

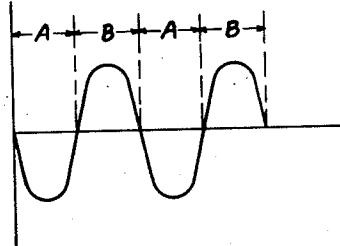
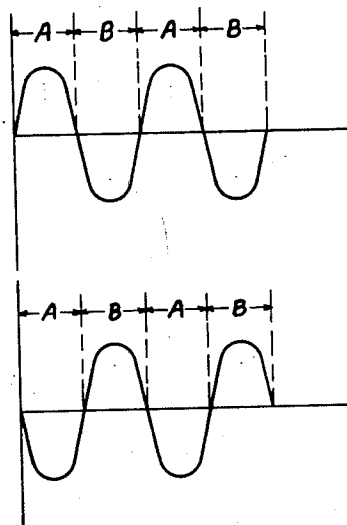
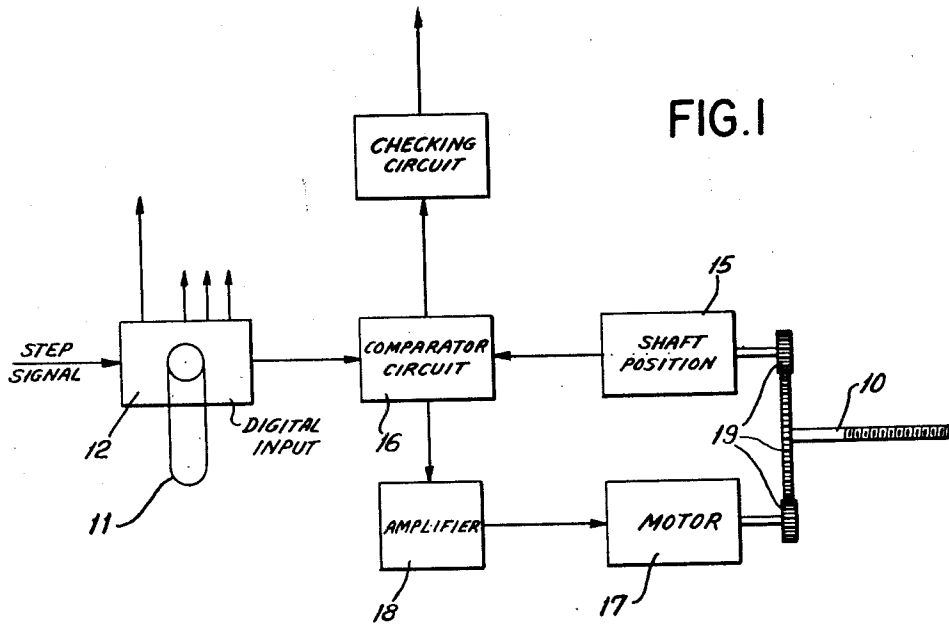
May 14, 1957

L. J. KAMM
DIGITAL SERVOMECHANISM

2,792,545

Filed Aug. 25, 1953

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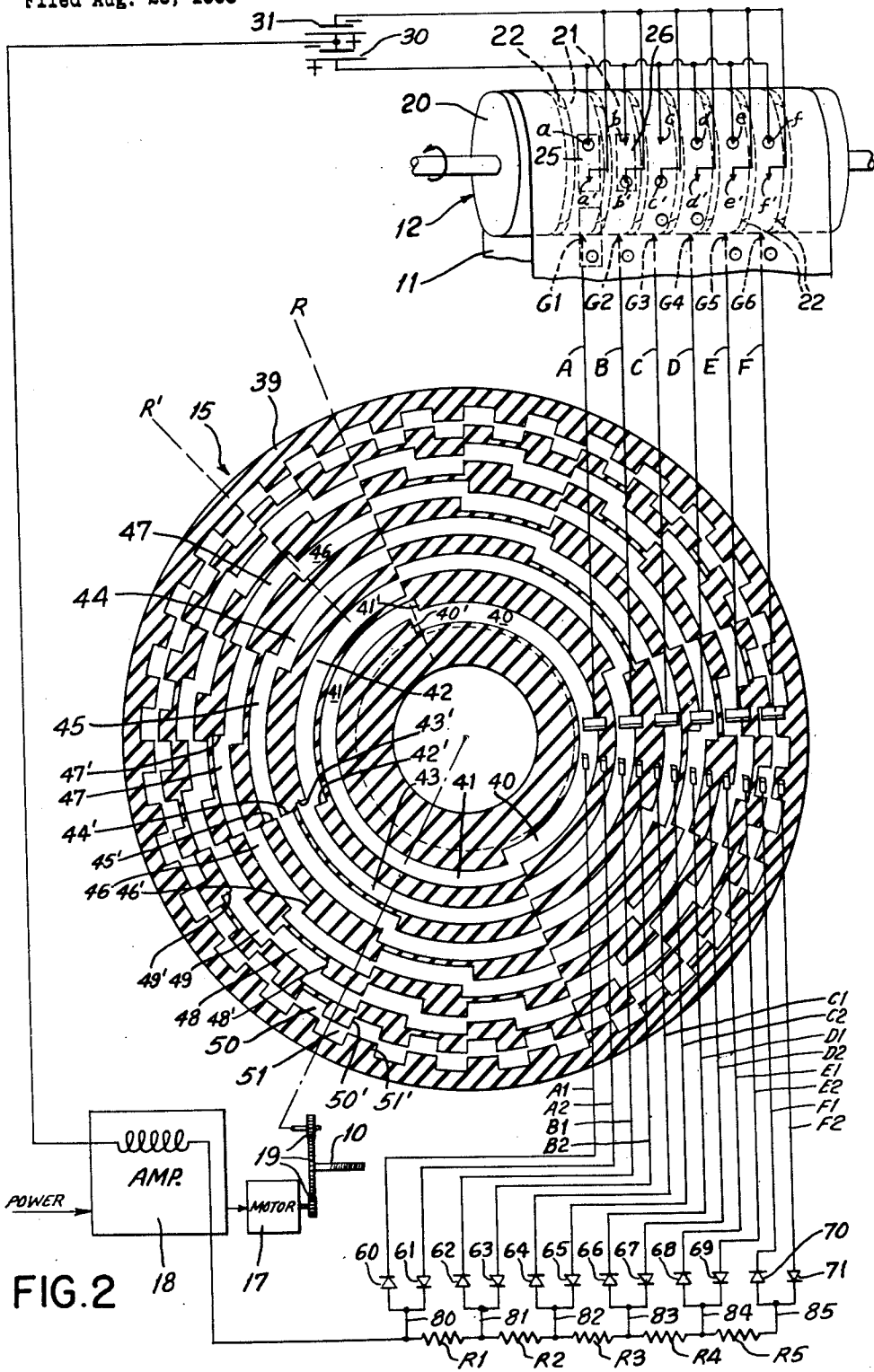
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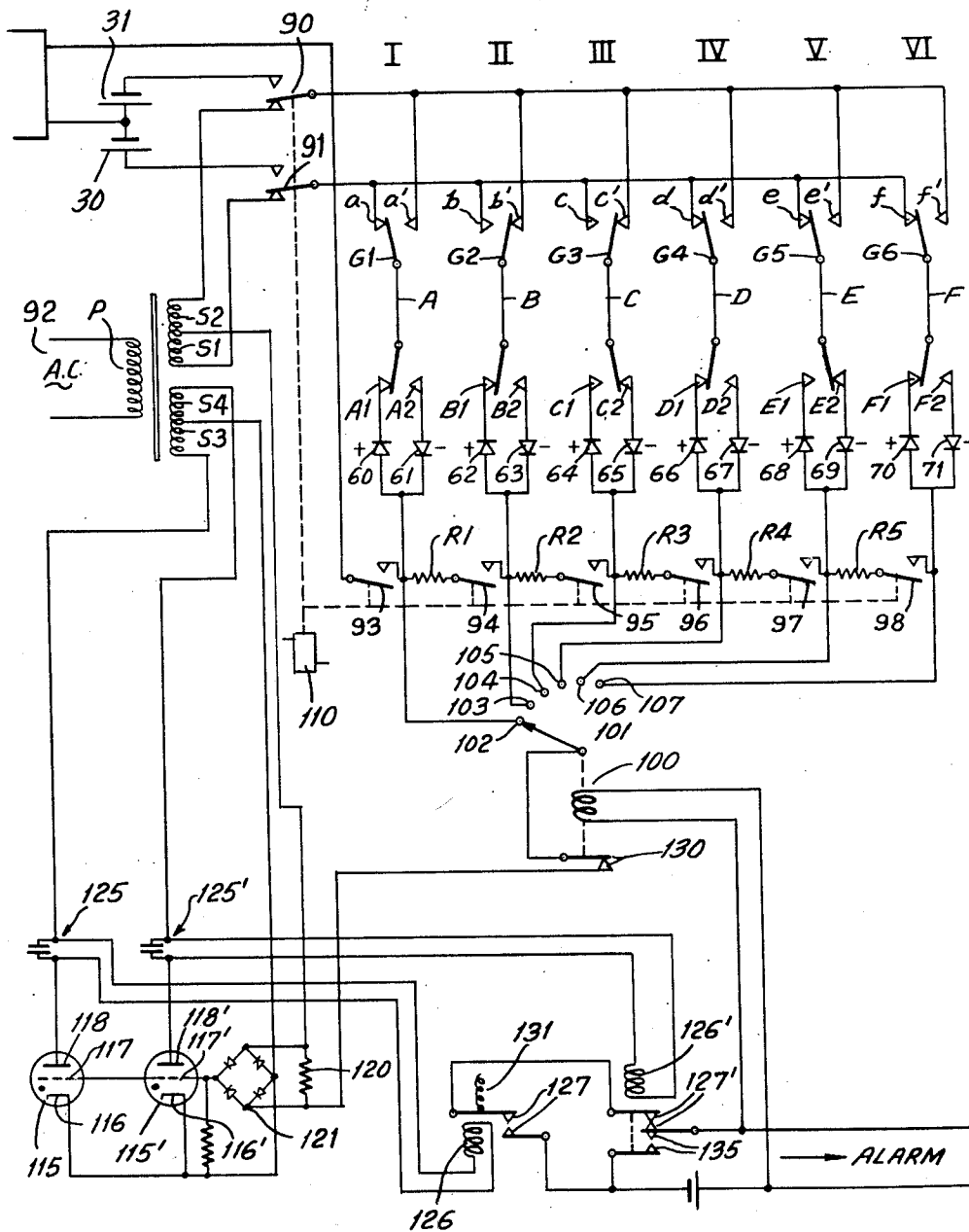
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FIG.3



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DIGITAL SERVOMECHANISM

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This invention relates to digital servomechanisms which have as their function the positioning of a member, such as a lead screw or other shaft, in a plurality of predetermined positions with a high degree of accuracy. The desired positions are indicated by a succession of binary digits which may be applied to a member such as a moving tape designed to be actuated in successive steps.

It is one of the objects of this invention to provide a novel arrangement of binary digits wherein each digit is represented by a pair of complementary positions, one of which is electrically conducting while the other is nonconducting, with electric contacts cooperating with both positions. By this arrangement a checkable system is obtained, since if both or neither positions are conducting, a fault exists.

In servomechanisms of this type it is customary to employ commutators having a plurality of sets of concentric contact segments ranging from coarse to fine. A plurality of contacts engage the respective segments, and a problem arises to prevent hunting or other improper positioning of the controlled member caused by the indefiniteness of engagement with the ends of the respective segments in any given position. It is therefore another object of this invention to provide an improved commutator and associated circuit which will eliminate ambiguity of positioning of the controlled member in any position of the commutator.

Servomechanisms of the type described employ a plurality of circuits which are selectively energized. It is another object of this invention to provide checkable operating circuits and a checking circuit whereby the operativeness of the respective circuits may be readily determined.

Further objects and advantages of this invention will become apparent in the following detailed description thereof.

In the accompanying drawings,

Fig. 1 is a block diagram of the digital servomechanism.

Fig. 2 is a wiring diagram of the servomechanism.

Fig. 3 is a wiring diagram of the checking circuit.

Figs. 4A and 4B are illustrative of certain checking procedure conditions.

Referring to Fig. 1, there is shown a servomechanism assembly. In such mechanism a member 10, which may be a lead screw or other operatable shaft, is to be successively moved to a plurality of predetermined positions. The desired positions may be indicated on a tape 11, for example, which controls a switching array 12 designed to control a plurality of circuits. The actual positions of the operated or controlled member 10 actuate a second switching array 15 in said circuits. Any difference between desired position and actual position of the controlled member will energize the circuits through the difference taker or comparator circuit 16 to energize a motor 17, by way of amplifier 18, in one direction or the other. The direction of operation of the motor is such as

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to operate the second switching array 15 through gearing 19 in a direction to eliminate said difference.

Referring to Fig. 2, there is disclosed the details of the servomechanism described generally above. The first switching array 12 may comprise the tape 11 operating over a roller 20 which may be formed of a plurality of electrically conducting rings 21 separated by insulation 22. Each ring cooperates with a width of tape carrying a column of binary numbers. Thus, as shown, there are six vertical rows on the tape cooperating with six rings on the roller. The normal binary digit may be indicated in one position on a tape by punching a hole for an "0" and leaving a blank for a "1." In the present apparatus each binary digit is represented by a pair of positions, one of which is punched and the other of which is not punched. Thus, the first digit indicated at 25 on the tape comprises a punched upper position and an unpunched lower position. The second digit indicated at 26 on the tape comprises a punched lower position and an unpunched upper position. The upper positions of each digit are connected through contacts *a*—*f* to one side of a power supply 30 (in the case shown, to the positive side), and the lower positions of each digit are connected through contacts *a'*—*f'* to an opposite side of a power supply 31 (in the case shown, to the negative side). Twin circuits are thus established for each binary digit, one twin circuit being open when the other twin circuit is closed. In the example shown, there will be twelve circuits in any setting of the tape, six circuits being open and six closed. The manner in which said circuits are employed to transmit the desired position of the controlled member 10 will be described below. The tape may be operated to successive positions by any suitable means, such as a one-revolution clutch, the brushes being lifted by a cam to prevent dragging over tape hole edges. Such mechanism is well-known and is not here shown.

Each ring 21 will make contact with either the upper or lower position of a binary digit, depending upon the position of the punched hole. Positive or negative current will thus be carried by contacts G1—G6 to conductors A—F overlying a commutator 39 which is geared to motor 17 through gearing 19 so that its position corresponds to the actual position of the controlled member 10. Since each binary digit comprises a pair of positions, here indicated as upper and lower positions, forming part of twin binary circuits, the commutator is also constructed so that a pair of segments corresponds to each pair of positions of each binary digit, one segment being conducting and one segment being nonconducting. Thus, the binary digit 25 corresponding to the coarsest setting, cooperates electrically through brush A with segment pair 40 (conducting) and 41' (nonconducting) and segment pair 40' (non conducting) and 41 (conducting), the segments 40, 40' being concentric with 41, 41', and the conducting and nonconducting segments in adjacent areas being arranged alternately. Similar arrangements exist for the next five successively finer settings 42—43, 44—45, 46—47, 48—49, 50—51. The conductors A—F each cover two concentric rows of segments. Separate brushes A1—A2, B1—B2, C1—C2, D1—D2, E1—E2, F1—F2 engage the twelve concentric rows of segments 40—51.

The brushes A1 and A2 cooperating with the coarsest segments on the commutator 39 are connected through oppositely arranged diodes 60, 61 to a common lead 80 to amplifier 18 whose output operates motor 17 in one direction or the other. Let us assume that the parts are positioned as shown in Fig. 2. Contact *a* is feeding positive current to conductor A which cooperates with coarsest segments 40, 41. We see that contact A1 is on segment 40, and therefore contact A1 connects the positive pole to diode 60 which, however, is arranged so that it does not pass current in the direction called for by the

battery. Also, contact A2 is on a nonconducting segment; therefore no current flows through the circuits of binary digit 25 which are said to be "matched" and no movement of the motor is required to effect such matching. Going now to the next digit, contact *b'* connects the negative pole to conductor B which cooperates with segments 42 and 43. We find contact B1 in engagement with segment 42 connecting the negative pole to diode 62. Diode 62 permits current to flow in the direction called for by the battery. This current flows through the amplifier to the battery center tap. The amplifier energizes motor 17 to rotate the commutator clockwise until contact B1 leaves segment 42 and contact B2 engages segment 43. The contacts C1—C2 cooperate in similar manner with segments 44—45 and with contacts *c—c'*, contacts D1—D2 cooperate with segments 46—47 and with contacts *d—d'*, contacts E1—E2 cooperate with segments 48—49 and with contacts *e—e'*, contacts F1—F2 cooperate with segments 50—51 and with contacts *f—f'*. In each case positive or negative polarity will be transmitted from contacts at the first switch array 12 to the commutator switch array and thence to one of the diodes 60—71. If the position of the commutator is matched with the position called for by the digit, no current will flow. If the position is not matched, current will flow to operate the motor and actuate the commutator in a matching direction until matching occurs.

It will be seen that each pair of diodes is connected to a common lead 80 to 85 inclusive and that between the successive common leads a chain of resistors R1 to R5 inclusive are included in the line leading to the amplifier 18. By this construction it is assured that the coarsest setting will always dominate the movement of the motor. Each unmatched binary digit circuit imposes either plus or minus polarity at its point (80 to 85) in the chain. Circulating currents therefore flow along the chain and through the resistors and diodes, but only the polarity closest to the amplifier influences amplifier current. Since the finer digits feed the amplifier via more chain resistors, the amplifier signal decreases as control passes from digit to digit down the chain (as each digit becomes matched), and the speed of the motor is throttled as the desired position is approached.

The contacting ends of the contacts A1 to F2 inclusive are arranged along a radius of the commutator in the same manner that the ends of the contact segments are arranged. In this manner, theoretically, the control should pass from the coarsest control contacts 40—41 to successively finer control contacts 42—43, 44—45, etc. The transition from contact to non-contacting segments, however, cannot be made so exact that certain of the contacts will not assume relatively incorrect positions with respect to the meeting edges of the contact segments. This is due to the fact that there are manufacturing tolerances in the commutator, that the contact brushes A1 to F2 are not points but actual areas, and to the fact that there are manufacturing tolerances in locating the brushes. Thus there are set up indefinitenesses in the transition from contact segments to noncontacting segments which may cause hunting or even incorrect setting of the commutator. To avoid such error there is provided herein that at any transition point, as for instance on the radial line R, the coarsest setting undergoing transition at this point, in this case the conducting segments 40 and 41, overlaps the transition line in each direction. In this overlap angle both diodes are in parallel so the circuit must be mismatched until the overlap is passed. This assures that the settings of the brushes on all the finer positions are past the ambiguous point of transition. Similarly, on a radius such as R' three sets of brushes in the finer range would ordinarily be subject to indefinite setting, but the coarsest segments in this setting, i. e., the segments 46—47, are provided with the overlap in each direction beyond the R' position. Sim-

ilarly in any transition region it will be found that the coarsest transition contacts are provided with the overlap in each direction beyond the transition line.

It is desirable to check the circuitry disclosed in Fig. 2, said circuitry being noted in Fig. 1 as difference-taker or comparator circuit which compares the condition denoted by the first switch array at the tape with that existing at the second switch array at the commutator in order to discover any faults which will interfere with the operation of the servomechanism. Among these faults are the following:

1. A short-circuit across the commutator brushes which will permit both diodes of one or more sections to conduct simultaneously and carry current both ways.
2. A low back resistance diode which will permit current to flow both ways.
3. A mismatch of contacts at the tape with the contacts at the commutator which remains uncorrected by the motor.
4. A dirty contact which will prevent any current flow.
5. A short-circuit at the tape contacts.

The fifth fault noted above will make itself known by blowing the D. C. fuses, but the other four faults will remain undetected unless a circuit checking system is provided.

Such a checking circuit is disclosed in Fig. 3 and calls for modifying the Fig. 2 circuit in several respects. Fig. 3 discloses the comparator circuit of Fig. 2 diagrammatically, the first switch array at the tape being shown by the sets of contacts *a—d'* to *f—f'* inclusive, and the second switch array at the commutator being disclosed by sets of contacts A1—A2 to F1—F2 inclusive. The circuit is modified by the insertion of switches 90 and 91, whereby energization of the comparator circuit may be transferred from D. C. sources 30, 31 to an A. C. source indicated at 92. Furthermore, the resistor chain R1 to R5 is provided with a plurality of switches 93 to 98 inclusive, whereby the comparator circuit may be broken up into a plurality of individual circuits, each comprising a set of contacts at the tape and the corresponding set of contacts at the commutator. Thus in the example disclosed, six individual circuits may be formed by breaking the contacts 93 to 98 inclusive and each of said circuits may be separately tested by means of a selector switch 100 having a switch or contact arm 101 movable over a set of contacts 102 to 107 inclusive for testing the six separate circuits thus formed. The switches 90, 91 and 93 to 98 inclusive may all be mechanically joined as illustrated by the dash lines so that they may be simultaneously operated by a single control member 110 to checking and operating positions respectively. In the position shown in Fig. 3 the control 110 has been operated to place the switches in the checking position.

With the parts in the checking position as shown in Fig. 3, A. C. voltage is applied to the successive individual circuits to be checked from the A. C. source 92 through a primary coil P to divided secondaries S1 and S2, the secondary S1 energizing contacts *a* to *f* inclusive while the secondary S2 energizes contacts *a'* to *f'* inclusive. The return for both circuits lies through the switch 100, the contact arm 101, and the successive contacts 102 to 107 inclusive. Beginning with the contact arm 101 on the contact 102, the A. C. circuit leads through diode 60 or 61, contacts A1 or A2, and contacts *a* or *a'*, depending upon the position of the tape switch array and the commutator switch array. Assuming contacts are closed at *a* and at A1, the circuit lies through winding S1, switch 91, contact *a*, contact A1, diode 60, contact 102, switch 100, return lead 111, and resistor 120. Assuming that the voltage generated in secondary S1 is as shown in Fig. 4A, there will be positive half waves in the intervals marked A, and negative half waves in the intervals marked B. At the same time the voltage generated in secondary S2 will be of opposite phase and negative half waves will be generated in the intervals A, while positive

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half waves will be generated in the intervals B. We now see that if there is a matching of the contacts at the tape switch array with the contacts at the commutator switch array as in position I, the current will flow in accordance with Fig. 4A because the positive half waves in the intervals A will be passed by the diode 60. Therefore current will flow through the circuit of secondary S1 in the A intervals. Similarly, in position III where there is matching by closing of contacts c' and C2, current will flow in the circuit of secondary S2 in the intervals A because negative current is flowing in these intervals and the diode 65 permits such negative flow. Thus when the contact arm 101 is on contact 104 current will flow through the secondary S2 in the intervals A.

In the case, however, where the motor has come to rest with a mismatch of the contacts at the tape switch array and the commutator switch array, as for example in position II, it will be seen that with the contact arm 101 on contact 103 current cannot flow in this circuit in the intervals A because secondary S2 in the intervals A applies negative voltage which will not be passed by diode 62 and current from the secondary S1 cannot flow because the circuit is broken at b . However, in the intervals B secondary S2 is transmitting positive current which will be passed by diode 62. Similarly, at switch position 106 negative current from S1 will flow during intervals B. Thus it will be seen that a matched condition of the switches in the tape and commutator arrays results in current flow in the intervals A while a mismatched condition of the corresponding sets of switches results in flow of current in the intervals B. A short-circuit across the diodes will also allow current to flow in the intervals B, as well as in the intervals A. A low back resistance diode likewise will conduct current both ways to allow current to flow in the intervals B. An open circuit at any contact will prevent current flow in either interval. Thus if means are provided for detecting flow of current separately in the intervals B and intervals A, the aforementioned faults will be detected and can be indicated. If the circuit is good, current will flow during A and not during B. If current flows during B or does not flow during A, a fault exists.

To accomplish the foregoing result, there is provided a second split secondary S3, S4 energized from the same primary P to generate voltages in phase with those generated in secondary windings S1 and S2 as shown in Figs. 4A and 4B. Secondary S3 comprises a circuit extending through a thyatron tube 115 and comprising a cathode 116, a grid 117, and a plate 118, so that in the intervals A it applies positive voltage to the plate 118 and places the thyatron 115 in position to fire, provided a positive pulse is applied to the grid 117 in the interval A. Such a pulse will be applied if current flows through the circuit being tested. Thus, as shown, with the switch arm 101 on contact 102 for testing position I, since the contacts of the switch arrays are in matched position, current will flow through the circuit to return lead 111 to impress a voltage across a resistor 120 which after being rectified by rectifier 121 is applied to the grid 117. Rectifier 121 makes either positive or negative test voltage positive before being applied to the tubes. Thus the circuit responds only to the time of the voltage, not its sign. Since as disclosed hereinbefore said current flow occurs in the intervals A, during which intervals secondary S3 is applying positive voltage to plate 118, the thyatron 115 will fire to impress a voltage on a relay 126. Capacitors 125, 125' filter the current to the relays. Relay 126 closes a set of contacts 127 to energize the switch 100. When switch 100 breaks the set of contacts 130 it de-energizes relay 126 whose spring 131 opens contacts 127. This de-energizes switch 100 which moves arm 101 from contact 102 to contact 103 as it releases.

The parts are now in position to test circuit II, but here we see that there is a mismatch of the contacts at the tape and commutator switch arrays, which as ex-

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plained hereinbefore causes current to flow in the B intervals. This means that current will flow through return lead 111 to impress a voltage across resistor 120 to apply a plus voltage on grid 117, but during the B interval when secondary S3 is not applying positive voltage to plate 118. This means that thyatron 115 will not fire, relay 126 will not be energized, contacts 127 will not close, and switch 100 will not be energized to move contact arm 101 to the next testing position, i. e., in engagement with contact 104. The positive pulse which has been delivered in the B interval from circuit II is also applied to the grid 117' of a thyatron 115' which is designed to be energized from secondary S4 to apply positive voltage to plate 118' in the intervals B as shown in Fig. 4B. Thus the thyatron 115' will fire to energize relay 126' to open a set of contacts 127' in the circuit of switch 100. These contacts 127' remain open so that all the parts remain in their frozen position with contact arm 101 on contact 103 until the fault is rectified and the parts restored to their operating position. At the same time that relay 126' open contact 127' it may also close a set of contacts 135 to energize any suitable indicator or alarm to call attention to the fact that a fault has been discovered.

If a short-circuit or leaky diode should exist, current would flow in both A and B intervals. Both tubes would fire and both relays would operate. However since relay 126' is operated, relay 126 cannot operate the switch 100 and the switch will remain unmoved from the faulty circuit.

If no current flows because of an open circuit, neither relay will operate and the switch will remain unmoved from the faulty circuit.

The satisfactory completion of a checking cycle can be monitored by conventional means, not shown.

Having described my invention, what I claim and desire to secure by Letters Patent is:

1. A digital servomechanism characterized by binary digits representing reference and feed-back data and comprising a reference part, a comparator part, an amplifier part, a motor part, and a feed-back part, said reference part and said feed back part each comprising a plurality of contact means, one of said contact means in each part corresponding to each of said binary digits, each of said contact means consisting of a first conductor, a second conductor, and a third conductor, means for connecting said first conductor to said second conductor, and means for connecting said first conductor to said third conductor.

2. A digital servomechanism as specified in claim 1, in which a tape is provided with binary digits, each binary digit comprising a perforated area and an unperforated area, said areas controlling the reference part contact means.

3. A digital servomechanism as specified in claim 2, in which a commutator is mounted for rotary movement, said commutator supporting the contacts of said feed-back part.

4. A digital servomechanism as specified in claim 2, in which a servomotor is provided, means whereby said servomotor is energized by the mismatch of the respective pairs of contacts of the first and second switching arrays, and means whereby said servomotor actuates said second switching array to operate the same to contact matching position.

5. A binary number comparator comprising a voltage source, a first switching array representing one binary number, a second switching array representing the other binary number, a set of diode pairs, and resistors; said voltage source having a neutral terminal, a relatively positive terminal, and a relatively negative terminal; said first switching array comprising one transfer contact assembly per binary digit, each of said transfer contact assemblies having one fixed contact connected to said positive terminal and having the other fixed contact connected to said negative terminal; said second switch-

ing array comprising one transfer contact assembly per binary digit, each moving contact of which is connected to the moving contact of the corresponding transfer contact of the first array and each fixed contact of which is connected to one of said diodes such that one fixed contact is connected to the cathode of one diode and the other fixed contact is connected to the anode of the other diode of a pair; the other terminals of the diodes of each pair being connected together; said diode connections being joined by said resistors so disposed that one resistor joins the diode connection associated with each digit to the diode connection associated with the next largest valued digit, the diode connection associated with the largest valued digit being one output terminal and the neutral terminal of the voltage source being the other output terminal.

6. A digital servomechanism as specified in claim 5, including means for establishing individual circuits comprising each binary number of the first switch array and the corresponding binary number of the second switch array, whereby each of said circuits may be separately checked.

7. A digital servomechanism as specified in claim 6, in which the means for establishing said individual circuits comprising each binary number of the first switch array and the corresponding binary number of the second switch array disconnects said circuits from the D. C. source of voltage and connects to an A. C. source of voltage.

8. A digital servomechanism as specified in claim 7, in which matching of the contacts in the individual circuits between first and second switch arrays causes the circuits to pass current only during one half cycle of the energizing voltage, and mismatch of the contacts causes the circuits to pass current during the other half cycle of the energizing voltage.

9. A digital servomechanism as specified in claim 8, in which means are provided responsive to the passing of current during the respective half cycles of the energizing voltage.

10. A digital servomechanism as specified in claim 9, in which said responsive means comprises a pair of grid controlled tubes, and means whereby said tubes are alternately rendered effective by said alternating source of voltage.

11. A digital servomechanism as specified in claim 5, in which is provided a checking circuit comprising a transformer, changeover switching means, a second switching means, and a phase responsive circuit, said transformer comprising an input winding, a center tapped winding having end terminals and a center terminal, said

changeover switching means comprising a plurality of co-acting two-position switching elements so disposed in the circuit that in one of said positions the circuit is as described in claim 5 while in the other of said positions the conductors connected to said plus and minus battery terminals are transferred to said end terminals of said center tapped winding and each of said resistors is disconnected at one end, said phase responsive circuit being connected between said center tap of said center tapped winding and said second switching means, said second switching means comprising contacts disposed to connect said phase responsive circuit to said diode pairs one at a time.

12. In a digital servomechanism as specified in claim 11, a phase responsive circuit comprising first and second grid controlled tubes, first and second relays connected in series with said first and second tubes respectively, an alternating voltage supply connected to said tubes and said relays in push-pull, an impedance connected between said center tap of said center tapped winding and said second switching means, and means to couple said impedance to said grids.

13. In a digital servomechanism a feed-back part comprising means to translate the continuously variable output of the servomechanism into binary type code, comprising transfer type switching contacts, certain of which remain doubly closed for a distance on each side of the position at which others effect transfers.

14. A digital servomechanism as specified in claim 13, in which the switching contacts are arranged in sets from coarse to progressively finer control, the coarsest set in any transfer position extending on each side of said position.

15. A digital servomechanism as specified in claim 14, in which the switching contacts are arranged in concentric sets from coarse to progressively finer control, the coarsest set in any radial transfer position extending on each side of said radius.

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