Feb. 19, 1963 G. E. MATHIAS ETAL 3,078,402

METHOD AND APPARATUS FOR SYNCHRONIZED DRIVES

Filed Oct. 20, 1958 9 Sheets-Sheet 1

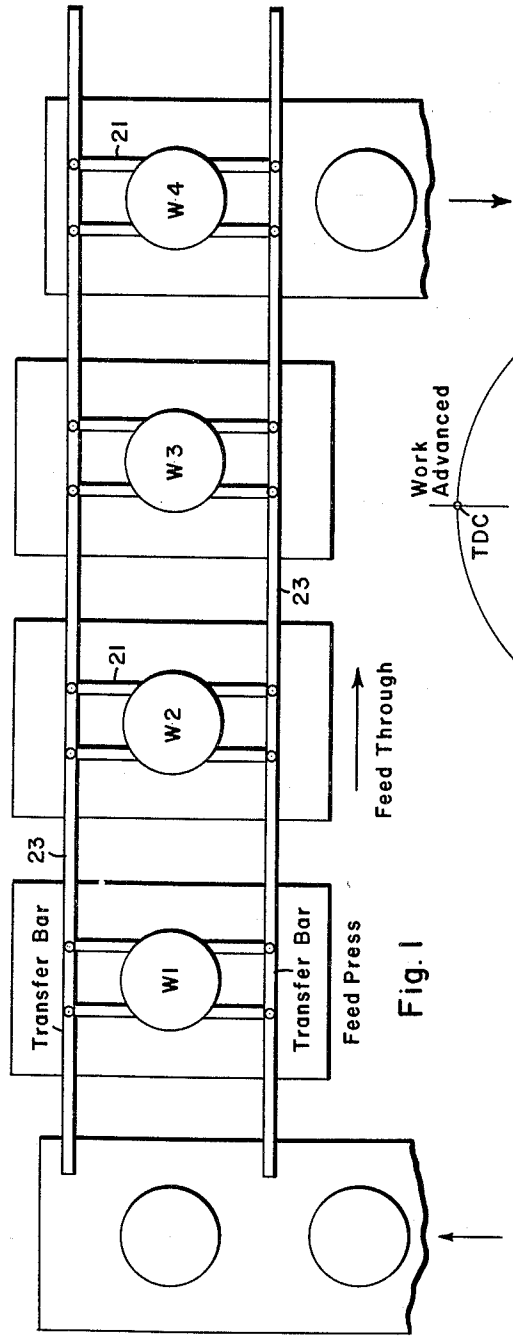


Fig. 1

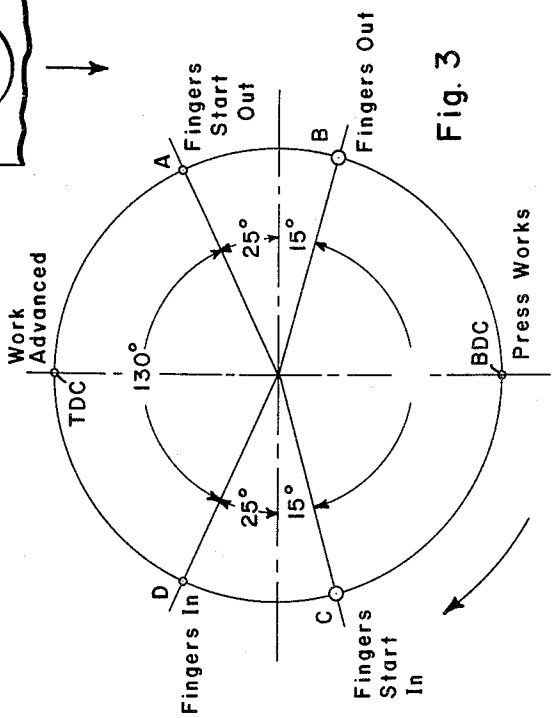


Fig. 3

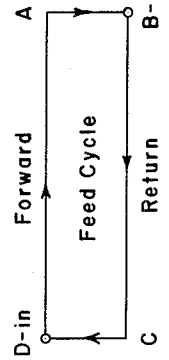


Fig. 2

WITNESSES

John E. Headley, Jr.

INVENTORS
Robert W. Egglestone
Gerald E. Mathias &
Charles G. Helmick, Jr.

BY Wyman & Diamond
ATTORNEY

METHOD AND APPARATUS FOR SYNCHRONIZED DRIVES

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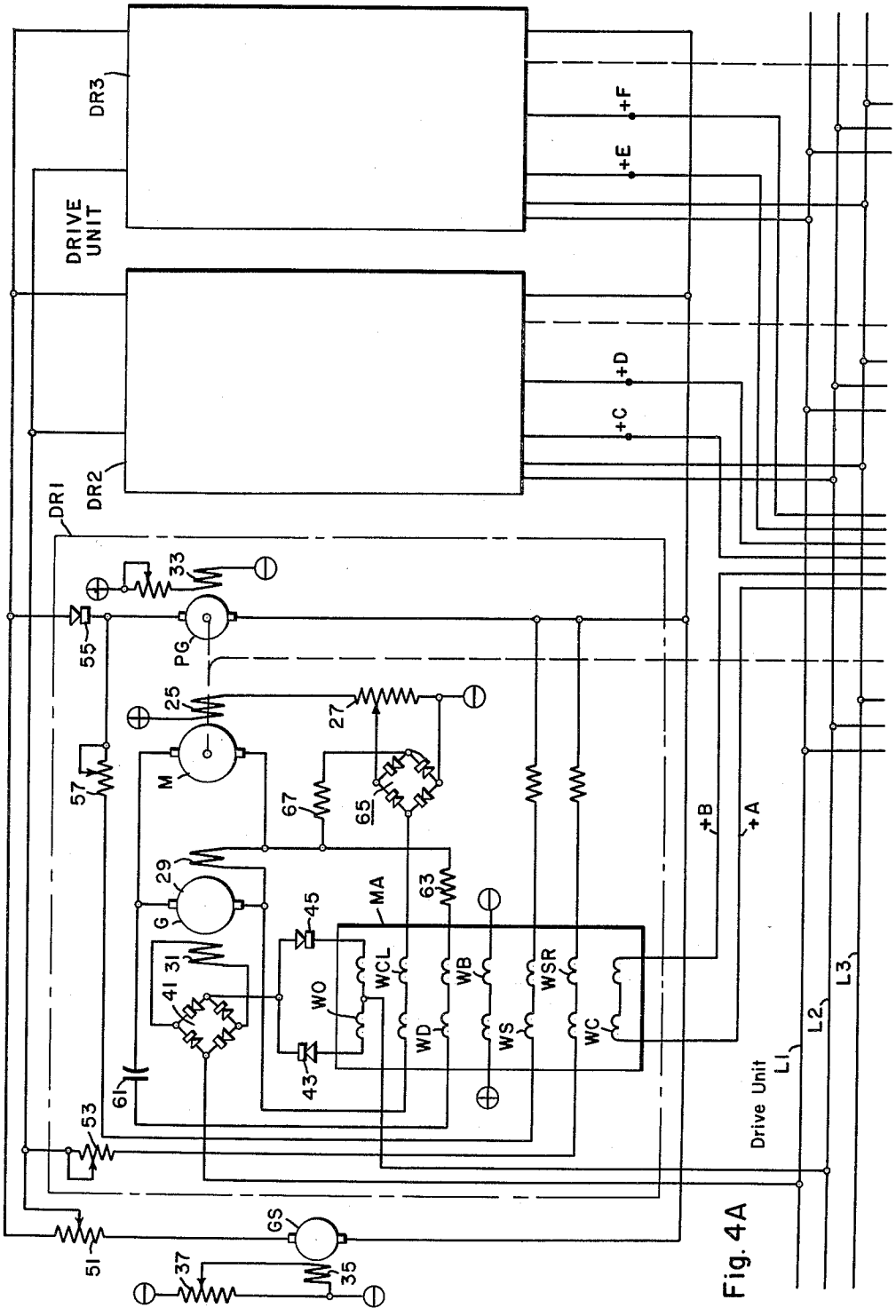


Fig. 4A

METHOD AND APPARATUS FOR SYNCHRONIZED DRIVES

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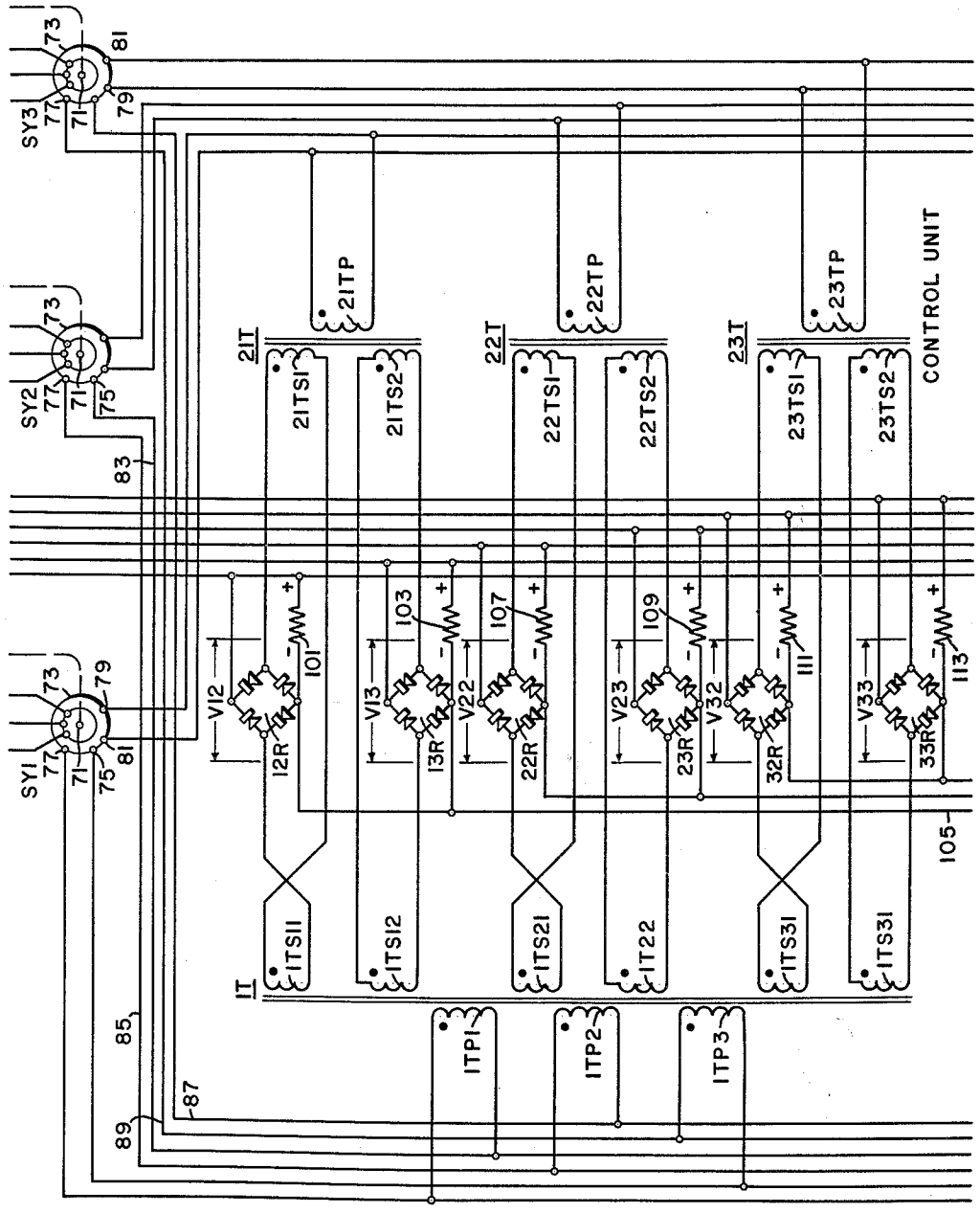


Fig. 4B

Feb. 19, 1963 G. E. MATHIAS ETAL 3,078,402

METHOD AND APPARATUS FOR SYNCHRONIZED DRIVES

Filed Oct. 20, 1958 9 Sheets-Sheet 4

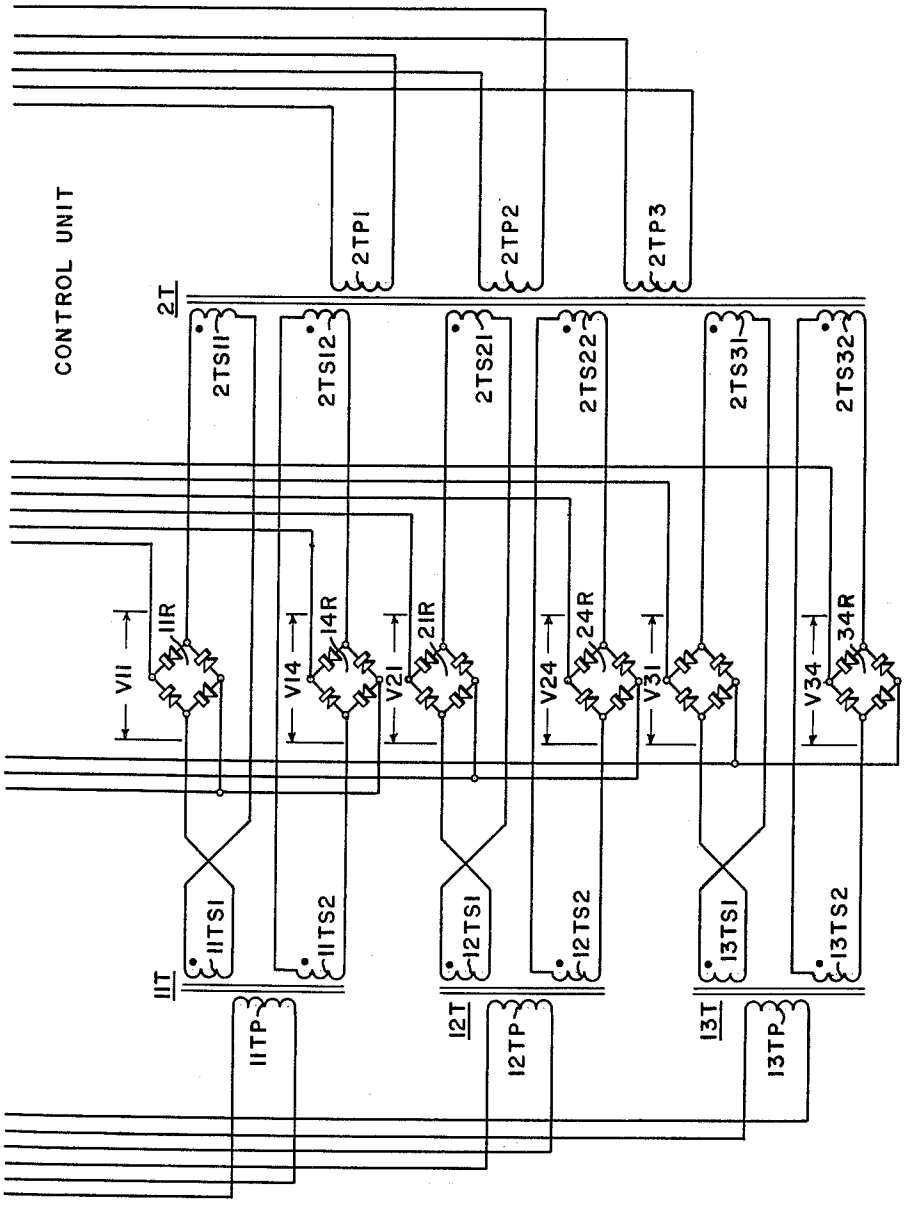


Fig. 4C

Fig. 5

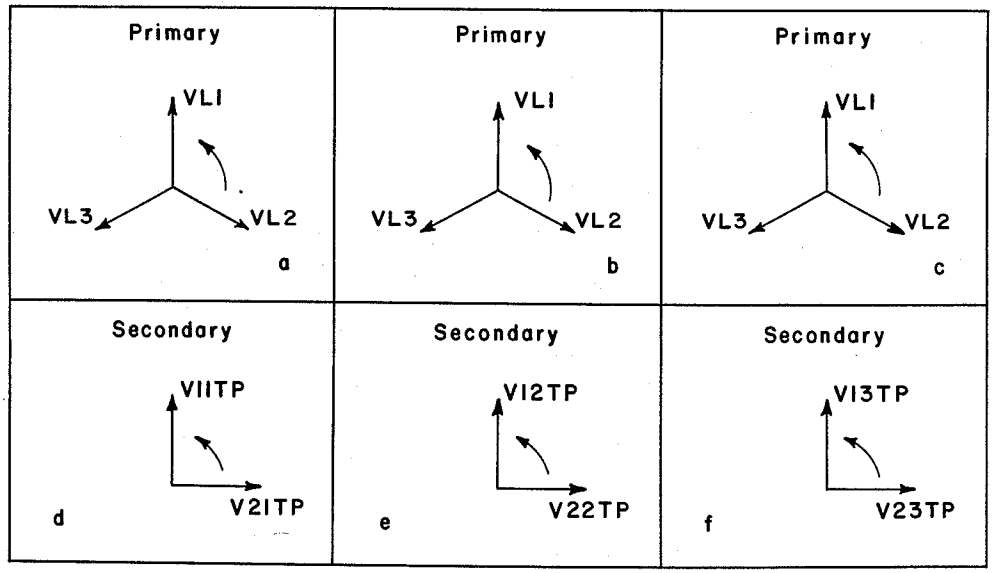
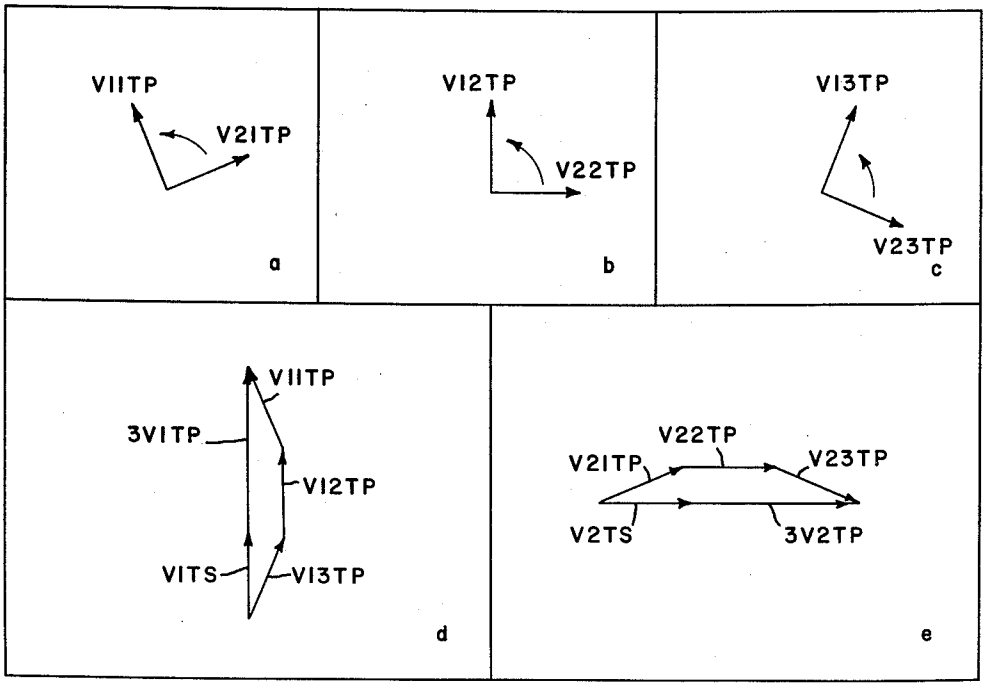

Primary
VL1
VL3
VL2
a
Primary
VL1
VL3
VL2
b
Primary
VL1
VL3
VL2
c
Secondary
V11TP
V21TP
d
Secondary
V12TP
V22TP
e
Secondary
V13TP
V23TP
f

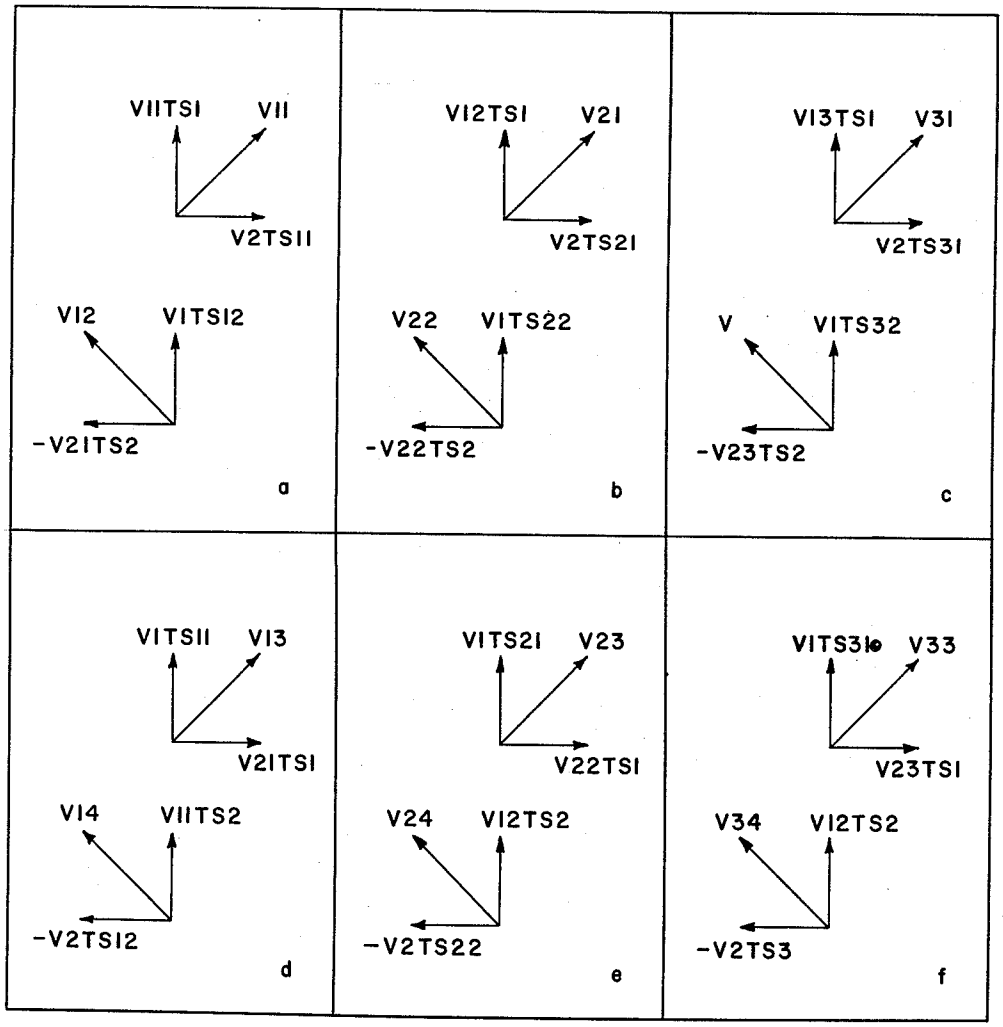
Fig. 7


V11TP
V21TP
a
V12TP
V22TP
b
V13TP
V23TP
c
V11TP
3V1TP
V12TP
V1TS
V13TP
d
V22TP
V21TP
V23TP
V2TS
3V2TP
e

METHOD AND APPARATUS FOR SYNCHRONIZED DRIVES

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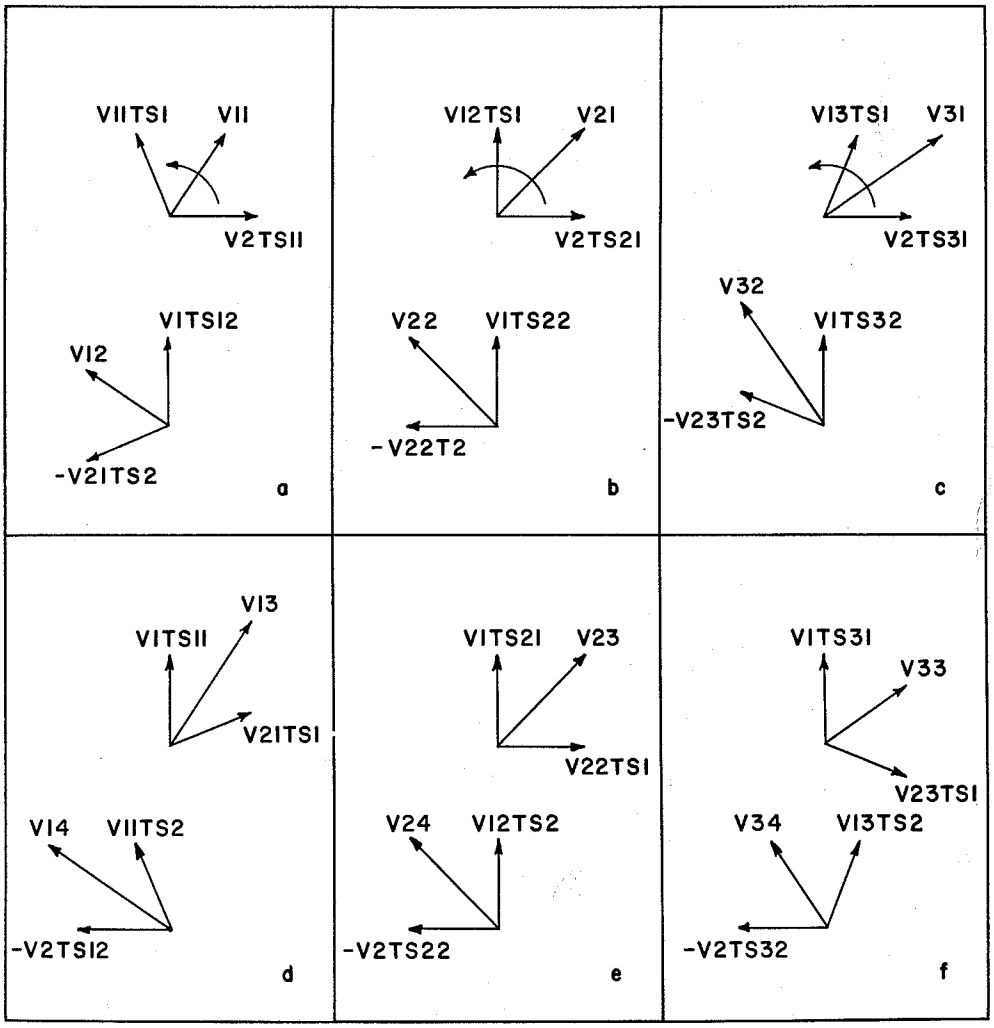
Fig. 6



VII; VI2 Rectified - VI3; VI4 Rectified = 0 V31; V32 Rectified - V33; V34 Rectified = 0

V21; V22 Rectified - V23; V24 Rectified = 0

Fig. 8



VII; VI2 Rectified – VI3; VI4 Rectified = -Q, V3I; V32 Rectified – V33; V34 Rectified = +Q

V2I; V22 Rectified – V23; V24 Rectified = 0

METHOD AND APPARATUS FOR SYNCHRONIZED DRIVES

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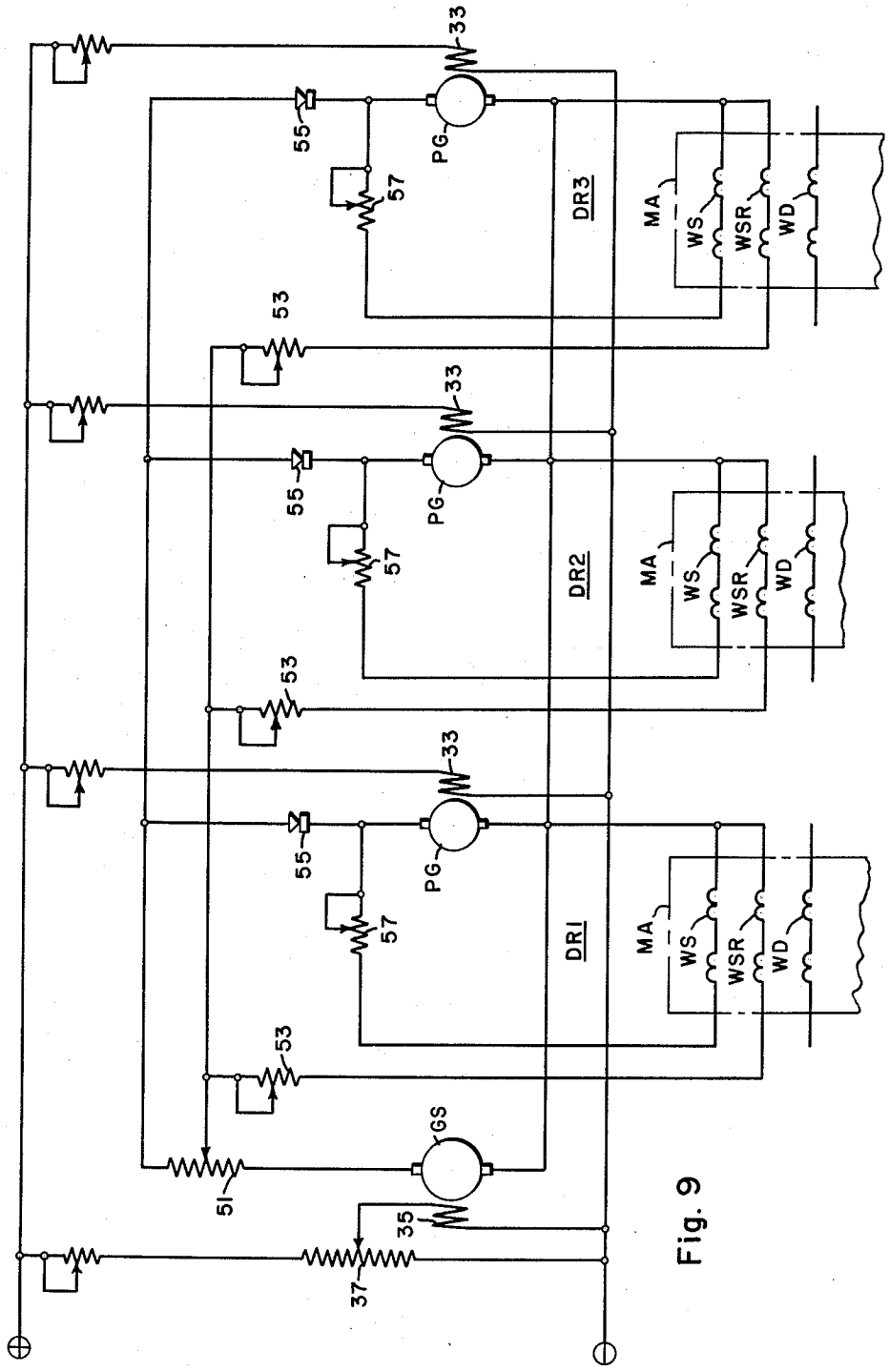


Fig. 9

METHOD AND APPARATUS FOR SYNCHRONIZED DRIVES

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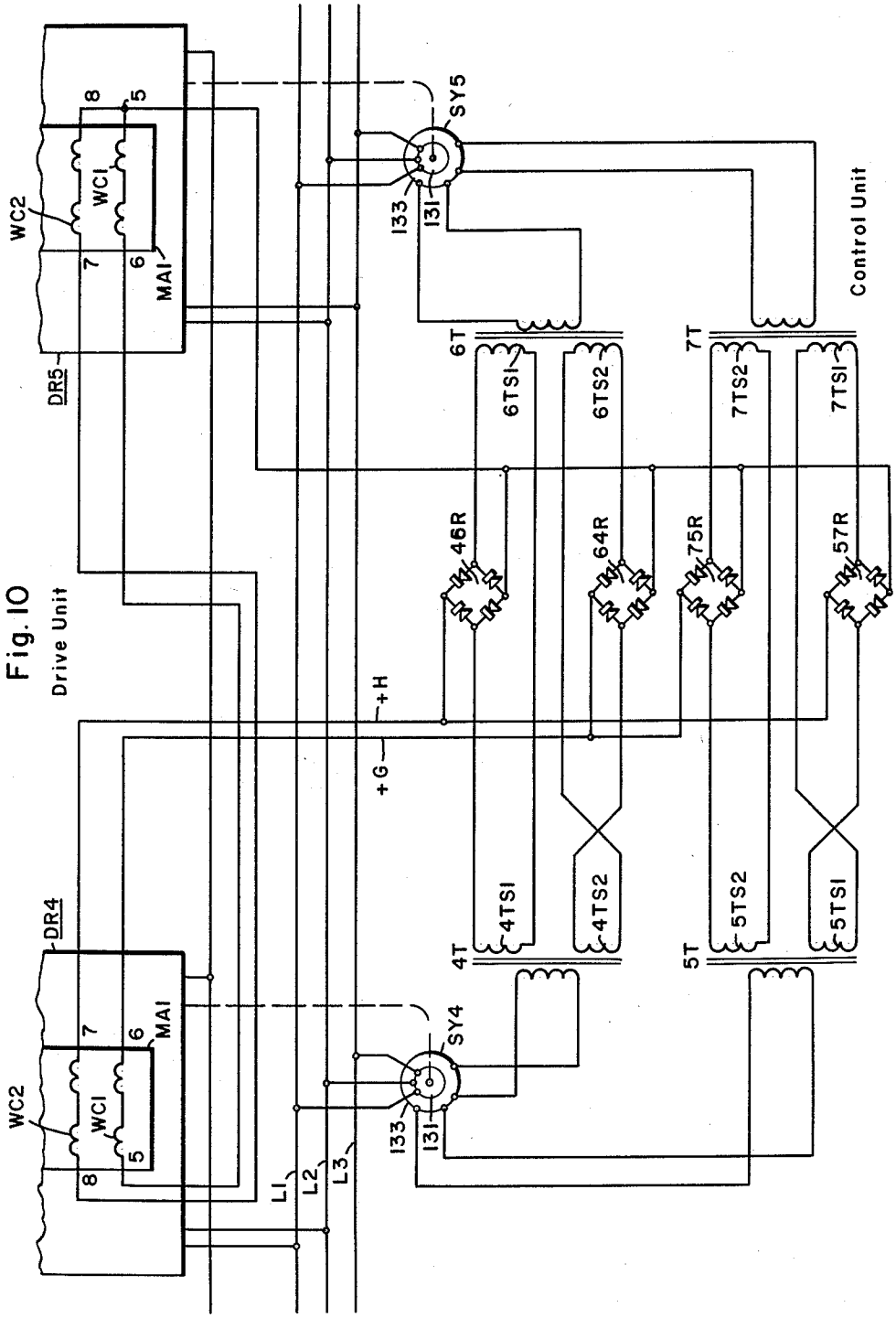


Fig. 10

United States Patent Office 3,078,402 Patented Feb. 19, 1963

3,078,402
METHOD AND APPARATUS FOR SYNCHRONIZED DRIVES

Gerald E. Mathias, Clarence Township, Erie County, N.Y., Charles G. Helmick, Jr., Pittsburgh, Pa., and Robert W. Egglestone, West Hartford, Conn., assignors to Westinghouse Electric Corporation, East Pittsburgh, Pa., a corporation of Pennsylvania

Filed Oct. 20, 1958, Ser. No. 768,194
9 Claims. (Cl. 318—72)

This invention relates to the control or regulator art and has particular relationship to the control or regulation of drives which are subjected to heavy loads that may vary over a wide range during each cycle of operation. Application Serial No. 670,318, filed July 5, 1957 to Gerald E. Mathias and Robert W. Egglestone for "Synchronized Conveyor Control" and assigned to Westinghouse Electric Corporation is incorporated in this application by reference.

The apparatus to which the invention disclosed in this application is particularly applicable is typified by a line of progressively operating presses which form work, say metal sheet, into a finished product, for example, a body part of an automotive vehicle. Such apparatus includes a plurality of dies on each of which the work is subjected to pressure exerted by a press. The work after being treated on one die is moved from this die to a succeeding die and following each movement is subjected to pressure by the press of the new die until after treatment in the last die of the series, the final product is achieved. Each press is moved continuously by a motor driven crank mechanism repeatedly engaging and forming the work. As each press engages the work it exerts increasing pressure on the work until the press passes through a dead-center position where it exerts the maximum pressure on the work.

Each press drive is provided with a flywheel which stores energy during the part of a cycle during which the drive is lightly loaded and releases energy during the part of the cycle during which the drive is loaded.

The loading imposed on the press drives by the different presses may be relatively high. For example, in a typical situation, the loading may be 1200 inch-tons. Each press drive must be capable of delivering substantial power, say of the order of 400 to 1000 horsepower. It is desirable that the work be produced at a relatively high speed and the presses must operate at a correspondingly high speed. A speed of 25 strokes or cycles per minute for each press is typical.

It is desirable that all presses work together in forming the work and that the presses be so synchronized that their compression operations be carried out after the work has been properly seated on the die and the mechanism for advancing the work has been retracted to its standby position and it is broadly an object of this invention to provide a method and apparatus for accomplishing such synchronization.

In arriving at this invention, it was realized from a study of the operation of the apparatus to be controlled that this apparatus has certain highly unusual operational features. Each drive passes through a cycle during one part of which its associated press is compressing or otherwise drawing, forming, or trimming the work and during another part of which its associated press is moving away from the work and the work is being advanced. During the forming part of the cycle, the press and its drive are heavily loaded and during the work-moving part of the cycle, the press and its drive are very lightly loaded. During the loaded part of the cycle, the drive may be constrained to move at a low speed and during the unloaded part of the cycle the drive is free to move

at a relatively high speed, the ratio of the latter speed to the former speed may be of the order of 2 or 3:1.

During a complete operation the loading of any press relative to the others may vary over a wide range. At the start of an operation, the raw material for the first work item is seated on the first die while the others are unloaded. One press is at this time heavily loaded while the other presses are unloaded. During the succeeding cycle two presses are loaded while the others are unloaded. This continues until all the presses are loaded. With all the presses loaded, the load on the different drives during the loading part of each of the cycles may vary widely. One of the presses may be carrying out a forming or drawing operation and subjecting its drive to a heavy load while at the same time another of the presses may be performing a trimming operation subjecting its drive to a relatively low load. At the completion of a series of operations, the presses are gradually unloaded in the inverse order to their loading during the start of an operation.

Under these variable loading conditions, it is desirable that the presses and their drives be synchronized. Synchronization by mechanically linking the drives is not satisfactory because the linkages are subjected to enormous stresses and difficulty is encountered in providing adequate linkages which are capable of responding with the speed required to the changes in the loading of the drives.

It is then a specific object of this invention to provide a method and apparatus for synchronizing a plurality of mechanically disconnected drives which are subjected to highly variable loads of high magnitude that may be different for the different drives.

Another specific object of this invention is to provide apparatus for synchronizing a plurality of drives which are not connected mechanically but which are required to operate together and which are subjected to highly variable loads which may differ for the different drives.

A further specific object of this invention is to provide a method and apparatus for coordinating the speeds and the positions of a plurality of drives subjected to highly variable loads so that the drives operate together in the desired manner.

An incidental object of this invention is to provide a novel method of speed control having general applicability but particularly suitable for the coordination of the operation of a plurality of drives which are operated together but which are subjected to highly variable large loads different for the different drives.

Another incidental object of this invention is to provide a novel method of controlling the speed of a plurality of drives, the operation of which is to be synchronized so that they operate together and which are subject to highly variable large loads different for the different drives.

This invention arises from the realization that the drives need not be maintained at the same speeds and at the same relative positions during their entire cycles of operation. It is only necessary that the speeds and relative position of the drives be such that they start the compressing operation together at a prescribed speed and that they repeatedly reach the starting speed prior to the start of each of the succeeding compressing operations. It has been realized then that the drives may be permitted to reach different speeds and to become displaced in position with reference to each other to a limited extend during the loaded part of the cycle provided that they are reset to operate together at a set speed during the unloaded part of the cycle.

In accordance with this invention in its specific aspects the drives include no mechanical interconnection but are provided with electrical interconnections which permit

the speeds of all drives to decrease once the speed of at least one of the drives drops below a predetermined set magnitude. This limits the position deviations of the drives from each other. As to the position deviations which do occur, the electrical interconnections operate in dependence upon the position deviation of each drive from the average position of all of the drives to bring the drives to the same relative positions. The corrections in speed and position are effected during the unloaded part of the cycle so that the drives are positionally and in speed together just before the loaded part of the cycle starts.

In accordance with a specific aspect of this invention, speed control apparatus is provided which includes a master speed reference for all of the drives. This speed reference cooperates with regulators connected to each of the drives to tend to maintain the speed of each of the drives at a magnitude corresponding to the reference so long as the speed of all drives is above a predetermined magnitude. When the speed of any drive drops below this predetermined magnitude, a portion of the master speed reference parameter is absorbed externally to the regulators so that the regulators all operate to tend to adjust the speeds of the drives to a new reference corresponding to the lower speed of the drive which has dropped to a speed below the predetermined magnitude. When the speeds of all the drives returns to the predetermined magnitude, the master speed reference parameter again becomes effective and the drives are returned to the speed corresponding to this master reference. For this purpose, it is important that each of the drives be supplied with power and be capable of drawing adequate power for the necessary acceleration from the lower speeds to the speed corresponding to the master reference.

In actual practice, the speed of one or more of the drives drops below the predetermined magnitude during the loaded part of the cycles. All drives are then permitted to drop to a lower speed by the reduced speed reference parameter. During the unloaded part of the cycle adequate power is supplied to the drives to produce the necessary acceleration to return the drives to the speed corresponding to the master reference. At the start of the succeeding loaded cycle the drives are then back to their original speeds.

The novel features considered characteristic of this invention are disclosed generally above. The invention itself both as to its organization and as to its method of operation together with additional objects and advantages thereof will be understood from the following description of a specific embodiment when read in connection with the accompanying drawings, in which:

FIGURE 1 is a diagrammatic view showing a drawing, blanking or coining press line to which the invention disclosed herein is applicable;

FIG. 2 is a diagram showing the operation of the process line illustrated in FIG. 1;

FIG. 3 is a circular diagram showing the angular extent of the different parts of the cycle of a press of the apparatus illustrated in FIG. 2;

FIGS. 4A, 4B and 4C together constitute a circuit diagram of a preferred embodiment of this invention with which the method in accordance with this invention may be conveniently practiced;

FIG. 5 presents vector diagrams corresponding to the position following elements or synchroties of FIGS. 4A, 4B and 4C;

FIG. 6 presents a series of vector diagrams showing the vector relationships of the potentials derivable from the position following elements of FIGS. 4A, 4B and 4C;

FIG. 7 presents a series of vector diagrams illustrating the vector relationship between the potentials derivable from the position following elements when the positions of certain of these elements are displaced with respect to the others;

FIG. 8 presents a series of vector diagrams showing the potentials derivable from the position following elements under the conditions illustrated in FIG. 7;

FIG. 9 is a circuit diagram illustrating in detail the speed control system of the apparatus shown in FIGS. 4A, 4B and 4C; and

FIG. 10 is a circuit diagram of a modification of this invention particularly applicable to a two-drive line.

The apparatus shown in FIG. 1 is a press line including a plurality of dies on which work W1, W2 and W3 is to be formed. The work may be moved onto the leading die (W1) and off the last die (W4) and from die to die by retractable fingers 21 carried by, and linked to, transfer bars 23. The fingers 21 and the bars 23 are actuated by mechanisms (not shown) which are mechanically tied to the drive for one of the presses and are thus synchronized with this one press. The fingers 21 are movable relatively to the bars 23 into engagement with the work and the bars 23 are movable to advance the fingers 21 with any work they are carrying or to return the fingers for each now advancing operation.

Each press (not shown) of the press line is actuated by a crank (not shown) which operates continuously as it is continuously driven by an associated drive. The cycle of operation of a press (not shown) of the press line is shown in FIG. 2 and FIG. 3 shows the circular movement of the driven end of the crank (not shown) which drives a press in a typical situation. FIG. 3 is labeled to correspond to FIG. 2 and in addition it includes the points BDC, the bottom dead center at which the work is subjected to the highest stresses, and TDC, top dead center where the press is most remote from the work.

It is assumed that in FIG. 1 the fingers 21 are in a position where they have seated the work W1, W2, W3 on the dies and are about to be retracted. This corresponds to points A of FIGS. 2 and 3.

The fingers 21 are retracted between A and B of the cycle and the return of the bars 23 to the back position is started. During this part of the cycle the presses move toward the work W1, W2, W3 engaging the work at a point in the cycle corresponding to B. Between parts B and BDC of the cycle the work is formed on the dies. Between BDC and C the presses are retracted. At point C, the bars 23 are in the extreme retracted position and the fingers 21 are moved out to engage the work. At point D, the fingers 21 are in engagement with the work. The leading fingers 21 are in engagement with raw material to be deposited on the leading press; the fourth set of fingers 21 with W3 which is finished. Between D and A the work is seated on the successive dies. While the fingers are moving as described, the presses are moving from positions corresponding to C to position A.

The compressing and retraction movements of the presses takes place during the part of the cycle represented by the arc BC. In a typical case, the arc BC subtends an angle of 150°. Thus, the compression part of the cycle constitutes about $\frac{5}{24}$ of the complete cycle. The fingers 21 are moving into or out of engagement with the work between parts C and D and A and B of the cycles and during these parts the presses must be out of the way.

This invention arises from the realization that it is not essential that the presses be so synchronized that they are together continuously througout the cycle or stroke. It is only necessary that the presses be properly positioned so that the compression part of the cycle starts when the work is properly seated. That is, the presses should be together at instant B. At instant C, the positions and speeds of the presses may have departed from synchronization to a limited extent. The departure must not be such that any press is in the path of the fingers 21 as they start in. The presses are brought

back together as the drives move during the unloaded part of the work cycle between positions C and B.

In practice the bars 23 and fingers 21 are mechanically linked to one of the presses, for example, the one corresponding to work W1. The drives for this one press and the others are linked electrically in such a way as to permit substantial change in speed and position during the loaded part of the cycle and correction during the unloaded part. In a typical situation in which the loading is 1200 inch-tons and the speed of the presses is 25 strokes per minute, the speed may drop as much as 5% during the loading part of the cycle, and the relative positions of the drives may change correspondingly. For the same loading where the rate of operation of the presses is 12.5 strokes per minute, the speed may drop as much as 20% and the relative positions depart correspondingly.

The apparatus shown in FIGS. 4A, 4B and 4C with which the invention is practiced includes a Drive Unit and a Control Unit. This apparatus is supplied from conductors L1, L2 and L3 which are energized from a commercial alternating current supply through the usual disconnects or circuit breakers (not shown).

The Drive Unit includes drives DR1, DR2 and DR3 each of which has a drive motor M connected to control a crank (not shown) which drives the corresponding press. The Control Unit operates to control the speeds of the motors M so that the positions of the motors of the drive units are properly related to the operation of the fingers 21.

Each drive DR1, DR2 and DR3 includes in addition to the motor M a generator G for energizing the motor, a tachometer or pilot generator PG, a speed reference generator or exciter GS and a magnetic amplifier MA for controlling the motor M. The motor M has a shunt field winding 25 which may be energized from a direct-current supply. The supply is indicating only symbolically but usually derives its power from the conductors L1, L2 and L3 through a rectifier. The positive and negative terminals of the field supply are connected to the field winding 25 through a variable resistor 27 which serves to derive a potential proportional to the field current. The generator G has a series field winding 29 and a shunt field winding 31. The operation of the motor M is controlled primarily by controlling the current flow through the shunt field winding 31. This is effected by the magnetic amplifier MA. The pilot generator PG has a shunt field winding 33 which is supplied from a direct-current supply. The speed reference generator GS also has a shunt field winding 35 which is supplied from a direct-current supply through a variable resistor 37. The resistor 37 serves to set the speed reference at the desired magnitude.

The magnetic amplifier MA includes an output winding WO, a position control winding WC, a speed reference winding WSR, a speed winding WS, a biasing winding WB, a damping winding WD and a current limit winding WCL. The output winding WO is center tapped. This winding is supplied from the conductors L1 and L2. These conductors are connected to the shunt winding 31 of generator G through the winding WO and through rectifiers 41, 43 and 45 which assure that the current flow through the windings WO is of such polarity as to produce a self-biasing effect characteristic of magnetic amplifier operation. The winding WC is supplied from the Control Unit.

The control of the speeds of the motors M of the three drives DR1, DR2 and DR3 is interdependent. The connection of the speed reference windings WSR and the speed windings WS of the magnetic amplifiers MA of the three drives is not individual to any one drive but involves all drives. This connection is shown in FIG. 9. The speed reference winding WSR of each of the magnetic amplifiers MA is supplied from the generator GS, in a circuit extending from the positive terminal of the generator through a master variable resistor 51 and associated variable resistor 53 individual to each winding, the winding WSR to the negative terminal of the exciter GS. The exciter GS is also connected in a circuit with each of the pilot generators PG. This circuit extends from the positive terminal of the generator GS through the variable resistor 51, a rectifier 55 individual to each generator PG, the pilot generator to the negative terminal. The speed winding WS of each of the magnetic amplifiers MA is supplied from the associated pilot generator PG in a circuit extending from the positive terminal of the generator PG through a variable resistor 57, the winding WS to the negative terminal. The rectifiers 55 are so poled that so long as the associated pilot generator PG produces a voltage of a predetermined magnitude, current flow through the resistor 51 and through the pilot generator from the speed reference GS is blocked. Thus, the full voltage of the exciter GS is available as a speed reference.

The ampere turns produced through WSR by the voltage of GS is balanced against the ampere turns produced through windings WS by the associated pilot generator PG. The windings WSR and WS are so poled in each magnetic amplifier that the higher the ampere turns of WSR, that is, the higher the voltage of GS, the higher the voltage of PG required to counteract the ampere-turns of WSR. The voltage of PG depends on the speed of the associated drive M. Thus, the higher the voltage supplied from exciter GS the higher the speed that a drive M is permitted to reach. As the total voltage of the exciter GS serves to set the speed reference, the motors M are permitted to reach the maximum speed. The motors M are thus permitted to reach the maximum speed so long as all pilot generators PG supply a voltage above a predetermined magnitude.

When any of the motors M drops to a speed such that its pilot generator PG puts out a voltage lower than the magnitude, current flows through the master resistor 51, the associated rectifier and the generator absorbing part of the voltage from the exciter GS available for speed reference. The speed reference is thus reduced for all motors M and motors are permitted to drop to a lower speed.

The winding WB is supplied from a suitable direct current source which may be varied to produce the desired bias. The damping winding WD has the function of suppressing oscillation of the generator G in response to surges. This winding is connected in a circuit with the generator G which extends from one terminal of the winding through a surge suppressing capacitor 61, the generator G, the series field winding 29, a resistor 63 to the other terminal. The current limiting winding WCL is connected in circuit with the series field winding 29 of the generator C and a rectifier 65. The rectifier 65 is of the bridge type with two of its opposite terminals connected across the variable resistor 27 in series with the shunt field winding 25 of the motor M and the other opposite terminals connected in series with winding WCL, a resistor 67 and the series field winding 29. Current can only flow through the winding WCL if the potential across the series field winding 29 exceeds the potential impressed by the variable resistor 27. The variable resistor may be so set that when the current through the series field winding 29 is excessive, current flows through WCL reducing the current flow through the armature of the generator G and the series field winding 29.

The magnetic amplifiers MA of the drives DR1, DR2 and DR3, the generator G and the motors M are controlled in dependence upon the relative positions of the drives through the windings WC of the magnetic amplifiers MA which are controlled from corresponding componnets of the Control Unit. The Control Unit includes a plurality of synchroties SY1, SY2 and SY3

which are, in effect, rotary transformers capable of producing a position reference signal. Each synchrotie has a three-phase rotor 71 and a two-phase stator 73. The brushes of the rotors 71 are connected to conductors L1, L2 and L3 respectively and are thus supplied with three-phase potential. Two-phase potential, the components of which have phase positions dependent on the positions of the rotors 71, is then derivable from each stator 73. Each synchrotie has two pairs of terminals 75 and 77 and 79 and 81. Single phase alternating potential is derivable from each pair and the potential for one pair of each synchrotie is displaced in phase by 90° with respect to the potential of the other pair.

The rotor 71 of SY1 is mechanically connected to the motor M of drive DR1, the rotor of SY2 to the motor M of DR2 and the rotor of SY3 to the motor M of DR3. The connection may be directly to the motor M in each case or to the crank which drives the associated press. The connection in each case is rigid so that the rotor of the synchrotie has a position corresponding to the position of the crank or to the position of the corresponding press.

The Control Unit also includes transformers 11T, 12T, 13T and 21T, 22T and 23T. The primary 11TP of 11T is connected to one pair of terminals 75—77 of SY1, the primary 12TP to a corresponding pair 75—77 of SY2 and the primary 13TP to a corresponding pair 75—77 of SY3. Primaries 11TP, 12TP and 13TP then carry alternating current supplied by the associated synchroties respectively and displaced in phase in dependence upon the angular displacements of the rotors of the associated synchroties from initial settings. The primaries 21TP, 22TP and 23TP are similarly connected to the other pairs of terminals 79—81 of SY1, SY2 and SY3 respectively. Each transformer 11T, 12T, 13T, 21T, 22T, 23T has a pair of secondaries 11TS1 and 11TS2, 12TS1 and 12TS2, 13TS1 and 13TS2, 21TS1 and 21TS2, 22TS1 and 22TS2, 23TS1 and 23TS2, respectively.

The Control Unit also includes a pair of transformers 1T and 2T. Each of these transformers has three primary windings 1TP1, 1TP2 and 1TP3 and 2TP1, 2TP2 and 2TP3. The windings 1TP1, 1TP2 and 1TP3 preferably have an equal number of turns as do the windings 2TP1, 2TP2, 2TP3. The primaries 1TP1, 1TP2 and 1TP3 are connected in a series network with corresponding pairs of the terminals 75 and 77 of SY1, SY2 and SY3 with the pairs of terminals 75 and 77 sandwiched between the primary windings 1TP1, 1TP2 and 1TP3. This series network extends from one of the terminals 77 of SY1 through 1TP1, a conductor 83, the terminals 75—77 of SY2, a conductor 85, 1TP2, a conductor 87, the terminals 75—77 of SY3, a conductor 89, 1TP3, to the remaining terminal 75 of SY1. The total potential impressed in series with the windings 1TP1, 1TP2 and 1TP3 of 1T is then equal to the vectorial sum of the potentials across the sandwiched terminals of SY1, SY2 and SY3. The primaries 2TP1, 2TP2 and 2TP3 are similarly connected in a series sandwiched circuit with the remaining corresponding terminals 79 and 81 of SY1, SY2 and SY3. The transformer 1T has a plurality of secondaries 1TS11, 1TS12, 1TS21, 1TS22, 1TS31 and 1TS32. The number of turns of these secondaries is equal to the number of turns on any winding of 1TP1, 1TP2 or 1TP3. Thus, the potential across any secondaries 1TS11 through 1TS32 is equal to one-third the potential impressed across the primary windings 1TP1, 1TP2 and 1TP3 or to the average potential across these windings. Transformer 2T has secondaries 2TS11, 2TS12, 2TS21, 2TS22, 2TS31 and 2TS32 similarly related to the primaries 2TP1, 2TP2 and 2TP3.

The Control Unit includes a plurality of rectifiers of the bridge type 11R, 12R, 13R, 14R, 21R, 22R, 23R, 24R, 31R, 32R, 33R, 34R. Each rectifier is of the bridge type and has alternating-current input terminals and direct-current output terminals. The secondaries 1TS11 and 21TS1 are connected to supply the alternating current terminals of 12R with the windings 1TS11 and 21TS1 so connected that the potentials across these windings add vectorially. In effect then, a potential equal to the vectorial sum of the average potential derived from one pair of terminals 75—77 each of SY1, SY2 and SY3 and the potential derived from the other set of terminals 79—81 of SY1 is impressed on the alternating current terminals of 12R. Similarly, windings 11TS1 and 2TS11 are connected to the alternating current terminals of 11R in such a sense that the vectors representing their potentials are additive. In this case, the potential impressed on the alternating current terminals of the rectifier 11R is equal to the vector sum of the average potential derivable from the pairs of terminals 79—81 of SY1, SY2 and SY3 and the potential derivable from the pair of terminals 75—77 of SY1. The direct current output terminals of the rectifiers 11R and 12R are connected to supply a resistor 101. The positive terminal of this resistor 101 is connected to one terminal labeled +A of the winding WC of the magnetic amplifier MA of drive DR1.

Secondaries 1TS12 and 21TS2 are connected to supply rectifier 13R. In this case, the windings are so connected that the potential across the alternating current terminals of 13R is equal to the vectorial difference of the potentials across 1TS12 and 21TS2. The potential across the alternating current terminals of 13R is thus equal to the vectorial difference of the average potential across the corresponding pairs of terminals 75—77 of SY1, SY2 and SY3 and the other pair of terminals 79—81 of SY1. Secondaries 11TS2 and 2TS12 are similarly connected to 14R. Again the alternating potential across 14R is equal to the vectorial difference of the potential derivable from the corresponding pairs of terminals 79—81 of SY1, SY2 and SY3 and the remaining terminals 75—77 of SY1. The direct current terminals of rectifiers 13R and 14R are connected to supply a resistor 103, the positive terminals of which is connected to the remaining terminal of the winding WC of DR1 which is labeled +B. +A and +B are electrically positive relative to conductor 105 connected to the negative terminals of 11R, 12R, 13R and 14R. The polarity and magnitude of the current flow through WC is dependent on the relative magnitudes of the potentials across the corresponding resistors 101 and 103.

Rectifiers 22R and 21R, 23R and 24R, 32R and 31R and 33R and 34R are similarly connected in pairs to supply resistors 107 and 109, and 111 and 113 respectively, the positive terminals of which are connected respectively to the conductors +C and +D of the winding WC of the magnetic amplifier MA of DR2 and to conductors +E and +F of the winding WC of DR3. In each case, signals are produced proportional respectively to the sum of and the difference between the average potential derived from one pair of output terminals 75 and 77 or 79 and 81 of the synchroties and the other pair of terminals 79 and 81 or 75 and 77 of one of the synchroties SY2 and SY3 respectively.

The average potential derivable from the corresponding pairs of terminals of SY1, SY2 and SY3 has a phase position dependent on the average phase position of the rotors 71 which, in turn, is dependent on the average positions of the cranks (not shown). The sums and differences derived serve to provide an error signal which when impressed on the corresponding magnetic amplifier MA so sets the corresponding generator G as to tend to correct for the deviation in position.

For an understanding of the relationship between the vectors representing the various potentials and between the potentials themselves, FIGS. 5, 6, 7 and 8 should be considered. In FIG. 5 vector diagrams *a*, *b* and *c* present the potentials impressed on the brushes of the rotors 71 of the synchroties SY1, SY2 and SY3 respectively from the conductors L1, L2 and L3. The corresponding potentials derivable from the secondary terminals 75—77

and 79—81 are represented in the vector diagrams *d*, *e* and *f*. V11TP corresponds to the potential derivable from one pair of terminals 75—77 of SY1. This potential is impressed across the primary 11TP as indicated by the symbol. V21TP represents the potential derivable from the other set of terminals 79—81 and impressed on 21TP. The potentials V11TP and V21TP are in quadrature. V12TP, V22TP, V13TP and V23TP are similarly related. Diagrams *d*, *e* and *f* represent the initial or standby settings of the rotors 71 in which V11TP, V12TP and V13TP are in phase and V21TP, V22TP and V23TP are also in phase.

In FIG. 6, diagrams *a*, *b* and *c* present the relationship of the potentials impressed across the alternating current terminals of the various rectifiers 11R through 34R initially or during standby when the potentials derivable from corresponding pairs of terminals 75—77 or 79—81 of the synchroties are in phase. In diagram *a*, V11TS1 and V2TS11 are presented vectorially. These vectors are added and their sum is V11. Diagram *b* shows the addition of vectors V12TS1 and V2TS21 to obtain vector V21. V31 is similarly obtained. V11, V21 and V31 are in phase. Similarly, vectors V12, V22 and V32 are shown in diagrams *a*, *b* and *c* of FIG. 6 as the difference between V1TS12 and V21TS2, V1TS22 and V22TS2, V1TS32 and V23TS2. In diagrams *d*, *e* and *f*, V13, V23 and V33 are similarly derived as vector sums as are also V14, V24 and V34.

The potential between conductor +A and the negative conductor 105 is the rectified potential V11 or V12. The potential between +B and 105 is the rectifier potential V13 or V14. V11 and V12 are equal as are also V13 and V14. Thus the potential difference between +A and +B presented by the equation in FIG. 6 is zero. Similarly the potential difference between +C and +D is zero and the potential difference between +E and +F is zero. Thus with the synchroties in phase the windings WC of the magnetic amplifiers MA of each of the drives DR1, DR2, DR3 are not supplied with current.

FIG. 7 presents the vector relationships which arise when there is a phase displacement between the rotors 71 of the synchroties SY1, SY2 and SY3. This figure is based on the assumption that during the operation, the phase position of the cranks have changed so that the crank of drive DR1 leads the crank of drive DR2 by approximately 22½ electrical degrees and the crank of drive DR3 lags the crank of DR2 by 22½ electrical degrees. The phase relationship of the potentials derivable from the related pairs of terminals of SY1, SY2 and SY3 is presented in vector diagrams *a*, *b* and *c*. The summation of the vectors corresponding to the potentials V11TP, V12TP, V13TP derivable from corresponding pairs of terminals 75—77 of the synchroties SY1, SY2, SY3 is shown in diagram *d*. In this case, the vectors are added to produce a sum equal to 3V1TP. One-third of this sum is the average potential V1TS which is the potential across any of the secondaries of 1T. Similarly, V2TS is derivable by the summation of the vectors V21TP, V22TP and V23TP which are the potentials derivable from the other corresponding pairs of terminals 79—81 of the synchroties SY1, SY2 and SY3.

FIG. 8 presents a series of vector diagrams similar to those of FIG. 6 but with the phase displacement corresponding to FIG. 7, *a*, *b* and *c*, rather than zero displacement (FIG. 5, *d*, *e* and *f*). In this case, the vectors representing potentials derived from the transformers 1T and 2T have a phase and magnitude equal to the average potentials V1TS and V2TS which are derived in diagrams D and E of FIG. 7. Thus, V2TS11 of diagram *a*, FIG. 8, has a phase and magnitude equal to V2TS of diagram *e*, FIG. 7. Similarly, V1TS12 has a phase and magnitude equal to V1TS of diagram *d*, FIG. 7. The potentials of the secondaries of transformers 11T, 12T, and 13T, 21T, 22T and 23T are represented by vectors which in phase and magnitude are the same as the vectors representing the potentials V11TP, V12TP, V13TP, V21TP, V22TP and V23TP of the corresponding primaries.

The vectorial sum of the various vectors in diagrams *a*, *b*, *c*, *d*, *e* and *f* of FIG. 8 are as represented in this view. V11 and V12 are now smaller than V13 and V14. The difference between the potentials derivable from the rectifiers 11R and 12R and 13R and 14R (resistors 101 and 103) is then a negative potential designated —Q in FIG. 8. V21, V22, V23 and V24 are all equal so that the difference in the potentials derivable from the rectifiers 21R and 22R and 23R and 24R (resistors 107 and 109) respectively, is zero. Similarly, the difference of the potentials derivable from the rectifiers 31R and 32R and 33R and 34R (resistors 111 and 113) is a positive potential designated +Q in FIG. 8.

The potential supplied by the pairs of rectifiers 11R and 12R, 13R and 14R, 21R and 22R, 23R and 24R, 31R and 32R and 33R and 34R is a relatively smooth direct current potential since in each case it is derived by rectifying two-phase potentials, the separate components of which are displaced by 90°. The relatively small ripple does not affect the operation of the apparatus.

The potentials derivable from the various resistors are impressed across the windings WC of the amplifiers MA in the drives DR1, DR2 and DR3. The potential impressed across winding WC of DR1 has a polarity such that the current flows from +B conductor to +A conductor and a magnitude proportional to the difference of the absolute magnitudes of the vectors V13, V14 and V11, V12. The winding WC of drive DR2 is supplied with no current through conductors +C and +D and the winding WC of drive DR3 is supplied with current flowing from conductor +E to conductor +F having a magnitude proportional to the difference between the absolute magnitudes of the vectors V31, V32 and V33, V34. The effect of this current flow through the various windings WC is to cause drive DR1 to rotate slower than drive DR2 and drive DR3 to rotate at a higher speed than drive DR2 so that ultimately the drives are pulled into synchronism. During this position adjustment the effect of the speed control components of the respective drives may be such that all drives are increasing in speed.

In the standby condition of the press line, the presses will be in the position in which they stopped during the prior operation. A press line of the type under consideration here usually includes relays or other like means to assure that the presses are stopped in an unloaded part of the cycle or stroke. It may be assumed then that the presses are stopped at some point between top dead center TDC (FIG. 3) and A. The transfer mechanism is mechanically tied to one of the presses, for example to the leading press which operates on work W1 of FIG. 1. With the press stopped between TDC and A the fingers 21 are in the retracted position.

In standby the conductors L1, L2 and L3 are connected through the circuit breakers or disconnects (not shown) to the commercial supply buses and are energized. The synchroties SY1, SY2 and SY3 may then be supplied with three-phase potential and two-phase potential may be derivable from their respective stators. The rotors of these synchroties are positioned together corresponding to the positions of the associated presses. Potentials derived from corresponding pairs of terminals 75—77 and 79—81 of the synchroties SY1, SY2 and SY3 are then in phase. The drives DR1, DR2 and DR3 are controlled from a starting circuit (not shown). Such a circuit would include contactors which would maintain the drives DR1, DR2 and DR3 deenergized so long as a starting switch or pushbutton (not shown) is open.

To carry out an operation a stack of the raw material to be formed is placed adjacent to the leading die in a

position where the raw material units may be picked up one by one by the fingers 21. To start the operation the starting pushbutton (not shown) is closed energizing the drives DR1, DR2 and DR3. Initially the windings WC of the magnetic amplifiers MA are not supplied with current since the secondary potentials V11TP, V12TP, V13TP and V21TP, V22TP, V23TP derivable from terminals 75—77 and 79—81 respectively of SY1, SY2 and SY3 are in phase. The drives DR1, DR2 and DR3 are controlled by the speed reference GS and since they are unloaded the motors M soon reach a speed corresponding to this reference. The motors M move the cranks which, in turn, move the presses. The presses being unloaded, the movement of the presses is substantially synchronized. At the point A (FIG. 3) the retraction of the fingers is started and at point B the fingers are completely retracted. Since none of the dies carries material to be formed the presses are unloaded as they are moved by the cranks from the point corresponding to B to BDC. The presses then remain in the same relative positions and continue to the point C.

At the point C, the fingers 21 start to move in. At this time the bars 23 are in the extreme left-hand position with respect to FIG. 1 and the fingers 21 associated with the leading press move towards the raw material. At point D the fingers associated with the leading press are fully engaging the first unit of the raw material. The movement now continues from D to A. At A the first unit of raw material is deposited on the leading press and the retraction of the finger 21 started. At B the fingers are retracted.

A unit of material W1 is now seated on the leading die while the other dies continue unloading. As the motors M continue to rotate the drive DR1 is subjected to a large load which reaches a maximum at bottom dead center BDC. The other drives are unloaded.

The effect on the drive DR1 of the loading of the leading press is to reduce the speed of the corresponding motor M substantially. This, in turn, reduces the potential of the associated pilot generator PG so that current can flow through the variable resistor 51 and through the pilot generator PG of drive DR1. A portion of the potential from exciter GS is then absorbed reducing the reference speed potential supplied to the reference windings WSR of all amplifiers MA (FIG. 9). The speeds of the motors M of drives DR2 and DR3 are then reduced substantially but since they are unloaded their speeds do not reach the low speed of the motor M of DR1. The leading press then is displaced in position with respect to the other presses and the phase of the potential derived from the synchrotie SY1 is correspondingly displaced (lags) with respect to the potentials derivable from SY2 and SY3.

At point BDC, the leading press and drive DR1 is unloaded. The speed of this press increases correspondingly permitting the speeds of the other presses to increase. Eventually, the speed of the leading press reaches a magnitude at which the associated pilot generator PG of drive DR1 produces a potential such as to block current flow to the variable resistor 51. At this point the full potential of the speed reference generator GS takes effect so that the motors M of all drives DR1, DR2 and DR3 are permitted to reach full speed.

While this change of speed operation is taking place, the relative positions of the presses are also being shifted because of the operation of the Control Unit. Initially the leading press lags with respect to the presses driven by drives DR2 and DR3 and thus with respect to the average position. The current flow through WC of drive DR1 is then from +A to +B. Correspondingly the current flow through the winding WC of drives DR2 and DR3 respectively is from +D to +C and from +F to +E respectively. The motor M of drive DR1 then is accelerated at a higher rate than the motors of drives DR2 and DR3 and eventually the presses pull into step. The presses are in step before point C is reached during the succeeding cycle.

As the motors M and the presses continue to move, the fingers 21 are again injected advancing the partly formed work W1 on the leading die to the second die and advancing raw material to the leading die. The above described process is then again repeated but this time two of the presses are loaded while the third is unloaded so that a correspondingly different change in speed and position takes place.

During the succeeding operation the first leading die is loaded with raw material, the second die with partly formed work from the first die and the third die with the partly formed work from the second die. Now all three presses are loaded and a corresponding operation involving the Control Unit and the Drive Unit takes place. The loading of the three presses may be different and the speeds and changes of positions introduced by the different loadings may be different. Whatever the relationship correction is effected by the Control Unit so that the presses are all together at the point C (FIG. 3).

At the end of an operation the leading press is first unloaded, the second press next and the third press last. The loading effect on the drives is then the converse to the effect produced at the start of an operation.

In FIG. 10 a modification of this invention in accordance with its broader aspects is shown. This view relates to a system for operating only two press units or like apparatus. The Drive Unit in this case includes two drives DR4 and DR5. Each drive DR4 and DR5 has a magnetic amplifier MA1 which has two position control windings WC1 and WC2 in addition to the other windings of the amplifiers MA.

The Control Unit in this case includes synchroties SY4 and SY5. Each synchrotie has a rotor 131 to which a three-phase potential is supplied from the conductors L1, L2 and L3 and a two-phase stator 133. The potentials from the pairs of terminals of the stator of SY4 are supplied to transformers 4T and 5T respectively. The potentials of the synchrotie SY5 is correspondingly supplied to transformers 6T and 7T respectively. The secondaries 4TS1 and 6TS1 supply a rectifier 46R, the direct current terminals of which are connected between a conductor labeled +H and a common negative conductor 135. Secondaries 5TS1 and 7TS1 correspondingly supply a rectifier 57R which also supplies direct current potential between conductors +H and conductor 135. The current between conductors +H and 135 flow through windings WC2 of the magnetic amplifiers MA1. Secondaries 4TS2 and 6TS2 and 5TS2 and 7TS2 are similarly connected to supply direct current between conductors +G and 135 through rectifiers 64R and 75R. The current flow supplied by rectifiers 45R and 57R and 64R and 75R depends on the relative positions of synchroties SY4 and SY5 and effects an adjustment in the drives DR4 and DR5 so that they become synchronized during the unloaded part of their strokes or cycles.

To facilitate a complete understanding of the invention disclosed herein, the following summary is presented.

The invention in its specific aspects relates to apparatus for maintaining the angular position of the cranks of a plurality of presses within a given angular tolerance. The presses may be drawing, blanking or coining presses with each press obtaining energy from a flywheel to supplement the synchrotie torque during the working portion of the press cycle. It is necessary for the speed of the press to decrease to release energy from the flywheel during the working cycle. Due to the press slowdown or speed regulation the angular velocity of the press crank is not constant. It is not desirable to have an angular position reference which has a constant angular displacement. It is desired to have an angular position reference which has an angular position time characteristic similar to that attained on a press actually doing work during its load cycle. If a given press were to serve as master angular

position reference, it would be necessary to choose a press which is the average of the presses in the line in the amount of speed regulation. Even with choosing such a press its position reference would be incorrect when the press line is actually being loaded or unloaded. The press line is considered being loaded when material is being fed to the start of the line with the presses at the end of the line having no material. The press line is considered being unloaded when no material is being fed to presses at the start of the line but material is still being worked at the end of the line. To obtain a position reference which is not determined by the loading on any single press a reference which is the average instantaneous angular position of all units is in accordance with this invention selected as a reference. This position reference signal is then compared to the position signal of each press and a signal is sent to the regulator corresponding to each press indicating whether the press position involved is in phase ahead of, or behind, the position reference.

The unit which is coupled to the press crank shaft consists of a wound rotor synchrotie which has a three-phase primary and a two-phase secondary. FIGS. 4A, 4B and 4C show the circuit diagram of three such position detection units SY1, SY2 and SY3. The primary of each of these units is on the rotor 71 and is excited from a common three-phase power supply L1, L2 and L3. The two-phase secondary is on the stator member 73 in each case and has a voltage induced into it by the rotating field of the primary member. The phase relationship between the primary and secondary voltages in any synchrotie SY1, SY2 and SY3 or between secondary voltages of different units depends upon the rotor position of the synchrotie.

FIG. 5 shows the vector relationship of the primaries and secondaries of the synchroties SY1, SY2 and SY3 when the synchroties are in the same relative position with respect to each other. Since the primary 71 of each unit is excited from a common three-phase power supply the primary vectors are in phase and are represented by vector diagrams *a*, *b* and *c*. Vector diagrams *d*, *e* and *f* correspond to the stators 73. Since the primary is excited from a three-phase power supply tjhe vectors V11, V12 and V13 are rotating, rotation in the counterclockwise direction being assumed. The alternating current voltages induced into the two-phase secondaries 73 of the synchroties SY1, SY2 and SY3 are representable by rotating vectors which rotate in the counterclockwise direction. With the synchroties at rest the speed of rotation of the primary and secondary vectors is equal and if the power supply is 60 cycles they rotate at 60-cycle frequency.

In explaining the operation it is assumed that the synchroties are of the four-pole type having rotating fields rotating at 1800 r.p.m., and that the synchroties are directly connected to the crankshaft of the presses and the press crankjshafts have a maximum speed of 25 revolutions per minute. It is also assumed that the direction of rotation of the rotors 71 of these units is counterclockwise. Since the rotating field from the rotor 71 of each synchrotie and the rotor are rotating in the same direction the speed of rotation of the flux on the stator member is 1825 revolutions per minute. This causes an induced frequency of approximately 60.8 cycles per second to be introduced in the secondary of each synchrotie.

The average position reference vector is obtained by adding voltage vectors V11TP, V12TP and V13TP vectorially and dividing by 3. This is accomplished by adding these voltages in sandwich series with three of the primary windings 1TP1, 1TP2 and 1TP3. The division by the factor of 3 is obtain by turns ratio between the primary and secondary windings of transformers 1TP1, 1TP2 and 1TP3. Since there are three of these primary windings, the turns ratio between each of these windings and each of the secondary windings is equal. Since the three primary windings are in series in the sandwich series arrangement the voltage appearing across an individual secondary winding is actually one-third the vector sum of primary voltages. In FIG. 5 it has been assumed that the secondary vectors of motors M are in phase. The secondary voltages derived from 1T, are for each secondary equal to V11TP, V12TP and V13TP. The vector for the secondary voltage 1T is then the average vector of V11TP, V12TP and V13TP. This is a reference vector.

The same addition is applied to vectors of V21TP, V22TP and V23TP to arrive at a reference vector corresponding to each of the secondary voltages of 2T. This is also a reference vector which lags the reference vector from 1T by 90 electrical degrees. Thus assume,

$$V1TS=V1TS11=V1TS12=V1TS21=V1TS22=V1TS31=V1TS32$$

$$V2TS=V2TS11=V2TS12=V2TS21=V2TS22=V2TS31=V2TS32$$

Then

$$V1TS=\frac{V11TP+V12TP+V13TP}{3}$$

and when *V11TP, V12TP, V13TP* are in phase

$$V1TS=V11TP=V12TP=V13TP$$

similarly

$$V2TS=V21TP=V22TP=V23TP$$

To obtain an electrical signal which indicates the relative position of each press to the reference vectors a vector addition method is applied. Input to the regulators shown on FIGS. 4A, 4B and 4C can be described as push-pull two-phase signal error. FIG. 6 shows the vector relationships which exist with the three synchroties in phase and are the vector sums of the potentials on transformer secondaries shown in FIGS. 4A, 4B and 4C. The polarities of the transformers are indicated in FIGS. 4A, 4B and 4C. Four rectifiers are used in each of the three position signal circuits. Considering the circuit of synchrotie SY1, rectifiers 11R, 12R, 13R, 14R are included. Rectifiers 11R and 12R provide for a two-phase full-wave rectified signal between +A and 105 for one side of the push-pull signal. Rectifiers 13 and 14 provide a two-phase full-wave rectified signal for the one half of the push-pull signal between +B and 105. Vector diagram *a* on FIG. 6 shows the vector addition of V11TS and V2TS11 to obtain V11 which is the voltage applied to rectifier 11R. Vector V1TS12 and minus V21TS provides for the vector sum of V12 which is the voltage applied to rectifier 12R. Note that V11 and V12 are 90° apart in time, hence, the output voltage between +A and 105 is a full-wave rectified two-phase potential with the magnitude of the voltage between +A and 105 proportional to the magnitude of vectors V11 and V12.

In FIG. 6, *d* shows the vectors for the voltages appearing across rectifiers 13R and 14R, with V13 and V14 being the two-phase alternating-current voltage to be rectified by these two rectifiers to provide a two-phase full-wave rectified voltage output between +B and 105. Since the magnitude of vectors V11, V12, V13 and V14 are all equal the potentional difference between +A and +B is zero; hence, no corrective action is sent to the regulator for correction of position.

The vector relationship for DR2 and DR3 are shown in FIG. 6, *b*, *c*, *e* and *f*. Since these drives are also assumed to be in phase they have duplicate outputs with zero output to amplifiers MA.

In FIG. 7 is shown another condition of the vector relationships to illustrate the signals obtained, SY1, 22½ degrees ahead of SY2 and SY3, 22½ degrees behind SY2. The corresponding vectors derived from the secondaries of the synchroties SY1, SY2 and SY3 are shown in diagrams *a*, *b*, *c*, of FIG. 7. FIG. 7, *d* shows the vector addition of V11TP, V12TP and V13TP which divided by a factor 3 gives the average V1TS. The magnitude of

vector V1TS is now slightly less than the magnitude of V11TP, V12TP or V13TP. This decrease in magnitude of the vector, however, does not affect the operation of the circuit since it appears in both phases of the two-phase circuit by the same amount. The phase relationship between the voltages for V11 and V12 is still 90° and since the signal to the regulators is obtained from the push-pull circuit by comparing the magnitudes of V11, V12 to the magnitudes of V13 and V14, both sides of the push-pull circuit are slightly attenuated by this decrease in magnitude of V1TS and V2TS and no net result except for a slight decrease in output signal occurs. In actual practice, the maximum displacement angle is anticipated to be approximately 10 electrical degrees instead of 22½; this gives a magnitude of V1TS of 99% of the magnitude of V11TP, V12TP or V13TP. Since the affect of the smaller magnitude of V1TS vector has negligible affect on the performance of the system for the ease of explanation of the operation no decrease is assumed. The V2TS reference vector is again obtained in the same manner as the V1TS vector (see FIG. 7, *e*). V2TS vector lags V1TS vector by 90 electrical degrees.

FIG. 8 shows the same addition of vectors as is shown in FIG. 5 except for the ahead of and behind phase positions of SY1 and SY3 units. Referring to FIG. 8 a vector V11 is obtained by the addition of V11TS1 and V2TS11. Vector V12 is obtained by the addition of minus V21TS7 and V1TS12. Note that the V11 and V12 vectors are still 90 degrees apart in time and their magnitudes have been diminished due to the vector addition of the different angular relationship between the position vectors V11TS1 and minus V21TS2 in respect to the reference vectors V1TS12 and V2TS11. FIG. 8, *d* gives the vector additions of V1TS11, an average, and V21TS1 from which is obtained vector V13, and of minus V2TS12, an average, and V11TS2 from which is obtained vector V14. V13 and V14 vectors are 90 degrees apart in time. The rectified voltage at +A to 105 is now proportional to the magnitude of the V11 and V12 vectors. The rectified voltage at +B to 105 is now proportional to V13 and V14 vectors which are considerably larger than the V11, V12 vectors. Therefore, +B is at a higher magnitude than +A and the current signal is supplied to the drive DR1 with current flowing from +B to +A. This signal is of such an affect as to slow down press drive DR1 to bring its position back to the reference position.

Since each of the three press signal arrangements are identical, a study of drive DR3 of FIG. 8 shows the affect of any unit being behind the average position. Referring to FIG. 8, *c*, the magnitude of voltage at +E is proportional to vector V31 and V32 and greater than the magnitude of the voltage at +F which is proportional to vectors V33 and V34. Since the voltage at +E is greater than the voltage at +F, current flows from E to F through the regulator R3 which is in the opposite direction to the flow obtained for drive DR1 and is now in a direction such as to increase the speed of the third press. Since the vectors V21 and V22, and V23 and V24 are of the same magnitude the same potential exists at +C and +D and no corrective action is required for drive DR2.

By the use of the two-phase rectified power supplies for obtaining corrective signals to the drives a direct current supply with much less ripple than would be obtained with single phase rectified supplies is obtained. Filters are necessary to filter the ripple voltage from the signal currents to the drives DR1, DR2, DR3, but with the greatly reduced ripple. By using the two-phase systems little time delay is induced by the filters.

The push-pull arrangement of obtaining signals for +A and +B, +C and +D, and +E and +F, has an advantage in that any regulation or change in magnitude of voltage due to attenuation in adding and averaging reference vectors or change in voltage due to rotational speed of the position detecting synchroties are compensated. The advantage of connecting the primaries of the transformers for reference vectors in sandwich series with the various voltages from the synchroties SY1, SY2 and SY3 allows a much greater range in the output voltages of the secondaries of these synchroties without exceeding low voltage class of insulation level. It also allows, if required, with simple switching to eliminate one or more of the press drives from the line.

In accordance with this invention, an angular position reference which is dependent upon the average angle of all units and a position error signal which is proportional to the actual angular error of each press in respect to the reference, with the signal being zero for correct position and of different polarities for ahead and behind positions is provided. This arrangement also obtains a signal which is practically linear with angular error and which is not affected by change of rectifier resistance since all rectifiers are operating in a region where their forward resistance is practically constant because of the phase rectification.

FIG. 10 shows a modification of the invention in accordance with its broader aspects applicable where only two presses are required to operate. This arrangement of only two presses does not require the obtaining of the average reference vectors but compares only the relative vectors between the two presses. The output arrangement on FIG. 9 is shown as connected to two control windings WC1 and WC2 of magnetic amplifiers MA1 of drives DR4 and DR5. In this arrangement the flux addition of the two windings on each amplifier gives the net results of the push-pull output of +G and +H to 135. In this arrangement the polarities of the control windings of one drive DR4 are reversed with respect to those of the other drive DR5 such that the current flows from 5 to 6 and 6 to 5 or 7 to 8 and 8 to 7 (see FIG. 10).

The press position circuits are shown with three-phase primary excitation. This excitation may be any polyphase number which would produce a rotating field. The rotating field is shown on the rotor structure; the field may be applied to either the stator or the rotor in accordance with the broader aspects of this invention. The output of the synchroties SY1, SY2 and SY3 is shown as two-phase on both FIGS. 4A, 4B, 4C and 10; they could also be single phase, three-phase, or any other polyphase output. The regulating components shown as magnetic amplifiers in FIGS. 4A, 4B, 4C and 10 may be Rototrol units in accordance with the broader aspects of this invention. Position reference units which have polyphase output other than two-phase may in accordance with the broader aspects of this invention be fed into a transformer arrangement obtaining a two-phase voltage for obtaining and measuring the position reference and position error quantities.

In FIGS. 4A, 4B, and 4C the error signals are supplied through +A and +B, +C and +D, +E and +F. Since these are all of positive polarities and are obtained from rectifiers it is necessary to use loading resistors between +A and 105 and between +B and 105. In FIG. 10 the outputs of the position error circuit from both sides of the push-pull arrangement are fed into separate windings. A magnetic addition of flux occurs in the amplifiers MA1 of FIG. 10 and the resulting flux developed by the two windings supplies the error correction signal.

While a preferred embodiment of this invention has been disclosed herein, many modifications thereof are feasible. The invention, then, is not to be restricted except insofar as is necessitated by the spirit of the prior art.

We claim as our invention:

1. A control system for apparatus for treating work progressively in a plurality of positions, said apparatus including means at each of said positions for treating said work and drive means connected to each of said treating means for actuating said treating means, the said control system including position regulating means connected to each of said drive means for adjusting the position of the

associated drive means, means connected to each of said drive means for deriving a signal dependent on the position of the associated drive means, means connected to said signal deriving means of all of said drive means for deriving a signal corresponding to the average of the position dependent signals of all of said drive means, means connected to each of said position dependent signal deriving means and to said average signal deriving means for deriving for each drive means a signal dependent on the algebraic difference between said average signal and the position dependent signal for the associated drive means, and means connected to each of said regulating means and to the associated difference signal deriving means for causing said regulating means to set the associated drive means to the position corresponding to said average signal.

2. In combination a first drive shaft, a second drive shaft, a third drive shaft, first, second and third means connected to said first, second and third shafts respectively, for deriving first, second and third signals dependent on the respective positions of said first, second and third shafts, means connected to said first, second and third means for deriving a signal dependent on the average of said first, second and third signals, first, second and third differential means connected to said average signal deriving means and to said first, second and third position signal deriving means for deriving first, second and third error signals dependent on the algebraic differences between said average signal and said first, second and third position signals respectively, first, second and third regulators connected to said first, second and third shafts respectively for adjusting the positions of said shafts, and means connected to said first, second and third regulators for impressing on said regulators said first, second and third error signals respectively to cause said regulators to adjust their respective shafts so as to suppress the associated error signals.

3. A control system for apparatus for treating work progressively in a plurality of positions, said apparatus including means at each of said positions for treating said work and drive means connected to each of said treating means for actuating said treating means, the said control system including, means connected to each of said drive means for deriving a signal dependent on the position of the associated drive means, means connected to said signal deriving means of all of said drive means for deriving a signal corresponding to the average of the position dependent signals of all of said drive means, means connected to each of said position dependent signal deriving means and to said average signal deriving means for deriving for each drive means a signal dependent on the algebraic difference between said average signal and the position dependent signal for the associated drive means, and means connected to each of said drive means and to the associated difference signal deriving means for setting the associated drive means to the position corresponding to said average signal.

4. In combination first, second and third drive shafts, means connected to said drive shafts for deriving a signal dependent on the average position of said drive shafts referred to a starting position of said shafts, first, second and third differential means connected to said average signal deriving means and to said first, second and third shafts respectively for deriving first, second and third error signals respectively dependent on the algebraic deviation of each of said shafts from its said starting position, and first, second and third correcting means connected to said first, second and third shafts respectively and to said first, second and third differential means respectively, for correcting the positions of said first, second and third shafts so as to suppress its associated error signal.

5. A control system for apparatus for treating work progressively in a plurality of positions during a plurality of steps, the said apparatus including means at each of said positions for treating said work and drive means connected to said treating means for actuating said treating means, each of said steps consisting of a cycle during one portion of which said work is treated and each said drive means is subjected to a high load, said high load being different for different drive means, and during the remaining portion of which said work is advanced from one said position to the succeeding said position, said drive means being subjected to a low load during said remaining portion, the said system comprising means connected to all said drive means for continuously deriving an average signal dependent of the average relative position of all said drive means, means connected to each said drive means and to said average signal producing means for deriving for each drive means an error signal dependent on the deviation of said last-named drive means from said average position, and means connected to each said error signal deriving means and to each said drive means for continuously applying the associated said error signal to each said drive means to correct the position of said last-named drive means so as to suppress said error signal.

6. In combination first drive means, second drive means, means for producing a speed reference signal, first means connected to said first drive means and to said signal producing means responsive to said signal for maintaining the speed of said first drive means at a magnitude corresponding to said signal, second means connected to said second drive means and to said signal producing means responsive to said signal for maintaining the speed of said second drive means at a magnitude corresponding to said signal, first means connected to said first drive means, to said signal producing means and to said first and second signal responsive means for absorbing a part of said signal external to said signal responsive means when the speed of said first drive means is reduced below a predetermined magnitude so that said first and second responsive means react with a signal corresponding to said last-named speed, and second means connected to said second drive means, to said signal producing means and to said first and second signal responsive means for absorbing a part of said signal external to said signal responsive means when the speed of said second drive means is reduced below a predetermined magnitude, so that said first and second responsive means react with a signal corresponding to said last-named speed.

7. In combination first drive means, a first tachometer connected to said drive means for producing a first potential corresponding to the speed of said drive means, second drive means, a second tachometer connected to said second drive means for producing a second potential corresponding to the speed of said second drive means, first rectifier means, second rectifier means, means producing a speed reference potential, impedance means, means connecting in series said reference potential, producing means, said impedance means, said first rectifier means and said first tachometer, with said first rectifier means poled to conduct under said reference potential and to block under said first potential, means connecting in series said reference potential producing means, said impedance means, said second rectifier means and said second tachometer, with said second rectifier means connected to conduct under said reference potential and to block under said second potential, first regulator means including a speed reference winding, a speed signal winding and an output winding, second regulating means including a speed reference winding, a speed signal winding, and an output winding, means connecting in a first series circuit said speed reference potential producing means, said impedance means, and said speed reference winding of said first regulator means, means connecting in a second series circuit said speed reference potential producing means, said impedance means, and said speed

reference winding of said second regulator, means connecting in a third series circuit said first tachometer and said speed signal winding of said first regulator means, means connecting in a fourth series circuit said second tachometer and said speed signal winding of said second regulator means, the ampere turns through said speed reference windings in said first and second circuits counteracting the ampere turns through said speed signal windings in said third and fourth circuits respectively, means connecting said output winding of said first regulator to said first drive means in regulating relationship therewith, and means connecting said output winding of said second regulator to said second drive means in controlling relationship therewith.

8. In combination first, second and third drive shafts, speed regulating means connected to said drive shafts for maintaining said shafts at a predetermined speed when all said shafts have a speed not loaded substantially lower than said speed and for permitting all said shafts to drop to a lower speed when at least one of said shafts drops substantially below said predetermined speed, means connected to said drive shafts for deriving a signal dependent on the average position of said drive shafts referred to a starting position of said shafts, first, second and third differential means connected to said average signal deriving means and to said first, second and third shafts respectively for deriving first, second and third error signals respectively dependent on the algebraic deviation of each of said shafts from its said starting position when said shafts are operating at said lower speeds, and first, second and third correcting means connected to said first, second and third shafts respectively and to said

first, second and third differential means respectively, for correcting the positions of said first, second and third shafts so as to suppress its associated error signal while increasing the speeds of said shafts to said predetermined speed.

9. In combination first drive means, second drive means, means for producing a speed reference signal, first means connected to said first drive means and to said signal producing means responsive to said signal for maintaining the speed of said first drive means at a magnitude corresponding to said signal, second means connected to said second drive means and to said signal producing means responsive to said signal for maintaining the speed of said second drive means at a magnitude corresponding to said signal, and means connected to said first drive means, to said signal producing means and to said first signal responsive means for absorbing a part of said signal external to said signal responsive means when the speed of said first drive means is reduced below a predetermined magnitude so that said first and second responsive means react with a signal corresponding to said last-named speed.

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