are in a way very large things. As you will note from Figure 1, there is considerable land as well as water between Tuckerton, New Jersey, and Hanover, Germany. If we assume that Tuckerton sends equally well in all directions, its messages must travel over an area which includes, as seen by the large circle 2, Hanover (Germany), Spain, Peru, Nome (Alaska), and the North Pole. Furthermore, it is well known that the range of a radio station varies. In order that this station may compete with the cable its minimum range must not fall below 4,000 miles for any very great part of the time; which means it must reach much further under the best conditions. I have found by some hundreds of tests that shorter waves of rapidly decreasing amplitude, such as were used by vessels, give rise to a range variation somewhat as shown in the smaller circles in Figure 2. That is, the range of these small stations is about ten times as great at

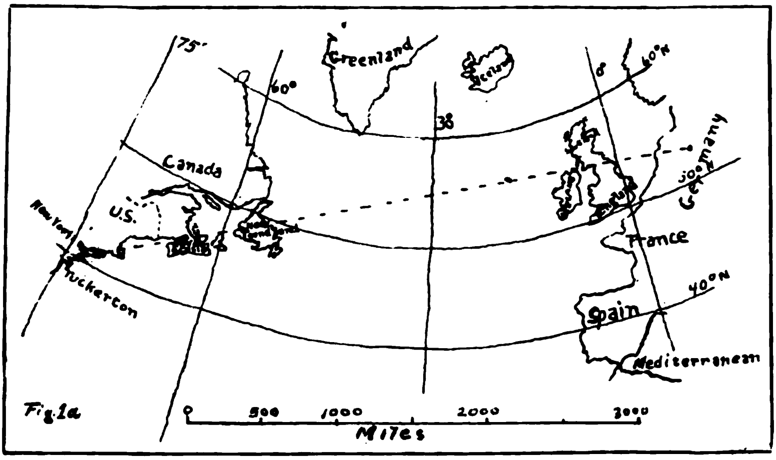

FIGURE 1.

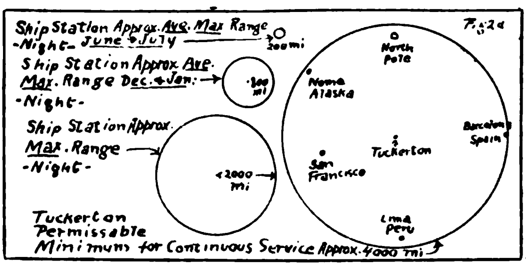

FIGURE 2.

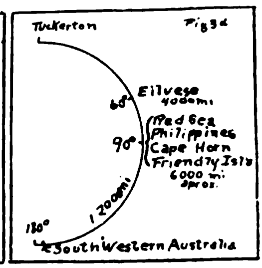

FIGURE 3.

night under the best winter conditions as it is under the average July day conditions. Ten times the normal Tuckerton range is 40,000 miles. If, on the basis of diminished variation with long equal amplitude waves and less total atmospheric variation over very long ranges, we discount this 40,000 mile range seventy per cent., we still have a possible range of 12,000 miles, which is half way around the earth. That is, Tuckerton under favorable conditions may be capable of transmitting as far as any station will transmit, so long as transmission is confined to this earth. Southwestern Australia is nearly opposite Tuckerton, and there are radio stations in that locality which possibly could be used with kites for such an experiment.

Time and news are now sent to many receiving stations in areas two thousand miles or more in diameter, and some of these receiving stations have cost but a few dollars. We may be very near to a time when news will be sent from one or two stations to a great many inexpensive receiving stations scattered all over the world.

E. F. W. Alexanderson: The development of the Goldschmidt alternator represents a masterful application of the principles of alternating current design. The difficulties that must have been encountered can best be appreciated by those who have done work along similar lines. When, on the instigation of Prof. Fessenden I took up the development of a 100,000 cycle alternator on behalf of the company with which I am connected, the difficulties encountered seemed to be almost insuperable, and a number of models had to be discarded before a practical machine was produced. The Goldschmidt alternator works on an entirely different principle. It might be said that the Goldschmidt alternator is equivalent to such dynamo machines as the induction motor, where the active field is produced by the armature reaction of the winding itself; while the 100,000 cycle alternator, to which I referred, is equivalent to the salient pole alternator, the field being produced by the shape of the pole pieces and the armature reaction being incidental. In the 100,000 cycle alternator the winding pitch is only 1–16 of an inch (1.5 mm.), and it is, therefore, evident, that the armature reaction can play no considerable part in creating the active field. In the Goldschmidt machine, on the other hand, the winding pitch is 1 centimeter, as we have been told.

It is difficult to come to an understanding of the two working principles without comparing them on the basis of the same frequency. When a machine is designed for 50,000 cycles, the problem is in many ways easier. For instance, a 200,000 cycle alternator, which has been built, has so small a pole pitch that a special winding had to be devised with less than one slot per pole. If the same principle is applied to a 50,000 cycle machine we get a winding pitch of one-half centimeter, which is not so far from the dimensions of the Goldschmidt machine, and the same principle of reducing the number of slots can be carried still further. Thus we will deal with structures of substantially the same dimensions.

The difference is in the method by which the pulsation in the magnetic field is produced. One machine has a rotor made as a solid disk, designed for high speed, while the other must be operated at a lower speed because the rotor supports laminations and windings.

For those who are familiar with the parallel operation of ordinary alternators, it may be of interest to know that the machine with which I am familiar can be synchronized, and operated in multiple, and it is worth noting that the constants which apply for parallel operation for ordinary machines apply to the same degree to a 100,000 cycle machine; in other words, the relation between reactance and resistance must be within certain limits, in order to insure stable operation. In connection with this subject I would ask whether it is possible to operate the Goldschmidt alternators in multiple. On general principles, it ought to be possible with any alternator, but with the rigid requirements of tuning in order to multiply the frequency, it is conceivable that these limitations would be outside the limitations of multiple operation.

I can confirm the statement in the paper that it is perfectly feasible to regulate the speed with sufficient accuracy for radio communication. In tests made with a receiver working on the Fessenden Heterodyne principle, by creating beats between two frequencies, it has been ascertained that the frequency can be kept so constant that no appreciable fluctuations are heard in the tone produced by the difference between the two frequencies.

I am much interested in what was said in the paper about the alternator for radio telephony. I demonstrated a number of years ago a trigger alternator for that purpose. It was built for 15,000 cycles and excited by telephone currents. In order to produce the necessary excitation, with as small an amount of energy as possible, a winding was used in which the same conductors served as a magnetizing winding and as an armature winding for the generated current. The results produced by this trigger alternator were very satisfactory. We obtained good articulation and large amplification, but another device was then developed which was more promising for this particular purpose. The object of this latter is to control the output of the radio frequency alternator in the same way as it might be controlled by regulation of the field strength. The controlling device is built like a transformer, with two magnetic circuits and two electrical circuits interlinked in such a way that there is no mutual induction between the two windings, but the exciting circuit controls the inductance of the radio frequency circuit by varying the iron core saturation. The current which can pass through the radio frequency coil is proportional to the exciting current. This device thus makes it possible to use an alternator with a solid field, and to get the same results as if it had a laminated field and were controlled by regulation of the field strength.

While it has proven possible to build radio frequency alternators of considerably higher frequency than the one described, and while there is every reason to think that other machines can be built in equally large units, the accomplished fact that an alternator as large as the one described has been successfully completed has given an impetus to radio communication by the continuous wave system. For this, we must congratulate the inventor, for this invention will undoubtedly prove of benefit to all those who are working along similar lines.

Lee de Forest: The paper is particularly interesting to me, because for two years I was associated with the development of another method of producing continuous oscillations: the development of the Poulsen arc for radio frequencies; and I should like briefly to sum up what occurred to me as the points of distinction between the two methods and the parallel advantages and disadvantages.

In the Goldschmidt machine the disadvantages are high cost and the necessity for absolute constancy of speed (tho the latter problem has now been sufficiently solved), complication of circuits and the constructions involved by them, and especially the lack of flexibility for changes of wave length. You will realize that in long distance radio telegraphy it is very important, at times, to be able to change the wave length very suddenly, because of the "selective absorption" by reflection from the outer atmosphere. In California we found, using certain wave lengths, that the intensity of signals changed from, say, 40 times audibility to 2 or 3 times audibility, and this effect appeared sometimes within a period of four or five minutes, generally near twilight. At the same time the "compensation wave," the wave length of which varied from that of the first by not more than 5 per cent., did not decrease to any such extent. Sometimes it was found to be increased in intensity. At such times, therefore, it is important to change the wave frequency very quickly. Such a change in frequency with the Goldschmidt system of circuits can not be made very readily, I believe.

Naturally, an apparatus as beautifully built and as costly as this would require higher salaried operators than the much simpler arc apparatus. Then again, the key control is limited to one wave length. I mean that one cannot change the wave length with the key as is done with the Poulsen system, but that signaling is done by controlling either the output direct, or the field excitation (and simultaneously the excitation of the motor, so that there will be no change of speed).

With the Poulsen arc, the disadvantages are the necessity for occasional changes of the carbon electrode, the attention which that requires on the part of the operator (who need be by no means exceptionally skillful), and the gas and water cooling supply. This latter, of course, is not a particular complication. The arc has probably a lower efficiency than the Goldschmidt alternator, altho in connection with that I will say that the efficiency of the large Poulsen generators has been increased from 20 per cent. to 60 per cent. during the last three years. This valuable work has been done entirely by American engineers.

Among the advantages of the Goldschmidt alternator are particularly the constancy of operation, for there should be no change whatever in the wave length or power output due to speed variation. This criticism, however, does not now apply to the larger Poulsen arcs, because the accidental changes in wave lengths are usually small and insufficient to interfere with the energy of the radiation. The larger power of the Goldschmidt alternator (at present 150 kilowatts in the antenna) has not yet been equalled at any Poulsen station. Sixty kilowatts in the antenna has been attained in the South San Francisco station. But one principal advantage of the Poulsen system is the utmost simplicity of the oscillating circuit, and that no condenser except that comprised by the antenna and earth is required. It is perfectly easy to change the wave length within reasonable limits instantly by simply throwing a switch. Ease of key control in the Poulsen system is a favorable factor. The key controls and short circuits a certain amount of inductance in the transmission antenna, and this permits both a sending wave and a "compensation wave," so that it is perfectly simple to transmit on either one at will merely by throwing a switch at the key itself. This double wave also adds to the secrecy of transmission. Amateurs, who are not equipped with refined apparatus for cutting out interference and tuning properly, especially on the long wave lengths, are generally baffled. This element of secrecy does not, of course, apply to stations equipped for reading either the Goldschmidt or the Federal stations. Both the Goldschmidt and Federal companies' systems represent great strides beyond all methods of transmission by sparks with slowly damped wave trains. But I do not think either of these systems is the last word in radio transmission. Apropos of the amounts of energy radiated, I would say that in Washington and in New York messages are now being received daily both from Hanover and from South San Francisco. The power at Hanover is 150 kilowatts in the antenna and at South San Francisco about 60 kilowatts, and I am credibly informed that the signals from South San Francisco are considerably stronger than those from Hanover. At night we get signals from an arc station at Honolulu using 25 kilowatts and practically 6,000 miles away (or a quarter of the earth's circumference) with surprising loudness.

John Stone Stone: Besides the very unusual and interesting dynamo described in this paper, the paper has considerable interest, as showing the extent of the very rapid evolution of the art of radio-telegraphy in two particulars:

1st. The increase in wave lengths used, and

2d. The gradual but rapid departure from the highly damped wave trains of the early open spark systems, first to the more persistent wave trains of the quenched spark system and finally to continuous or undamped wave trains.

I notice that the author regards both of these features as advantageous, but I am inclined to believe that so far as the enormous increase in wave length described in this paper is concerned, he is making a virtue of necessity, since the difficulty of constructing a dynamo to produce directly currents of more than 50,000 cycles at a capacity of 100 K. W. or more is at present evidently well-nigh insurmountable.

If the wave length used at the station described, with its gigantic antenna, had been that corresponding to the fundamental of the antenna, or approximately 1,500 meters, instead of 6,000 meters, the radiating capacity of the antenna for given antenna current would have been 16 times greater, and what is perhaps more important, the receiving or absorptive power of the antenna of distant receiving station would also have been increased 16 fold. Furthermore, this is but one of the numerous advantages that would follow from a decrease of the wave length. But to obtain a wave length of 1,500 meters would require a current having a frequency of 200,000 cycles.

On the other hand, there is no question of the great advantages which result in the use of continuous or undamped wave trains. There is not sufficient time now to enumerate these. I feel that the continuous wave train has come to stay, while I believe that the wave lengths developed at high power, long range stations must eventually be reduced to as near the fundamental or natural wave length of the antenna at such stations as is practicable.

If the continuous or undamped wave train is destined to completely supercede the damp wave trains, as I believe it is, this does not mean that high frequency dynamos will nescessarily be used to supply the electrical energy at the frequency radiated. I say this for the reason that the antenna of the average radio station is incapable of radiating or absorbing any practically effective amount of energy per second at wave lengths of three thousand meters or more, while this is the shortest wave length that a dynamo of more than a small fraction of a K. W. capacity has been able to generate. Moreover, when we consider the enormous gyroscopic force of the rotor in either the Goldschmidt or the Alexanderson dynamo, we see that the use of such high frequency dynamos on board ship is out of the question, as either of these machines would tear itself to pieces, if operated at full speed on anything but a practically immovable foundation. In this connection it is to be remembered that a majority of the radio stations is to be found on board ships. Further, in this connection, ships' antenna systems are necessarily entirely too small to radiate or receive energy effectively at a frequency of the order developed by high frequency dynamos.

It seems as if in spite of the great skill and originality displayed by Goldschmidt, Alexanderson and others in designing high-frequency dynamos, we should, nevertheless, ultimately be forced to use the undamped oscillator of the general type first suggested by Elihu Thompson in 1892, or thereabouts. I understand that a modified form of such an oscillator with a capacity of 100 K. W. has been used with some success recently by the Federal Telegraph Company on the Pacific Coast in telegraphing from San Francisco to Honolulu and to ships on the Pacific Ocean. This oscillator is practically unlimited as to the frequency of the current it can generate.

John Stone Stone (by letter): The high frequency dynamo of this paper resembles a dynamo I designed some fourteen years ago, and differs from it chiefly in that my dynamo had no winding on the rotor. In fact my dynamo had but one winding, which served both as field and armature winding.

In its simplest form, illustrated in Figure 4, the machine develops, on open circuit, an e.m.f. comprising a fundamental *and all the odd* harmonics, but the instant you begin to draw a current corresponding to one of these *odd* harmonics, say of the frequency n, there immediately springs into existence in the e.m.f. of the machine, *all the even* harmonics of the fundamental, but chiefly, the even harmonics of the frequencies $n-1$ and $n+1$.

The elementary theory of this early machine of mine is very simple, and because there is no winding on the rotor, there is a minimum of magnetic drag or transverse field, so that the elementary theory gives a much closer approximation to the actual behavior of the machine than could be expected of an elementary theory of the Goldschmidt dynamo. Nevertheless this elementary theory of my simpler machine does not differ materially from that of the Goldschmidt dynamo described by Mr. Mayer and sheds considerable light on the behavior of the Goldschmidt dynamo. For that reason I venture to touch upon it here.

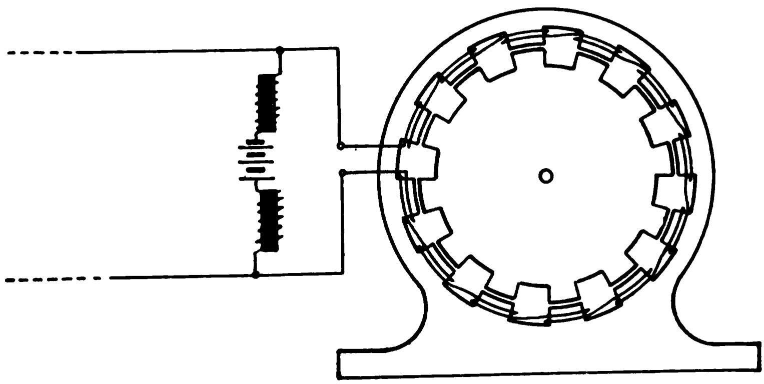

FIGURE 4.

The approximate value of the permeance per pole of the machine, as it varies with time, is given graphically by the zig-zag full line (1) of Figure 5, and analytically by the cosine series.

$$P = P_0 - P_1 \left(\cos \omega t + \frac{1}{3^2} \cos 3\,\omega t + \frac{1}{5^2} \cos 5\,\omega t \ldots\ldots\right)$$

in which $\frac{P_0}{P_1}$ is but slightly greater than unity.

If I_0 (full line 3 of Figure 5) be the constant unidirectional exciting current, the total excitation flux per pole will be

$$\phi_0 = \Phi_0 - \Phi_1 \left(\cos \omega t + \frac{1}{3^2} \cos 3\,\omega t + \frac{1}{5^2} \cos 5\,\omega t \ldots\ldots\right)$$

where $\Phi_0 = 4\pi N I_0 P_0$

and $\Phi_1 = 4\pi N I_0 P_1$

N being the number of turns of the winding per pole.

This flux ϕ_0 may be represented graphically by the same zig-zag line (1) of Figure 5, if, as in the case of the particular

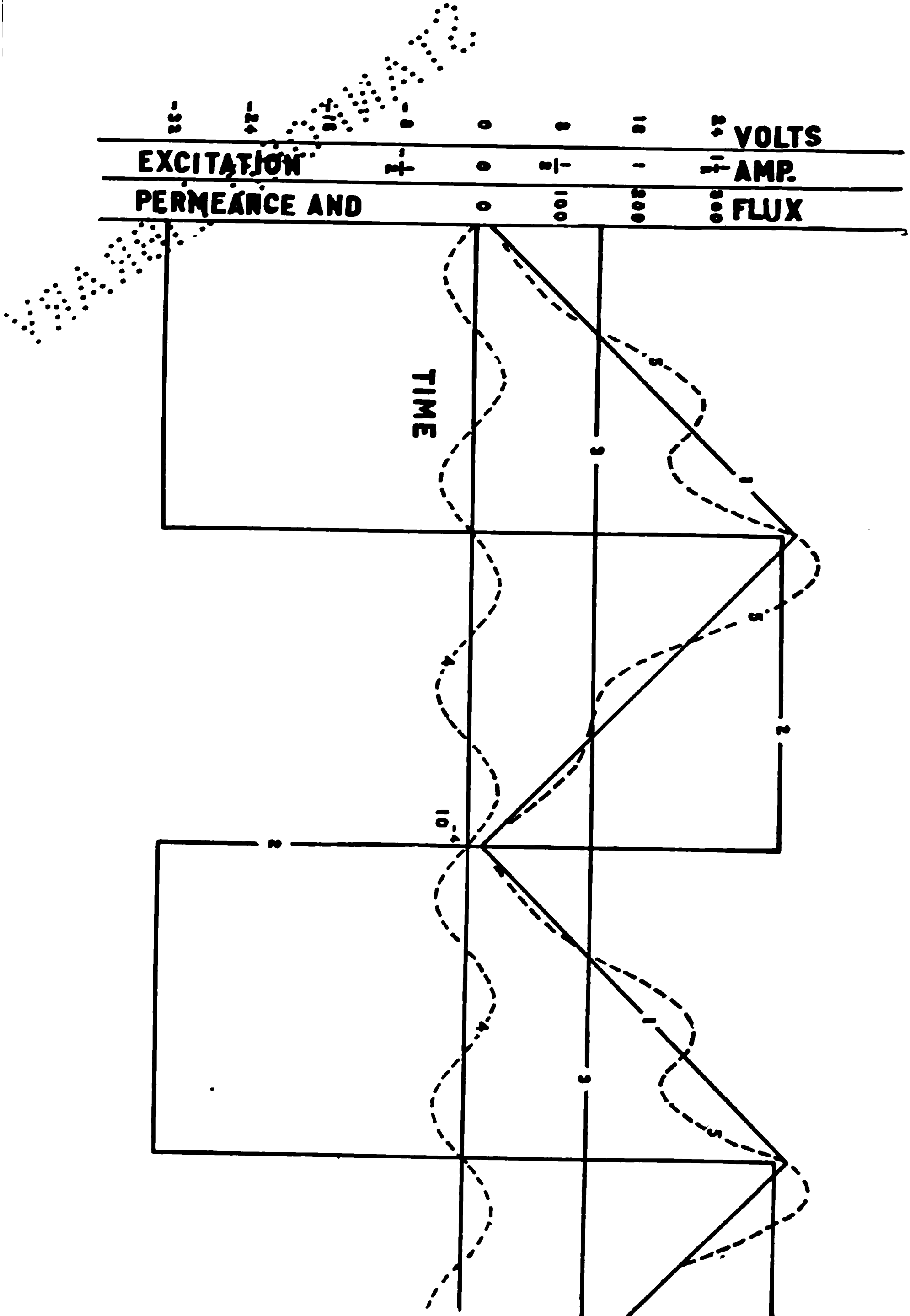

FIGURE 5.

machine therein illustrated, the magnetomotive force of excitation per pole is unity.

The induced e.m.f of the machine on open circuit will be represented by the succession of rectangles of the full line (2) Figure 5, and analytically by the expression

$$e_0 = -E_0 \left(\sin \omega t + \tfrac{1}{3} \sin 3\,\omega t + \tfrac{1}{5} \sin 5\,\omega t \ldots\ldots\right)$$

But let us now see what happens when we draw off a current from this machine. Suppose we draw off a current of periodicity 5ω and of that periodicity only. Further, for the sake of simplicity, suppose we so adjust matters that the current is in phase with the e.m.f. engendering it. Let us call this current—$I_5 \sin 5\,\omega t$, then the magnetomotive force per pole due to it will be —$F_5 \sin 5\omega t$ where $F_5 = 4\pi N I_5$. The flux per pole due to this current will be

$$\phi_5 = -F_5 P_0 \sin 5\,\omega t + \tfrac{1}{2} F_5 P_1 (0.04070 \sin 2\,\omega t + 0.9877 \sin 4\,\omega t + 0.9918 \sin 6\,\omega t + 0.1052 \sin 8\,\omega t + 0.0356 \sin 10\,\omega t \ldots\ldots)$$

This shows the importance of the *even* harmonics introduced by permitting a current to be developed of a frequency of one of the *odd* harmonics of the fundamental. We see that of the even harmonics only the components of periodicity 4ω and 6ω are of much importance. These even harmonics will give rise to voltages in the windings of the machine and the question immediately suggests itself, what will result from permitting a current to flow which has the frequency of one of these even harmonics? What will its effect be on the e.m.f. of periodicity 5ω? Will it help or will it hinder the machine in developing a current of periodicity 5ω? Let us draw a current—$I_4 \sin 4\,\omega t$. Then the flux per pole due to it will be

$$\phi_4 = -F_4 P_0 \sin 4\,\omega t + \tfrac{1}{2} F_4 P_1 (0.07111 \sin \omega t + 0.9796 \sin 3\,\omega t + 0.9876 \sin 5\,\omega t + 0.1028 \sin 7\,\omega t \ldots\ldots)$$

From this expression we see that, other things being equal, drawing off a current of periodicity 4ω increases the e.m.f. of the machine at periodicity 5ω and that in order to increase the output at periodicity 5ω it is desirable to draw off a current at both periodicities 4ω and 6ω.

Further consideration of the subject along the same lines shows that drawing off currents of frequency corresponding to the fundamental and to each of the harmonics, assists in the development of the e.m.f. of any one of the other harmonics.

A good deal that is of interest, in a quantitive way, can be dug out of such an elementary theory of these machines.

Of course on open circuit, even my machine shows slight even as well as pronounced odd harmonics in its E.M.F. These even harmonics are due to hysteresis and to eddy currents. Since each of those phenomena produces a lag in the change of flux of the rotor, they make the machine act exactly as if there were a winding on the rotor and small currents were being drawn from this second winding, one corresponding to each of the odd harmonics.

The resonant circuits used to draw off the component currents in the case of such machines should each have sufficient selectivity $\sqrt{\frac{L_n}{C_n R_n^2}}$ to prevent the passage through it of any appreciable amount of current of a frequency different from n, namely that which the circuit in question is designed to draw from the machine, but it should not *per se* be resonant to the frequency n, of the current it is designed to pass. It should have, for such a current, a negative reactance equal to the positive reactance of the winding of the machine for that frequency.

The values of the auxiliary inductances of these branch circuits do not affect the various components of the voltage of the machine in the same way as does the inductance due to the leakage flux of the machine and we may therefore safely conclude that they do not act as a simple loose coupling between the two circuits of the Goldschmidt dynamo to reduce the number and magnitude of the harmonics developed, as has been suggested by Professor Pupin. They exert no harmful effect. In this connection it is to be noted that there is a separate inductance coil and condenser in each tuned branch circuit.

In Figure 5, the dotted line 4 illustrates a current of periodicity 3ω drawn from the machine, and the dotted line 5 illustrates the resulting modification of the flux when the amplitude of the current corresponding to the third harmonic is one-fourth the value of the excitation current (3) of Figure 5.

On the occasion of the presentation of Mr. Mayer's paper before the American Institute of Electrical Engineers and the Institute of Radio Engineers, Professor M. I. Pupin discussed the Goldschmidt alternator critically. He drew certain conclusions as to the maximum efficiency of such machines as limited by magnetic leakage between rotor and stator and the effective resistance of the machine. He further claimed priority in the development of the theory of such machines. According to Professor Pupin, the tone wheel was analogous to the "heterodyne" receiver, being based on the beat principle, whereby thru the interaction of tones of inaudible frequencies a note of audible frequency is produced.

Because the stress of other duties prevented him from giving the necessary time to the revision of his discussion, Professor Pupin requested the Editor to withdraw it from publication. This has accordingly been done.

A portion of the answers by Professor Goldschmidt and Mr. Mayer are however published, for the technical information of the readers of the PROCEEDINGS.—(EDITOR'S NOTE.)

Dr. Rudolph Goldschmidt (by letter to Mr. Mayer): . . . I was very pleased to hear that so prominent a man as Professor Pupin has become interested in my invention, especially as he himself has studied the problem of the production of very high frequency energy by the reflection principle. Since he has stated that a great variety of higher harmonics are obtained in the circuits, I believe he has not applied the actual principle of my invention, which involves, as you know, the building up of the highest frequency energy by providing paths of minimum impedence for all the lower frequencies. This latter method is the only one which makes these machines practicable. I think you would do well to invite Professor Pupin to see the machine working at Tuckerton. I have no doubt that he will be convinced that not only is the principle correct but also that the machine works perfectly as a whole. It will further be evident to him that any amount of power can be obtained by simply increasing the dimensions, as with any ordinary dynamo.

At the same time Professor Pupin may satisfy himself that the method of reception of signals by means of the tone wheel is not at all related to the method of reception involving beats and tone production in the telephone receiver used in conjunction with a crystal rectifier. The tone wheel is an actual frequency transformer, which directly changes the radio frequency energy into audio frequency energy.

(Mr. Mayer has informed the Editor that an invitation to visit the Tuckerton station was sent Professor Pupin on May 27, 1914.)

Mr. Emil Mayer (by letter): I wish to express my regret that, because of the late hour at which the original discussion on my paper terminated, it was not possible for me to answer the speakers on that occasion.

. . . It has been stated by Professor Pupin in connection with his claims to priority that higher harmonics are produced in a simple closed circuit rotating in a magnetic field. These harmonics are undoubtedly present, but this is far from being the principle of the Goldschmidt alternator. No doubt there are higher harmonics of all values produced when the field is not sinusoidal but of such space or time distribution that, when analyzed, these upper frequency components of the field would be discovered. But of all these frequencies, the Goldschmidt alternator uses *only the fundamental.* And if it were possible to produce by direct current excitation a field such that only this pure fundamental frequency were present in the first circuit, a Goldschmidt alternator of maximum efficiency would be obtained. The machine conceived by Professor Pupin must therefore be entirely different in nature from the Goldschmidt alternator.

As has already been pointed out in this paper, magnetic leakage is a serious factor in limiting the output of all radio frequency alternators. But it is in just this respect that we find one of the advantages of the Goldschmidt principle, for Goldschmidt is able to design his alternator for a much lower frequency than the one which is radiated. A smaller number of poles is therefore required, and accordingly a very much lower magnetic leakage is secured. As a matter of fact, the experimentally determined ratio of exciting direct current to final antenna current after a fourfold frequency transformation is one to one if the antenna resistance is not higher than 6 ohms. This shows that the magnetic leakage cannot be excessively large.

. . . It has been claimed by Professor Pupin that an exact theory shows that all the lower frequencies exist in their full strength. . . . This is not the case. On the contrary, the exact mathematical theory enables us to calculate in advance what must be the constants of the different circuits (inductance, resistance, and capacity), in order that the lower frequencies shall cancel absolutely. The very simplest experimenting with such alternators as these shows that the addition of any one of the higher frequency circuits markedly reduces the lower frequency currents, provided that correct tuning methods are employed. This same reduction applies, naturally, to the corresponding lower frequency magnetic fields, and consequently to their respective hysteresis and eddy current losses. . . . The extent to which these losses are reduced is perhaps best shown by the fact that with 150 kilowatts input for the driving motor, an antenna current of 150 amperes is obtained while a rapid succession of dots and dashes were sent.

That the tone wheel depends on the beat principle may be positively denied. Beats are produced if two frequencies of nearly the same value are combined. In the case of the tone wheel, there is energy of only *one* frequency present, and this energy, by purely mechanical means, is changed into an audible form. There are no beats produced. . . .

In answer to Mr. Alexanderson's question as to the feasibility of running Goldschmidt alternators in parallel, it is possible to respond affirmatively. So long as the driving power is reasonably constant this can be done. In an alternator of this kind, the "synchronising force," that is, the available energy which corrects discrepancies from the "in phase" position of the moving parts of the machines when the driving power of one of the machines changes slightly, is comparatively low. The reason for this is that the rotating masses are very large in proportion to the output per pole.

I agree heartily with Mr. Alexanderson's statement that it is not difficult to keep the speed of these machines constant. The trigger control devices which Mr. Alexanderson described seem to me very ingenious, and I should be interested to learn more of them.

A few remarks may be added to Dr. de Forest's summary of the relative advantages and disadvantages of the Goldschmidt and Poulsen systems. He has overestimated the trouble required to keep the alternator speed constant and the amount of skill required on the part of the operator. All the operator has to do is press a key and watch the ammeter. These duties are no more difficult than removing arc electrodes, etc. Dr. de Forest has also overestimated the difficulty of changing wave lengths quickly. Using the Goldschmidt alternator, it is very easy to arrange matters so that such changes of wave length can be secured by merely throwing over a few switches and increasing or decreasing the speed of the machine. Naturally the adjustments must be properly made in advance, and not more than two or three given wave lengths will, in general, be available.

So far as over-all efficiency in operation is concerned, a great advantage of the Goldschmidt system is that in the interval between signals the full energy is not radiated unnecessarily. Control of the radiated energy is by means of the exciting current, which is made and broken, so that between signals the machine is running at approximately no load. As to the comparative loudness of the signals received from San Francisco and from Hanover in Washington and New York, there may be some special reason for this effect applicable to these latter stations only. At Tuckerton, however, the signals from Hanover are very much louder than those from San Francisco.

As Mr. Stone has said regarding the best wave length for long-distance service, there is no doubt that for trans-Atlantic work there is a minimum absorption and a maximum efficiency of transmission at a wave length which is considerably higher than that naturally radiated by our antenna. Whether or not this most desirable wave length is above or below the one we are now using remains to be determined. Which ever, however, it will be readily possible by certain mechanical devices to work at the desired frequency with, perhaps, a slight diminution of over-all efficiency.

Since the date of the opening of the Tuckerton station, it has been successfully received at Eilvese with sufficient strength to permit the use of a photographic recorder (Einthoven thread galvanometer), according to information received by the Editor.—(Editor's Note.)