SERVO CONTROL SYSTEM

Filed Nov. 2, 1945 2 Sheets-Sheet 1

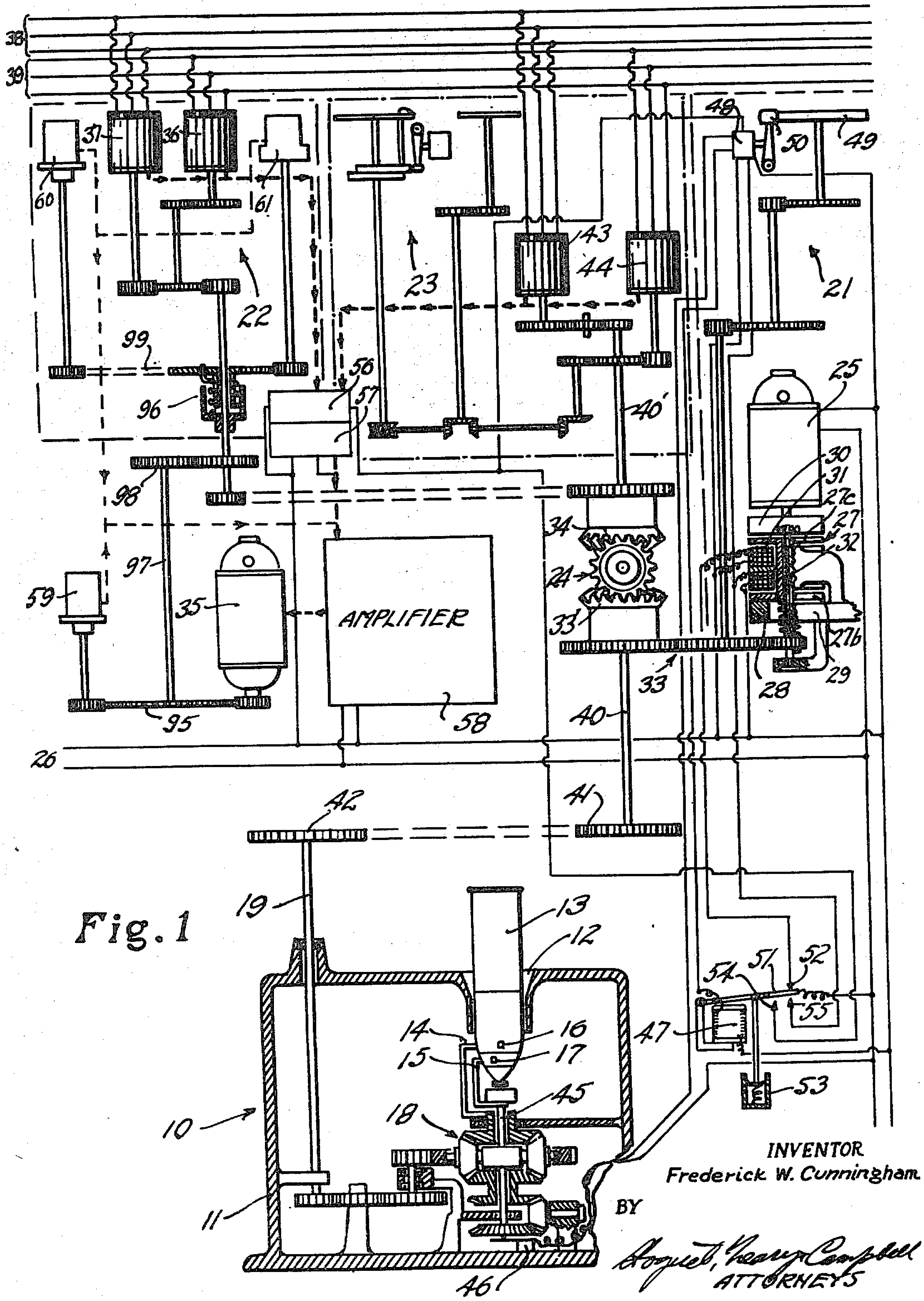

Fig. 1

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SERVO CONTROL SYSTEM

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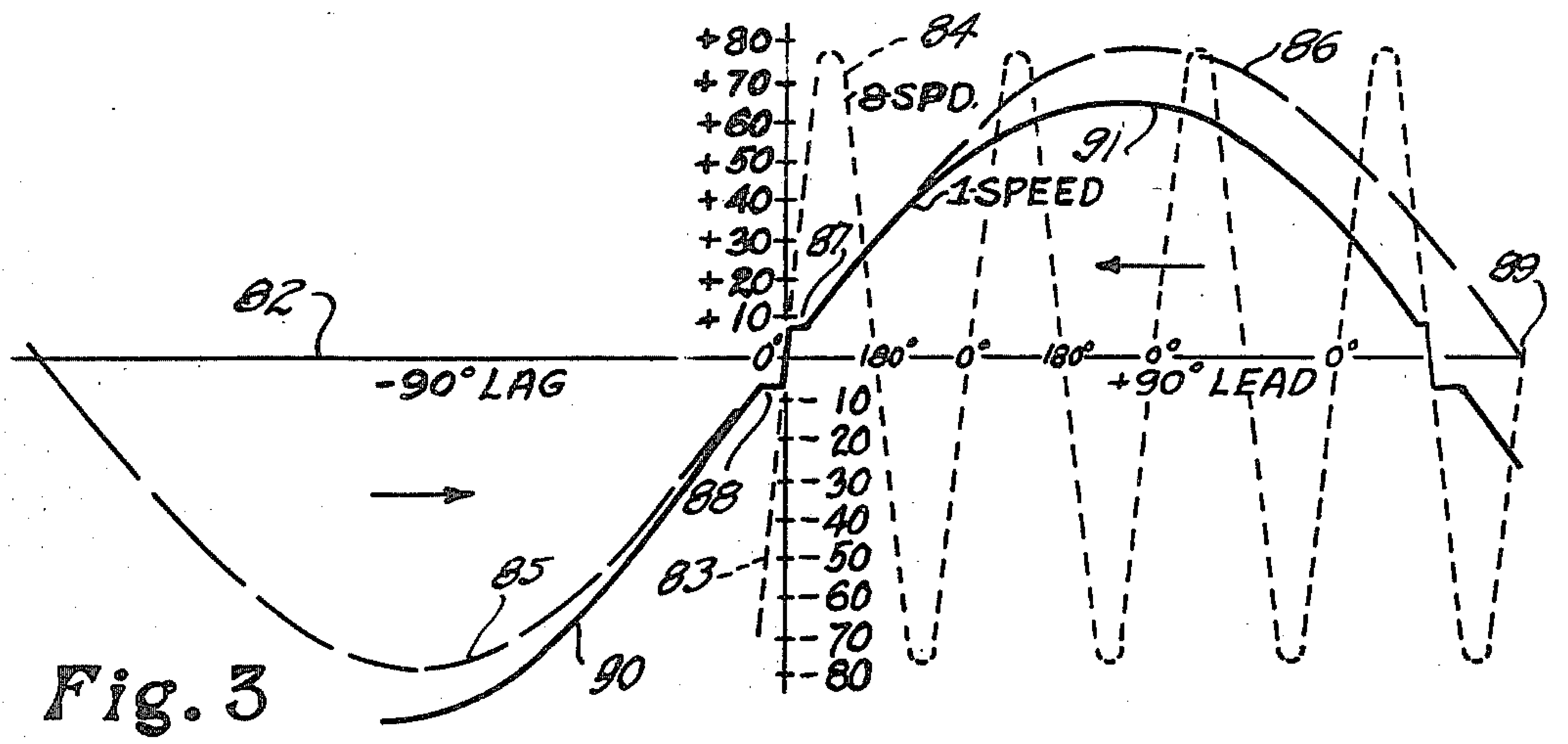

Fig. 3

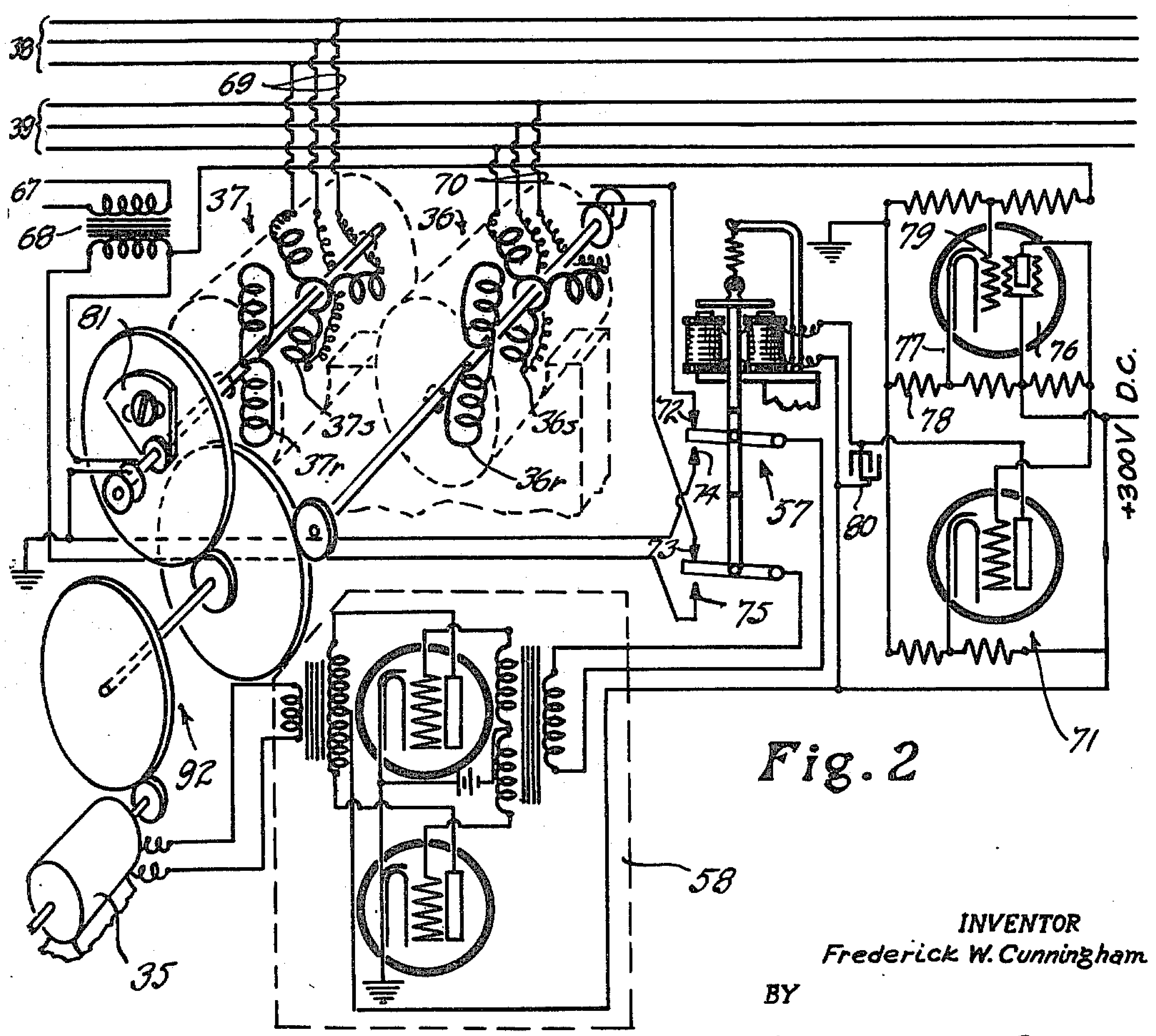

Fig. 2

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SERVO CONTROL SYSTEM

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17 Claims. (Cl. 89—6)

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This invention relates to servo control systems, and has particular reference to an accurate servo mechanism for precisely reproducing a series of intermittent and irregular adjustments at a remote point.

The uses of servo mechanisms of various forms have increased materially and much improvement has been directed particularly toward making them more accurate by minimizing overrunning, hunting, and the like. Most servo systems are used for transmitting continuous movements or movements of substantial duration, so that the overrunning and hunting problems are not as serious as in the cases where the transmitted movements are short and rapid, for in that event a hunting oscillation may be a large percentage of the transmitted movement, whereby a substantial error is introduced. An example of a requirement for precise remote adjustments without transmission error is the fuse adjustments on a continuous series of gun shells in ordnance and the like.

In modern fuse-setting practice the nose of each shell of a series is placed in a pot which has a pair of concentric pawls rotatable about the center line of the shell for finding and attaching themselves to corresponding slots in the nose of the shell. The pawls are adapted to make, firstly, a rapid motion past each other seeking the slots in the shell and, secondly, when they have found the slots, a further motion to precisely set or determine the fuse-setting and keep it current, that is, in strict synchronism with the continuously changing fuse-setting order until the instant of removal of the shell from the pot for firing. Such a fuse-setting mechanism has only one mechanical input which is required not only to find and engage the fuse but to also set it, with the aid of the present invention. The present invention may be readily adapted for the precise setting of fuses equipped with fuse-setting lugs instead of fuse-setting slots, and the term "slots" as used herein is intended to apply equally well to an equivalent detent for engagement by the setting means.

In accordance with the present invention, an accurate servo control system is provided in which the order of transmitted movements is reproduced at low speed, whereby the synchronism is retained under all conditions and actual transmission is effected at high speed so that the transmitted movements are precisely reproduced without transmission lag, thus enabling the system to be employed with safety and confidence for the setting of fuses on a continuous series of gun

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shells, and for other uses requiring reliability and precision.

The invention utilizes self-synchronous electrical transmission in which the usual pair of synchronous units is doubled and are of the so-called control transformer type comprising a distributed three-phase stator winding operating with a shuttle type armature having a single coil thereon like a self-synchronous receiver in construction. The action, however, is of the null type, a servomotor being provided to bring the rotor to its null or zero voltage position in respect to the stator field and to continuously keep it there, the servo-motor being operated by the amplified error voltages from the rotor coil. The motion of this servo-motor in response to the control transformer error voltages is transmitted to the fuse-setter input through a mechanical differential, in order that a second motor may cooperate with it, the purpose of this second motor being to initially find and engage the setting slots of the shell to be set while the servo-motor creates and keeps a mechanical fuse-setting value at all times in synchronism with the electrical fuse-setting order received by the self-synchronous system. Both motors operate while engagement of the fuse is being effected, but during fuse-setting the servomotor alone is operating. Control of the interaction of the two motors is accomplished by an electro-mechanical arrangement of relays and cam-switches as will be hereinafter described. The placing of a shell in the fuse pot of the fusesetter trips a trigger which initiates a cycle of operations comprising (1) engaging the fuse, (2) rough-setting the fuse, and finally, (3) justifying the fuse-setting and resetting the apparatus for a repetition of the cycle. Means are also provided to smooth the action of the apparatus and to prevent incorrect synchronizing under any operating conditions.

For a more complete understanding of the invention, reference may be had to the accompanying drawings, in which:

Figure 1 is a schematic view of the servo control system of this invention;

Fig. 2 is a schematic electrical diagram of the synchronizing means included in the invention; and

Fig. 3 is a graph of the electrical action of the same.

Referring to Fig. 1 of the drawings, numeral 10 designates the fuse-setter operated by the mechanism of the present invention, and including the housing 11 having the shell-receiving pot 12 into which the nose of the shell 13 is adapted to be inserted for setting the fuse thereof. With the shell 13 in that position the fuse-setting pawls 14 and 15 are spring-pressed against the smooth curve of the shell nose as indicated, and are vertically aligned with the fuse-setting slots 16 and 17, respectively, positioned in the shell nose, as shown. With this arrangement, rotation of the pawls 14 and 15 about the axes of the shell will cause them to engage the corresponding shell slots 16 and 17.

As shown in Fig. 1, these pawls 14 and 15 are inter-connected by gearing, including a mechanical differential gear 18, in such a way that the pawls travel oppositely to each other upon rotation of the single input shaft 19. For one direction of rotation of input shaft 19 the pawls 14 and 15 separate, and for the opposite direction of input rotation they approach each other. Because of the differential gearing 18, the pawls 14 and 15 are free to rotate in the same direction, while the input shaft 19 remains at rest. By this arrangement the angle of separation between the two pawls 14 and 15 represents fuse-setting angle when the device is synchronized in accordance with the invention and the orientation of the pawls as a pair has no significance, being made necessary by reason of the random orientation of the fuse slots 16 and 17 on the shell 13 when inserted in the fuse-setter 10.

According to the present invention, when the shell 13 is inserted in the pot 12, its nose engages and depresses rod 45 which closes switch 46 to set into rotation the pawls 14 and 15 in a manner to be described. When the shell 13 is so inserted in pot 12, with random orientation of the slots 16 and 17, the pawls 14 and 15 will be given relative rotation of at least two turns and will thus locate and engage their respective shell slots 16 and 17. When slots 16 and 17 have been found, their included angle may then be adjusted to correspond to fuse-setting order, both these actions being effected precisely, in a very short time, as will be described.

The mechanism for operating the fuse-setting instrument 10 includes the assembly of mechanism shown in Fig. 1, and comprises a fuse-slot engagement drive unit designated 21, a rough fuse-setting unit designated 22, and an arcuate fuse-setting or justifying unit designated 23. These three units are connected mechanically through the differential 24 and by the various electrical connections shown.

The fuse-slot engagement unit 21 is driven by the continuously running electric motor 25 supplied from the service wires 26 and having a clutch-brake combination which operates when electrically energized to release the output disc *27b* from the fixed braking surface 28 carried on the frame 29 of the unit. Simultaneously clutch disc *27c* is pressed against the rapidly rotating clutch surface of the motor flywheel 30. The transfer is made magnetically by the double coil solenoid 27, the coil 31 being the brake coil, and the coil 32 being the clutch coil of the energizing solenoid. By this arrangement, when the engagement gearing 33 is not operating, it is held very rigidly by the brake 28 and, when the gearing is required to run, the clutch operates very quickly, since the plate *27c* drops directly against the rapidly running motor flywheel 30.

By this drive from motor 25, clutch *27c*, 30, gearing 33, shaft 40 connected to the spider of differential 24, gearing 41, 42, and shaft 19, the fuse-setter pawls 14 and 15 are suddenly accelerated into rapid rotation past each other through a relative angle of at least two turns plus one additional turn to take care of any rapid change of fuse-setting which may occur during the engaging period. Exactly three turns of the fuse-setter pawls 14 and 15 is desired to avoid a loss of precise synchronism when engagement is complete, as well as to assure engagement of the fuse slots 16 and 17, the clutch-brake-motor combination 25–32 being adapted to give precisely three turns of the fuse-setter pawls 14 and 15 with a very small margin of error.

While this engagement of the fuse slots 16 and 17 by pawls 14 and 15 is taking place, fuse-setting angle change is also being applied to the end gear 34 of the differential 24 by the fuse-setting follow-up motor 35 and the control transformers 36 and 37 fed by the high-speed and low speed synchronized supply lines 39 and 38, respectively. Follow-up motor 35 is energized by conventional electronic amplifier 58 connected to power line 26 and amplifying the modulated inputs from 36, 37, 43 and 44, as will be described.

The fuse-setting angle change value so applied to differential gear 34 passes through differential 24 and merges with the slot-engaging motion from end gear 33' to appear on spider shaft 40 and gear 41, and fuse-setter mechanism 10 through gearing 42 and shaft 19, so that the motion appears as a change in angular spacing of pawls 14 and 15. Thus, the fuse-setting value is kept up to date for the fuse although temporarily set aside by the fuse-engaging motion from motor 25. However, before the pawls 14 and 15 have completed the relative three turns required, they have engaged and set the fuse slots 16 and 17 to approximate fuse value.

This fuse value is not quite accurate because of the difficulty of getting exactly three turns at the fuse from motor 25 without a dead stop of such rapidly moving parts as to give prohibitive stresses in the mechanism. For this reason, a slight re-synchronizing operation is necessary to compensate for the inaccuracy in the pawl-engaging rotation, whenever the engaging operation has occurred, for it is obvious that if exactly three turns of the pawls could be given by the motor 25, synchronism would remain undisturbed and would be the case if the number of turns is any integer. However, since it is impractical to obtain exact integral turns from motor 25, it follows that the net angle between the pawls 14 and 15, after any engaging operation, is in error by the angle by which the motor 25 input varies from integral value. In other words, the mechanical circuit traced from the rotor of control transformer 37, for instance, to the fuse pawl separation angle of the pawls 14 and 15, will exhibit an angular misalignment equal to the error by which the input engagement angle from motor 25 varies from an integral value.

In order to correct such misalignment, a second direct mechanical control for the fuse-setter shaft 19 is provided and includes a second pair of control transformers 43 and 44 supplied electrically by the same fuse-setting order from synchronous supply busses 38 and 39. This mechanical connection comprises an extension 40' of the differential spider shaft 40 to the rotor of control transformer 43, so that the same angle value applied as input to shaft 19 is likewise applied to that transformer rotor. Accordingly, when the aforementioned slot-engagement movement of pawls 14 and 15 is completed, and a slight misalignment of shaft 19 results, the rotor of control transformer 37 is aligned in its fuse-setting-order magnetic field, but the rotor of control transformer 43 is out of alignment with its similar field. Consequently, when the final shift is made from control transformer 36 to control transformer 44, a quick spin of a few turns of motor 35 is caused to take place and the fuse-setting angle at 19 is quickly and exactly justified, to continue following the input fuse-setting angle accurately thereafter until the shell 13 is removed and another one inserted at 12 for setting in the same way.

The energization of clutch coil 32 to effect the pawl-engaging operation of fuse-setter 10 is initiated by the aforementioned activation by the nose of the shell 13 of the rod 45 to close the switch 46, which applies current from source 26 to the delayed response type relay 47. Both the relay 47 and switch 46 are in series with a multiple switch 48 operated by a cam 49 and follower 50. Before a shell is inserted in the unit 10 the contact arm 51 of the relay 47 is held up against the contact 52 by spring 53. Hence the brake coil 31 is energized and the disc 27b is held immovably against the stationary brake disc 28, the differential gear 24 consequently acting as a simple straight gearing. Also, at this time the cam 49 is at rest, but the angle between the pawls 14 and 15 is changing according to fuse-setting order on the bus wires 38 and 39.

Energization of relay 47 as the result of insertion of shell 13 in pot 12, causes its armature to break contact between the elements 51 and 52, thus releasing brake 27b—28 and to make contact between element 51 and the two lower contacts 54 and 55. The closure of contact 55 causes energization of clutch coil 32 to move clutch-plate 27c immediately into driving contact with spinning motor flywheel 30, so that motor 25 can make a quick swing of pawls 14 and 15 to engage them in slots 16 and 17 on shell 13. This motion also turns cam 49, which throws lever 50 to operate switch 48. Switch 48 then appropriates control from relay 47 by by-passing contacts 54 and 55 and, by breaking the coil circuit, also allows relay contact 51 to go slowly back against stop contact 52. This action resets the brake 28—27b immediately upon one turn of cam 49, which is equivalent to the three turns of pawls 14 and 15.

At this time also, the cam 49 will transfer control from control transformers 36, 37 back to control transformers 43 and 44 by action of shift relay 56 by breaking of contact 51, 54 at relay 47. In other words, introduction of a shell 13 at 12 initiates a three-turn cycle of the pawls 14, 15 under control of a different pair of control transformers, in order that synchronism may be retained for a quick application of fuse-setting to the fuse when the engaging cycle is completed and control restored to the regular control transformers 43 and 44 which have the advantage of direct connection to the load. By this means of engaging the fuse slots 16 and 17, synchronism is retained at all times by the other set of control transformers 36, 37 within a small margin of error so that the required final justification of the fuse-setting value is not great enough to consume any appreciable time.

As stated, follow-up motor 35 is continuously following fuse-setting order as electrically demanded by the control transformers, transformers 43 and 44 operating when setting the fuse and the transformers 36 and 37 operating when the fuse-engaging operation is occurring. In either case, the high speed control transformer 36 or 44 of one pair or the other are in control for the major part of the operation, the low speed transformers 37 or 43 being in control only when synchronism is lost, as for instance, when the machine is starting into operation.

The relay 57, shown in detail in Fig. 2, is provided to swing control from low speed to high speed and back as often as necessary, being operated by the error voltage output of the low speed control transformers themselves. For instance, when a low speed control transformer 37 or 43 is controlling the motor 35 and it is following closely, the relay 57, responsive to the low error voltage from the same, quickly switches control to the corresponding high speed unit for greater accuracy of following.

Conversely, should the error voltage from the low speed unit rise, thus indicating loss of synchronism, then before the misalignment can become serious, the relay 57 shifts control of motor 35 back to the corresponding "one speed" control transformer, which cannot lose synchronism at any time. From the relay 57 the error voltages are fed, as shown, to the amplifier 58 the power output of which feeds the motor 35 as previously explained. The circuit also includes damping and compensating generators indicated at 59, 60 and 61 for smooth action, as will be described.

Referring particularly to Fig. 2, the relay 57 which operates as described to maintain synchronism under all conditions, includes the low speed or rough control transformer 37, whose stator is supplied by lead wires 69 from low speed self-synchronous bus wires 38, whereby the signal actuated rotating field of transformer 37 is established. Similarly, high speed or fine control transformer 36 is supplied by the stator lead wires 70 from high-speed self-synchronous bus wires 39. It will be understood that bus wires 38 carry the low-speed or rough following self-synchronous transmission of the signal or order to be reproduced mechanically by motor 35, and that numeral 39 designates the self-synchronous bus-wires for the high-speed or accurate transmission which appropriates control when the low-speed system has achieved rough synchronism. At 67 is shown the usual alternating current bus wires for supplying power to any other self-synchronous units, not shown, on the lines 38 and 39, here also supplying a transformer 68 for a purpose to be described.

As is usual in self-synchronous servo-systems, the low speed system is only in control when the mechanical parts slip out of synchronism with the signal order, for instance while the instrument is de-energized. In such a case, as soon as the apparatus is again energized the follow-up motor will be under control of the high-speed control transformer 36 because the relay 57 is de-energized and the relay spring is holding its relay contacts 72 and 73 closed. But if synchronization has been lost while the apparatus was de-energized, the error voltage from the displaced rotor of low-speed control transformer 37 will be greater than the predetermined permissible value, the vacuum tube amplifier 71 will be triggered, the relay 57 will open the contacts 72 and 73 and close the contacts 74 and 75 and the low-speed control transformer 37 will assume control. This control transformer will seek rough alignment and, when it has found it, the error voltage from its rotor will drop and the relay 57 will switch back to the high speed or precision control by transformer 36 for normal following of the signal.

The switching mechanism includes vacuum tube 76 biased negatively by the well-known means of connecting its cathode 77 to ground by means of a resistance 78 in the plate circuit, so that any voltage to operate relay 57 applied to grid 79, must be positive and of greater voltage than the biasing voltage. The voltage from control transformer 37 is, of course, a single phase alternating voltage but the positive peaks of the waves will affect amplification if they lie above the critical or predetermined voltage value, the pulsations being smoothed out sufficiently by the condenser 80. This arrangement provides an accurate and reliable shifting device from control transformer 36 to control transformer 37 whenever loss of synchronism exceeds a predetermined value, indicating angular deviation between the signal on busses 38 and 39 and the mechanical output from motor 35.

Such a system is practical and reliable except under the remote circumstance that synchronization should fall 180° out of step. Thus, if the normal synchronizing point is 0°, there is another possible synchronizing point at 180°, and should the instrument be de-energized and during de-energization the mechanical output 19 turned so that the rotor of the slow speed control transformer 37 is rotated nearly 180° from its correct synchronizing position, the device will synchronize at this point rather than find its way back to true synchronism at 0°, which impairs the effectiveness of the instrument as a servo-system. This condition of control transformer 37 is illustrated in Fig. 3, which also illustrates the electrical action of both transformers 36 and 37.

In Fig. 3 horizontal line 82 represents zero voltage output from rotor coils 37*r* and 36*r* of respective control transformers 37 and 36 and the point of the center marked 0° the condition of synchronism which is the condition when the field of the rotor coil 36*r* is being maintained at right angles to the resultant field of the three-phase type stator winding 36*s* carrying the rotating signal and there is no voltage induced in the rotor coil 36*r*. This coil 36*r* is driven through gearing 92 by the servo-motor 35 at a rate eight times as fast as the signal itself varies, and its voltage wave is therefore labeled "8 speed" in Fig. 3. When the rotor 36*r* of the control transformer 36 lags behind its rotating signal field, the voltage value induced in it for each degree of lag may be plotted as the dotted line curve 83. Similarly, for each degree that the rotor 36*r* leads the signal field, the opposite sign voltages may be plotted as the dotted line curve 84. Likewise the voltages which would be generated in the rotor coil 37*r* of low speed control transformer 37 when it is losing synchronism may be plotted as the dash line curve 85, 86. The points 87 and 88 on the curve portions 84 and 83, respectively, indicate the permissible error voltages beyond which the relay 57 operates, to switch control from high to low speed control as described. The voltage in control, beyond these points would normally be found on the curve 85, 86.

In the system of the present invention, however, this curve 85, 86 is not employed because at 180° out of synchronism, as at point 89, there is a second accidental synchronizing point. A voltage error curve 90, 91 is therefore substituted, which does not align at 180° with the extended high speed curve 84 and therefore the second synchronizing point is eliminated. This curve 90, 91 may be shown to be the curve 85, 86 with its zero point shifted to the left and downwards along itself by means of the mechanical offset device at 81 and the action of the transformer 68. The offset device 81 comprises a lever fixed on the shaft of rotor 37*r* and shiftable relatively to the gearing 92 to throw the rotor coil 37*r* of the control transformer 37 out of angular alignment with the rotor coil 36*r* of control transformer 36, thus shifting curve 85, 86 bodily to the left and the constant root-mean-square voltage from transformer 68 realigns curve 85, 86 at zero with the high speed curve 83, 84. In the diagram of Fig. 3 and considering the action of the relay 57, the actual operating error voltage output curve of a pair of transformers 36, 37 is that shown by the full line, composed of that part of the high speed curve 83, 84 across zero between 87 and 88, and the balance of the amended low-speed curve 90, 91.

The operation of the mechanism just described and illustrated in Fig. 2, for preventing asynchronism or pseudo synchronism, the synchronous bus wires 38 and 39 transmit to the control transformers 37 and 36 a set of three space-phased alternating currents, the root-mean-square values of which are peculiar to the angle value of the signal required to be reproduced, as is well understood in self-synchronous transmission. These currents flowing in stator winding 37*s* produce a directional field in which the rotor coil 37*r* has some orientation. If the synchronism is accurate within the limit predetermined by the biasing voltage on the resistor 78, as previously explained, no effect will be caused by induction on the coil 37*r* because its output circuit is interrupted at the points 74 and 75 of relay 57.

At the same time, the high speed synchronous bus wires 39 are feeding space-phased currents to stator coils 36*s* of control transformer 36, designating an angle eight times as great as the angle produced in control transformer 37, so that induction from stator coil 36*s* produces voltage in rotor coil 36*r* eight times as great as the voltage produced in rotor coil 37*r*. This voltage passes through contacts 72 and 73 to the power anplifier 58, thus causing servo-motor 35 to run in the right direction to adjust the rotor coil 36*r* through gearing 92 precisely into non-inductive or null position in the field produced by stator winding 36*s*, thereby reducing the voltage on coil 36*r* to zero.

Thereafter, if the field of stator coil 36*s* rotates, it will be understood that the rotor coil 36*r* will be compelled by motor 35 to follow that field, thus keeping its output shaft accurately aligned with the signal through the action of control transformer 36 only. Under these ideal conditions, synchronism is maintained and the operation occurs along that portion of curve 90, 91 of Fig. 3 embraced between the two shift points 87 and 88.

However, should there be a large initial misalignment between the motor 35 and the signal, so as to induce in rotor coil 37*r* a voltage greater than that indicated by points 87 and 88 on Fig. 3, then the period of accurate following described above is preceded by a period when control transformer 37 governs the motor 35, because such excess voltage will have dominated the blocking bias on tube 76, causing relay 57 to switch rotor coil 36*r* out of control and rotor coil 37*r* into control of amplifier 58 and the servo-motor 35. In this case, before the relay 57 operates, the action will occur at some point on the curve between the points 87 and 88 and will then shift to curve 85 or 86, as described above.

Finally, in an extreme case, the output shaft 19 may have been turned manually to about 160° out of alignment with the signal, or temporary failure in the amplifier 58 may have caused misalignment of the motor 35, so that the action occurs on the extended portion of the curve 84 which is embraced between the points 83 and 84. The control transformer 36 is therefore in control but, due to the fact that voltages in this area are opposite to those in the area between points 87 and 88 on the curve, the motor 35 is driven away from synchronism at this point towards the correct point of alignment at 0°, under control of transformer 36 until its rotor coil voltage becomes greater than that indicated at points 83 and 84 when the motion towards synchronizing is continued under control of transformer 37. Eventually, however, when point 87 is reached, control will be again given to transformer 36 and the action will be normal and accurate.

In the servo control system described, in which the error between the demand quantity and the response actuates the servo-motor 35, regeneration in the circuit causes oscillation in the response, as is well understood. In order to make such a system dead-beat, the mechanism shown in Fig. 1 is used, including a generator 59 which may be driven by the servo-motor 35 through gearing 95 and the resulting speed-proportional voltage output of generator 59 fed in to the amplifier 58 of the servo-motor circuit to oppose the driving current. This method destroys the phase relations on which the undesired oscillation is based, but introduces a dynamic error in the servo control system since it follows a value which lags the order signal value to be reproduced. In order to prevent such lag, a second like generator 60 is also driven by the servo-motor 35 but through a flexible drive 96 by shaft 97 and gearing 98, 99. When the speed of the servo-motor 35 is uniform, the voltages from the two generators 59 and 60 exactly nullify each other, but when there is acceleration, the output of the flexibly driven generator 60 falls out of phase with the rigidly driven generator 59 and a voltage opposed to the driving voltage results which damps the oscillation.

If the flexibility of the flexible drive 96 is such that any acceleration belonging to the signal to be reproduced is unable to flex it to any appreciable extent, then any extensive flexing will be due to acceleration of the servo-motor 35 when it is attempting to achieve synchronism and it is under such conditions that the damping voltage takes effect. Any tendency of the flexible drive 96 itself to oscillate is controlled by use of a viscous damping device 61, preferably of the eddy-current type fixed on the flexibly driven generator shaft.

The detailed operation of the servo control system of this invention has been described as the description of its construction progressed. The system accordingly accurately transmits small and rapid angular adjustments without hunting or other unintended oscillations to remote points in series to enable fuse-setting of a series of projectiles and the like. Although the invention has been illustrated and described in connection with fuse-setting operations, the invention is not limited thereby but is adaptable to other uses without material change and to variations in construction within the scope of the appended claims.

I claim:

1. In an electro-mechanical servo-control system adapted to be actuated in accordance with the movements of remote self-synchronous transmitting means, the combination of a driven member, means for driving said driven member, a transformer having a stator winding energized by said transmitting means and a rotor winding inductively coupled to said stator winding, a servo-motor electrically connected to said rotor winding for energization in accordance with the voltage induced therein, a differential interposed between said driven member and the means for driving the same, and operative connections between said servo-motor and said differential for modifying the drive of said driven member by said driving means in accordance with signals transmitted by said transmitting means.

2. In an electro-mechanical servo-control system adapted to be actuated in accordance with the movements of remote self-synchronous transmitting means, the combination of a driven member, means for driving said driven member, a transformer having a stator winding energized by said transmitting means and a rotor winding inductively coupled to said stator winding, a servo-motor electrically connected to said rotor winding for energization in accordance with the voltage induced therein, operative connections between said servo-motor and said rotor winding for driving the same to non-inductive relation with said stator winding, a differential interposed between said driven member and the means for driving the same, and operative connections between said servo-motor and said differential for modifying the drive of said driven member by said driving means in accordance with signals transmitted by said transmitting means.

3. In an electro-mechanical servo-control system adapted to be actuated in accordance with the movements of remote self-synchronous transmitting means, the combination of a rotary driven member, means for driving said driven member, timing mechanism adjusted in accordance with the movements of said driven member for regulating the angle of rotation thereof by said driving means, a transformer having a stator winding energized by said transmitting means and a rotor winding inductively coupled to said stator winding, a servo-motor electrically connected to said rotor winding for energization in accordance with the voltage induced therein, a differential interposed between said driven member and the means for driving the same, and operative connections between said servo-motor and said differential for modifying the angle of drive of said driven member by said driving means in accordance with signals transmitted by said transmitting means.

4. In an electro-mechanical servo-control system adapted to be actuated in accordance with the movements of remote self-synchronous transmitting means, the combination of a rotary driven member, means for driving said driven member, a normally disengaged clutch means interposed between said driving means and said driven member, timing mechanism actuating said clutch to effect a predetermined angle of rotation of said driven member, a transformer having a stator winding energized by said transmitting means and a rotor winding inductively coupled to said stator winding, a servo-motor electrically connected to said rotor winding for energization in accordance with the voltage induced therein, a differential interposed between said driven member and the means for driving the same, and operative connections between said servo-motor and said differential for modifying the angle of drive of said driven member by said

driving means in accordance with signals transmitted by said transmitting means.

5. In an electro-mechanical servo-control system adapted to be actuated in accordance with the movements of remote self-synchronous transmitting means, the combination of a rotary driven member, means for driving said driven member, a normally disengaged electromagnetic clutch means interposed between said driving means and said driven member, a switch controlling said clutch, timing mechanism actuating said clutch switch to effect a predetermined angle of rotation of said driven member, a transformer having a stator winding energized by said transmitting means and a rotor winding inductively coupled to said stator winding, a servo-motor electrically connected to said rotor winding for energization in accordance with the voltage induced therein, a differential interposed between said driven member and the means for driving the same, and operative connections between said servo-motor and said differential for modifying the angle of drive of said driven member by said driving means in accordance with signals transmitted by said transmitting means.

6. In an electro-mechanical servo-control system adapted to be actuated in accordance with the movements of remote self-synchronous transmitting means, the combination of a rotary driven member, means for driving said driven member, timing mechanism actuated in accordance with the movements of said driven member for regulating the angle of rotation thereof by said driving means, a transformer having a stator winding energized by said transmitting means and a rotor winding inductively coupled to said stator winding, a servo-motor electrically connected to said rotor winding for energization in accordance with the voltage induced therein, operative connections between said servo-motor and said rotor winding for driving the same to non-inductive relation with said stator winding, a differential interposed between said driven member and the means for driving the same, and operative connections between said servo-motor and said differential for modifying the angle of drive of said driven member by said driving means in accordance with signals transmitted by said transmitting means.

7. In an electro-mechanical servo-control system adapted to be actuated in accordance with the movements of remote self-synchronous transmitting means, the combination of a rotary driven member, means for driving said driven member, a normally disengaged clutch means interposed between said driving means and said driven member, timing mechanism actuating said clutch to effect a predetermined angle of rotation of said driven member, a transformer having a stator winding energized by said transmitting means and a rotor winding inductively coupled to said stator winding, a servo-motor electrically connected to said rotor winding for energization in accordance with the voltage induced therein, operative connections between said servo-motor and said rotor winding for driving the same to non-inductive relation with said stator winding, a differential interposed between said driven member and the means for driving the same, and operative connections between said servo-motor and said differential for modifying the angle of drive of said driven member by said driving means in accordance with signals transmitted by said transmitting means.

8. In an electro-mechanical servo-control system adapted to be actuated in accordance with the movements of remote self-synchronous transmitting means, the combination of a rotary driven member, means for driving said driven member, a normally disengaged electromagnetic clutch means interposed between said driving means and said driven member, a switch controlling said clutch, timing mechanism actuating said clutch switch to effect a predetermined angle of rotation of said driven member, a transformer having a stator winding energized by said transmitting means and a rotor winding inductively coupled to said stator winding, a servo-motor electrically connected to said rotor winding for energization in accordance with the voltage induced therein, operative connections between said servo-motor and said rotor winding for driving the same to non-inductive relation with said stator winding, a differential interposed between said driven member and the means for driving the same, and operative connections between said servo-motor and said differential for modifying the angle of drive of said driven member by said driving means in accordance with signals transmitted by said transmitting means.

9. In an electro-mechanical servo-control system adapted to be actuated in accordance with the movements of remote self-synchronous transmitting means, the combination of a rotary driven member, means for driving said driven member, a high-speed transformer and a low-speed transformer each having a stator winding energized by said transmitting means and a rotor winding inductively coupled to each stator winding, a servo-motor alternatively electrically connected to said rotor winding of one of said transformers for energization in accordance with the voltage induced therein, a relay interposed between said servo-motor and the rotor windings of said transformers, means responsive to asynchronism between said servo-motor and said transmitting means for energizing said relay to selectively connect the corresponding rotor winding to said servo-motor, a differential interposed between said driven member and the means for driving the same, and operative connections between said servo-motor and said differential for modifying the drive of said driven member by said driving means in accordance with signals transmitted by said transmitting means.

10. In an electro-mechanical servo-control system, adapted to be actuated in accordance with the movements of remote self-synchronous transmitting means, the combination of a rotary driven member, means for driving said driven member, a high-speed transformer and a low-speed transformer each having a stator winding energized by said transmitting means and a rotor winding inductively coupled to said stator winding, a servo-motor alternatively electrically connected to said rotor winding of one of said transformers for energization in accordance with the voltage induced therein, a relay interposed between said servo-motor and the rotor windings of said transformers, means responsive to asynchronism between said servo-motor and said transmitting means for energizing said relay to selectively energize said transformers, gearing between the rotor windings of said transformers, means for varying the angular relationship between the rotor winding of one of said transformers and the other rotor winding and said gearing to prevent pseudo asynchronism between said servo-motor and said transmitting means, a differential interposed between said

driven member and the means for driving the same, and operative connections between said servo-motor and said differential for modifying the drive of said driven member by said driving means in accordance with signals transmitted by said transmitting means.

11. In an electro-mechanical servo-control system adapted to be actuated in accordance with the movements of remote self-synchronous transmitting means, the combination of a rotary member, means for driving said driven member, a high-speed and a low-speed transformer each having a stator winding energized by said transmitting means and a rotor winding inductively coupled to said stator winding, a servo-motor alternatively electrically connected to said rotor winding of one of said transformers for energization in accordance with the voltage induced therein, a relay for selectively connecting one of said rotor windings to said servo-motor, gearing between the rotor windings of said transformers, means for varying the angular relationship between the one rotor winding and the other and said gearing for preventing pseudo-synchronism between said servo-motor and said transmitting means, a differential interposed between said driven member and the means for driving the same, and operative connections between said servo-motor and said differential for modifying the drive of said driven member by said driving means in accordance with signals transmitted by said transmitting means.

12. In an electro-mechanical servo-control system adapted to be actuated in accordance with the movements of remote self-synchronous transmitting means, the combination of a rotary member, means for driving said driven member, a high-speed transformer and a low-speed transformer each having a stator winding energized by said transmitting means and a rotor winding inductively coupled to said stator winding, a servo-motor alternatively electrically connected to said rotor winding of one of said transformers for energization in accordance with the voltage induced therein, a relay interposed between said servo-motor and the rotor windings of said transformers, means responsive to asynchronism between said servo-motor and said transmitting means for energizing said relay to selectively energize said transformers, operative connections between said servo-motor and said rotor winding for driving the same to non-inductive relation with said stator winding, a differential interposed between said driven member and the means for driving the same, and operative connections between said servo-motor and said differential for modifying the drive of said driven member by said driving means in accordance with signals transmitted by said transmitting means.

13. In an electro-mechanical servo-control system adapted to be actuated in accordance with the movements of remote self-synchronous transmitting means, the combination of a rotary driven member, means for driving said driven member, a high-speed transformer and a low-speed transformer each having a stator winding energized by said transmitting means and a rotor winding inductively coupled to said stator winding, a servo-motor alternatively electrically connected to said rotor winding for energization in accordance with the voltage induced therein, a relay interposed between said servo-motor and the rotor windings of said transformers, means responsive to asynchronism between said servo-motor and said transmitting means for energizing said relay to selectively energize said transformers, gearing between the rotor windings of said transformers, means for varying the angular relationships between the rotor winding of one of said transformers and the other rotor winding and said gearing to prevent pseudo synchronism between said servo-motor and said transmitting means, operative connections between said servo-motor and said rotor winding for driving the same to non-inductive relation with said stator winding, a differential interposed between said driven member and the means for driving the same, and operative connections between said servo-motor and said differential for modifying the drive of said driven member by said driving means in accordance with signals transmitted by said transmitting means.

14. In an electro-mechanical servo-control system adapted to be actuated in accordance with the movements of remote self-synchronous transmitting means, the combination of a rotary driven member, means for driving said driven member, a high-speed transformer and a low-speed transformer each having a stator winding energized by said transmitting means and a rotor winding inductively coupled to said stator winding, a servo-motor alternately electrically connected to said rotor winding of one of said transformers for energization in accordance with the voltage induced therein, a relay for selectively connecting one of said rotor windings to said servo-motor, gearing between the rotor windings of said transformers, means for varying the angular relationship between one rotor winding and the other and said gearing for preventing pseudo-synchronism between said servo-motor and said transmitting means, operative connections between said servo-motor and said rotor winding for driving the same to non-inductive relation with said stator winding, a differential interposed between said driven member and the means for driving the same, and operative connections between said servo-motor and said differential for modifying the drive of said driven member by said driving means in accordance with signals transmitted by said transmitting means.

15. In an electro-mechanical servo-control system adapted to be actuated in accordance with the movements of remote self-synchronous transmitting means, the combination of a rotary driven member, means for driving said driven member, a transformer having a stator winding energized by said transmitting means and a rotor winding inductively coupled to said stator winding, a servo-motor electrically connected to said rotor winding for energization in accordance with the voltage induced therein, a differential interposed between said driven member and the means for driving the same, operative connections between said servo-motor and said differential for modifying the angle of drive of said driven member by said driving means in accordance with signals transmitted by said transmitting means, a second transformer having a stator winding energized by said transmitting means and a rotor having a winding inductively coupled to said stator winding for rotation in response to the field of said stator winding, and operative connections between said second rotor and said driven member for further modifying the angle thereof.

16. In an electro-mechanical servo-control system for setting fuses on shells equipped with fuse slots or their equivalent in accordance with the movement of a remote self-synchronous fuse-

angle transmitting means, the combination of a shell nose receiving pot, relatively rotary pawls thereon for engaging the shell fuse slots, a motor for driving said fuse pawls around the nose of the shell for engagement with the corresponding fuse slots thereon, a switch in the circuit of the motor for energizing the same, means responsive to the insertion of a shell nose in said pot for actuating said switch, timing means driven by said motor for controlling the angle of rotation of said pawls, a high-speed transformer and a low-speed transformer each having a stator winding energized by said fuse angle transmitting means and a rotor winding inductively coupled to the corresponding stator winding, a servo-motor alternatively energized by the voltage induced in one of said stator windings, gearing connecting the rotor windings of said transformers, a two-way switch interposed between the rotor winding and said servo-motor, a relay responsive to asynchronism between one of said transformers and said transmitting means for actuating said switch to shift the connection of said servo-motor from one to the other rotor windings, operative connections between said servo-motor and said gearing for driving the active rotor winding to non-inductive relation with its corresponding stator winding, a differential interposed between said motor and servo-motor and having an output, and operative connections between said differential output and said fuse pawls for setting the fuse slots on said shell in accordance with transmitted fuse angle after said pawls are engaged by said motor with said fuse slots.

17. In an electro-mechanical servo-control system for setting fuses on shells equipped with fuse slots or their equivalent in accordance with the movement of a remote self-synchronous fuse-angle transmitting means, the combination of a shell nose receiving pot, relatively rotary pawls thereon for engaging the shell fuse slots, a motor for driving said fuse pawls around the nose of the shell for engagement with the corresponding fuse slots thereon, a switch in the circuit of the motor for energizing the same, means responsive to the insertion of a shell nose in said pot for actuating said switch, timing means driven by said motor for controlling the angle of rotation of said pawls, a high-speed transformer and a low-speed transformer each having a stator winding energized by said fuse angle transmitting means and a rotor winding inductively coupled to the corresponding stator winding, a servo-motor alternatively energized by the voltage induced in one of said stator windings, gearing connecting the rotor windings of said transformers, a two-way switch interposed between the rotor winding and said servo-motor, a relay responsive to asynchronism between one of said transformers and said transmitting means for actuating said switch to shift the connection of said servo-motor from one to the other rotor windings, operative connections between said servo-motor and said gearing for driving the active rotor winding to a non-inductive relation with its corresponding stator winding, a differential interposed between said motor and servo-motor and having an output, operative connections between said differential output and said fuse pawls for setting the fuse slots on said shell in accordance with transmitted fuse angle after said pawls are engaged by said motor with said fuse slots, a third transformer having a stator winding energized by said fuse angle transmitting means and a rotor having a winding, and operative connections between said third transformer rotor and said differential output for justifying the fuse-setting of said fuse slots.

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REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
1,299,509	Rey	Apr. 8, 1919
1,500,860	Yo	July 8, 1924
1,985,982	Edwards	Jan. 1, 1935
2,115,086	Riggs	Apr. 26, 1938
2,351,743	Chappell et al.	June 6, 1944