United States Patent

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[54] APPARATUS FOR FINE ADJUSTMENT OF SIGNAL FREQUENCY

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[52] **U.S. Cl.** **58/23**, 307/269, 328/72

[51] **Int. Cl.** **G04c 3/00**, H03k 5/00, H03k 17/00

[58] **Field of Search** 58/23, 24–26, 33; 307/269; 318/301, 341, 449, 314, 318, 138, 41; 328/63, 72, 155; 335/205, 206; 200/38

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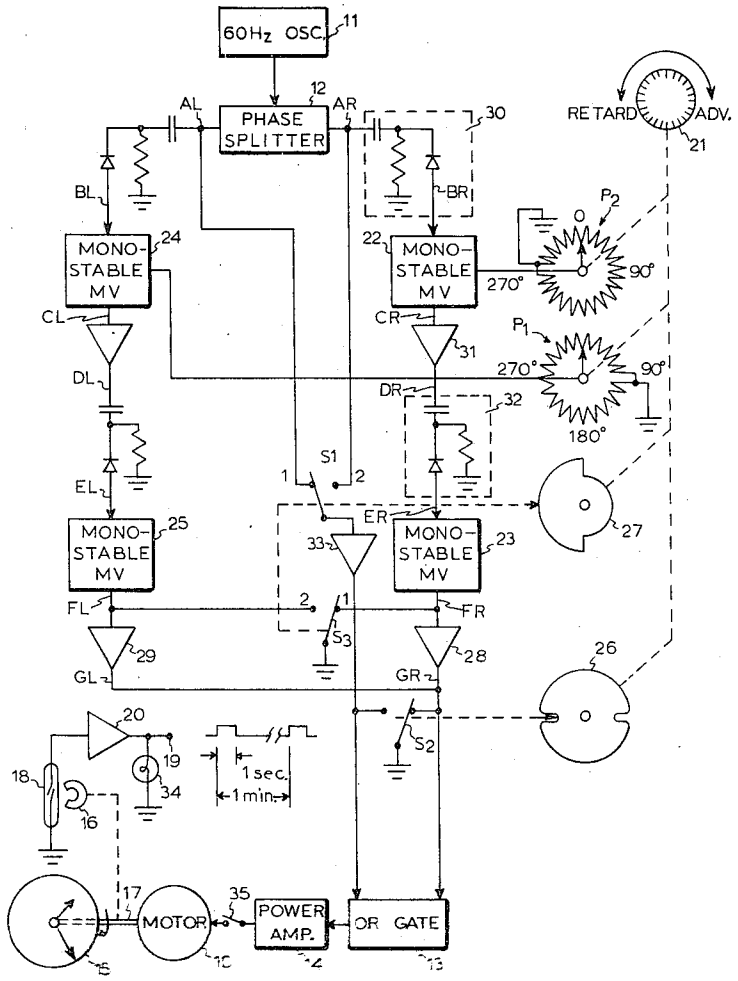
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[57] **ABSTRACT**

A clock is so driven by a constant frequency signal through a phase splitter that, to advance or retard the time in increments of half the cycle period of the constant frequency signal, a control knob is turned clockwise or counterclockwise in half-turn increments. A pair of annular potentiometers, each having a single point connected to ground, are driven by the knob in such a fashion that while the resistance of one is cyclically increasing and decreasing, the other is cyclically decreasing and increasing. The separate potentiometers are connected to monostable multivibrators (MV's) triggered by the frequency standard to vary their duty cycles as a function of resistance. Each variable MV triggers a separate MV at the end of its duty cycle to produce output pulses having fixed durations equal to the period of half a cycle of the constant frequency signal. The device is driven alternately by output pulses of the separate MV while time is being adjusted. A cam synchronizes the transfer from one output MV to the other at the midpoint of a half turn of the knob thereby allowing the phase of the frequency standard applied to the motor to be advanced or retarded 90° through one MV and another 90° through the other MV. A magnet is driven by the clock motor in a circular path over a reed switch to periodically produce a pulse to be used as a time signal from the clock and in comparing the time of the clock with a time standard to within a fraction of a second.

16 Claims, 4 Drawing Figures



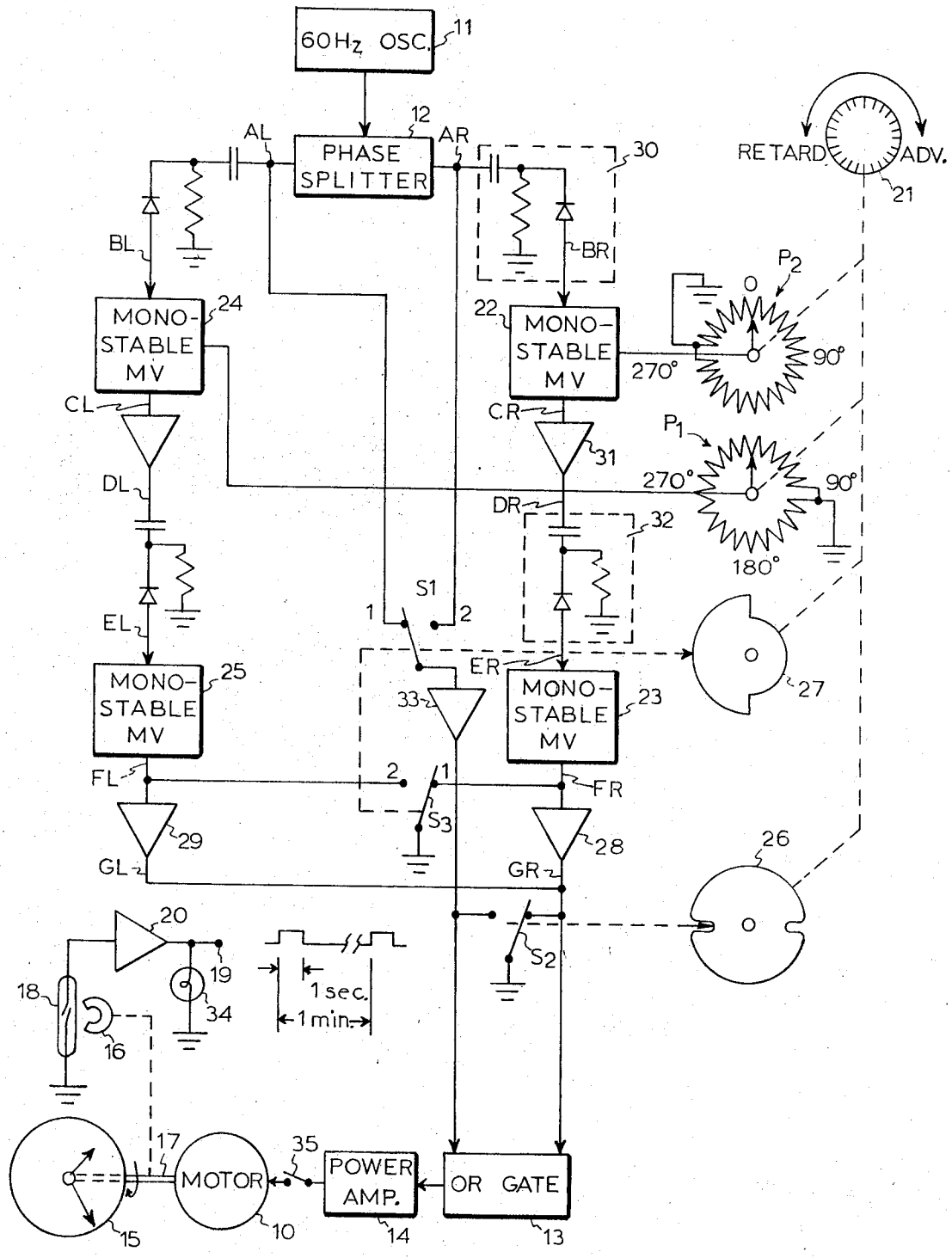
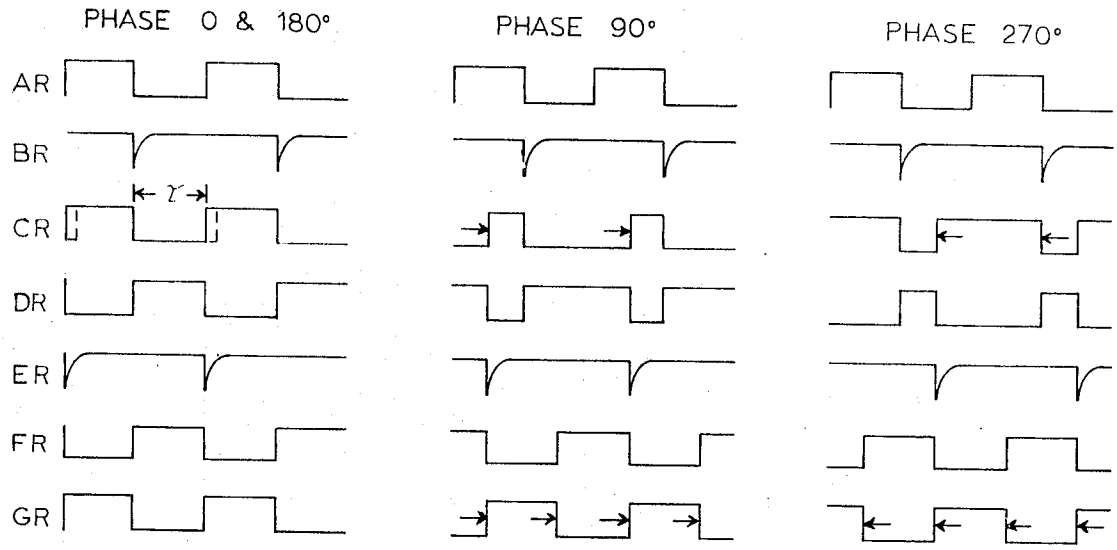


FIG. 1

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ATTORNEYS

RIGHT CHANNEL (P_2)



LEFT CHANNEL (P_1)

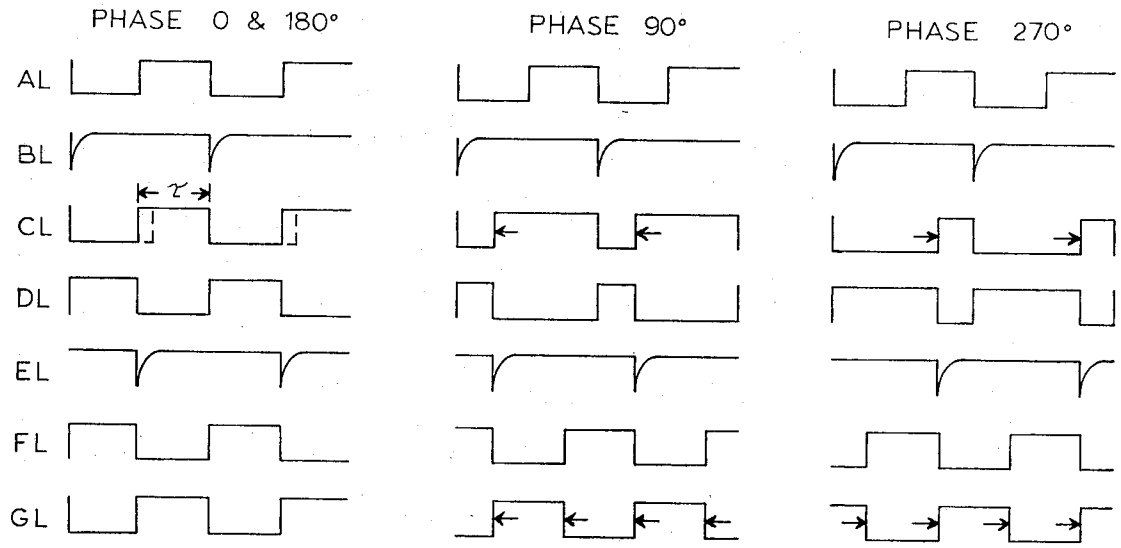


FIG. 2

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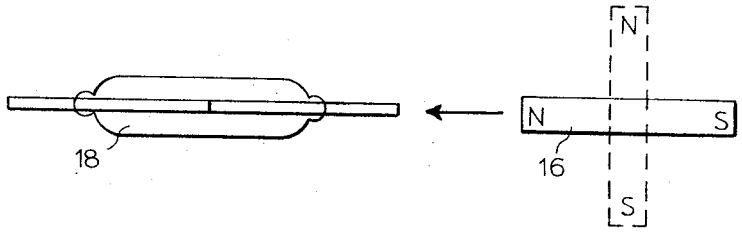


FIG. 3a

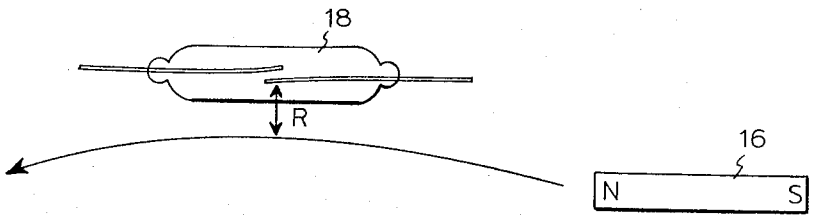


FIG. 3b

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APPARATUS FOR FINE ADJUSTMENT OF SIGNAL FREQUENCY

BACKGROUND OF THE INVENTION

This invention relates to apparatus for making fine adjustments of a constant frequency signal, and more particularly, for advancing and retarding with precision devices driven by a frequency standard.

It is frequently necessary to advance or retard the operation of a device driven by a constant frequency signal for a fraction of a cycle of the constant frequency signal, or for a selected number of such fractions. For example, in a synchronometer used as an extremely accurate clock, an operator can set the time to within a fraction of a second using an accurate time standard, such as a time code transmitted by the U.S. National Bureau of Standards. However, it is extremely difficult, if not impossible, for the operator to set the time correctly to within a fraction of one-tenth of a second.

An object of the present invention is to provide an apparatus for making fine adjustments on the frequency of a signal.

Another object is to provide an apparatus for advancing or retarding a device driven by a constant frequency signal in increments of a fraction of one cycle of the constant frequency signal.

A further object is to provide an apparatus for precisely setting an accurate clock driven by a constant frequency signal to within a period equal to a fraction of one cycle of the constant frequency signal once the difference between the time of the clock and a time standard has been determined.

Still another object is to provide an apparatus for generating a minute mark pulse useful in determining the difference between the time of a clock and a time standard to within a fraction of 1 second.

SUMMARY OF THE INVENTION

In accordance with the present invention, the frequency of a constant frequency signal is adjusted (increased or decreased) by operating a control in one of two directions, the adjustment introduced by operating the control a predetermined increment being a phase shift of the constant frequency signal equal to the period of one-half cycle of the constant frequency signal. The control is preferably a rotary one so that it may be operated in one direction or the other an indefinite number of increments.

A device may be driven by the constant frequency signal through a phase splitter using one phase at a given time and the opposite phase at the end of each incremental operation of the control. During the first half of the incremental operation of the control, the phase of the signal being applied to the device from the phase splitter is advanced, or retarded, by 90° while the signal of opposite phase is retarded, or advanced by 90°. The direction of phase shift for the signal being applied depends upon the direction the control is operated.

During the second half of an incremental operation of the control, the signal of opposite phase is substituted and advanced, or retarded 90°. Operation of the control through another increment in the same direction further advances, or retards, the signal applied to the driven device another half cycle. Thus, the control will alternately advance and retard the signal of a given phase during successive half increments of operation while the signal of the opposite phase is alternately retarded and advanced during successive half increments of the control operation. However, at the moment the phase shifting is reversed, a switch is actuated to connect the other signal from the phase splitter to the device being driven so that, during the last half of the incremental motion of the control, the signal being applied to the device is shifted another 90° in the same direction as the signal applied during the first half of the incremental motion. In that manner, the device being driven effectively receives a continuous signal that is shifted 180° as the control is operated through one increment

such as a half turn of a control knob. A technique for fine adjustment of a clock to within a fraction of a second consists of producing a short pulse to mark each minute of the time being kept by the clock, and comparing that pulse with a corresponding pulse of a time standard. By knowing the time difference between the leading edge of the clock-generated pulse and the time standard pulse the error can be determined to within a fraction of a second. That time difference may then be divided by the period of one-half cycle of the frequency standard to determine the number of increments the control should be operated.

The direction of operation corresponds to the direction of the error. A novel technique for generating the minute mark pulse consists of driving a magnet in a circular motion with the clock motor such that one revolution is completed in one minute. As the magnet swings by a reed switch, contacts of the reed switch close to provide a pulse of short duration.

The novel features of the invention that are considered characteristic are set forth with particularity in the appended claims. The invention will best be understood from the following description when read in connection with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** illustrates diagrammatically an implementation of the present invention.

FIG. **2** illustrates a timing diagram for signals appearing at indicated points in the system of FIG. **1**.

FIGS. *3a*, *3b* illustrate the manner in which a magnet is oriented to produce minute marking pulses as the magnet swings by a reed switch.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to FIG. **1**, a clock motor **10** is driven by a constant frequency of 60 Hz. from an oscillator **11** through a phase splitter **12**, a switch S_1, a coupling network **33**, an OR-gate **13** and a power amplifier **14**. The switch S_1 in position one as shown connects to the motor **10** the drive signal of the phase shown by the waveform AL in FIG. **2** under the column heading "phase 0 & 180°," but as may be more fully appreciated hereinafter, the switch S_1 may at times connect the signal from the phase splitter **12** of the opposite phase shown by the waveform AR in the same column.

The clock motor **10** drives the hands of a clock **15** and a permanent magnet **16** through suitable gear trains such that the combination of the oscillator **11**, the motor **10**, and the clock **15** provide a synchronometer that may be used as an extremely accurate clock. The motor **10** is preferably a synchronous motor with a gear train selected to produce one revolution of a drive shaft **17** per minute. The permanent magnet **16** may then be directly driven in a circle by a boom connected to the shaft **17** such that the permanent magnet **16** passes over a magnetic reed switch **18** once per revolution of the shaft **17** to provide a square pulse at an output terminal **19** through amplifier **20**. The pulse thus produced may be used for comparing the time of the clock **15** to a time standard, such as the time standard broadcast by the U.S. National Bureau of Standards over station WWVB at Fort Collins, Colorado.

To adjust the time of the clock **15**, a knob is rotated clockwise to advance the time and counterclockwise to retard the time in half-turn increments, each half-turn increment introducing an adjustment equal to the period of one-half cycle of the frequency provided by the oscillator **11**. Since the period of one cycle of a 60 Hz. signal is 16.67 milliseconds, the clock may be adjusted to an accuracy of ±4.2 milliseconds. The method used to make this fine adjustment is a novel technique implemented by a right-hand channel comprising monostable multivibrators **22** and **23**, and a left-hand channel comprising monostable multivibrators, **24** and **25**.

When the knob **21** is rotated, a switch S_2 is actuated from a first position shown to its second position. When actuated, the

switch S_2 grounds the signal from the switch S_1 to the OR gate **13**, and simultaneously removes ground from a second input to the OR-gate **13** to allow the motor **10** to be driven by a signal GR (FIG. 2) from the right channel or a signal GL (FIG. 2) from the left channel.

The switch S_2 is actuated by a cam **26** which is ganged with a cam **27** for direct rotation by the knob **21**. Thus, as the knob **21** is rotated, the switch S_2 is actuated by the cam **26** but for the first quarter of a turn the switch S_1, and a switch S_3 (ganged with the switch S_1), will remain in the position shown. Accordingly, when the switch S_2 is actuated to its second position, the motor **10** continues to be driven via an inverter **29**, by a signal GL (FIGS. 1 and 2) of the same phase as the signal AL since the right channel is grounded by the switch S_3 at a point between the monostable multivibrator **23** and an inverter **28**. Then as the knob is rotated through 90°, the phase of the signal GL applied to the motor **10** through the left channel is advanced or retarded 90° according to whether the knob **21** is rotated clockwise or counterclockwise.

Assuming the knob **21** is rotated clockwise, the phase of the signal GL is advanced a maximum of 90° as the wiping arm of a potentiometer P_1 ganged with the cam **27** is rotated through 90°. As the knob **21** is rotated further through another quarter turn, the phase of the signal GL delivered by the left channel is retarded through 90° such that the phase for the 180° position of the potentiometer P_1 is the same as for the zero position. It is therefore necessary to disconnect the left-hand channel from the motor **10** when the direction of the phase shift in the left channel reverses. That is accomplished by the cam **27** which after one-quarter turn following the actuation of the switch S_2 will actuate the switches S_1 and S_3 to their second position, thereby connecting the right-hand column to the motor **10**.

A wiper of a potentiometer P_2 ganged with the wiper of the potentiometer P_1 is phased to provide a cyclical increase and decrease in resistance out of phase with cyclical increase and decrease in resistance provided by the wiper of the potentiometer P_1. Thus the potentiometer P_2 causes a signal to the motor **10** through the right-hand channel to be retarded 90° to coincide with the phase from the inverter **29** after one quarter turn of the knob **21**. Thereafter, the phase shift of the signal through the right channel reverses so that the phase shift of the signal applied to the motor **10** through the right-hand channel is advanced through 90° as the knob **21** is rotated through a second quarter turn. The net result of a half turn of the knob **21** clockwise is an advancement of the signal applied to the motor **10** through the OR-gate **13** an amount equal to half a cycle of the constant frequency signal from the oscillator **11**. With a constant frequency signal of 60 Hz., the effect is advancement of the clock **15** by 8.3 milliseconds.

During the last part of that half turn of the knob **21** just described, the phase of the signal through the right channel will be approaching the initial phase so that when that half turn has been completed, and the switch S_2 has been returned to its initial position by the cam **26**, the phase of the signal GR (FIG. 2) at the output of the inverter **28** will coincide with the phase of the signal AR (FIG. 2) at the output of the phase splitter **12**, i.e., the phase shift through the right channel will have been returned to zero, but the signal applied to the motor **10** will have been advanced 180° from the phase of the signal AL. Therefore, once the switch S_2 has been returned to its initial position, the motor **10** is driven directly by the signal AR through the switch S_1.

If the knob **21** is rotated another half-turn increment clockwise, the time of the clock **15** will be advanced another 8.3 milliseconds. In so doing, the switches S_1 will be returned to the positions shown. The process may be repeated for any number of half turns of the knob **21** to continue to advance the clock **15** indefinitely. If the direction of rotation of the knob **21** is reversed, the entire procedure is reversed and the clock **15** is retarded.

The reason for changing the positions of the switches S_1 and S_3 during each half turn of the knob **21** is that once the signal in a given channel has been advanced 90°, the signal is shifted back to its initial phase while the phase of the signal in the other channel is being shifted in an opposite direction back to its initial phase. That opposite direction is in the same direction as the initial phase shift in the given channel. Therefore, the burden of advancing the clock **15** is shifted from the given channel to the other at the middle, i.e., at the 90° phase shift point. Switch S_1 assures the presence of a signal of the correct phase at the OR-gate **13** when S_2 returns to its original position at the end of each half turn. The system works in reverse to retard the clock **15** by turning the knob **21** counterclockwise.

The entire procedure may be compared to the operation of shipping merchandise from point A to point B with a first carrier which is met at midpoint by a second carrier from point B. Once the two carriers meet at the midpoint, the burden is shifted from the first carrier to the second carrier and each reverses its direction. Merchandise can, of course, be just as easily shipped from point B to point A in the same manner.

The manner in which signals through the right and left channels are advanced and retarded by operation of the potentiometers P_1 and P_2 will now be described more fully with reference to FIG. 2. The operation of each channel without any phase shift, which is with the wipers of the potentiometers P_1 and P_2 in the positions shown, will first be described with reference to the first column of FIG. 2 labeled "phase 0 & 180°."

In the right channel the signal AR from the phase splitter **12** is differentiated to provide the signal BR by a network **30**. Each negative pulse of that signal BR triggers a monostable multivibrator to produce a duty cycle (negative pulse) of a period τ equal to the period of a half cycle of the frequency standard. An inverter **31** provides the signal DR which is differentiated by a network **32** to provide the signal ER. Each negative pulse of the signal ER triggers the monostable multivibrator **23** to provide a fixed duty cycle (negative pulse of a fixed period) equal to half the period of one cycle of the frequency standard. The inverter **28** receives the signal FR and provides the signal GR at the input terminal of the OR-gate **13**.

If the control knob **21** is rotated 90° clockwise, the wiper of the potentiometer P_2 is rotated clockwise 90° to increase the resistance between the wiper and circuit ground to a maximum. The wiper of the potentiometer P_2 is connected to the monostable multivibrator **22** in such a manner as to increase its duty cycle, i.e., increase the negative pulse of the signal CR by 90° of a cycle of the constant frequency signal as shown under the column for phase 90°.

The duty cycle of the multivibrator **22** may be increased by using the change in resistance provided by the potentiometer P_2 to increase its time constant. Alternatively, the change in resistance can be used to so vary a bias voltage on the multivibrator as to increase the duty cycle without varying the RC time constant of the circuit. The alternative will provide better control of the duty cycle. These and other possible arrangements may require reorientation of the potentiometers P_1 and P_2 by 180°, depending on the design of the monostable multivibrators employed.

When the CR signal is inverted and differentiated, the negative pulses of the signal ER are delayed 90° (as shown by the waveform GR of the column "phase 90°" of FIG. 2). However, as will be explained more fully hereinafter, this retarded signal is not applied to the motor **10** since turning the knob **21** clockwise will advance the clock **15**, not retard it.

As the knob **21** is rotated further clockwise another 90° the wiper of the potentiometer P_2 reaches a position 180° from the position shown, at which time the resistance between the wiper and ground is the same as when the wiper is in the position shown. Accordingly, the duty cycle of the multivibrator **22** is restored, i.e., the negative pulse of the signal CR is restored to the width of the original period τ, and the output signal from the inverter **28** is advanced to its original phase. Then if the wiper of the potentiometer P_2 is rotated another

90° clockwise to 270°, the resistance between the wiper and ground will be reduced to a minimum thereby decreasing the duty cycle of the monostable multivibrator **22**, i.e., reduce the period of the negative pulse in the signal CR by 25 percent of the period of the 60 Hz. frequency signal. After processing by the inverter **31**, the shorter duty cycle pulses are differentiated and the negative excursions used to trigger the monostable multivibrator **23**. This occurs earlier by the equivalent of 25 percent of the period equal to 90°. Consequently, the phase of the signal GR applied to the OR-gate **13** is advanced by 90° from the phase of the frequency standard as shown under the heading "phase 270°" of FIG. **2**.

The left channel is controlled by the potentiometer P_1 to advance and retard the signal routed through it to the OR-gate **13** in a similar, but complementary, fashion as may be seen by comparing the signals under the heading "phase 90°" of the left channel with the signals under the heading "phase 90°" of the right channel. Thus, while the signal delivered by the right channel is being retarded, the signal delivered by the left channel is being advanced. Similarly, as shown by the signals under the headings "phase 270°" for the right and left channels, while the signal delivered by the right channel is being advanced, the signal delivered by the left channel is being retarded.

It should be noted that in each channel the signal delivered is first retarded and then advanced, or advanced and then retarded, as the control knob **21** is rotated from zero to 180° and from 180° to zero in the same direction. Therefore, to advance or retard the clock **15** by the period of a half cycle of the constant frequency signal upon rotating the knob **21** through 180°, it is necessary to switch the OR-gate **13** from one channel to the other after the knob **21** has rotated wipers of the potentiometers P_1 and P_2 to the 90° or 270° position.

For example, starting with the switches S_1 and S_3 in the position shown, rotating the knob **21** clockwise a quarter of a turn will advance the phase of the signal GL delivered by the inverter **29** by 90°. Further rotation of the knob **21** will retard that phase 90° thereby nullifying any advancement achieved over the first quarter of a turn of the knob **21**. Accordingly, as the knob **21** is rotated past 90°, the cam **27** actuates the switches S_1 and S_3 to connect the switch S_1 to the right-hand channel and connect the switch S_3 to the left-hand channel.

The position of the switch S_1 at the midway point of a half turn of the knob **21** is not important since the switch S_2 will continue to be in its second position to ground the signal from the switch S_1, but the position of the switch S_3 at that time grounds the signal at the output of the monostable multivibrator **25** and allows the signal in the right channel to be delivered to the OR-gate **13**. At that time, the signal in the right channel is exactly in phase with the signal in the left channel as may be seen by comparing the signal GR to the signal GL in the "phase 90°" column.

Now operating with the right channel as the control knob **21** is rotated another 90°, the signal delivered to the motor **10** is advanced another 90° to the phase shown by the signal GR under the "phase 0 & 180°" column. When the 180° position of the potentiometer wipers is reached, the cam **26** returns the switch S_2 to its first position as shown to allow the signal AR to drive the motor **10** directly since it is then in phase with the signal GR. If the control **21** is rotated through another 90° the switch S_2 is again actuated to its second position to ground the switch S_1 which is at that time in its second position. A buffer amplifier **33** prevents the output terminal of the phase splitter **12** connected to the differentiating network **30** from being grounded. Then as the wipers of the potentiometers proceed from the 180° to the 270° position, the output of the inverter **28** is advanced 90° as shown under the heading "phase 270°" of FIG. **2**.

Further rotation of the control **21** beyond 270° places the cam **27** in a position to change the switches S_1 and S_3 to their alternate positions, the positions shown. The switch S_3 then grounds the input to the inverter **28** and allows the signal GL to be transmitted by the inverter **29** to drive the motor **10**. The signal GL is advanced over the next quarter turn of the control knob **21** to the position shown under the heading "phase 0 & 180°."

zero position shown, the cam **26** returns the switch S_2 to the position shown to allow the signal AL to be transmitted through the switch S_1 to the OR-gate **13**. At that time, the signal GL is in phase with the signal AL. Thus, one full clockwise turn of the control knob **21** provides advancement of the clock **15** by a period equal to the period of one cycle of the 60 Hz. frequency signal.

Turning the knob counterclockwise rotates the wipers in the potentiometers P_1 and P_2 in the opposite direction so that although operation is similar, the result is the reverse, namely retardation of the clock **15**. Thus the control knob **21** subtracts one cycle from the 60 Hz. signal driving the clock motor **10** for each counterclockwise revolution.

As noted hereinbefore, duration of one cycle is 16.67 milliseconds thereby providing adjustment with an accuracy of ±4.2 milliseconds. However, this technique is not limited to that degree of accuracy. If greater accuracy were desired, a higher frequency signal would be used, such as 1 Megahertz, with decade dividers and with the system of FIG. **1** between the oscillator and the first divider, and with identical systems between successive pairs of dividers. This would provide a decade clock setting arrangement in which each revolution of the control knob for the first system would produce a 1 microsecond change. Rotation of successive control knobs would correspondingly produce 10, 100, etc. microsecond change per revolution. The 8.3 millisecond adjustment provided in the system of FIG. **1** for half-turn increments was chosen for the clock **15** as a matter of convenience for operation in a particular environment. Accordingly, the method and apparatus of the present invention is not to be limited by the implementation illustrated in FIG. **1**.

Since clocks of this type are usually required to continue operation during powerline failures and are in some applications run at locations where powerlines are not available, minimum drain from a battery power supply is desirable. To minimize power drain, both the right and left channels may be deenergized when not in use. This is done when the switch S_2 is in the position shown and adjustments are not being made. When an adjustment is to be made, power can be restored to the right and left channels before turning the control knob **21**. Once power is restored, the inverter **28** or the inverter **20** is ready to deliver a signal to the OR-gate **13** the instant the switch S_2 is operated to its second position.

Before an adjustment is made on the clock **15**, its time is compared with a time standard. If the time difference is more than about one-quarter second, the operator need only wait until the next minute mark pulse from the amplifier **20** energizes a lamp **34** to open a switch **35** thereby deenergizing the clock motor **10**.

Once the switch **35** has been opened as soon as the lamp **34** is energized, the clock **15** can be set to the correct time 1 minute ahead. Then as the minute marker from the frequency standard being used is observed, the switch **35** is closed and operation of the clock **15** is set to within a few tenths of a second of the correct time. This degree of accuracy in the preliminary setting is readily obtained because the method used depends only on the difference in reaction time of the operator to two closely spaced events.

It should be noted that the switch **35** may be electronically opened and closed such as by a flip-flop controlled circuit. The flip-flop would, of course, require means for disabling it until a time correction is to be made. When the next WWVB minute mark pulse sets it, the switch **35** would be opened upon the flip-flop being set. Then the very next WWVB minute mark pulse would reset the flip-flop and thereby reclose the switch **35**. In the meantime, the operator would manually set the time as before, and once the switch **35** is closed, fine adjustment would be made as required.

For fine adjustment, the leading edge of a minute mark pulse at the output terminal **19** is compared with the leading

edge of the minute mark pulse of the time standard being used, such as the time signal transmitted by the U.S. National Bureau of Standards Station WWVB which includes a minute mark pulse every minute that time signals are being transmitted. Although an oscilloscope may be used for precise comparison and measurement of any time difference, for most applications it would be sufficient to superimpose the minute mark pulse at the output terminal **19** on the time signal being recorded on a standard strip chart recorder.

The WWVB time code format has provision for 60 code pulses per minute each beginning precisely on the second so the minute mark pulse of the time standard can itself be used to gauge the magnitude of any difference. Once the magnitude of any difference is determined it is mentally divided by 8.3 milliseconds to determine the number of half turns that the control **21** should be operated. The direction of the operation is of course indicated by whether the minute mark pulse at the output terminal **19** leads or lags the time standard minute mark.

Once the control **21** has been operated the necessary number of half turns, the position of the minute mark pulse at the output terminal **19** with respect to the time standard minute mark may be observed to determine whether there is still any error. An overcorrection presents no problem for once it has been determined that too much change has been introduced in the clock **15**, the control **21** can be operated in the opposite direction for the necessary number of half turns. In that manner the clock **15** is adjusted by simply rotating the knob **21** to add or subtract pulses in the signal to the motor **10**. For each half turn (the increment the knob **21** can be operated), a half cycle is added or subtracted to the 60 Hz. signal applied to the motor **10** in the time it takes to operate the control knob **21**.

The fineness of adjustment which this technique affords is limited only by the period of the frequency standard, which can be made as small as desired to a limit determined only by the upper range of the frequency response of circuits used to implement the technique. Coarse as well as fine adjustments can be made using this technique by cascading systems which implement the technique with frequency dividers between systems such that operation of the control for the system having the highest frequency will provide fine adjustment, and operation of the control for the system having a lower frequency will provide intermediate adjustment, and operation of the control for the system having a lower frequency will provide coarse adjustment. The output of each system is the input to the next, and the output of the system having the lowest frequency drives the device. When the device being driven is a clock motor, operation of the controls will permit advancing or retarding the clock in increments equal to the period of one-half cycle of the frequency present at the input of each such system.

As noted hereinbefore, the basic actuating mechanism for the minute mark pulse is the reed switch **18** operated by the permanent magnet **16** mounted on the end of a boom which is rotated by the clock motor **10**. The time of closing and opening of the reed is determined by the strength and shape of the magnetic field seen by it as the magnet **16** sweeps by. If the axis of the magnet (a line between the poles of the magnet) is in line with the longitudinal axis of the reed switch **18** as shown in FIGS. *3a* and *3b*, the duration of the closure will be a maximum.

Close spacing (with a strong magnet passing by the reed switch at a close range R shown in FIG. *3b*) will in fact produce three separate closures as the magnet sweeps by it. However, this can be changed to a single closure by adjusting the magnet on its boom to a position further away from the reed switch, i.e., by increasing R. Alternatively, it can be changed to a single closure by reducing the flux of the magnet.

If the magnet **16** is rotated by 90° to the position shown in FIG. *3a* by a dotted line, and its poles are kept equidistant from the longitudinal axis of the reed, the magnet will sweep by without affecting a contact closure. Between these two extremes the magnet **16** can be adjusted to effectively and repeatedly produce a closure of the reed switch **18**. A very wide range of closed to open time as a percentage of a single revolution of the magnet **16** may be obtained by proper selection and adjustment of the following parameters: size, shape and flux density of magnets; pole piece and/or shunt configuration as required; radius of the magnet mounting boom; spacing and orientation of the magnet with respect to the reed switch; and use of additional permanent magnets for reed switch biasing. A 1-second closure may be readily achieved by a standard cylindrical magnet with elevated segment shaped poles, and adjustment to a 1-second closure is readily accomplished by rotation of the cylindrical magnet about its axis.

Although a particular embodiment has been disclosed to illustrate the present invention, many modifications may be made by those skilled in the art to meet particular requirements and operating environments. Still other optional modifications will be obvious to one skilled in the art. For example, all switches may be electronic and the cams electronically simulated in response to signals derived from a control which may also be electronic. For example, the function of the cam **27** may be carried out by a coincidence detector which receives the signals GL and GR to switch the input to the power amplifier from one to the other when coincidence is detected, each time the control has been actuated to advance or retard the motor **10**. The potentiometers P_1 and P_2 may be rotary tap switches with suitable resistors between taps, and if the control is electronic, the rotary tap switches may also be electronic, such as switches actuated by a ring counter using pulses from the oscillator to drive the ring counter through a frequency divider to keep the phase shifting operations to such a low rate that the motor will be able to follow without cogging or other malfunction. For instance, a 12 position rotary switch has been used to provide 30° phase shifts between taps by relatively slow (manual) operation of the control without the motor cogging. An all electronic system could also be constructed using a triangular wave signal in place of the rotary tap switch or potentiometers which would produce a smooth and continuous phase or frequency shift for fine adjustments of signal frequency, instead of a momentary adjustment of signal frequency to advance or retard a device driven thereby. Accordingly, inasmuch as it is recognized that modifications and variations falling within the spirit of the invention will be obvious to those skilled in the art, it is not intended that the scope of the invention be determined by the disclosed exemplary embodiment.

What is claimed is:

1. Apparatus for advancing or retarding a device driven by a signal of substantially constant frequency in increments of a fraction of one cycle of said constant frequency signal comprising:

phase-splitting means for deriving from said constant frequency signal first and second signals 180° out of phase;

a control adapted to be operated in increments in a first direction to advance said device and in a second direction opposite said first direction to retard said device;

first phase shifting means coupling said first signal to said device for shifting the phase of said first signal 90° in a given direction in response to operation of said control through a first half of an operational increment in said first direction, for shifting the phase of said first signal 90° in an opposite direction in response to operation of said control through a second half of said operational increment in said first direction for a net phase shift of 0°, and for reversing directions of the phase shifts during each half of an operational increment said control is operated in said second direction;

second phase shifting means coupling said second signal to said device for shifting the phase of said second signal 90° in said opposite direction from said first signal in response to operation of said control through said first half of an operational increment in said first direction, for shifting

the phase of said second signal 90° in an opposite direction in response to operation of said control through a second half of said operational increment in said first direction for a net phase shift of 0°, and for reversing directions of the phase shifts during each half of an operational increment said control is operated in said second direction; and

means responsive to said control for alternately utilizing said first and second phase shifting means during successive halves of said operational increment of said control in either of said first and second directions, the transition being made when said net phase shift of each of said first and second phase shifting means is substantially zero.

2. Apparatus as defined in claim 1 wherein each of said first and second phase shifting means comprises:

a first monostable multivibrator having a variable duty cycle;

means responsive to said phase splitting means for triggering said first monostable multivibrator at a given point of each cycle of one of said first and second signals;

a second monostable multivibrator having a fixed duty cycle equal to a half cycle period of said constant frequency signal;

means responsive to said first monostable multivibrator for triggering said second monostable multivibrator at the end of each duty cycle of said first monostable multivibrator; and

duty cycle control means responsive to said control for alternately increasing and decreasing the duty cycle of said first monostable multivibrator to 75 percent and 25 percent of the period of one cycle of said constant frequency signal.

3. Apparatus as defined in claim 2 wherein said control comprises:

a variable parameter so connected to said first monostable multivibrator as to affect said duty cycle by a maximum of plus and minus 25 percent; and

means responsive to said control for alternately increasing said parameter to a maximum and decreasing said parameter to a minimum during successive operations of said control, and stopping at an intermediate value at the end of each operation, said maximum and minimum values being reached at intermediate points of the successive operations.

4. Apparatus as defined in claim 3 wherein said control is a rotary device and said variable parameter comprises an annular potentiometer having a wiper and a single takeoff point connected to said monostable multivibrator, and said last named means comprises a one-to-one drive connection from said rotary device to said wiper.

5. Apparatus as defined in claim 1 wherein said device comprises:

a clock;

a motor for driving said clock;

a magnet so connected to said motor as to be driven in a circular path at a predetermined rate; and

a reed switch disposed near said circular path of said magnet, whereby said reed switch is closed once per revolution of said magnet as said magnet swings by to mark the passing of a predetermined period.

6. Apparatus as defined in claim 5 including a lamp and means connected to said reed switch for energizing said lamp while said reed switch is closed.

7. Apparatus for advancing or retarding a device driven by a signal of a substantially constant frequency in increments of a fraction of one cycle of said constant frequency signal comprising:

phase splitting means for deriving from said constant frequency signal first and second signals 180° out of phase;

a control adapted to be operated in increments in a first direction to advance said device and in a second direction opposite said first direction to retard said device;

first phase shifting means connected to said first signal for shifting the phase of said first signal 90° in a given direction in response to operation of said control through a first half of an operational increment in said first direction, for shifting the phase of said first signal 90° in an opposite direction in response to operation of said control through a second half of said operation increment in said first direction for a net phase shift of 0°, and for reversing directions of the phase shifts during each half of an operational increment said control is operated in said second direction;

second phase shifting means connected to said second signal for shifting the phase of said second signal 90° in said opposite direction in response to operation of said control through said first half of an operational increment in said first direction, for shifting the phase of said second signal 90° in said given direction in response to operation of said control through a second half of said operational increment in said first direction for a net phase shift of 0°, and for reversing directions of the phase shifts during each half of an operational increment said control is operated in said second direction; and

means responsive to said control for alternately applying to said device phase shifted signals from said first and second means during operation of said control, and while said control is not being operated for applying to said device a signal of the same phase as the signal of said first and second means last applied.

8. Apparatus as defined in claim 7 wherein each of said first and second phase shifting means comprises:

a first monostable multivibrator having a variable duty cycle;

means responsive to said phase splitting means for triggering said first monostable multivibrator at a given point of each cycle of one of said first and second signals;

a second monostable multivibrator having a fixed duty cycle equal to a half-cycle period of said constant frequency signal;

means responsive to said first monostable multivibrator for triggering said second monostable multivibrator at the end of each duty cycle of said first monostable multivibrator; and

duty cycle control means responsive to said control for alternately increasing and decreasing the duty cycle of said first monostable multivibrator to 75 percent and 25 percent of said constant frequency signal.

9. Apparatus as defined in claim 8 wherein said control comprises:

variable resistance so connected to said first monostable multivibrator as to affect said duty cycle by a maximum of plus and minus 25 percent; and

means responsive to said control for alternately increasing said resistance to a maximum and decreasing said resistance to a minimum during successive operations of said control, and stopping at an intermediate value at the end of each operation, said maximum and minimum values being reached at intermediate points of the successive operations.

10. Apparatus as defined in claim 9 wherein said control is a rotary device and said variable resistance comprises an annular potentiometer having a wiper and a single takeoff point connected to said monostable multivibrator, and said last named means comprises a one-to-one drive connection from said rotary device to said wiper.

11. Apparatus for introducing a phase shift in a constant frequency signal in increments of a fraction of one cycle of the constant frequency signal comprising:

phase splitting means for deriving from said constant frequency signal first and second signals 180° out of phase;

a control adapted to be operated in increments in a first direction to advance phase of said constant frequency signal and in a second direction opposite said first

direction to retard phase of said constant frequency signal;

first phase shifting means for producing a first phase shifted signal by shifting the phase of said first signal 90° in a given direction in response to operation of said control through a first half of an operational increment in said first direction, for shifting the phase of said first signal 90° in an opposite direction in response to operation of said control through a second half of said operational increment in said first direction for a net phase shift of 0°, and for reversing directions of the phase shifts during each half of an operational increment said control is operated in said second direction;

second phase shifting means for producing a second phase shifted signal by shifting the phase of said second signal 90° in said opposite direction from said first signal in response to operation of said control through said first half of an operational increment in said first direction, for shifting the phase of said second signal 90° in said given direction in response to operation of said control through a second half of said operational increment in said first direction for a net phase shift of 0°, and for reversing directions of the phase shifts during each half of an operational increment said control is operated in said second direction; and

means responsive to said control for alternately transmitting for use said first and second phase shifted signals during successive halves of said operational increment of said control in either of said one and second directions, the transition being made when said net phase shift of each of said first and second phase shifted signals is substantially zero.

12. Apparatus as defined in claim **11** wherein each of said first and second phase shifting means comprises:

a first monostable multivibrator having a variable duty cycle;

means responsive to said phase splitting means for triggering said first monostable multivibrator at a given point of each cycle of one of said first and second signals;

a second monostable multivibrator having a fixed duty cycle equal to a half-cycle period of said constant frequency signal;

means responsive to said first monostable multivibrator for triggering said second monostable multivibrator at the end of each duty cycle of said first monostable multivibrator; and

duty cycle control means responsive to said control for alternately increasing and decreasing the duty cycle of said first monostable multivibrator to 75 percent and 25 percent of the period of one cycle of said constant frequency signal.

13. Apparatus as defined in claim **12** wherein said control comprises:

a variable parameter so connected to said first monostable multivibrator as to affect said duty cycle by a maximum of plus and minus 25 percent; and

means responsive to said control for alternately increasing said parameter to a maximum and decreasing said parameter to a minimum during successive operations of said control, and stopping at an intermediate value at the end of each operation, said maximum and minimum values being reached at intermediate points of the successive operations.

14. Apparatus as defined in claim **13** wherein said control is a rotary device and said variable parameter comprises an annular potentiometer having a wiper and a single takeoff point connected to said monostable multivibrator, and said last-named means comprises a one-to-one drive connection from said rotary device to said wiper.

15. In a clock driven by a motor which in turn is driven directly by an electrical signal, apparatus for producing periodic timing pulses, each pulse of predetermined duration comprising:

a reed switch;

means connected to said reed switch for producing a pulse in response to each closure of said reed switch; and

a magnet driven in a fixed circular path past said reed switch by said motor to produce a closure of said reed switch, the field of said magnet being oriented to produce a closure of said reed switch each time said magnet is driven by said reed switch with each closure occurring for said predetermined duration.

16. The combination of claim **15** wherein said orientation is with the axis of said field from pole to pole of said magnet at an angle between 0° and 90° with respect to the longitudinal axis of said reed switch, said angle being selected for a given magnet and a given distance of said circular path at the closest point from said reed switch to produce just one closure of said reed switch of said predetermined duration during each pass of said magnet over said reed switch.

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