

EXCERPTS:

IV. Apparatus for Transformation by Condenser Discharges; Damped Waves

Tesla

This work [Fig. 31] was begun already in 1889. This type of apparatus is identified with my name as certain as the law of gravitation is with that of Newton. I know that some have claimed that Professor Thomson also invented the so-called Tesla coil, but those feeble chirps ne'er went beyond Swampscott. Professor Thomson is an odd sort of man; very ingenious, but he never was a wireless expert; he never could be. Moreover, it is important to realize that this principle is universally employed everywhere. The greatest men of science have told me that this was my best achievement and, in connection with this apparatus [referring to schematics of Fig. 31], I may say that a lot of liberties have been taken. For instance, a man fills this space [break D] with hydrogen; he employs all my instrumentalities, everything that is necessary, but calls it a new wireless system -- the Poulsen arc. I cannot stop it. Another man puts in here [referring to space between self-inductive lines L L] a kind of gap -- he gets a Nobel prize for doing it. My name is not mentioned. Still another man inserts here [conductor B] a mercury[-arc] rectifier. That is my friend Cooper Hewitt. But, as a matter of fact, those devices have nothing to do with the performance.

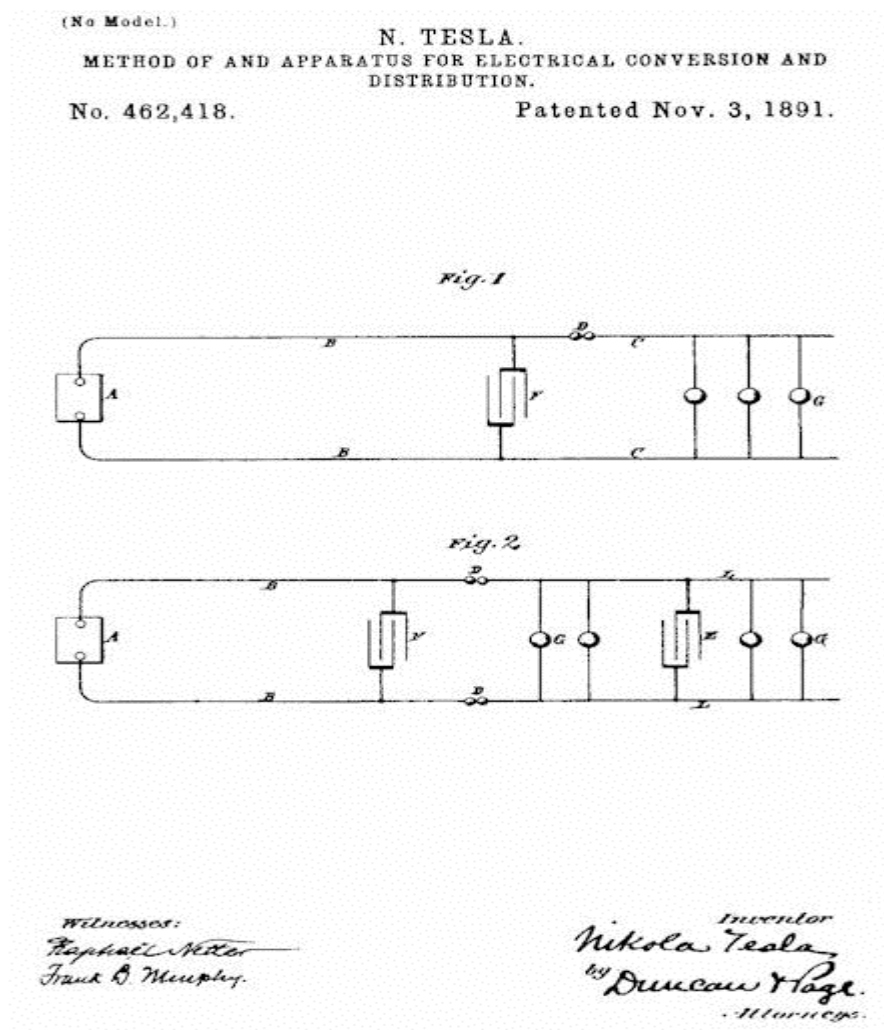


Figure 31. Method of Transformation of electrical energy by oscillatory condenser discharges described in U.S. Patent No. 462,418 of November 3, 1891. Application filed February 4, 1891. Announcement of this invention was made in Tesla's

lecture before the American Institute of Electrical Engineers at Columbia College, May 20, 1891, where it was predicted that this apparatus afforded vast possibilities and would play an important part in the future. Illustrated and described in T.C Martin book, Figs. 126 and 127, pp. 191-194.

If these men knew what I do, they would not touch my arrangements; they would leave my apparatus as it is. Marconi puts in here [break D] two wheels. I showed only one wheel; he shows two. And he says, "See what happens when the wheels are rotated; a wonderful thing happens!" What is the wonderful thing? Why, when the teeth of the wheels pass one another, the currents are broken and interrupted. That is the wonderful thing that happens? The Lord himself could not make anything else happen unless he broke his own laws. So, in this way, invention has been degraded, debased, prostituted, more in connection with my apparatus than in anything else. Not a vestige of invention as a creative effort is in the thousands of arrangements that you see under the name of other people -- not a vestige of invention. It is exactly like in car couplings on which 6,000 patents have been taken out; but all the couplings are constructed and operated exactly the same way. The inventive effort involved is about the same as that of which a 30-year-old mule is capable. This is a fact.

This is one of most beautiful things ever produced in the way of apparatus: I take a generator of any kind. With the generator I charge a condenser. Then I discharge the condenser under conditions which result in the production of vibrations. Now, it was known since Lord Kelvin that the condenser discharge would give this vibration, but I perfected my apparatus to such a degree that it became an instrument utilizable in the arts, in a much broader way than Lord Kelvin had contemplated as possible. In fact, years afterwards when Lord Kelvin honored me by presenting to the British Association one of my oscillators of a perfected form, he said that it was "a wonderful development and destined to be of great importance."

[Returning to a discussion of Fig. 31], [E] is supposed to be a condenser. That [A] is the generator. Now then, supposing that this is a generator of steady pressure. I can obtain oscillations of any frequency I desire. I can make them damped or undamped. I can make them of one direction or alternating in direction as I choose. At G are devices which operate -- lamps, or anything else. Some experimenters who have gone after me have found a difficulty. They said,

"No, we cannot produce a constant train of oscillations."

Well, it is not my fault. I never have had the slightest difficulty. I produced constant oscillations and I have described how I produced them. Anyone who has no more than my own skill can do it.

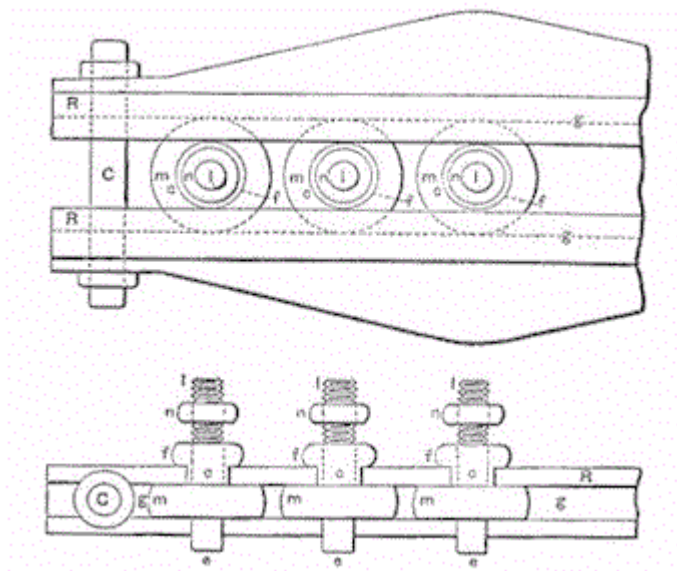


Figure 32.

Quenched spark gap. (Tesla at that time pointed out the future of quenching and showed that oscillations can be maintained without a spark being visible to the naked eye between the knobs.) Illustrated in T.C. Martin book, Figs. 135 and 136, p. 211.

This [Fig. 32] is another improvement in that particular device, which was the weakness of the

invention and which I tried to eliminate. This device incorporated many spark gaps in series. It had a peculiar feature; namely, through the great number of gaps, I was able, as I have pointed out in my writings, to produce oscillations without even a spark being visible between the knobs. This device is now known in the art as the "quenched spark gap." Professor Wein has formulated a beautiful theory about it, which I understand has netted him the Nobel prize. Wein's theories are admirable. The only trouble is that he has overlooked one very important fact. It is this: If the apparatus is properly designed and operated, there is no use for the quenched gap, for the oscillations are continuous anyway. The radio men who came after me had the problem before them of making a bell sound, and they immersed it in mercury. Now, you know mercury is heavy. When they struck their bell, the mercury did not permit it to vibrate long because it took away all the energy. I put my bell in a vacuum and make it vibrate for hours. I have designed circuits in connection with an enterprise in 1898 for transmission of energy which, once started, would vibrate three years, and even after that the oscillations could still be detected. Professor Wein's theory is very beautiful, but it really has no practical meaning. It will become useless as soon as the inefficient apparatus of the day, with antennae that radiate energy rapidly, [are] replaced by a scientifically designed oscillator which does not give out energy except when it gets up to a tremendous electromagnetic momentum.

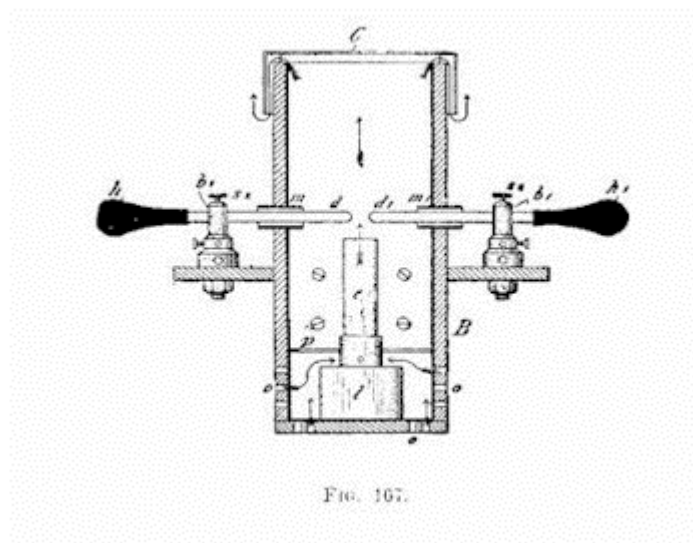


Figure 33.

The discharger working in an atmosphere, chiefly consisting of hydrogen, still further weakened by heat. The use of hydrogen in this connection has been claimed as a discovery and patented. Presented in Tesla's lectures before the Franklin Institute and the National Electric Light Association. T.C. Martin book, Fig. 167. pp. 307-308.

In this form of break [Fig. 33], I changed the atmosphere in which the arc was operating. The atmosphere was mostly hydrogen, and with this device I performed my experiments before the Franklin Institute in Philadelphia and the National Electric Light Association in St. Louis. This has been used by Poulsen and it is now called the "Poulsen arc" and "Poulsen system." But, of course, there is no invention in it. I am on record with prior publications, and besides, the hydrogen does not have any other effect except that it lowers the tension under which the device can operate. It has the disadvantage of producing asymmetrical or distorted waves, and the impulses obtained are not best suited for tuning.

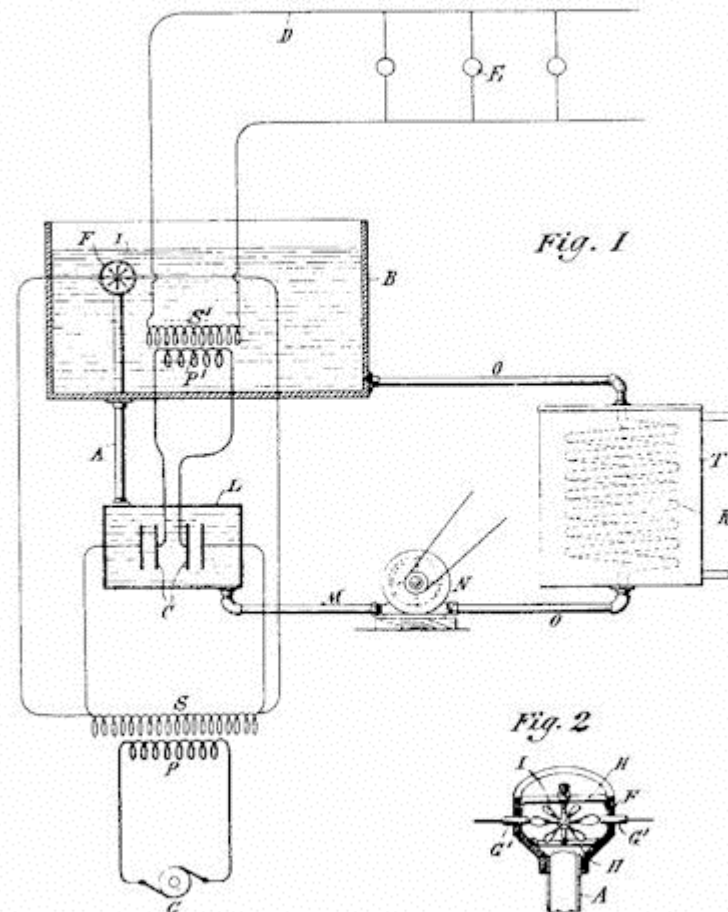
(No Model.)

N. TESLA.

MEANS FOR GENERATING ELECTRIC CURRENTS.

No. 514,168.

Patented Feb. 6, 1894.



Witnesses
Raphael Netter
James H. Cotton

Inventor
Nikola Tesla
By His Attorneys
Duncan & Page

Figure 34.
Oscillatory apparatus with interrupter in oil. Exhibited in the Chicago Exposition of 1893 before Helmholtz. Described in U.S. Patent No. 514,168 of February 6, 1894. Application filed August 2, 1893.

This [Fig. 34] is the apparatus used in the Chicago Exposition of 1893, at which time I explained for the first time to Professor Helmholtz my plan for transmitting energy. After I had shown Professor Helmholtz and other scientific men there certain phenomena, he asked me,

"Now, what is all this intended for?"

I told him I was trying to develop an apparatus for transmitting energy without wire for telegraphy, telephony, and other purposes. When I explained to Professor Helmholtz the whole idea, I said,

"Excellency, do you think that my plan is realizable?"

He replied,

"Why, certainly it is, but first you must produce the apparatus."

I started then and there to produce the apparatus.

Counsel

Was that conversation at the the Chicago Exposition?

Tesla

Yes. It took place in a pavilion which was built especially for exhibiting my inventions and discoveries. I believe Professor Wedding was there and some other scientists whom I cannot remember now. I showed Professor Helmholtz my vacuum tubes and performed many other experiments.

Counsel

Will you describe this apparatus in a little more detail?

Tesla

The apparatus [Fig. 34], as you see, comprised primary and secondary coils immersed in a large tank of oil. The break was automatically effected by means of a turbine. The oil was circulated by a pump, and the current [i.e., stream flow] of oil drove the turbine which effected the make and break. Owing to the fact that the oil used was a very good insulator, rapidly flowing and of great dielectric strength, these make-and-break points were very close together, and the arcs extremely short. The effects were accordingly more intense. Here [T in Diag. 1 of Fig. 34] is a cooler through which the oil was circulated. The oil was forced through the gaps at great speed, and as it flowed out it was supplied again to the tank and the current driving the turbine.

Counsel

That device [Diag. 2 of Fig. 34] you call a turbine?

Tesla

Yes. It had vanes like those of a propeller and constituted a rotary break in the circuit.

Counsel

What was your prime source [of power]?

Tesla

The primary source was an alternator with a frequency of 133 cycles and, if I recollect rightly, the pressure [at the secondary] was about 20,000 volts. I may have had 10,000 volts. I am not sure what it was, but it must have been certainly from 10,000 to 20,000 volts -- within that range.

Counsel

I notice you have two sets of transformers in there marked S and S', have you not?

Tesla

This [S'] is my oscillatory circuit. That [S] is the transformer from which the condenser was charged. Here [at S] we had 20,000 volts, or whatever it was, from the commercial transformer and here [at S'] is my secondary which generated the high frequency currents. The rotary gap is shown in detail [Diag. 2 of Fig. 34].

I had a special reason for showing this. To meet that great man Helmholtz and other scientific men, and to bring before them for the first time the results of years of previous labor, was an important moment in my life -- particularly because Professor Helmholtz gave me the assurance himself that what I explained to him was realizable, provided that I could produce the apparatus. I was very much encouraged.

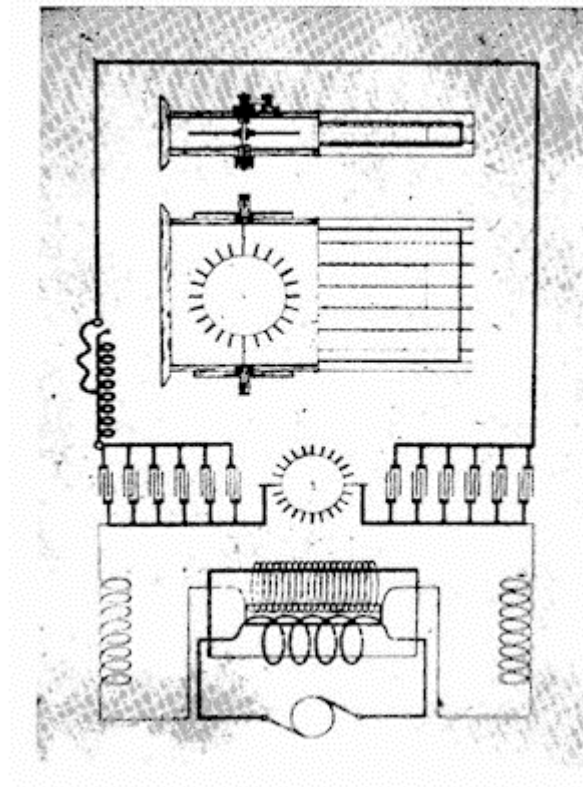


Figure 35.

Apparatus with mechanical break as installed on a large scale in the laboratory at South Fifth Avenue and subsequently at 46 East Houston Street. Described in U.S. Patent No. 645,576 of March 20, 1900. Application filed September 2, 1897.

This [Fig. 35] is the apparatus I had at 35 South Fifth Avenue and also Houston Street. It shows the whole arrangement as I had it for the demonstration of effects which I investigated.[*] This cable you see [square loop in top half of Fig. 35] is stretched around the hall. These are my condensers. There is the mechanically operated break, and that is a transformer charged from the generator. That is the way I had it for the production of current effects which were rather of damped character because, at that period, I used circuits of great activity which radiated rapidly. In the Houston Street laboratory, I could take in my hands a coil tuned to my body and collect $\frac{3}{4}$ horsepower anywhere in the room without tangible connection, and I have often disillusioned my visitors in regard to such wonderful effects. Sometimes, I would produce flames shooting out from my head and run a motor in my hands, or light six or eight lamps. They could not understand these manifestations of energy and thought that it was a genuine transmission of power. I told them that these phenomena were wonderful, but that a system of transmission, based on the same principle, was absolutely worthless. It was a transmission by electromagnetic waves. The solution lay in a different direction. I am showing you this [diagram] simply as a typical form of apparatus of that period, and if you go over the literature of the present day you will find that the newest arrangements have nothing better to show.

Counsel

What was the make and break frequency that you got from that apparatus?

Tesla

It was 5,000, 6,000 -- sometimes higher still. I had two oppositely rotating discs which I will show you and with which I could have reached, probably, 15,000 or 18,000.

Counsel

What wave frequencies did you develop?

Tesla

I could operate from a few thousand up to a million per second, if I wanted.

Counsel

What did you actually use?

Tesla

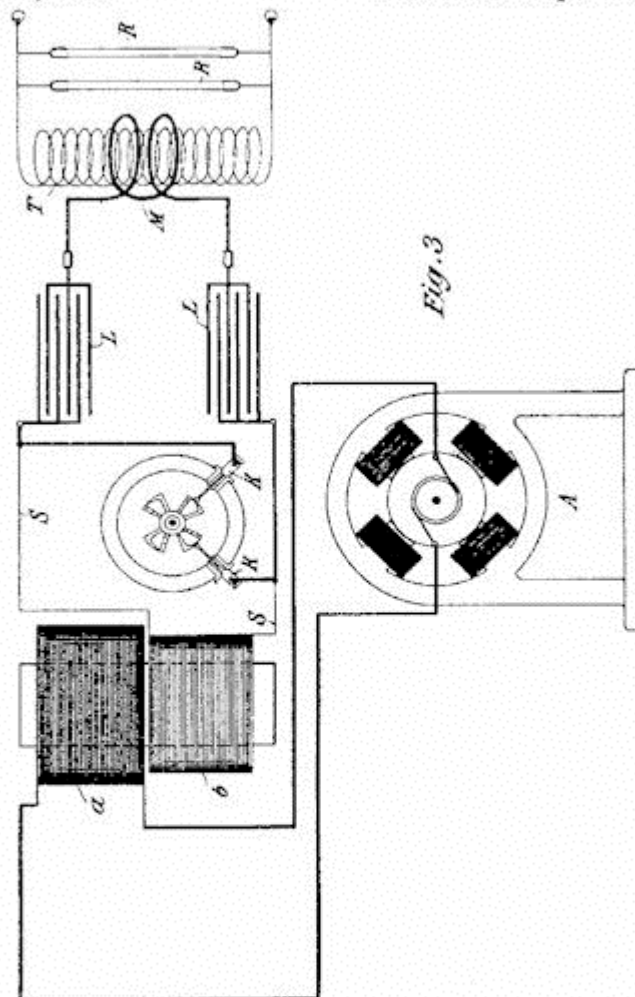
In these demonstrations, which I showed these effects, these most powerful effects that were the sight of New York at that time, I operated with frequencies from 30,000 to 80,000. At that time I could pick up a wire, coil it up, and tell what the vibration would be, without any test, because I was experimenting day and night.

N. TESLA.

APPARATUS FOR PRODUCING ELECTRICAL CURRENTS OF
HIGH FREQUENCY.

No. 568,180.

Patented Sept. 22, 1896.



WITNESSES:

Edwin B. Hopkinson.
Benjamin J. Gassner

Nikola Tesla

INVENTOR

BY

Herr, Curtis Page, ATTORNEYS

Figure 36.

Isochronous mechanical break used in the laboratory at 35 South Fifth Avenue. Described in U.S. Patent Nos. 568,179 and 568,180 of September 22, 1896. Applications filed July 6 and 9, 1896. (Diagram taken from Patent No. 568,180.)

This [Fig. 36] is a form of break which I developed in working with alternators. I recognized that it was of tremendous advantage to break at the peak of the wave. If I used just an ordinary break, it would make and break the current at low as well as high points of the wave. Of this apparatus I had two forms; one in which I drove the break right from the shaft of the dynamo and the other in which I drove it with an isochronous motor. Then, by a movement of these knobs (K K), I would make the adjustments so that the makes would occur exactly at the top of the wave. That is a form of break which is embodied in hundreds of patents and used now extensively.

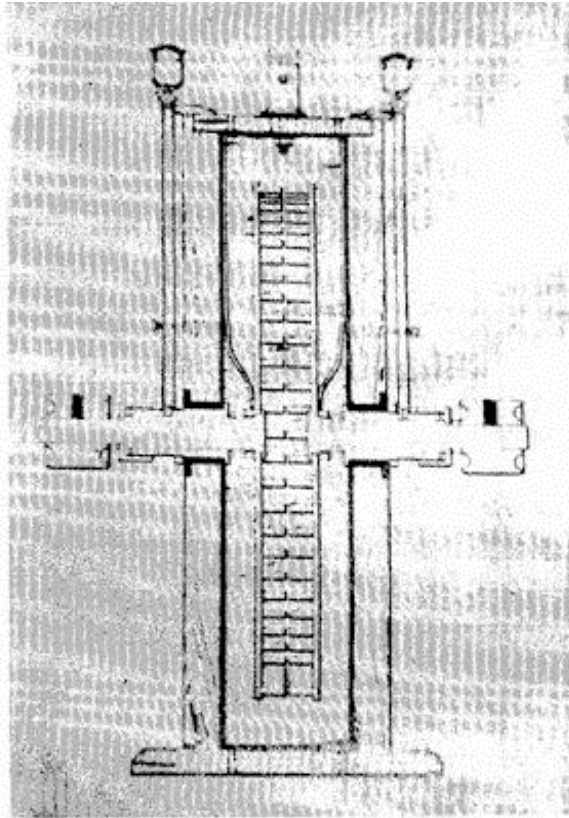


Figure 37.

Mechanical break with two oppositely rotating discs used for the purpose of increasing the number of breaks and alternating oscillations practically undamped. (Subsequently patented by others.)

Here [Fig. 37] I show an apparatus that was installed in the Houston Street laboratory prior to the other break because I wanted to get as high a number of impulses as possible. The drawing dates from the spring of 1896. It is a break with which I could reach from 15,000 to 18,000 interruptions per second. I used it very much until later I found it was not necessary. That is the innocent device which Marconi thought a great invention.

Counsel

This is also a rotary gap?

Tesla

Yes, and it consists of two discs of aluminum, with teeth of aluminum on the side. They were rotated by two motors in opposite directions, and as they rotated they alternately closed and opened the circuit. In some instances I used an uneven number of teeth on one and an even number on the other so that I could produce as many breaks as I desired. I will show you later an apparatus more perfect than this one, and of a different kind, in which I have 24 stationary contacts, and 25 rotating elements that established the contact and broke it, so that by one revolution I obtained 24 times 25, or 600 interruptions [per revolution].

Counsel

Whenever you say "the break", you mean "a spark gap"?

Tesla Yes; otherwise I use the term "circuit controller," preferably.

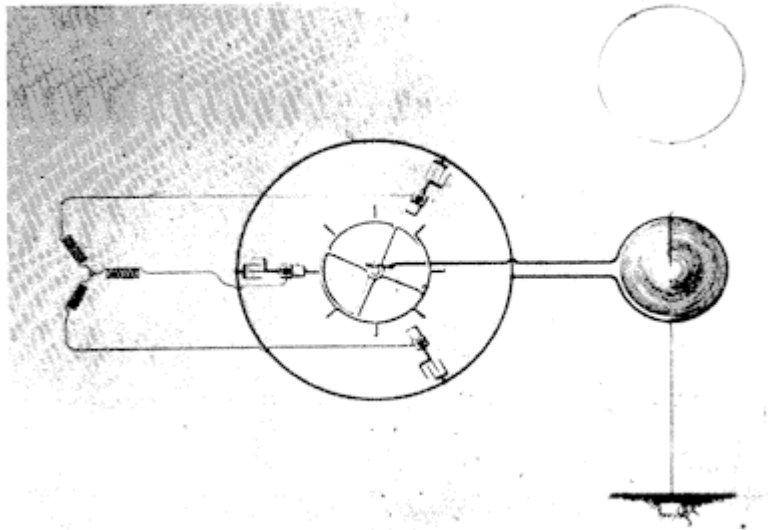


Figure 38.
Use of multi-phase generator with mechanical break. Experiments in the laboratory at 35 South Fifth Avenue and subsequently.

This [Fig. 38] illustrates another development in a different direction. In order to increase the number of breaks, I employed currents of different phase. I had in my laboratory, permanently, a two-phase dynamo and could get phases between; that is, from two phases, 90 apart, I could obtain four phases, 45 apart. Here is an arrangement shown as I had it, working with three phases [60 apart, and could obtain six phases, 30 apart], and later on I had one with four phases [45 apart, and could obtain eight phases 22 1/2 apart]. You see, as I multiplied the number of the phases, I increased the number of the fundamental discharges.

Counsel

What is the date of this apparatus?

Tesla

This I employed already in the 35 South Fifth Avenue laboratory, because I remember that I gave entertainments to several scientific societies and it was then present there. I know on one occasion there was the Society of Architects, and another, the Electrotherapeutic Society, and then I had distinguished men like Mark Twain and Joseph Jefferson -- I gave them a demonstration which was published in Martin's article in the Century Magazine of April 1895, and I know that on these occasions I used a two-phase arrangement. Later on I made it four phase. That apparatus existed, therefore, prior to the destruction of my laboratory in 1895.

Counsel

Do you recall any publication in which this diagram was illustrated?

Tesla

I made no publication, and I vividly remember that when I installed my apparatus on Long Island I had an arrangement with four transformers and four phases 45 apart. After I had been using this apparatus there, several years afterwards, I ran across a patent, I believe held by the General Electric Company, describing precisely the same arrangement.[*] It was a similar experience as with that patent of Fessenden on the compressed air condenser. Any time I want to use these improvements all I need to do is to produce my records and that will settle the patents.

Counsel

When was that drawing [Fig. 38]?

Tesla

This is from an old patent drawing which was made by Mr. Netter.

Counsel

But that did not go to patent?

Tesla

No. I have hundreds of inventions that were to be patented but side-stepped. The expense was too great and I could not do it. This form of apparatus with two and four phases was used prior to the destruction of my laboratory in 1895, and it was installed on a large scale with four phases in my plant on Long Island with which I was to telephone around the world, but that is a long story.

Counsel

In that use you made of it at your laboratory, was that connected up as shown there [Fig. 38], to an antenna?

Tesla

I used the apparatus, yes, in connection with the antenna too, but this is from a patent drawing in which an antenna is shown; I mean, I used it in every connection. [Fig. 38] illustrates an antenna with my transmitting circuit, but the apparatus was used in all my work, in all my investigations.

Counsel

And when this was connected in and used in an antenna, did you use it as in other instances -- go off and listen to the notes which you received?

Tesla

Oh, certainly. But I remember that, besides this, I had different kinds of apparatus. Then I had a sensibly damped wave because at that time I still was laboring under the same difficulties as some do this day -- I had not learned how to produce a circuit which would give me, with very few fundamental impulses, a perfectly continuous wave. That came with the perfection of the devices. When I came to my experiments in Colorado, I could take my apparatus like that and get a continuous or undamped wave, almost without exception, between individual discharges.

Counsel

Speaking of your not having perfectly undamped waves at that time, you were referring to that character of circuit?

Tesla

Yes, but with another kind of circuit I could, of course. The advantage of this apparatus was the delivering of energy at short intervals whereby one could increase activity, and with this scheme I was able to perform all of those wonderful experiments which have been reprinted from time to time in the technical papers. I would take energy out of a circuit at rates of hundreds or thousands of horsepower. In Colorado, I reached 18 million horsepower activities, but that was always by this device: Energy stored in the condenser and discharged in an inconceivably small interval of time. You could not produce that activity with an undamped wave. The damped wave is of advantage because it gives you, with a generator of 1 kilowatt, an activity of 2,000, 3,000, 4,000, or 5,000 kilowatts; whereas, if you have a continuous or undamped wave, 1 kilowatt gives you only wave energy at the rate of 1 kilowatt and nothing more. That is the reason why the system with a quenched gap has become popular.

I have refined this so that I have been able to take energy out of engines by drawing on their momentum. For instance, if the engine is of 200 horsepower, I take the energy out for a minute interval of time, at a rate of 5,000 or 6,000 horsepower, then I store [it] in a condenser and discharge

the same at the rate of several millions of horsepower. That is how these wonderful effects are produced. The condenser is the most wonderful instrument, as I have stated in my writings, because it enables us to attain greater activities than are practical with explosives. There is no limit to the energy which you can develop with a condenser. There is a limit to the energy which you can develop with an explosive.

A common experiment, for instance, in my laboratory on Houston Street, was to pass through a coil energy at a rate of several thousand horsepower, put a piece of thick tinfoil on a stick, and approach it to that coil. The tinfoil would melt, and would not only melt, but while it was still in that form, it would be evaporated and the whole process took place in so small an interval of time that it was like a cannon shot. Instantly I put it there, there was an explosion. That was a striking experiment. It simply showed the power of the condenser, and at that time I was so reckless that in order to demonstrate to my visitors that my theories were correct, I would stick my head into that coil and I was not hurt; but, I would not do it now.

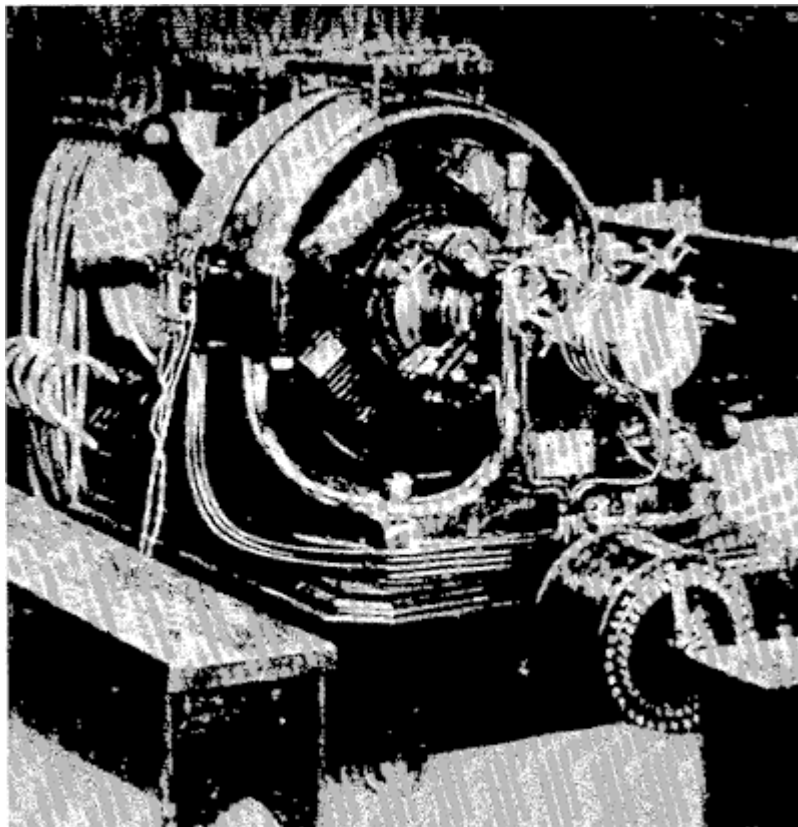


Figure 39

Apparatus furnishing direct currents of high tension, producing undamped electrical oscillations of high frequency. (This is also shown in [Fig. 27]). Apparatus built in 1895.

[Fig. 39] shows a four-phase machine which was furnished me by the Westinghouse Electric Company at the close of 1895. My laboratory burned out in May, and I urged my friend, Mr. Albert Schmidt, who was the Superintendent, to give me this alternator as soon as possible. He worked day and night until he got it out, and he certainly did notable work because while the machine was rated at 30 horsepower, I have run it at 150 horsepower.

By the way, and this is a painful reflection, it was Schmidt and I who developed this type of frame and this general arrangement which is universally adopted now -- a base, with the magnets cast below, split at the center line, and a corresponding upper part. That is now used everywhere. I remember years ago, some of my friends, Messrs. Crocker and Wheeler, started with those long magnets and I told them, "The sooner you throw these away and adopt this construction, the better it will be for you." They have got it now; it is all right.

Counsel

How is this machine [Fig. 39] shown in connection with that?

Tesla

This dynamo [Fig. 39], you see, is a two-phase machine; that is, I develop from it currents of two-phase. Now, there are four transformers. You see them down here [lower left of Fig. 39] that furnish the primary energy. From these two phases I develop four phases. [However,] this involves something else which I have referred to before; namely, an arrangement which enables me to produce from these alternating currents direct currents and undamped -- absolutely undamped -- isochronous oscillations of any period I like.

This is accomplished in the following manner: The secondaries of the four transformers could each develop 44,000 volts. They were specially built for me by the Westinghouse Company. They could, however, be connected in such a way that each would give 11,000 volts, and then I would take these 11,000 volts and these four phases and commutate them by a commutator consisting of aluminum plates, or aluminum segments, which were rotated in synchronism with the alternator. Then I obtained a continuous pressure; that is, direct current of a tension of 44,000 volts, and with these 44,000 volts I charged my condensers. Then by discharging the condensers, either through a stationary gap or through a gap with a mechanical interrupter, I obtained any frequency I desired, and perfectly undamped waves. This arrangement was installed in 1901 in my wireless plant at Long Island, with which I was to telephone around the world.

Counsel

Who built that machine?

Tesla

The Westinghouse Company, [under direction of] Mr. Albert Schmidt, Superintendent. It was especially built for me and furnished to my laboratory on Houston Street.

While I was with the Westinghouse Company, I did two things in addition to bringing my motors to them. I had discovered that Bessemer steel was a much better material for transformers and motors than the soft iron which was previously used. When I came to Pittsburgh, my motors gave results which their motors could not at first produce, and I told them that I had used Bessemer steel. I discovered, in following up the analysis of the steels which were used, that the Bessemer was not steel but really soft iron. The Westinghouse people then adopted my suggestion. At first, Mr. Shallenberger and other electricians there objected very much, but I persuaded them and when the transformers were built we found that we could get 2 1/2 times the output we got before.

The Westinghouse people kept it a secret for a long time and no one understood how they could make such fine transformers, but all they did was to use the Bessemer steel, on my suggestion, instead of the soft iron the General Electric and other people used. Mr. Westinghouse especially requested me to join efforts with Mr. Schmidt and improve the design of his machines, and we did so. We evolved this design, introduced the ready-made coils, which are pressed on the armature, and other improvements. I took a couple of patents out with Mr. Schmidt, and Mr. Westinghouse was very nice about it. I think he compensated me with \$10,000, or something like that, for my suggestions.

Counsel

You have spoken of the use of that machine at Houston Street. In what way was it used?

Tesla

I used this machine, as I said, either to produce alternating currents and then interrupt them with a mechanical break at the high peaks of the wave; or, I used alternating currents and interrupted them with an independent rotating break having a great number of teeth. Or, I generated continuous currents by commutating the high tension alternating currents of the transformer. At that time I had two transformers from which I obtained a constant pressure, charged the condenser, and produced

undamped waves of any frequency I wanted. As to the machine here [Fig. 39], that is the way it was arranged. It was for the generation of continuous electromotive force and production of undamped waves -- from 1895 and on.

Counsel

What sort of apparatus was it connected up to for the purpose of absorbing these waves?

Tesla

It was the same as shown here [Fig. 38]. It was connected to the condensers, and these condensers were discharged through a primary which excited the secondary; the antenna was included in the secondary. At other times we discharged the condensers directly so that I could use the antenna without the secondary.

Counsel

In the same way did you note the operation of these waves?

Tesla

We did, of course, only in most cases the instrument of reception was different. When I operated with these continuous, or undamped, waves, generated in this way, I usually went to high frequencies. I did operate [at] a very few thousand, but that gave me a smaller output. Such a machine you have to operate at high frequencies to get power.

Counsel

What do you mean by high frequencies?

Tesla

I mean frequencies of 30,000, 40,000, 50,000, or something like that.

Counsel

And by means of that machine, you put undamped waves of frequency about 50,000 into that antenna at Houston Street in 1895?

Tesla

No, not in 1895. Late in 1895 the machine was furnished and I began to operate in early 1896. That is when I began to operate.

Counsel

Then you did this, that I speak of, in 1896?

Tesla

Yes, from 1896 to 1899, right along.

Counsel

When you used frequencies like that in your antenna, was your antenna tuned or untuned?

Tesla

I could not use it untuned. That would be absurd.

Counsel

What form of device did you use, and where did you use it, for noting the generation of these

oscillations or waves in the antenna?

Tesla

I suppose I had hundreds of devices, but the first device that I used, and it was very successful, was an improvement on the bolometer. I met Professor Langley in 1892 at the Royal Institution. He said to me, after I had delivered a lecture, that they were all proud of me. I spoke to him of the bolometer, and remarked that it was a beautiful instrument. I then said,

"Professor Langley, I have a suggestion for making an improvement in the bolometer, if you will embody it in the principle."

I explained to him how the bolometer could be improved. Professor Langley was very much interested and wrote in his notebook what I suggested. I used what I have termed a small-mass resistance, but of much smaller mass than in the bolometer of Langley, and of much smaller mass than that of any of the devices which have been recorded in patents issued since. Those are clumsy things. I used masses that were not a millionth of the smallest mass described in any of the patents, or in the publications. With such an instrument, I operated, for instance, in West Point -- I received signals from my laboratory on Houston Street in West Point.

Counsel

This was then the machine that you used when working with West Point?

Tesla

I operated once or twice with it at that distance, but usually as I was investigating in the city. My work at that time was to prepare for the development of a commercial plant, and with me the question was not to transmit signals, but to see what intensity I could get to put me in position to calculate out my apparatus, the dimensions and the forms, before I began the undertaking. It was nothing but preparatory work for the construction of a commercial plant, and I demonstrated its practicability through my experiments, a plant which was to accomplish much more than all others.

Counsel

What was the horsepower activity in the oscillating circuits when you used this machine?

Tesla

Usually something like 50 horsepower, and I would get, I should say, approximately 30 horsepower in the antenna; that is, I would get 30 horsepower in the oscillating circuit.

Counsel

I understood a little while ago when you made the statement of using several thousand horsepower put into a condenser, you could take out of the condenser a million horsepower. I wondered if you got the same condition with this machine.

Tesla

Yes; I charged the condenser with 40,000 volts. When it was charged full, I discharged it suddenly, through a short circuit which gave me a very rapid rate of oscillation. Let us suppose that I had stored in the condenser 10 watts. Then, for such a wave there is a flux of energy of $(4 \times 10^4)^2$, and this is multiplied by the frequency of 100,000. You see, it may go into thousands or millions of horsepower.

Counsel

What I wanted to get at was, did that depend upon the suddenness of the discharge?

Tesla

Yes. It is merely the electrical analogue of a pile driver or a hammer. You accumulate energy

through a long distance and then you deliver it with a tremendous suddenness. The distance through which the mass moves is small -- the pressure immense.

Counsel

Did you find that that was the best condition for transmitting energy without the use of wire?

Tesla

No, I did not use that method when I was transmitting energy. I used it only in the production of those freaks for which I have been called a magician. If I had used merely undamped waves, I would have been an ordinary electrician like everybody else.

Counsel

You have referred to some delicate receiving instruments. Did you have any trouble with those burning out on account of static?

Tesla

My dear sir, I burned out so many instruments before I discovered what was the matter with them! They burned out instantly until I learned how to make them so that they could not burn out. Yes, that was a great trouble in the beginning.

Counsel

Did you succeed in getting them so they would not burn out?

Tesla

Yes. If lightning struck close by, it would not burn out my instrument that has a millionth of the smallest mass used in the instruments of others.

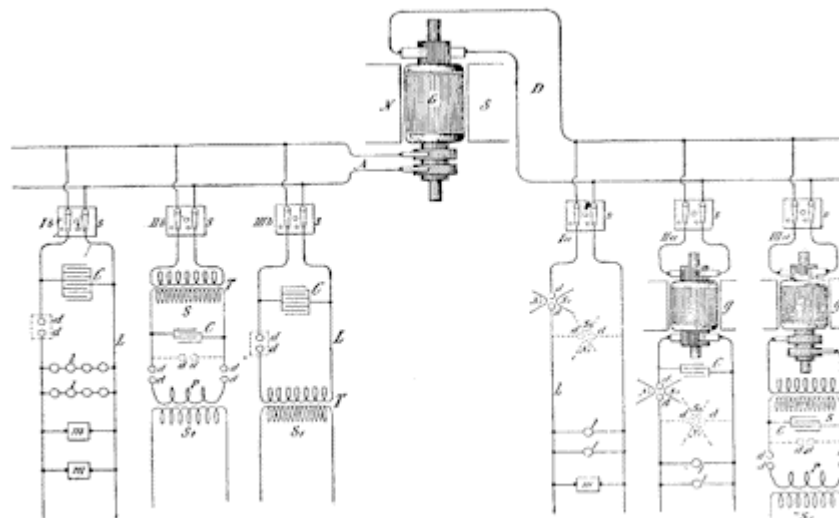


Figure 40.

Apparatus and method of conversion by condenser discharges applicable to both alternating and direct currents. Described in lectures before the Franklin Institute and the National Electric Light Association early in 1893. Illustrated in T.C. Martin book, Fig. 165, pp. 302-317.

This [Fig. 40] is a systematic representation of the various ways which I gave in my lecture before the Franklin Institute and the National Electric Light Association, embodying the general arrangements for the obtainment of continuous waves, undamped or damped waves, from direct and alternating current supply. On the one side [right] you have direct, on the other side alternating current supply. Some electricians have had difficulties in operating some of this apparatus. I had

none. I can take an ordinary circuit of 50 volts and produce from it absolutely undamped oscillations and never have the slightest difficulty about it.

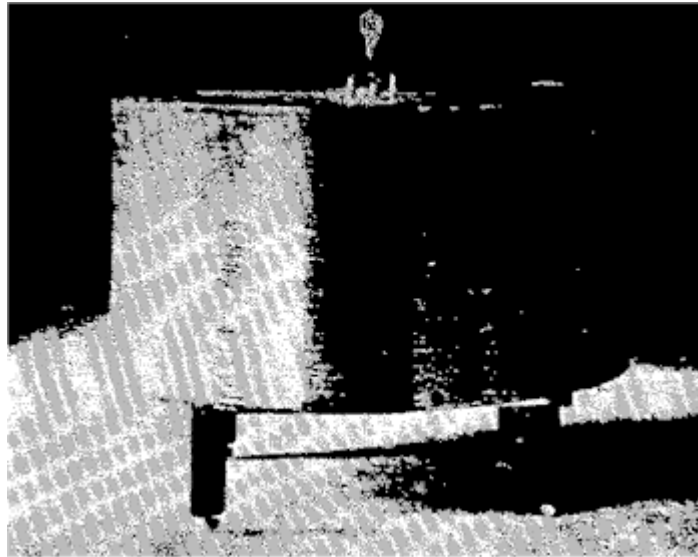


Figure 41.
Illustrating one of the early experiments with a tuned transformer in the laboratory at South Fifth Avenue.

Now I come to a few pieces of apparatus which I used in the Houston Street laboratory and the South Fifth Avenue laboratory. I have here [Fig. 41] what you might call a tuning coil. I employed usually another secondary and had my condensers on the table. You see one of the coils in action. This is a tuned circuit which responds to electromagnetic waves which are sent through the room.

Counsel

This is being used as a receiver of waves?

Tesla

Yes.

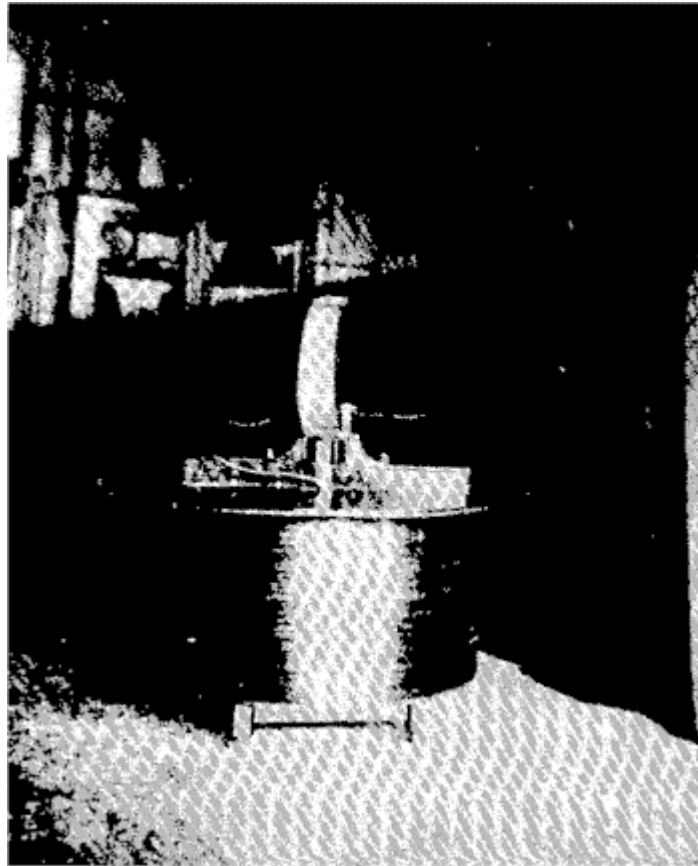


Figure 42.

Another illustration of one of the early experiments with a tuned transformer in the laboratory at South Fifth Avenue. (Article by T.C. Martin ["Tesla's Oscillator and Other Inventions"], *Century Magazine*, April 1895, Fig. 9, p. 926.)

This [instrument shown in Fig. 42] was used in the laboratory on South Fifth Avenue. Here [large circular disc lying on top of coil] is the tuning table with the condensers, a thick primary, and another secondary wire. Sometimes I would operate with two vibrations and I would tune the first circuit to one and the second to the other. Here [referring to cabinets in back of room] you see some of my historical apparatus. Professor Fairfield Osborn[*] came once to my laboratory and said to me, "Why on earth do you keep it in this laboratory?" I had all of this apparatus, 400 pieces, absolutely priceless, and he offered to take it over to the Museum. But I did not heed his advice, and it is gone.

Counsel

Where were the waves sent from?

Tesla

The whole room was energized by electromagnetic waves and the receiver responded at any place in the hall. The hall was bigger than this room [shown in Fig. 42], twice as long, and anywhere the intensity of action was the same. These discs [vertical, on top of tuning table] were, I think, about 14 or 15 inches in diameter, and you could see the streamers [shown as white between the discs] anywhere in the room. In a hall twice as long as this, wherever I placed the instrument, it would respond to the electromagnetic waves.

Counsel

In this particular instance you are speaking of, the waves were generated right there at 35 South Fifth Avenue?

Tesla

Yes.

Counsel

Was that the apparatus in which you had the primaries running entirely around the room?

Tesla

Yes. This was shown to many people and societies.

This [Fig. 43] shows the first single step I made toward the evolution of an apparatus which, given primary oscillations, will transform them into oscillations capable of penetrating the medium. That experiment, which was marvelous at the time it was performed, was shown for the first time in 1894. I remember the incident perfectly. I called Mr. Edward Adams, the banker, to come and see it, and he was the first man to observe it and to hear my explanation of what it meant.



Figure 43.
Apparatus in action illustrating the first step in the evolution of the magnifying transmitter in the laboratory at 35 South Fifth Avenue. (Article by T.C. Martin ["Tesla's Oscillator and Other Inventions"], Century Magazine, April 1895, Fig. 15, p. 932.)

This coil, which I have subsequently shown in my patents Nos. 645,576 and 649,621, in the form of a spiral, was, as you see, [earlier] in the form of a cone. The idea was to put the coil, with reference to the primary, in an inductive connection which was not close -- we call it now a loose coupling -- but free to permit a great resonant rise. That was the first single step, as I say, toward the evolution of an invention which I have called my "magnifying transmitter." That means, a circuit connected to ground and to the antenna, of a tremendous electromagnetic momentum and small damping factor, with all the conditions so determined that an immense accumulation of electrical energy can take place.

It was along this line that I finally arrived at the results described in my article in the Century

Magazine of June 1900. [Fig. 43] shows an alternator; not the alternator that was furnished for my laboratory on Houston Street -- that was another one, [but] at 35 South Fifth Avenue [and] operated on the same principle. Here [lower left] are the condensers, primary, and all the rest. The discharge there was 5 or 6 feet, comparatively small to what I subsequently obtained. I have produced discharges of 100 feet, and could produce some of 1,000 feet if necessary, with the greatest facility.

Counsel

Mr. Tesla, at that point, what did you mean by electro-magnetic momentum?

Tesla

I mean that you have to have in the circuit, inertia. You have to have a large self-inductance in order that you may accomplish two things: First, a comparatively low frequency, which will reduce the radiation of the electromagnetic waves to a comparatively small value, and second, a great resonant effect. That is not possible in an antenna, for instance, of large capacity and small self-inductance. A large capacity and small self-inductance is the poorest kind of circuit which can be constructed; it gives a very small resonant effect. That was the reason why in my experiments in Colorado the energies were 1,000 times greater than in the present antennae.

Counsel

You say the energy was 1,000 times greater. Do you mean that the voltage was increased, or the current, or both?

Tesla

Yes [both]. To be more explicit, I take a very large self-inductance and a comparatively small capacity, which I have constructed in a certain way so that the electricity cannot leak out. I thus obtain a low frequency; but, as you know, the electromagnetic radiation is proportionate to the square root of the capacity divided by the self-induction. I do not permit the energy to go out; I accumulate in that circuit a tremendous energy. When the high potential is attained, if I want to give off electromagnetic waves, I do so, but I prefer to reduce those waves in quantity and pass a current into the earth, because electromagnetic wave energy is not recoverable while that [earth] current is entirely recoverable, being the energy stored in an elastic system.

Counsel

What elastic system do you refer to?

Tesla

I mean this: If you pass a current into a circuit with large self-induction, and no radiation takes place, and you have a low resistance, there is no possibility of this energy getting out into space; therefore, the impressed impulses accumulate.

Counsel

Let's see if I understand this correctly. If you have radiation or electromagnetic waves going from your system, the energy is wasted?

Tesla

Absolutely wasted. From my circuit you can get either electromagnetic waves, 90 percent of electromagnetic waves if you like, and 10 percent in the current energy that passes through the earth. Or, you can reverse the process and get 10 percent of the energy in electromagnetic waves and 90 percent in energy of the current that passes through the earth.

It is just like this: I have invented a knife. The knife can cut with the sharp edge. I tell the man who applies my invention, you must cut with the sharp edge. I know perfectly well you can cut butter with the blunt edge, but my knife is not intended for this. You must not make the antenna give off 90 percent in electromagnetic and 10 percent in current waves, because the electromagnetic waves are

lost by the time you are a few arcs around the planet, while the current travels to the uttermost distance of the globe and can be recovered.

This view, by the way, is now confirmed. Note, for instance, the mathematical treatise of Sommerfeld,[*] who shows that my theory is correct, that I was right in my explanations of the phenomena, and that the profession was completely misled. This is the reason why these followers of mine in high frequency currents have made a mistake. They wanted to make high frequency alternators of 200,000 cycles with the idea that they would produce electromagnetic waves, 90 percent in electromagnetic waves and the rest in current energy. I only used low alternations, and I produced 90 percent in current energy and only 10 percent in electromagnetic waves, which are wasted, and that is why I got my results. . . .

You see, the apparatus which I have devised was an apparatus enabling one to produce tremendous differences of potential and currents in an antenna circuit. These requirements must be fulfilled, whether you transmit by currents of conduction, or whether you transmit by electromagnetic waves. You want high potential currents, you want a great amount of vibratory energy; but you can graduate this vibratory energy. By proper design and choice of wave lengths, you can arrange it so that you get, for instance, 5 percent in these electromagnetic waves and 95 percent in the current that goes through the earth. That is what I am doing. Or you can get, as these radio men, 95 percent in the energy of electromagnetic waves and only 5 percent in the energy of the current. . . . The apparatus is suitable for one or the other method. I am not producing radiation with my system; I am suppressing electromagnetic waves. . . . In my system, you should free yourself of the idea that there is radiation, that the energy is radiated. It is not radiated; it is conserved. . . .