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MODERN ELECTRIC CLOCKS
by
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The work of any individual is quite likely to have a different appearance when examined from the perspective of centuries after his death. For example, when Columbus was voyaging across the trackless ocean, then only searching for a passage to India, the discovery of a new world was not in his picture at all. To-day we only think of Columbus as having discovered a new world. Likewise this Clock Club, in giving consideration as it does to the work of the early American clock makers, is perhaps more greatly interested in certain features of their product, such for example, as the artistic appearance and the slow evolution of the case and dial, than in the technical problems which in all probability occupied most of the original artizan's thoughts and activities. I doubt very much whether the Willards worried half as much about the shape and appearance of the cases which they made as they did about the movements that went into these cases, and yet to-day the cases are of paramount interest. My story will probably appear less exciting to you than that of the early clock makers. In fact my tale would probably appeal more strongly to a group of engineers who are especially interested in science and technique. It may well be that one or two centuries from now some other aspect of this work will be more interesting and perhaps seem more important.

Let me recall in the beginning that there are two distinct functions of clocks. One is to measure time accurately as possible and the other is to tell time with the greatest possible convenience. The work which I have done has a great deal more to do with the second function than with the first, for I must plead at the start that I am innocent of having made any advance in the accuracy of measuring time. My work has been wholly concerned with providing devices which would tell the time with the very greatest convenience and with a high degree of accuracy wherever other modern conveniences of civilization are found. Centuries ago the very early clock makers recognized the desirability of telling the time over as wide an area as possible, and therefore, their timekeepers were provided with bells which rang out the hours. It was from the French name for bells that the word clock came. That method of telling time, although it represented a great advance, is wholly inadequate for modern civilization. We now need to know the minutes as well as the hours, and so striking clocks are no longer dominant. Our modern clocks must tell the minutes and even the seconds with precision, if we are to keep abreast with the procession.

Prior to 1916 when the work which I will describe to you began, the only timekeepers which were used on a very extensive scale consisted of separate clocks, each one of which was constructed to measure time independently. Mr. Brown's clock had no connection with Mr. Jones' clock and either one of them had only that degree of accuracy which was imparted by the design and construction of the movement, aided or hindered by skill or lack of skill in regulating by Mr. Brown or Mr. Jones. The result, as you know, was that the average clocks were frail reeds as regards accuracy of time measurement. It was necessary to set them at rather frequent intervals if the owners expected to keep engagements and make train connections. Moreover all of these separate clocks had one particularly annoying feature which was that they would stop running unless wound up at regular intervals of a day or a week.

For a hundred years, more or less, inventors yearning for mental exercise have concerned themselves with the problem of using electricity to drive clocks. Springs and weights, although reasonably satisfactory for that purpose, can supply only a very limited amount of energy, but electric batteries and generators are not limited in this respect. A multitude of ways were discovered whereby electric energy could be used to keep a clock train running. From time to time many forms of electrically driven clocks have appeared on the market, but they have only been sold in small quantities and each particular variety has folded up after a while and passed into oblivion. The reasons have been, first, that all these various electric clocks were more costly, usually more delicate, more likely to get out of order, and generally speaking, no better time-keepers than the common variety. They had the advantage that no winding was necessary, but this was offset by the fact that the batteries were somewhat uncertain in durability. For public buildings, however, battery-driven systems of clocks with time-telling units scattered throughout a given building, all of the units being energized and synchronized from a central master clock, were coming into wide general use by the beginning of this century. Such clock systems eliminated the burdensome labor of winding numerous units and more important still they insured uniformity in the time-telling function of the various clocks. Moreover these clocks minimized the cost of measuring time accurately, because only a single unit was used for this function. The obvious weakness of these electric clock systems was the necessity for separate sets of wires to carry energy and synchronizing impulses from the master clock. Such a system was practically out of the question for widespread use in a community, although the Western Union Telegraph Company established limited systems of this kind in our great cities where people were willing to pay a substantial rental charge per month for time service. The Western Union systems were substantially the same in principle as the building installations. They utilized a single master clock at a central point with wire connections to various stores and offices throughout a city where the service was under contract.

Like most of the other electric clock inventors I had dreams of various methods whereby electricity from batteries could be used to drive clocks. As far back as 1908 I filed a patent application on a rather crude form of electrically driven clock which represented the result of several years of desultory experimenting during my spare time. This work until then and for several years later was simply a hobby which gave me the same kind of pleasure as collecting stamps or playing bridge does to other people. However, as is often the case, the habit grew stronger and developed into a compelling urge. Eventually I engaged assistance and organized a small independent company for the purpose of making further developments in electric clocks which were still of the battery type. This was done without severing my regular job of superintending the work of a manufacturing company. In 1916 the inadequacy of the battery clocks which I had been able to design and build impressed me so forcibly that I began exploring other possibilities in the art of telling time. The need of some simple mechanism which would have universal application made me think, as a few people had done in the preceding decades, of the possibility of utilizing the existing communication systems for the distribution of time.

The two great networks which were then available were the telephone system, then reaching a very largo portion of the houses and offices of the well-to-do people, and the electric light and power lines which covered a still more extensive territory. Of these two systems of communication, the one which appealed to me more strongly was the electric light system, because this carried abundant power for the purpose of driving clocks and, far more important, it contained the germ of a system for measuring time. In 1916 more than 90% of all electric light, heat and power was distributed in the form of so called alternating current. The alternations of this current might conceivably be used to measure time intervals provided they could be properly controlled. The other 10% of electric power was distributed in the form of so called direct or constant current which flowed smoothly in one direction like the current from a battery, and there was nothing about this current itself which could be used to measure time. At least three or four other people in various parts of the world had thought of the possibility of using alternating current for time-telling purposes, as was afterwards discovered by a thorough investigation. However, none of these individuals had taken any effective action towards turning the dream into reality and consequently there was not anywhere in the world twenty years ago a place where alternating current was being used to operate clocks. Unfortunately we have not in this ancient room a regular supply of alternating current because the older cities were, in the beginning, provided with direct current systems by the original power companies. The cost of these systems, which required immense amounts of copper to be buried under the streets was so great that even after the use of alternating current became almost universal many of the older networks like the one in the center of Boston were still continued in use. Consequently, in this district where only direct current is available, modern electric clocks cannot be used.

For the purpose of this lecture, however, I have brought a small alternating current generator which is capable of developing a supply of alternating current suitable for demonstration and I can now show you how alternating current differs from direct current. You will notice that the rapidly revolving Neon lamp of the demonstration device appears, when supplied with direct current, as a smooth ring of light, which means that the brightness of the lamp remains practically constant as it revolves rapidly in the circle. When, however, the same revolving lamp is supplied with alternating current you will see that the circle of light becomes a chain resembling separate links of light. Each one of these links of light is caused by an electric wave or impulse in the wire through which the current flows. The fact that some of the links are on the outside and an equal number on the inside means that these impulses which flow in the wire are first in one direction and then in the other direction, which explains the designation "alternating". If you will take the trouble to count the separate links of light in the whole circle you will find that there are six in the outer row and six in the inner row or twelve altogether. When I tell you that the lamp is revolving ten times every second you will see that there are 120 of these separate alternations of electricity in the wire every second.

For convenience the alternating current is characterized by the number of pairs of these alternations, each pair being called a cycle so that this particular current has 60 cycles a second. Now in the demonstration device the number of these cycles every second is not exactly sixty but only approximately that value and that was the situation in 1916 when I dreamed of utilizing this alternating current for time-telling purposes. It seemed to me possible that the number of these cycles or pairs of alternations per second could be made equal to exactly 60 on the average, if I could only persuade the operators of the power stations to adopt a different method of regulating the speed of the generators, which alone determined the rate of alternations. Before this could be done it was necessary to provide some means whereby the time characteristics of these alternations could be used to drive the hands of a clock. You can readily understand I think that if each of these flashes of light which you see so clearly could be used to move a gear wheel having a very large number of teeth, by the space of a single tooth, this imaginary gear wheel might be connected to the hands of a clock so that this hand would creep along the same small distance on the dial for each alternation and thus behave exactly the same as any ordinary clock hand. You will recall that an escapement serves precisely the same function since it permits the hands of a clock to move a small distance for each swing of the pendulum and if you can imagine these flashes of light serving in place of the oscillations of a pendulum with some kind of an escapement which would form a connecting link between the flashes of light and the hands of a clock you may visualize exactly what I had in mind.

When alternating current was first used to distribute light and heat in 1886 there were no satisfactory motors which could be used for power purposes. The great advantage of the alternating current over the direct current lay in the fact that, through what is called magnetic induction, current could be distributed at a high voltage and then transformed by means of motionless magnetic devices called transformers to low voltage which would be safe for household use. It was not possible to use these transformers with direct current and consequently such current could not be transmitted economically for great distances from the power station. However, the motors which had been successfully developed to convert direct current into power would not perform even reasonably well when supplied with alternating current. The problem of building a successful alternating current motor was not solved until Nikola Tesla and Elihu Thompson discovered how to produce a so-called rotating magnetic field in a stationary iron structure when supplied with alternating current. Then it became feasible to build alternating current motors which were rather crude at first, but have now been developed to a point where, for many purposes, they are equal to or better than direct current motors.

I have here a simple apparatus designed to demonstrate the production of a rotating magnetic field in a stationary structure and the effect of such a field in causing the rotation of a movable member. In order that you may appreciate the rotation of the field I have a commutating device which can supply current from a battery into any one of four soft iron pole pieces arranged around the circumference of a circle. Any one of these four pole pieces is thus magnetized by current passing through a coil of wire similar to that which is used in an electric bell. The commutator can be turned by hand as slowly as desired and there is a small electric lamp located on each pole piece so that you can see which one is magnetized at any instant. Inside the circle of these pole pieces is a thin smooth hardened steel disc which, like all hardened steel, has the power of becoming permanently magnetized and when so magnetized it has the properties of a needle of a compass. That is to say one end of the magnetic axis tends to point toward the north pole. When the demonstration device was first put in service the hardened steel disc had not been magnetized so that it did not have a magnetic axis tending to point in any definite direction. The instant, however, I turn on the current from the battery and thus set up a north magnetic pole in the position indicated by the little electric lamp and, by the way, the structure is so arranged that a south magnetic pole is always set up diametrically opposite, the magnetic force passing through the hardened disc immediately magnetizes the disc in the diametrical direction of this force. Now the disc has become a permanent magnet like a compass needle and this means that if the north pole is shifted by means of the commutator, either to the right or to the left of its present position, the disc will tend to follow, as you can see by the motion of the arrow which has been painted upon its surface. From this time on you will see that the white arrow follows the lighted lamp however fast I turn the commutator, so that I now have a motor in which there is a rotating part capable of delivering power moving inside a perfectly stationary structure. The intangible thing which is rotating and dragging this steel disc around is the magnetic field which is following exactly the rotation of my hand. I am in fact sending alternating current impulses into the field.

Now a commercial alternating current motor is not quite as simple as this demonstration device. In the first place the alternations are so rapid that the eye could not possibly follow such a field, if it were set up in this particular structure, and in the second place there is no commutator in most alternating current motors. However, the fundamental thing, namely, the rotating field does exist in all alternating current motors. This rotating field may be very easily produced in magnetic structures by several methods, but the simplest of these methods is by the use of what are called shading coils mounted on magnetic poles. Most ordinary alternating current motors do not have rotating parts which follow the rotating magnetic field with the exactness of this demonstrating device. Usually the tendency is for the rotor to run almost, but not quite as fast as the field. The difference between the field speed and the rotor speed is called slip and the amount of slip depends upon the load. In small commercial motors the rotor may slip as much as 10% behind the field. This means that if the field is revolving 3600 times per minute, the rotor would revolve when loaded less than 3300 times per minute; although when the rotor is carrying a very light load its speed would be nearly 3600 turns per minute. You will observe that in alternating current motors of this kind there 1s a very strong tendency for the speed of the motor to be dependent upon the number of alternations of the current and not upon its strength or voltage. In accuracy. There could be no slip between the rotor and the rotating field, otherwise my clocks would be unreliable. A motor having these characteristics was long ago designated as "synchronous" from two Greek words meaning "equal time".

In 1916 very few synchronous motors were used for power purposes and none of them were in any respect adaptable for driving common clocks. By utilizing the same principle which is illustrated in this demonstrating device, namely, a rotor of hardened steel which could be permanently magnetized and then made to revolve synchronously in a rotating field there was created a device admirably suited to drive even small clocks. As you can readily see, this device is one that may be made very small and inexpensive, while because of its simplicity and the very light weight of the moving parts durability may be readily secured. Motors of this type are not well adapted to develop power, nor are they efficient when compared with commercial motors, but the work of driving hands of a clock is so light that these little motors, of which I will hand you samples for inspection, are very suitable. The power output of the first motors which I made for driving clocks was in the neighborhood of one millionth of a horsepower, but minute as this seems it still represents very much more power than is delivered by an ordinary spring clock movement. This is illustrated by the weight lifting capacity of this demonstrating apparatus. You can see that a very strong spring clock movement is able to lift on a drum mounted on its second hand arbor, which turns one revolution per minute, a small weight amounting to 1/4 oz. Alongside is a Telechron clock motor which has a shaft revolving one revolution per minute and this motor will easily lift through a drum of the same diameter a weight of 35 oz. Moreover I would point out that the spring clock movement even when tightly wound has its rate very considerably affected by lifting the tiny weight, while the Telechron motor does not change its rate to the smallest degree with a load 140 times as great.

As soon as a satisfactory motor which could be used to drive the hands of a clock became available, in the early summer of 1916, the next problem which I faced was to bring about in some manner the accurate regulation of the order to use the alternating current for accurate time-telling purpose I was compelled to devise a small reliable alternating current motor in which the rotor would follow the alternations of the current with extreme alternating current impulses which were being sent in all directions over the wires so that these impulses in connection with the newly designed motor might be used to supply power companies' customers with a dependable time-telling device. For the solution of this problem two things were necessary, first, an instrument that could conveniently be used by power station attendants for the purpose of regulating the frequency of the alternations, and, second, creation of a state of mind among the power company managers that would justify them in giving this extraordinary new service to the public. The second part of the problem was, on the whole, more difficult than the first. It took only a few months to design and build a thoroughly satisfactory master clock which could be used at power stations so as to indicate errors in the average frequency, which were hundreds of times smaller than could be measured with the instruments then in use.

Several years elapsed, however, before resistance on the part of some of the managers of the electric light companies was overcome to a point where they would give this new service. This was because some of them felt that the added responsibility might be serious and many of them believed that the new service would be of no financial advantage to their companies on account of the very small power consumption of the clock motors. However, most of the managers were public spirited and progressive and they could see a real opportunity which eventually became evident to all. At that time the meters for measuring electricity were scarcely sensitive enough to register the current consumed by a single clock on any customer's premises so that the company might get no returns, but better meters soon became available and in the course of a few years power companies found the revenue received from current used by these tiny motors was really an important matter. The value of current used by a single clock during a year will vary anywhere from $.50 to $1.50, depending upon the rate. If $.75 per year be taken as a fair average, you will see that a company having 100,000 of these clocks on its lines would receive a return of $75,000 a year from the current used. As a matter of fact this income is mostly extra profit, because the motors run 24 hours a day and the load is absolutely steady. For 100,000 clocks a generator with a capacity of 300 k.w. is adequate. Modern generators range from 25,000 to more than 100,000 k.w. capacity. Consequently this represents a very trifling portion of the output of one large generator. This means of course that the money invested in generating equipment, transmission lines, etc., to operate these 100,000 clocks is really small compared with $75,000 per year return. There is no other electrical device which yields as large a return on the investment to the power companies. Furthermore there are a good many power companies that have several times 100,000 clocks on their lines. It is estimated that the number of electric clocks now running in the United States is above ten million. As a result these clocks have become of considerable economic importance to power companies, which explains their eagerness in stimulating sales.

The growth in the sale of these modern electric clocks was very gradual after the first system became available in 1916. Only a few thousand were sold each year for the next three or four years. By 1921, however, the success of those in use and the publicity which followed stimulated sales to a point where manufacturers of other kinds of clocks began to take notice, but it was not until 1927, ten years after the system first became available, that forms of synchronous electric clocks other than the ones which I have described to you began to appear on the market. Then a group of rival manufacturers began to grow and within a few years there were over hundred different concerns which were selling synchronous electric clocks intended for use on systems that had been established quite generally throughout the country. Nearly all of these new forms of clocks differed from the original type in that they possessed no starting power, that is to say, it was necessary to start them manually and whenever there was an interruption in the power supply they would stop and not run until they had again been started by hand. While they were running they kept just as good time as the original type of self-starting synchronous clocks, but most of them were defective in some respect or other so that within another period of a few years they began to disappear from the market. Most of them were noisy, nearly all were short lived, and the universal habit of stopping after every interruption proved to be nuisance in many cases.

You will notice that the Telechron clocks of which there is a display in this room are provided with an indicating device so as to give a signal after an interruption. Such interruptions, of course, make an error in the time indicated by the clock equal to that of the interruption. Generally speaking interruptions are short so that the warning signal is sufficient for most purposes to take care of the usual interruptions in the current. When it becomes very necessary to eliminate the effect of interruptions, as in public building installations and some other places, Telechron clocks are built either with sustaining mechanisms which keep the hands in motion during an interruption or with resetting apparatus which automatically measures the length of an interruption and then after the current returns moves the hands forward to make correction.

On account of the relatively great power of this little synchronous motor as compared with spring clock movements many new uses have been found for this kind of time-keeping device. Prior to 1916 there were a number of recorders on the market which depended on spring clocks to drive charts or perform other services that had a time function, but the performance of these devices was limited by the relatively weak power of the spring clock movements. When Telechron motors became available for power which was a hundred times greater than that of the spring clock movements, the instrument makers began to redesign their mechanisms so as to be of greater service to their customers. Many kinds of new devices making use of these synchronous motors were also developed.

Consequently a large part of the output of Telechron motors each year is used in instruments and devices that cannot be considered as ordinary clocks. In fact hundreds of thousands of motors are used annually for such purposes. Another field of usefulness for these new time-keeping motors is apparent for the very large dials such as are used in tower clocks. Instead of requiring a very heavy weight, a long pendulum and an expensive movement a tower clock with a dial several feet in diameter can be perfectly operated by means of one of these tiny motors which I hold in my hand. The use of large clocks especially those having Neon illumination has spread into the advertising field and wherever you go now-a-days you will find frequent outdoor signs which are seeking the good-will of observers by showing the time of day on very large clock dials.

In the modern electric clocks, as I have already intimated, the function of measuring time is separate from the function of telling time. Two devices are necessary, first a single very reliable and accurate master clock located at some central point on a power system, and second an unlimited number of synchronous motor clocks located wherever convenient on the distribution system of the power company. The same generators, wires, and transformers which carry light, heat and power to all the company's customers also carry without any extra charge accurate time impulses to those modern electric clocks. The only thing that is necessary for the electric clock to do is to translate the alternating current impulses into time indications. Therefore, they serve to tell the time which is accurately measured by another device. As a result of this arrangement the mechanical construction of the electric clock is of a very different nature from that of the ordinary spring and weight-driven clock. In the latter conservation of power is of the utmost importance. Only a slight amount of energy is available in a tightly wound spring or a lifted weight and this naturally must be used in the most miserly way if the delicate time-measuring escapement device is to perform accurately. Therefore, we find that in the ordinary clocks and watches the gear wheels are made very light, the teeth are made very perfect and the bearings are made as nearly frictionless as possible so as to reduce to the minimum the power needed to drive the escapement and all other moving parts.

In the electric clock, however, it is not difficult to provide an abundance of power which can be used for the simple task of keeping the clock hands in motion. There is no escarpment to bother about. Consequently the gear train which connects the spinning rotor with the clock hands may be of relatively coarse construction, with bearings that might be considered crude in the former type of clocks. The two important conditions which must be met are that the gear train from rotor to hands is durable and capable of running for a long time without attention and that in operation the moving parts are very quiet. It is really immaterial whether the teeth of the slower moving members of the train are cut or stamped or whether the gear wheels are solid or poked, the bearings coarse or delicate. The most difficult problem is to make sure that the faster moving members of the train are well lubricated and will remain so for a period of years and that there is not anywhere in the device a troublesome source of noise.

People have become accustomed to the ticking of ordinary clocks, but in twenty years they have not become accustomed to the much fainter buzzing or humming sound which is emitted by some of the electric clocks on the market. The modern electric clock is required for public acceptance to be practically silent. Such a result is not easy to obtain because wherever alternating current is used to set up a magnetic field, there is a tendency to generate a humming sound. Motion which cannot be seen by the eye is ample to make a very disagreeable sound. Consequently while the manufacturer of modern electric clocks escapes naturally some of the very difficult manufacturing problems which are connected with other kinds of clocks, he is obliged to solve this new problem of noise, if he is to make a success of his product.

Synchronous motor clocks may be readily substituted for practically all forms of ordinary clocks and their field of usefulness may be extended far beyond that of spring and weight-driven clocks. The electric movements are small and compact so that they may be mounted in any ordinary form of case. The dial may be readily illuminated by using a trifling amount of the energy which is available inside the case itself. They have already become the most popular form of alarm clock. They may be arranged to show the time of day by moving numerals in place of moving hands. They may be arranged to switch electric current on and off at predetermined times or to give signals according to a regular program. In fact there seems to be no limit to the field of usefulness of these new time-keepers.