June 2, 1942. R. W. CARLISLE 2,285,016

SYNCHRONIZING SYSTEM

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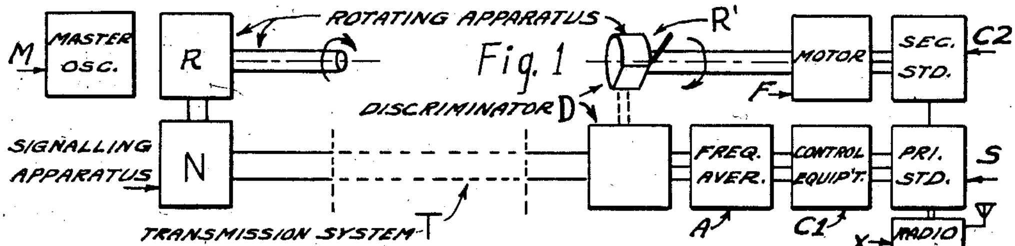

Fig. 1

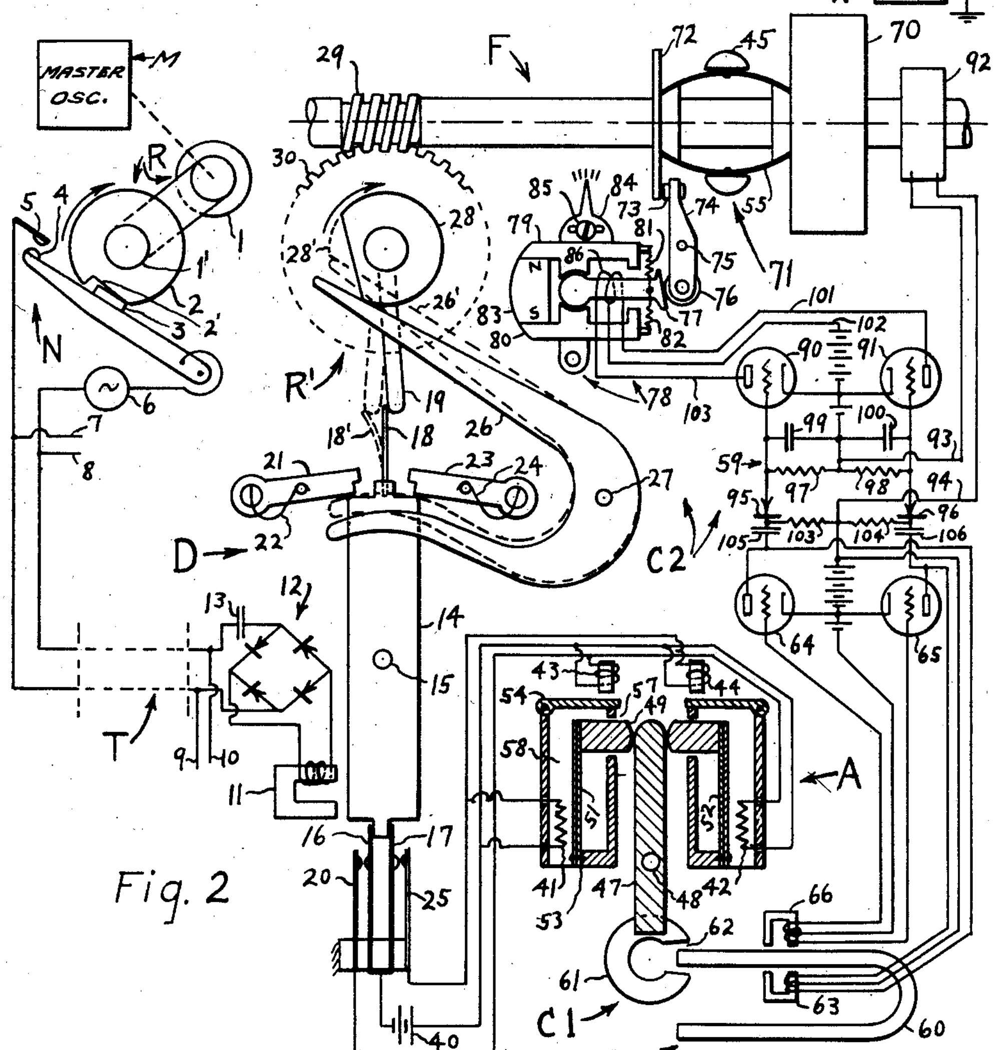

Fig. 2

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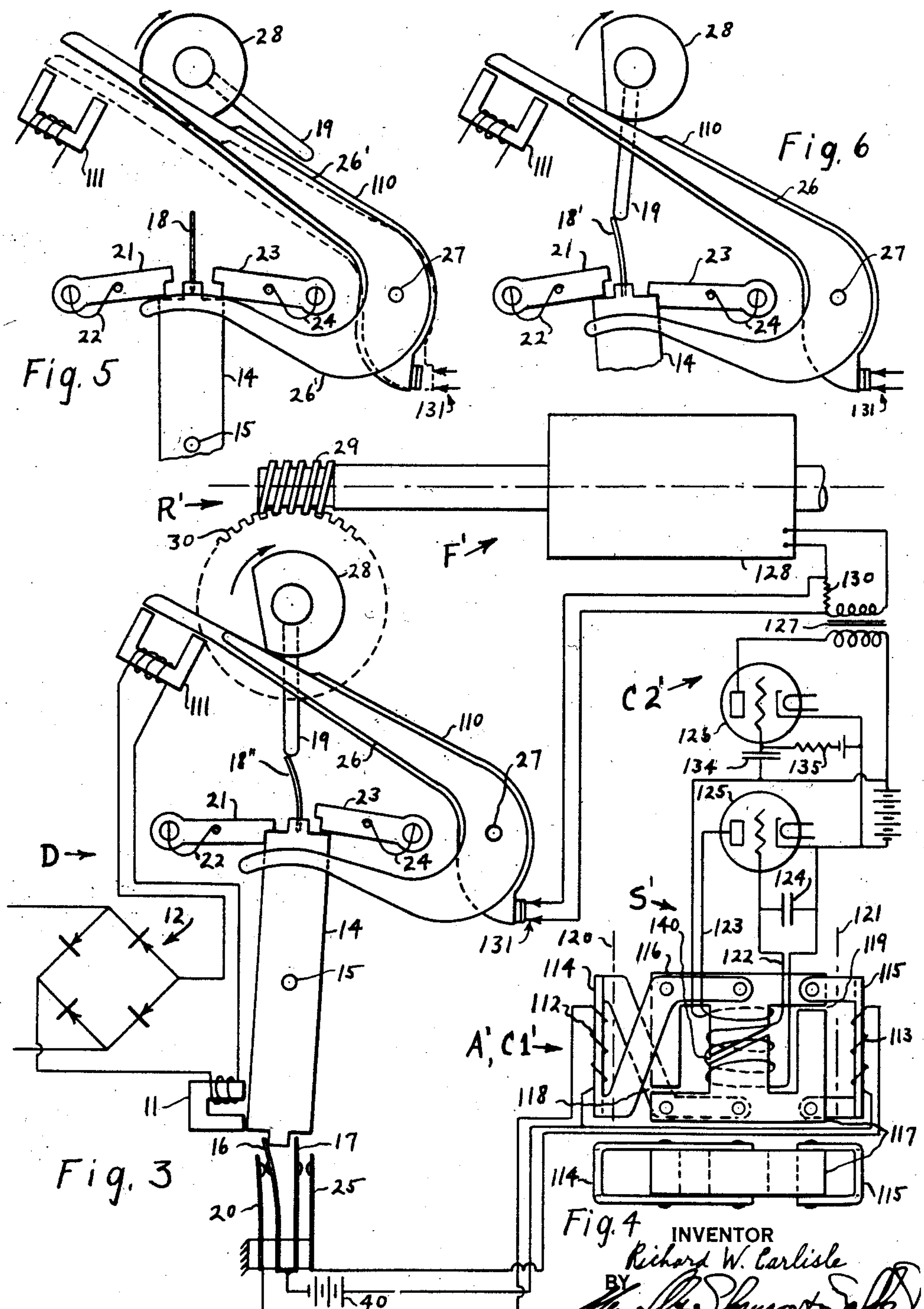

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SYNCHRONIZING SYSTEM

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10 Claims. (Cl. 250—36)

This invention relates to apparatus in which one set of apparatus having a cyclically repetitive action of definite frequency of recurrence, such as rotating machinery or vibratory apparatus or an electrical oscillator, is synchronized with one or more different sets of apparatus of a frequency similar or multiply-related thereto, without continuous direct mechanical connection or mechanical coupling between the two sets of apparatus. This is equivalent to remote control of the frequency of rotation of machine parts, the vibration of vibratory apparatus or the oscillation of electrical circuits. The remote synchronization of rotating machinery is closely associated with that of electrical systems since it is always accomplished by the use of alternating currents having a frequency which is a function of the speed of rotation.

When it is desired to exercise remote control of the cyclic frequency of the apparatus just enumerated, it has been customary in the prior art to transmit from the master apparatus to the follower apparatus a continuous electrical control tone whose frequency is significant to the cyclic frequency of the master apparatus. This control tone is utilized at the follower apparatus to control the cyclic frequency of said apparatus in any one of a number of ways well known in the electrical art and more particularly in the art of electrical power transmission, the art of time-keeping by means of master clocks and controlled clocks, commonly known as "slave" clocks, the art of controlling prime movers by means of standard frequency devices, the art of synchronizing radio broadcast stations and the art of transmitting facsimile pictures by wire or radio. By "slave" clocks is meant clocks which are arranged to be kept in synchronization with a master or reference clock.

Synchronization is effected in all of these cases in one of a limited number of ways or a combination thereof, the method chosen being dependent on the percentage of total elapsed time that the control tone is available at the follower apparatus. In some cases, the control tone is continuously available at the follower apparatus, in which case a portion of the energy available in each cycle is utilized to control the frequency of the follower apparatus. In other cases, the control tone is available only for relatively short intervals, in which case it has been customary to pull the follower apparatus into synchronism with the control tone for the period that the control tone is available, and to make corrections during that interval for any advance or retardation of the follower apparatus relative to the master apparatus. In the intervening intervals, the follower apparatus is by necessity permitted to carry on independently at a cyclic rate dependent entirely upon its own previous setting and accuracy of manufacture. Since great accuracy is required in many cases, the expense incurred becomes very large.

It is the primary object of this invention to provide means whereby follower apparatus is synchronized to master apparatus without utilizing either a continuously available control tone or independent, perfectly accurate cyclic control equipment in the follower apparatus. In general, synchronization is effected by relative sequence in time of periodic impulses transmitted from the master cyclic apparatus to the follower apparatus, as compared to similar impulses generated at the follower apparatus.

It is another object of this invention to provide means for correcting the cyclic frequency of a follower apparatus during intervals when the control tone is available, and of maintaining that correction during the subsequent period when the control tone is not available. This differs from anything in the prior art, in that previously the rate of cyclic action of follower apparatus was altered only during periods in which the master apparatus was coupled thereto. For instance, in the case of telegraph-controlled clocks the actual elapsed time was periodically corrected but not the independent rate of keeping time.

It is another object of this invention to accomplish this correction of cyclic frequency in a progressive and cumulative manner, whereby the frequency of the follower apparatus is made to approach that of the master apparatus by successive corrections made during intervals when the control tone is being received by the follower apparatus.

It is another object to accomplish this correction of frequency in conformance with the average frequency of the control tone, so that accidental variations introduced during transmission will not cause deviations in the follower apparatus frequency.

It is another object of this invention to provide simplified and economical means for accomplishing progressive synchronization. This involves the use of a heat motor for controlling cyclic speed, which is an ancillary object of the invention, particularly with respect to the further ancillary object, which is to minimize the time required for the heat motor to warm up to the proper temperature for stable operation.

It is another object of this invention to effect extremely rapid synchronization of follower apparatus with master apparatus by using two separate systems of synchronization, the first providing an approximate or coarse synchronization and pulling the follower apparatus into approximate synchronization, and the second providing the accurate isosynchronization.

It is still another object of this invention to synchronize a radio station with a master control at a different point.

It is still another object of this invention to synchronize a facsimile recorder with a facsimile scanner.

It is another object of this invention to synchronize an electric power generating station with a frequency standard without transmitting a continuous synchronizing wave.

According to my invention, I transmit electrical impulses significant to the rate of cyclic operation of a master apparatus to a follower apparatus, comprised of electrical and mechanical cyclic apparatus which is arranged to operate with a natural cyclic frequency near that of the master apparatus, determine the relative advance of the follower apparatus by comparing the mechanical advance of the follower apparatus with the transmitted electrical impulses, and make suitable corrections of the cyclic frequency of the follower apparatus to cause it to approach or equal that of the master apparatus. These corrections are made either instantaneously or gradually, according to whether the transmitted impulses can be relied upon at any instant, or must be averaged over a period of time in order to provide a reliable indication of the master cyclic frequency. The cyclic follower apparatus being controlled may consist either of non-synchronous engines or electrical machinery, or synchronous electrical apparatus.

This invention, both as to its organization and as to its method of operation, together with additional objects and advantages thereof, will best be understood from the following description of certain specific embodiments of my invention, when read in connection with the following claims, in which:

Fig. 1 is a schematic diagram of a complete synchronizing system layout illustrating the synchronizing steps typical to this invention;

Fig. 2 shows a complete synchronizing system utilizing a tuning fork and governor controlled motor;

Fig. 3 shows a dual synchronizing system, providing coarse and fine synchronizing action and utilizing a thermal magnetic frequency control unit;

Fig. 4 is an elevation of the magnetic control unit shown in Fig. 3 with the coils omitted;

Fig. 5 shows a portion of the system of Fig. 3 at a different instant in its cycle of operation; and

Fig. 6 shows the same portion of the system of Fig. 3 at another instant.

Schematic synchronizing system

Referring to Fig. 1, master cyclic apparatus M such as an oscillator or a synchronous motor or alternator having, optionally, a rotating or reciprocating member R, is electrically connected to cyclic signalling apparatus N, which may be comprised of electrical transformation apparatus or electrical circuit interruption means or the like. The cyclic signalling apparatus N is connected to electrical transmission means T.

At the far end of the electrical transmission means T is the substation apparatus, comprised of follower cyclic apparatus F and the intermediate control apparatus therefor. This is comprised of the primary frequency standard apparatus S, which controls the frequency of cyclic action of the follower cyclic apparatus F and R′ by means of the secondary cyclic control apparatus **C2**. The primary frequency standard apparatus S is connected indirectly to the electrical transmission means T through the frequency discriminatory apparatus D and the frequency correction averaging apparatus A. The various parts of the substation apparatus will, as hereinafter to be explained in detail, operate according to the following principles:

The follower primary frequency standard apparatus S is comprised of an oscillator having sufficient accuracy to oscillate substantially in synchronism with the master cyclic apparatus M for a limited period of time, but not having sufficient accuracy to remain in synchronism therewith indefinitely. The difference between the frequency of this follower primary standard and that of the master cyclic apparatus (as transmitted over the electrical transmission means T) is detected by the frequency discriminatory means D. This frequency difference is averaged over a predetermined period of time by the frequency correction averaging apparatus A, with the effect that any variations in phase in the transmitting means will not immediately affect the follower primary standard, which is thereby enabled to maintain greater accuracy than would be possible by controlling the follower frequency directly from the transmission means. This feature is very valuable in controlling one oscillator of extreme accuracy from another with only poor transmission facilities therebetween, as in the case of synchronizing radio broadcast stations several hundred or thousands of miles apart to the same radio frequency to within a few cycles by means of a telephone line. Another advantageous feature of the system as herein to be set forth is that continuous connection between master and follower oscillators is not necessary, since arrangements can be made for correcting the frequency of the follower frequency standard apparatus by short-interval transmissions at spaced periods. The primary frequency control apparatus **C1** sets the frequency of the follower primary frequency standard S to conform to the average of the frequency transmitted from the master station. The secondary cyclic control apparatus **C2** controls the follower cyclic apparatus F and R′ from the primary frequency standard S.

Master cyclic apparatus

The frequency of the standard S may be used to control a radio transmitter X, as schematically illustrated.

In the complete synchronizing system of Fig. 2, master rotating apparatus R, which may be controlled in speed for example by the master cyclic apparatus M, is indicated specifically by the motor **1** and rotating shaft **1′**. The cyclic signalling apparatus N is indicated by the cam **2** with the rider **3** and contacts **4** and **5**. The cam **2** is shown affixed to the shafts **1** and **2**, having an indented portion **2′**. Bearing on this cam is the rider 3, the sudden movement of which as it drops into said indentation causes the contacts 4 and 5 to close, thus instantaneously completing the electrical circuit through the generator 6 to the electrical transmission means T. It may be seen that the indentation 2′ in the cam is of such a shape as to make instantaneous contact of contacts 4 and 5. Alternatively, when due provision is made at the substation for synchronizing therewith, the generator 6 may be synchronous with the master cyclic apparatus M. Other signals may be sent over the transmission line T at the same time as the synchronizing signals but at different frequencies, and at all frequencies during the intervals between synchronizing signals.

Follower apparatus

The remainder of Fig. 2 shows substation equipment, the follower cyclic apparatus being indicated by R′. Other functions of the substation equipment are to control the speed of rotation of the follower apparatus R′ and the frequency of any electrical currents synchronously associated therewith. The equipment consists, in general, of the engine or motor 70, the alternator 92, the governor 71, the worm 29 driving the worm wheel 30, and the cam 28 driven by the wheel 30. Electrical connections are made from the transmission means T to the electro-mechanical translating device 11, which in this embodiment of my invention is an electromagnet. If currents other than those required for synchronizing are transmitted with the synchronizing tone, separation may be made by means of electrical filters, as well known in the art, and indicated schematically by the capacitor 13. The rectifying device 12 may optionally be used to supply direct current to the magnet 11 in order to secure improved operation. Currents other than the synchronizing tone may be received through the connections 9 and 10.

Frequency discriminator apparatus

The main control element of the cyclic frequency discriminatory apparatus D, the general function of which was discussed in connection with Fig. 1, is the differentially actuated arm 14. This arm is completely shown in Figs. 2 and 3 and partially shown in Figs. 5 and 6, each view being taken at a different part of the synchronizing action. The specific function of this apparatus is to determine the relative sequence in time of impulses originating at the master apparatus and impulses generated by the follower apparatus. This arm 14 is pivoted at some point 15. When not being actuated to one side or the other, it is retained in a central position by the springs 16, 17, which in this particular embodiment of my invention function also as part of the switching system shown below the lever 14.

At the top of the lever is affixed an elongated member 18, disposed within the circle of action of the elongated member 19, which is affixed to the rotating cyclic apparatus R′. One or the other of these members 18, 19 is preferably made flexible, in this case member 18 being shown flexible and adapted for deformation as indicated at 18′. At 18′ in Fig. 3 it is shown deformed nearly enough to permit the pin 19 to pass it. It may be seen that with arm 14 in the central position and a synchronizing current actuating the magnet 11, if the members 18 and 19 come into contact at the same instant, then providing the length and flexibility of the members 18 and 19 is predetermined to a correct value, the pull of member 18 on the arm 14 will be equal and opposite to that of the magnet 11. In this case, depicted in Fig. 2, no motion of the arm 14 will occur, it will remain in its central position, and as will hereinafter be explained, the control system dependent upon the action of this arm 14 will retain the cyclic frequency of the follower apparatus R′ unchanged. The time interval required for this electro-mechanical interaction is an extremely small part of the time required for one revolution of the follower apparatus R′, hence, it will be seen that the action as described is an extremely sensitive and accurate method of detecting the difference between the frequency of cyclic action of the follower apparatus R′ and that of the master apparatus R. The arm 14 is moved one way or the other by either the rotating pin 19 pushing on the flexible arm 18, or the magnet 11 pulling on the lever. If the master station apparatus is leading the follower apparatus, the magnet will exert its pull first, and the arm 14 will be moved clockwise as shown in Fig. 3. The arm 14 retains exactly the same action and functions in the system of Figs. 3, 5 and 6 as it does in the system of Fig. 2, although an additional lever 110 has been added to the pivot 27 and other changes have been made in the secondary cyclic control apparatus as hereinafter to be described. The arm 14 when pushed clockwise as in Fig. 3, will be locked in this position by the latch 21, impelled in turn by the spring 22. The contacts 16 and 20 will then be closed. When the lever 26 rides on the depressed or flat portion of the cam 28 as shown by 26′ in dotted lines in Fig. 2 and also shown in Fig. 5, the latches 21 and 23 will be raised and the control arm 14 will be immediately returned to the central position by the resilient action of members 16 and 17.

On the other hand, if the master station is lagging the follower station, the pin 19 will exert the controlling push, and the arm 14 will be moved counter-clockwise as indicated in Fig. 6. This will cause the contacts on switch members 17 and 25 to close.

The switch members 16, 17, 20 and 25 control the frequency of the secondary frequency standard apparatus S. This control system may be as schematically illustrated in Fig. 1, and as shown in Fig. 2. In this embodiment the primary frequency control apparatus C1 and the frequency correction apparatus A is used, but simplification may be made as shown in Fig. 3, or by omitting the correction averaging apparatus A. In the event the averaging apparatus A is eliminated the frequency correction may be directly effected, for example, by mechanically connecting the control arm 14 with the frequency control apparatus C1, i. e., by affixing the control magnet 61 to the arm 14.

Frequency correction averaging apparatus

The frequency correction averaging apparatus A, in a form suited to the control of an electro-mechanical oscillator as shown in Fig. 2, is constructed as follows. The circuit completed by contacts 16 and 20 connects through the battery 40 to the actuating element 41 of a time-delayed motor device A, the action of which is so arranged that the amplitude of motion of the armature 47 of said motor is proportional to the duration of closure of said contacts 16 and 20. This frequency correction apparatus A may take the form of an electric motor of standard type geared down and arranged to progressively move said armature **47** by means well known in the art, but in the present embodiment of this invention great simplification has been effected in the apparatus required by utilization of a heat motor for this purpose. The heat motor as herein described comprises a heat responsive element **51** and a heater. Such heat motors are commonly made as shown by juxtaposing the heating element **41** to the bimetallic element **51** and supporting this bimetallic element **51** from one end **53** with the other end arranged to actuate the control member **47** by means of the pressure member **49** which projects through the window **57** in the heat retaining chamber **58**. Insofar as I know, a heat motor has never been used in this manner before, particularly with the purpose of securing control action with a predetermined time delay and correction averaging action. This averaging action is specifically controlled by means for storing the heat generated by the actuating element **41**, which in this embodiment is comprised of the chamber **58**, the controllable shutter **54** on the upper portion thereof and the magnet **43** arranged for opening and closing said shutter.

This shutter **54** is arranged to be opened when the other heating element **42** is connected to the battery **40**, so that although the shutter acts to assist in the storage of heat in the medium around the thermal control element **51** and thus makes the frequency correction action progressive when lever **14** becomes reversed in position, the heat stored in the surrounding medium is released quickly and undesired time lag is avoided. However, in cases where the electrical transmission means T is unreliable by reason of variable phase distortion or the like it is desirable to average the control action over a considerable period of time and in these cases the shutters may be left closed or eliminated. It may be noted that the heating element **41** is preferably not wound around the bimetallic element **51** as in some relatively quick-acting light control devices, but instead is spaced from the heat sensitive element in order to establish a definite time delay action.

Simplification of averaging apparatus

It may be seen in Fig. 2 that complete control of the frequency correction means C**1** may be secured by the single heat sensitive element **51**, and that complete control of the latter is secured by closing and opening of the electrical contacts **16** and **20** under control of lever **14**, and furthermore that two positions of lever **14** (one in which the contacts are open and the other in which they are closed) are sufficient to distinguish between the condition in which the follower apparatus has a faster cyclic speed than the master apparatus and that in which it is slower. The condition of absolute synchronism is relatively unusual, and a slight variation one way or the other falls into one of the above classifications. It follows therefore that the apparatus shown in Fig. 2 may be simplified by omitting the heat sensitive element **52** and its associated apparatus, which is similar to that associated with the element **51** but oppositely disposed and connected.

In this case, however, a definite advantage of the dual control system is lost. With the system constituted as shown, the primary standard frequency apparatus S may be tuned as close to the frequency of the master cyclic apparatus as possible with the control member C**1** in its central position, from which position the control elements will cause it to deviate in conformance with changes in the frequency of the follower cyclic apparatus R′, and no time interval will be required when starting up the apparatus for the control elements **51** or **52** to take control of the lever **47**. On the other hand, if only one control element **51** is used, the frequency of the secondary standard must be set off synchronism, when the heat sensitive element is cold, by such an interval as to provide sufficient control range to cover variations in cyclic frequency of the follower apparatus. As the heat sensitive element **51** warms up it will then take control of the follower frequency and hold it in synchronism, but a warming-up period will be necessary.

Follower primary standard and control apparatus

The action of the follower primary frequency standard is as follows. It is constituted of an oscillator having sufficient intrinsic accuracy to keep the follower cyclic apparatus substantially synchronous with the master cyclic apparatus for a number of revolutions or alternations of said master apparatus. Among the most accurate oscillators known are crystals and tuning forks. The principles of control described herein can be applied to either of these types or to any other type of oscillator known, such as a common vacuum tube oscillator, but for the purpose of illustrating the manner in which an oscillator can be controlled according to the principles of this invention, a tuning fork **60** has been chosen.

The principle by which control is established is that some frequency-determining part of the oscillator, (which in the case of an electrical oscillator would preferably be the inductance or capacitance) is varied by means as well known in the art controlled by the frequency discriminatory apparatus D. In the particular embodiment of my invention shown in the drawings, which comprises a new method of controlling a tuning fork by changing its effective stiffness, a magnet **61** is affixed to the end of the control lever **47**, which is pivoted at some point **48** and controlled by the thermal elements **51** and (optionally) **52** as hereinbefore described. This magnet **61** has an air gap **62** disposed towards the tuning fork **50**, which has magnetic permeance, and the magnet is so supported on the lever **47** that by the motion of said lever the magnet is made to partially surround or move away from the end of said tuning fork. The effect of this action is as follows: when the magnet is removed from the tuning fork, the latter vibrates with a certain frequency which is determined by its mass and stiffness. As the magnet is approached to one end of the fork, the end thus surrounded is attracted alternately to one pole of the magnet or the other, whichever is nearest. This attraction of the magnet for the fork end has an effect on the motion of the fork of such a nature as to partially counteract the restoring force due to the stiffness of the fork. The effective stiffness of the fork is thus reduced, which in turn causes the resonant frequency of the fork to be diminished, which is the purpose of the structure just described. Alternatively, an electro-magnet could be used and control effected by changing the current through it, but it is believed easier to move a permanent magnet with a heat motor than to control a current therewith.

The tuning fork **60** is arranged to be driven by the driving electro-magnet **63**, energy being supplied by the vacuum tubes **64** and **65**, the grids of which are actuated by the pick-up electromagnet **66**.

The output of tubes **64** and **65** is used to control the follower cyclic apparatus F. In systems constructed according to the prior art, it is customary to couple the follower apparatus to a synchronous motor. It is customary to amplify a tuning fork output to a level sufficient to control such a synchronous motor. In cases where a high voltage direct current is not available for plate supply to the power tubes however, as in the case of districts having only 110 volts or less direct current supply, it becomes impractical to amplify the tuning fork output to a sufficiently high level to control a synchronous motor.

Secondary cyclic control apparatus

Secondary cyclic control apparatus C2 is herein disclosed whereby the above-mentioned difficulty is obviated, viz. high amplification of the tuning fork output is not required for control of the follower apparatus. The control system constructed according to my invention is designed to control a motor or engine **70**, which may be either an electrical motor having reasonably stable speed characteristics, or an engine or prime mover such as a turbine. A governor **71** is shown for imparting speed stability but is not essential to this invention, and any appropriate control can be used, such as a throttle for a steam engine. In the drawings, an electromagnet control unit **78** is shown arranged to control the governor, but it may equally well be used for direct control of an engine by means of a throttle or the like, as well known in the art.

In the embodiment shown in the drawings, a centrifugal governor is shown controlling the motor **70**, comprised of the revolving friction plate **72**, balls **45** mounted on springs **55**, and the friction pad **73** affixed to the arm **74**. This arm is pivoted at some point **75** and equipped at one end with a low-friction contact member **76** which in the drawings is shown as a roller. This member **76** is arranged to ride on the sloping end surface of the armature **77** of the electromechanical translating device **78**. This device may be constructed like any well known electric meter or loudspeaker driving element. In the embodiment shown herein the armature **77** is pivotally supported between the pole pieces **79** and **80**, and drawn to a central position therebetween by the springs **81** and **82**. A magnet **83** is affixed between the pole pieces. Manual means of adjusting the magnetic control assembly **78** is provided, which in the embodiment shown consists of slotted supporting means **84** and a set screw **85**. A coil **86** is shown surrounding the armature **77** and connected to the output of the tubes **90** and **91**. The action of this magnetic control unit **78** is such that when the direct current output of one of said tubes **90** and **91** is greater than that of the other, the armature **77** will be instantaneously drawn to one side, thereby causing the governor control member **76** to move on the sloped end surface of the armature **77** and thereby alter the speed of the motor **70**.

The arrangement shown by which the armature **77** acts in the manner of a cam upon the governor control member **74** is so arranged in order that the position of the governor friction pad will not be affected by surges of power in the motor, since the rigidly-supported pivot of the control member **77** takes up any shocks.

The speed of the motor **70** is transformed into electrical signals whose frequency is significant to the motor speed by means of the synchronous alternator **92**. In cases where this is used only to supply a control voltage to the electrical network **59**, it may be extremely small and cheap. In other cases, as will hereinafter be described, an alternator in this mechanical position may be utilized to supply mechanical power to a system, in which case a relatively larger alternator will be required.

The individual grid circuits of tubes **90** and **91** are connected through the rectifiers **95** and **96** to the plates of tubes **64** and **65**. The direct current circuits for these rectifiers are completed by the resistors **97** and **98**, by which the grid potential tubes **90** and **91** are controlled, also by resistors **103** and **104**, the plate potential of tubes **64** and **65** being segregated from the rectifiers by condensers **105** and **106**. This circuit **59** constitutes a modulating and rectifying bridge circuit in which the potential across the grids of the output tubes **90** and **91** is proportional to the difference between the frequency of the alternator or tone wheel **92** and that of the tuning fork **60**. Frequencies higher than this difference frequency are suppressed by filter condensers **99** and **100**.

The exact polarity of the connections required to make each part of the system operate to keep the system in synchronism is not necessarily indicated accurately in the drawings, since it is well known that any connections may be reversed in practice in order to correct the polarity and make any given portion of the system operative in the correct sense.

Direct control of electrical oscillator

The system shown in Fig. 3 illustrates a case in which synchronizing signals may be averaged over a considerable period of time and yet direct control established over a relatively simple electrical oscillator.

The extra lever **110** moving on the pivot **27** and the magnet **111** are not concerned with the operation of the control arm **14** and the electrical oscillator controlled therefrom, and will be described hereinafter in the discussion of dual synchronization.

In Fig. 3, the arm **14** is controlled by the magnet **11** or the rotating member **19** according to whether the follower apparatus R′ lags or leads the master station, as described in connection with Fig. 2. The switch members **16**, **17**, **20** and **25** select one or the other of heating elements **112**, **113** to be heated by the action of the battery **40**. These heaters **112**, **113** respectively are associated with the thermally extensible members **114** and **115**, in such a manner that heating of these members causes an increase or decrease in their respective lengths as may be desired. This member **115** is in turn so arranged and affixed to the electromagnet core members **116** and **117** that as it expands the air gap **119** therebetween is respectively increased. On the other hand, the ends of the member **114** are so crossed in their relation to the magnetic core members **116**, **117** that as the member **114** expands these members are drawn together to reduce the air gap **118**. In order to accentuate this effect a heat insulating shield may be interposed between the heated portion of the member **114** and the crossed portions, at the point indicated by the dot-dash line **120**. As an alternative to using crossed arms on one thermally expansive member, one member may be constructed of thermally positive and the other of thermally negative material. A heat shield may also be used on arm 115 as indicated by the dot-dash line 121.

A coil interlinking the magnet core is indicated with its leads 122 connected across the condenser 124 to the grid circuit of the vacuum tube 125. The plate circuit of this tube is coupled for purposes of oscillation to the magnetic core by the coil having the leads 123. A central air gap 140 between the magnetic members 114 and 115 permits free movement of these parts under the control of the thermal elements 114 and 115. The latter flex as required to provide effectively pivotal movement of one magnetic member 114 relative to the other 115.

Other oscillation circuits may be used as well known in the art within the scope of my invention, and other means of varying inductance or capacitance may be utilized. What I have shown is a structure in which the action of a differentially controlled arm 14 starts a gradual frequency correction action which is cumulatively corrective until the follower apparatus is in synchronism with the master station. In this structure the functions schematically illustrated in Fig. 1 of averaging of incoming frequency (A), local frequency correction (C1) and secondary standard oscillator (S) have been combined in a simple manner. Amplification may be utilized as indicated by the vacuum tube 126 to provide power for driving the alternator 128, the output coupling transformer 127 being used as required. The condenser 134 is a coupling member and the resistor 135 is for bias control. Other motive power may be used as required to assist the alternator 128 to carry part of the load. The resistor 130 is for the purpose of coarse synchronization, to be described hereinafter.

Simplification of secondary cyclic control apparatus

Referring again to Figure 2, in one embodiment of my invention, the member 47 of the control motor A may be utilized in the same manner as member 77 of the control motor 78 (eliminating this control motor, with standard S and the circuit 59), to control the speed of the governor 71. This greatly simplifies the equipment at a sacrifice of accuracy, since the stabilizing effect of the frequency standard S is lost. This is, however, sufficiently accurate for the remote control of various mechanical systems.

In another embodiment of my invention, the governor 77, its associated control apparatus 78, and the control circuit 59 (excluding vacuum tubes 64 and 65) may be eliminated. The follower apparatus is then driven directly from the synchronous apparatus 92, the electrical connections 93 and 94, of which are made to the output, suitably amplified as well known in the art, of vacuum tubes 64 and 65. This is applicable to the remote control of slave clocks and telegraph and facsimile picture recording apparatus.

Remote control of radio transmitter

In one embodiment of my invention, the frequency of the follower standard S may be utilized to control a radio transmitter, as shown in Fig. 1.

Methods of synchronizing a radio transmitter with an oscillator of relatively low frequency are well known in the art. These methods consist, for example, in taking the oscillations from a crystal oscillator, or some other oscillator such as the tuning fork shown in Fig. 2, and passing these oscillations through frequency doublers or multivibrator circuits until the desired multiple of the original frequency is obtained, and then synchronizing the radio transmitter with the wave so generated. In my invention the frequency of the crystal or tuning fork may be reset by a remote master oscillator, as is illustrated in Figs. 1 and 2, with good stability even though the link between the remote master oscillator and the crystal or tuning fork controlling the radio station is subject to distortion or interruption. The output of the oscillator is taken in Fig. 2 at the plates of the oscillator tubes 64 and 65, and this output controls the radio transmitter X of Fig. 1. In Fig. 3 an oscillator S' is shown driving an alternator 128, and this voltage may be run through doubler circuits to supply the excitation for the radio transmitter. In either case the follower apparatus may be a synchronous electric motor, such as an electric clock, and the clock may be geared to drive the cam system R'.

This system has certain advantages over previously known remote radio transmitter control systems. The older systems consist in general of telephone line transmission of an audio frequency wave, and the suitable frequency doubler as heretofore mentioned. The telephone transmission lines are often unstable and these instabilities are reflected directly into the transmitter. In the system as shown in this application the transmitter follows the average of a period, and greater stability may be obtained than in any system heretofore known in the art.

Dual synchronization

The rotating or reciprocating mechanical apparatus R' described herein is controlled by an electric wave whose cyclic frequency may for convenience and efficiency be much greater than that of the mechanical members. For instance, the electrical wave may have a frequency upwards of 60 cycles per second, whereas the low speed mechanical shaft carrying the cam 28 may revolve only once per second. Furthermore, the electrical oscillatory control methods herein set forth are prearranged to provide only gradual control of the secondary standard frequency.

There remains the problem of quickly synchronizing the slowly rotating apparatus when starting it. For this purpose I have shown in Figs. 3, 5 and 6 how a relatively coarse synchronizing device may be combined with the previously described apparatus to produce this dual synchronizing action with only slight additional cost.

The coarse synchronizing apparatus utilizes the lever 110 arranged to pivot on the pin 27 like the lever 26 but independently thereof, as indicated in Fig. 5; the magnet 111, arranged to act substantially coincidentally with the magnet 11; and coarse speed control means shown in this embodiment as a resistor 130 in series with the alternator 128 and electrical means consisting of the electrical contacts 131 are arranged to effectively remove or alter the speed control means 130 under suitable conditions as indicated in Figs. 3 and 6.

When the follower apparatus is substantially in synchronism with the master station, the synchronizing impulses will reach the follower apparatus and actuate the magnet 111 during the period that the flat side of the cam 28 is presented to the lever 110. It is obvious that if the magnet attracts and holds the lever 111 in its normal position during this period when it would normally move pivotally to follow the cam, no movement of the lever 110 will occur and therefore the contacts remain closed and no coarse synchronizing action will occur. If, however, the cam is materially fast, the lever 110 will move towards the cam center for an instant the contacts will open and the alternator will for that instant be slowed down. If the cam is materially slow, the lever 110 will move a number of times as the cam rotates and the alternator will slow down in corresponding intervals and allow the cam to lock into synchronism after dropping one (or possibly more than one) revolution. Due provision must, of course, be made for bringing the synchronous motor 128 up to synchronous speed when full voltage is applied thereto. This synchronizing action may be adjusted by suitable selection of the angle of cam rotation as subtended by the flat surface thereon and by adjustment of the electrical contacts 131.

After the cam is coarsely synchronized in this manner, exact isosynchronism is maintained by the remainder of the apparatus herein described.

My invention may advantageously be used to synchronize a facsimile recorder with a facsimile scanner. In this application the scanner may be controlled in speed by the apparatus M, as is illustrated in the figures by the apparatus R. The recorder may be the apparatus R′ with the synchronizing equipment shown in any of the figures. As an illustration of a facsimile system to which the synchronizing system may advantageously be applied I refer to my prior U. S. Patent No. 2,180,397. In this patent the scanner drum corresponds to the rotating apparatus R and the recorder drum to the follower rotating apparatus R′.

My invention may be used to control of remote power generating stations. As previously set forth, the apparatus 70 may be either an engine or a motor. For example, a prime mover such as a steam turbine may be used with speed control mechanism characteristic of the type of prime mover. In Fig. 2 this speed control is represented by 71, and the associated control apparatus is shown at 78. The driving medium may on the other hand, be an electric motor. In the case of a prime mover the rate of rotation is accurately controlled by the governing apparatus, and in the event that the prime mover is turning an electrical alternator, as shown at 92, the frequency of the generated alternating current output is also accurately controlled.

Summary

In applying my invention, the master cyclic apparatus M of Fig. 1 may be, for example, (*a*) a master clock, (*b*) a facsimile picture transmitter (preferably controlled by an oscillator having good frequency stability), (*c*) a tone source of relatively low frequency synchronized with an electrical oscillating device of relatively high frequency such as a crystal oscillator used to control a radio transmitter, or (*d*) an electrical or mechanical power device with which synchronism is desired at a remote point or points. The cyclic signalling apparatus N may be a contacting device associated with items (*a*) or (*b*) as mentioned above, or a contacting device associated with a synchronous motor driven by items (*c*) or (*d*), as well known in the art. At the follower station, the apparatus will in general conform to the same class such as (*a*), (*b*), (*c*) or (*d*) or consist of a system of any type mentioned, to be controlled by a master clock (*a*) or master oscillator (*c*) at the master station. The follower station may have all the component parts D, A, C1, S, C2, F and R′ as shown in the drawings or any parts not essential to the general principles herein described may be cut out in a specific application as described in the previous section of this application.

While I have shown and described particular forms of my invention in the foregoing specification and the accompanying drawings, it is to be understood that they are merely illustrative and that one skilled in the art could effect many changes and additions without departing from the spirit and scope thereof.

What I claim is:

1. A system for synchronizing a follower station with a master oscillator, said master oscillator being connected with the follower station through a transmission line subject to deleterious outside influences, which comprises generating secondary oscillations having a frequency which is near that of the master oscillator, operating synchronous mechanical means in synchronism with said secondary oscillations, discriminating between the frequency of the oscillations of the master oscillator and the speed of the mechanical means, operating electro-mechanical time delay means having a time delay spanning several cycles of the follower synchronous mechanical means in response to said discrimination, and controlling the frequency of said secondary oscillations by the action of said electro-mechanical time delay means.

2. In a synchronizing system, in combination, a master station having cyclic action of a definite frequency, means responsive to the cyclic action of the master station for generating significant impulses, a follower station having cyclic action of a related nature and related frequency, means for transmitting said significant impulses from said master station to said follower station, a member moving synchronously with the cyclic action of the follower station a yieldably supported control member disposed near said moving member, electro-mechanical translating means arranged to exert a force on said control member in response to said significant impulses, means for exerting an effectively opposite force on said control member at one portion of the movement of said cyclically moving follower station, means for retaining said control member in the position to which it is moved by one or the other of said force exerting means, means for altering the frequency of cyclic action of the follower station by the action of said control member, and means for releasing said control member at regular intervals and returning it to a neutral position.

3. In a synchronizing system the combination as defined in claim 2, in which the means for retaining said control member in position comprises a latch, means for snapping said latch on said control member, and means for lifting said latch from said control member once for each cyclic movement of the follower apparatus.

4. A synchronizing system as described in claim 2, and which is characterized by having a second control member and control means associated therewith, said second control member being arranged for altering the frequency of cyclic action of the follower station through much larger in-

crements than the first-named control member.

5. A system for synchronizing a follower station with a master oscillator, said master oscillator being connected with the follower station through a transmission line subject to deleterious outside influences, which comprises generating secondary oscillations having a frequency which is near that of the master oscillator, operating synchronous mechanical means in synchronism with said secondary oscillations, discriminating between the frequency of the oscillations of the master oscillator and the speed of the mechanical means, operating thermal electro-mechanical time delay means in response to said discrimination, and controlling the frequency of said secondary oscillations by the action of said thermal electro-mechanical time delay means.

6. In a frequency discriminating device, in combination, an armature, a set of contacts adapted to be closed by said armature when it is in one extreme position and another set of contacts adapted to be closed by said armature when it is in another extreme position, resilient means adapted to urge the armature into a mid-position, mechanical means to force the armature to one extreme position, electro-mechanical means adapted to force the armature into its other extreme position, means for locking the armature when it assumes one of its extreme positions, and means to periodically unlock the locking means.

7. In a synchronizing system, a master oscillator, and a second oscillator having an inductor as one of its frequency determining elements, thermally responsive means arranged for controlling the inductance of said inductor and means responsive to frequency differences between the two oscillators for controlling the temperature of said thermally responsive means.

8. In a synchronizing system, a master oscillator, a second oscillator having an iron core inductor as one of its frequency determining elements, said inductor having an air gap in said core, a member having a finite coefficient of thermal expansion affixed to said core and arranged to control by its length the length of said air gap, and means responsive to frequency differences between said oscillators for controlling the temperature of said member.

9. In a synchronizing system, a master oscillator, and a second oscillator having an iron core inductor as one of its frequency determining elements, a plurality of air gaps in said iron core, a member affixed to said core and arranged to increase one of said air gaps when its temperature is increased, a second member affixed to said core and arranged to decrease an air gap when its temperature is increased, and means for heating one or the other of said members in response to frequency differences between the first and second oscillators, whereby the inductance of the inductor may be controlled and the second oscillator maintained at a frequency determined by the first oscillator.

10. In a synchronizing system, a master oscillator and an electro-mechanical oscillator having an elongated vibratory member, resilient means associated with the elongated vibratory member for controlling the frequency thereof, means for varying the effective stiffness of the resilient means, said means comprising a magnet having an air gap greater of width than the thickness of said vibratory member, means for supporting said magnet so as to permit the air gap to encompass the end of said vibratory member, and thermo-responsive means controlled by the difference in frequency between the master oscillator and the second-named oscillator for moving said magnet.

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