United States Patent

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[54] DIGITAL CONTROL OF PRESS SYNCHRONIZATION

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[52] **U.S. Cl.** **318/85**

[51] **Int. Cl.** **H02p 5/50**

[58] **Field of Search** ..... 318/85, 604, 318, 314, 632; 328/133, 134; 307/252 W, 233

[56] **References Cited**

UNITED STATES PATENTS

2,928,033	3/1960	Abbott	318/604
3,408,549	10/1968	Shimabukuro	318/85
3,064,173	11/1962	Breen	318/85
3,333,089	7/1967	Saylor	318/632

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[57] **ABSTRACT**

For automatically synchronizing the operation of a line of independently driven presses, each equipped with a variable speed drive, a digital control system in which respective digital signals representative of the instantaneous phase positions of the several presses in the line are each differentially compared against a digital reference signal representative of reference phase position. As a result of the differential comparisons, if the phase of any given press leads or lags the reference phase, a phase error is detected. This phase error is converted to an analog control signal which has a sense dependent on whether the press phase is leading or lagging the reference phase and a magnitude dependent on the amount of such lead or lag, and the control signal is fed back to the press drive to speed up or slow down the press as necessary to bring it back into step. The digital reference phase position signal cycles at the desired line operating speed, so that all presses operate in synchronism at that speed.

5 Claims, 4 Drawing Figures

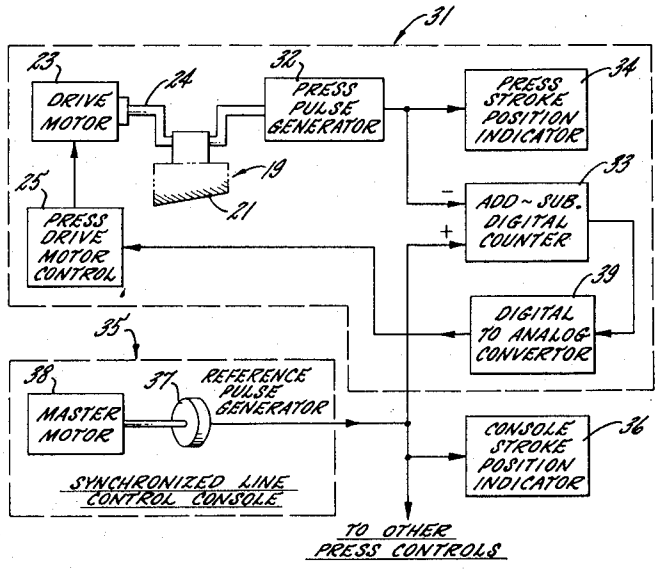
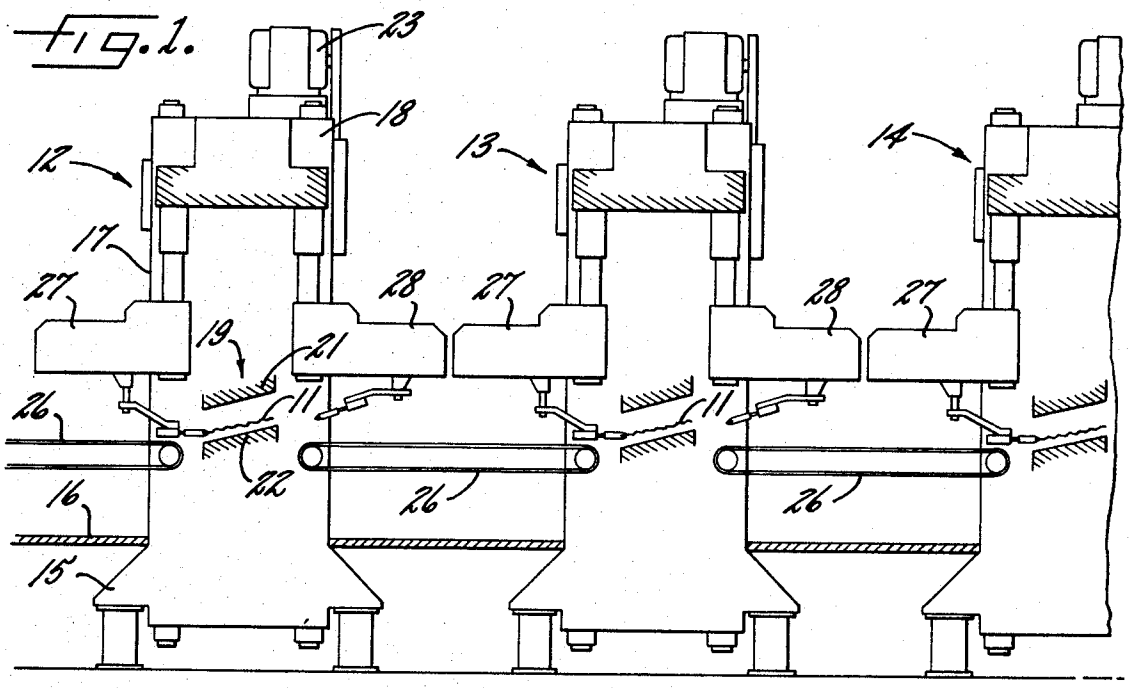


Fig. 1.



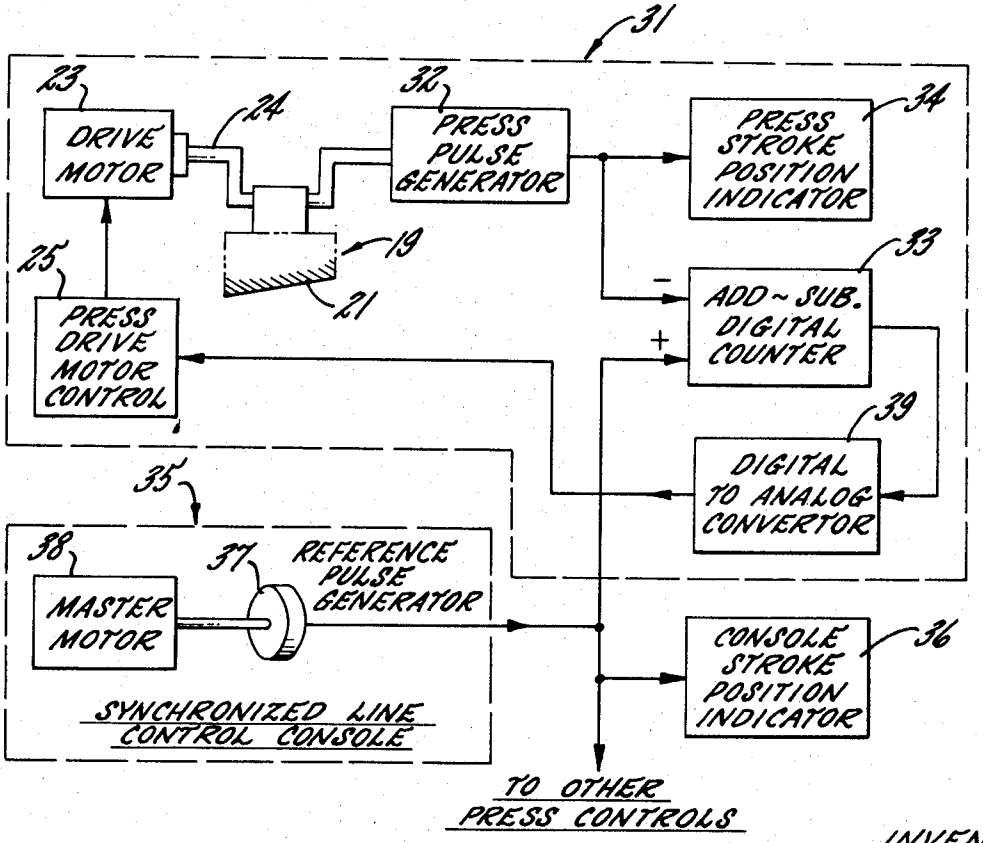


Fig. 2.

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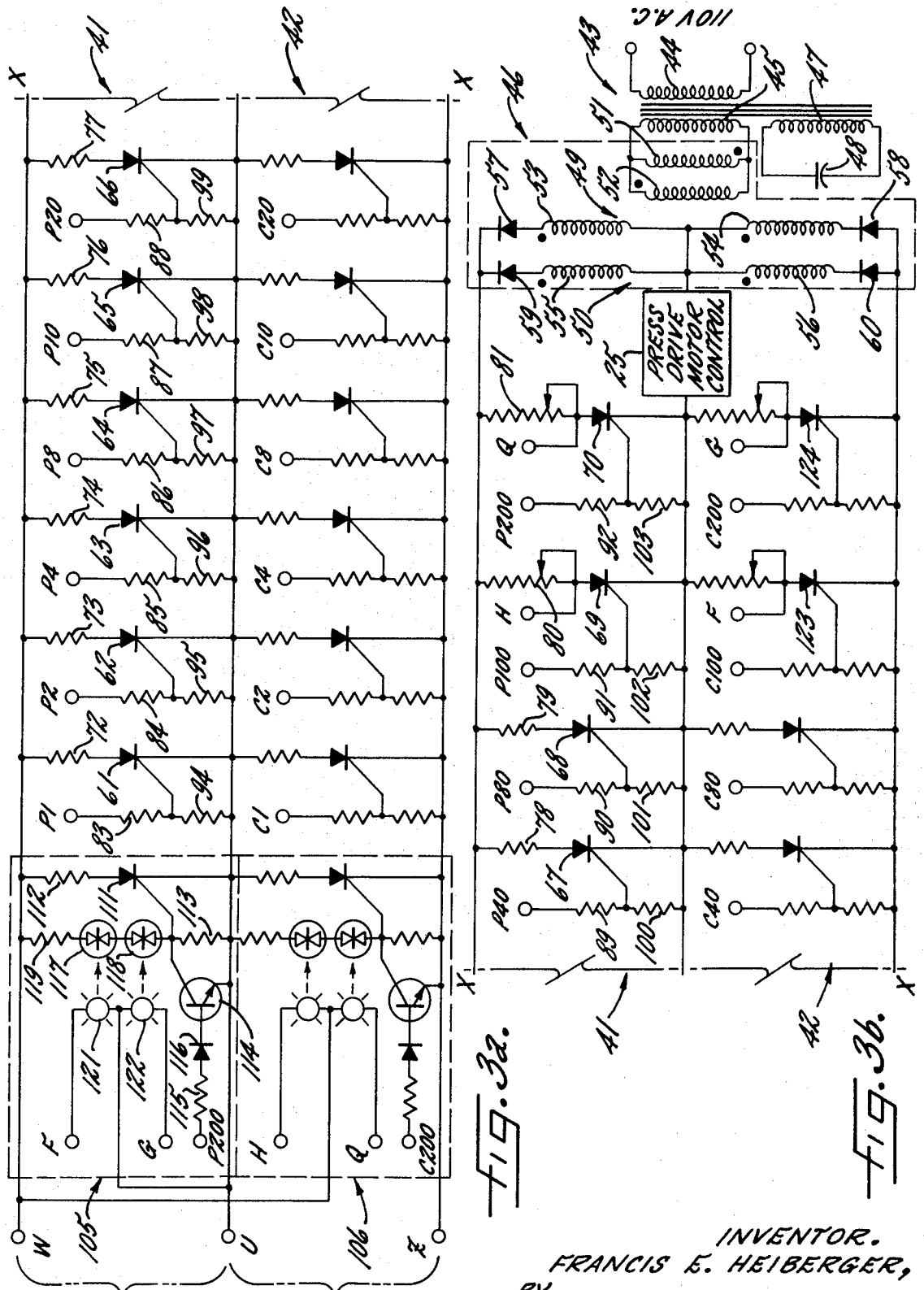


FIG. 3a.

FIG. 3b.

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DIGITAL CONTROL OF PRESS SYNCHRONIZATION

BACKGROUND OF THE INVENTION

The present invention relates to power presses, and more particularly to a digital control system for synchronizing the operation of a line of independently driven presses.

As will be appreciated, press line synchronization presents a fairly unique control problem, since it requires that several presses, each generally having a tremendous inertia, be kept in step with one another, despite that the load on any given press varies with time and that at any given time the loads on the respective presses may differ considerably. Indeed, until relatively recently, there was no control system for automatically synchronizing a line of independently driven power presses. Instead, the benefits of having the presses independently driven or operable in a continuous mode were sacrificed in the interest of synchronization. For example, one approach that was taken was to interconnect the drive shafts of the several presses to thereby mechanically and forcibly hold the presses in step. But, this was not a satisfactory solution, since the presses generally all had to have substantially the same crown heights to facilitate the mechanical interconnection of their drive shafts. Also, it was very difficult and time consuming to add or remove presses from the line, and the common drive shaft was subjected to extreme torques. Another approach that was taken was to use the operation of one press to trigger the operation of the next, and so on down the line. But, again, this was not a satisfactory solution, primarily due to the severe limitations it placed on the attainable line operating speed. A further approach was to provide means for an operator to manually adjust the relative phase positions of the several presses, together with a limit switch to shut down the line when the phase error between the fastest and slowest press therein exceeded a predetermined limit, so that the line could be manually readjusted whenever it got out of synchronism. This approach not only required the frequent intervention of an operator, but also substantially prevented operation of the line in a continuous mode, since the limits of tolerable phase error were generally exceeded in no more than approximately twenty strokes.

However, the basic problem was finally solved, as disclosed and claimed in Danly U.S. Pat. No. 3,199,439, by recognizing that the operation of a line of independently driven presses, each equipped with a variable speed drive, could by synchronized at any desired operating speed, up to a limit imposed by the mechanical capabilities of the presses, by feeding back to each press drive a phase error signal obtained by continuously comparing the press phase position against an externally generated reference phase position. With that arrangement, if any given press tends to get out of step, a phase error signal is supplied to the press drive to increase or decrease the press speed as necessary to maintain the press in step. Thus, any corrective action required is provided when only minor changes in press speed suffice and, therefore, the necessary corrections are readily made despite the high inertias of the presses.

SUMMARY OF THE INVENTION

An object of the present invention is to provide a relatively compact and lightweight control system for synchronizing the operation of a line of independently driven presses. A related object is to provide a control system of the foregoing type which requires only negligible amounts of power for its operation. More specifically, it is an object of this invention to provide a digital control system, which permits any number of standard or custom built presses to be operated as a closely synchronized press line.

BRIEF DESCRIPTION OF THE DRAWINGS

Other objects and advantages of the present invention will become apparent when the following detailed description is read in connection with the attached drawings, in which:

FIG. 1 is a side elevation, partly diagrammatic, to illustrate a portion of a typical press line with which the present invention can be advantageously employed;

FIG. 2 is a block diagram of an exemplary embodiment of the control system of the present invention, and illustrates its association with an exemplary one of the presses shown in FIG. 1; and

FIGS. 3A and 3B, when interconnected as indicated at X—X, form a schematic diagram of a combined add-subtract digital counter and digital to analog converter suitable for use in the control system illustrated in FIG. 2.

DETAILED DESCRIPTION OF THE ILLUSTRATED EMBODIMENT

While the invention will be described in connection with a single illustrated embodiment, it is to be understood that the intent is not to limit it to that embodiment To the contrary, the intent is to cover all alternatives, modifications and equivalents that come within the spirit and scope of the invention.

THE TYPICAL PRESS LINE

Turning now to the drawings, and particularly to FIG. 1, there is shown a portion of an automated press line for performing successive operations on a workpiece 11 as the workpiece passes down the line. Only three presses 12, 13 and 14 are shown, but it will be understood that in practice the present invention may be used to synchronize the operation of any number of presses.

As here illustrated, the presses are identical and of generally conventional construction. For example, the press 12 includes a massive base 15, which is anchored below the floor 16, and a frame 17 topped by a crown 18. Reciprocatingly mounted in the press frame 17 there is a slide, diagrammatically indicated at 19, with cooperating upper and lower dies 21 and 22, respectively. To drive the press 12, a motor 23 is mounted on the press crown 18 and coupled to the press drive or crank shaft 24 (FIG. 2) which, in turn, is coupled to the press slide 19.

The coupling between the press motor 23, crank shaft 24 and slide 19 is not shown in detail, since it may be entirely conventional. If the details of the coupling are of interest, reference may be had to the trade brochures and descriptive bulletins of the press manufacturers, as well as to Danly U.S. Pat. Nos. 3,199,439 and 3,199,443. For present purposes it suffices to simply note that the press drive motor 23 and its associated speed control 25 provide an electrically responsive, variable speed drive for the press 12, and that the drive for the press 12 is independent of the similar variable speed drives provided for the other presses 13 and 14 in the line.

As illustrated, for transporting the workpieces 11 down the press line, there are respective conveyors 26 leading up to and away from the input and the output sides of each press. Further, each press is equipped with an input transfer mechanism 27 and an output transfer mechanism 28. The input and output transfer mechanisms for any given press, as well as at least one of the adjacent conveyors 26, are coupled (by means not shown) to the press drive motor 23 for operation in coordination with the movement of the press slide 19. The details of the transfer mechanisms 27 and 28 and of the coupling between the press drive motor 23, transfer mechanisms 27 and 28, and associated conveyors 26 form no part of the present invention. Therefore, for a discussion of such details, reference is again made to the aforementioned Danly U.S. Pat. Nos. 3,199,439 and 3,199,443. For now it suffices to note that the coordination of the conveyors 26 and transfer mechanisms 27 and 28 with their associated presses provides a generally continuous flow of workpieces 11 along the line, while assuring that each press is loaded and unloaded during its operating cycle at predetermined points selected to assure ample clearance between the dies 21 and 22 for free movement of one workpiece out of and another workpiece into the work area of the press.

THE CONTROL SYSTEM

With the characteristics of a typical press line now in mind, attention is directed to the control system provided in accordance with the present invention for automatically synchronizing the operation of the press line. Referring to FIG. **2**, the control system is described with reference to the control of the phase position of only the press **12**, since the control circuits for the other presses are identical to the one press control circuit **31** shown. It will, of course, be understood that the description of the control system as applied to the press **12** is equally applicable to the control system as applied to any of the other presses.

In accordance with the present invention, a digital signal representative of the phase position of the press **12** is differentially compared against a digital signal representative of a reference phase position, so that if there is any lead or lag in the press phase position relative to the reference phase position, a phase error signal is obtained. The phase error signal is presented as an analog signal, which has a sense dependent on whether the phase of the exemplary press **12** is leading or lagging the reference phase and a magnitude dependent on the amount of any such lead or lag. The analog signal is, in turn, supplied as a feedback signal for correctively energizing the press drive to slow down or speed up the press as necessary to eliminate the lead or lag.

More particularly, the press control circuit **31** includes a pulse generator **32**, which is driven at the operating speed of the press **12**, such as by being coupled directly to the press crank shaft **24**, to supply a digital signal which is representative of the existing press phase position. The digital press phase position signal uniquely identifies the existing press phase position and changes with each incremental change of such position, say each 1°, through the full 360° of the press cycle. As shown, the press phase position signal is applied to one input of an add-subtract digital counter **33** and also to a press stroke position indicator **34**. The position indicator **34** is a conventional digital counter, which supplies a readout from which an operator can determine the press phase position at any given instant. Typically, it is automatically reset (by means not shown) when the press phase passes through its 360° phase cross over point.

An external pulse generating means **35** supplies a digital phase position reference signal which uniquely identifies the existing reference phase position and which cycles at a frequency or repetition rate corresponding to the desired operating speed for the press line. The phase position reference signal is applied to the second input of the add-subtract digital counter **33** and to a stroke position indicator **36**. The stroke position indicator **36** again comprises a conventional counter, which is automatically reset (by means not shown) when the reference phase position signal passes through its 360° phase crossover point. It provides a readout from which the operator can determine the reference phase position at any given instant.

Of course, the digital reference phase position signal may be supplied in a number of different ways. For example, as shown, the usual control console for the control line may include a reference pulse generator **37** driven by a master motor **38**. Unlike the press motor **23**, the load on the master motor **38** remains substantially constant. Thus, once the speed of the master motor **38** is adjusted to the desired operating speed for the press line, it remains substantially constant.

To eliminate any lead or lag of the phase of the press **12** relative to the reference phase, the digital signals supplied by the pulse generators **32** and **37** are differentially compared in the add-subtract digital counter **33** thereby providing a phase error signal, which is converted in a digital to analog converter **39** to supply an analog control signal that has a sense dependent on whether the press phase leads or lags the reference phase and a magnitude dependent on the amount of the lead or lag. The control signal is, in turn, fed back to the press drive speed control means, herein referred to as a press drive motor control **25**, to correctively energize the press drive for speeding up or slowing down the press **12** as necessary to bring the press phase back into step with the reference phase. As will be appreciated, similar corrections are provided when necessary for each of the other press operating speeds, so that each press in the line is in phase with the reference phase and, therefore, in step or synchronism with each of the other presses in the line.

While the details of the pulse generators **32** and **37** are not here shown, it will be understood that they may suitably be conventional units, such as binary coded decimal discs. As far as the present invention is concerned, the one important characteristic of the pulse generators **32** and **37** is that they supply respective digital signals which can be processed to yield an analog control signal with a sense dependent on whether the phase of the exemplary press **12** leads or lags the reference phase and a magnitude dependent on the amount of any such lead or lag. It will, of course, be understood that by proper selection of the add-subtract digital counter **33** and the digital to analog converter **39**, a variety of digital signals could satisfy the above requirements. However, for purposes of the further description of the illustrated embodiment, it will be assumed that the pulse generators **32** and **37** are binary coded decimal discs and that the digital signals supplied thereby are both based on the same predetermined binary coded decimal system.

Further, it will be understood that the synchronized presses are not necessarily "in phase" with one another in the sense that their slides are necessarily at the same stroke positions at any given instant. To the contrary, the zero phase position for each press is selected so that as the press operates in phase with the reference, its stroke is timed relative to the strokes of the other presses for the most efficient performance of the operation of the particular press on the workpiece **11**. Thus, one press may be at top stroke, while another press is at bottom stroke or any other stroke position.

A SUITABLE COUNTER-CONVERTER

Turning now to FIGS. **3***a* and **3***b*, to provide an even fuller understanding of the present invention, there is shown an exemplary circuit for performing the functions of the add-subtract digital counter **33** and the digital to analog converter **39** in the digital press synchronizing system of FIG. **2**. Specifically, FIGS. **3***a* and **3***b*, when joined as indicated at X—X, illustrate a combined counter-converter which differentially compares the digital press and reference phase position signals and converts whatever difference there may be therebetween from digital to analog form, thereby providing for the press drive motor control **25** a control signal which has a sense dependent on whether the press phase is leading or lagging the reference phase and a magnitude dependent on the amount of any such lead or lag so as to speed up or slow down the press **12** as necessary to bring it back into step or synchronism with the other presses in the line. As will be appreciated, the counter-converter of FIGS. **3***a* and **3***b* carries out the functions of both the add-subtract digital counter **33** and the digital to analog converter **39** of FIG. **2**.

The power requirements of the counter-converter are quite nominal and are primarily dictated by the power required by the press speed control means; i.e., the press drive motor control **25**. Such power as is required can normally be supplied by a readily available line source, such as the 110 volt A.C. source indicated. Thus, there is shown an input transformer **43**, which has its primary winding **44** connected across the source and its secondary winding **45** feeding a full wave rectifier **46**. To stabilize the voltage developed across the secondary winding **46**, the input transformer **43** may further include a tertiary or stabilizing winding **47** tuned in the usual manner to the line frequency by a parallel connected capacitor **48**. The full wave rectifier **46** here illustrated comprises a pair of transformers **49** and **50**, which have their respective primary windings **51** and **52** connected in parallel across the input transformer secondary winding **45** and their respective split

secondary windings **53**, **54** and **55**, **56** connected in parallel through respective diodes **57**, **58**, **59** and **60** between a pair of buses W and Z. The transformers **49** and **58** are oppositely wound (as indicated by the dot notation) and the diodes **57–60** are poled for conventional full wave rectification, so that the buses W and Z are supplied with D.C. potentials, which have ripple frequencies twice as high as the source frequency and which are positive and negative, respectively, relative to a common bus U.

As previously mentioned, in the illustrated embodiment, the digital signals supplied by the pulse generators **32** and **37** are based on the same predetermined binary coded decimal system. For example, the digital press phase position signal supplied by the pulse generator **32** comprises a plurality of binary digits or "bits", each of which has two possible states "1" or "0", such as a high voltage level and a low voltage level, to indicate the presence or absence, respectively, of a predetermined amount of angular rotation in the particular press phase position existing at any particular time. Accordingly, to derive the desired control signal from the digital press and reference phase position signals, the counter-converter comprises identical but oppositely poled summing banks **41** and **42** for converting the digital press and reference phase position signals to respective corresponding analog signals. The summing banks **41** and **42** are symmetrically connected via the common bus U to the press drive motor control **25**, so that their respective analog signals are applied thereto in bucking relationship, with the result that the net energization or control signal for the press drive motor control **25** has a sense dependent on whether the press phase leads or lags the reference phase and a magnitude dependent on the amount of any such lead or lag.

As is apparent, with the exception of the aforementioned polarity difference, the summing banks **41** and **42** are identical. Taking the summing bank **41** as being exemplary, it will be seen that to convert the digital press phase position signal supplied by the pulse generator **32** into a corresponding analog signal, the summing bank includes for each bit of the digital press phase position signal a corresponding switching device **61–70** and series connected weighting resistors **72–81**. As here depicted, the switching devices **61–70** are silicon controlled rectifiers, which have their anode-cathode power circuits connected in parallel between the positive D.C. bus W and the common bus U, with the result that the analog signal supplied by the summing bank **41** is the summation of any and all current flow through the anode-cathode circuits of the controlled rectifiers **61–70**. The bits of the digital press phase position signal are separately applied as indicated to the gates of the corresponding controlled rectifiers **61–70**, so that each of the controlled rectifiers operates in a conductive or non-conductive state in dependence on the logic level of the particular bit applied thereto; i.e., in a conductive state when the bit is at a high voltage (or "1") level and a non-conductive state when the bit is at a low voltage (or "0") level. The weighting resistors **72–81** are connected in series in the anode-cathode circuits of the controlled rectifiers **61–70**, respectively, and their values are selected so that the current drawn by the controlled rectifiers **61–70** in response to any given digital press phase position signal is proportional to the press phase position represented thereby. In keeping with accepted practices, each of the controlled rectifiers **61–70** is further shown as having a respective resistor **94–103** connected across its gate-cathode circuit to provide a path for reset current flow.

Of course, the press and reference phase positions continuously and repetitively cycle through 360° and, therefore, may at times be on opposite sides of their respective phase crossover points; say at 15° and 350°. As will be appreciated, under such circumstances, the appropriate control signal for the press drive motor control **25** cannot be derived simply by differentially comparing or bucking analog signals representative of the respective phase positions against one another. To the contrary, it is necessary to increase the level of the analog signal for the phase position that is past its phase crossover point by an amount proportional to 360° of angular rotation to provide a proper basis for comparing it with the analog signal representative of the other phase position. To this end, the summing banks **41** and **42** of the counter-converter shown further include respective auxiliary circuits **105** and **106**. When the press phase position is leading and past its phase crossover point while the reference phase position is still short of its phase crossover point, the auxiliary circuit **105** increases the total current supplied by the summing bank **41** by an amount proportional to 360° of angular rotation. On the other hand, when the press phase position is lagging and still short of its phase crossover point while the reference phase position is past its phase crossover point, the auxiliary circuit **106** increases the total current supplied by the summing bank **42** by an amount proportional to 360° of angular rotation.

Again, with the exception of the polarity difference, the auxiliary circuits **105** and **106** are essentially identical. Therefore, referring to the auxiliary circuit **105** for descriptive purposes, it will be seen that it includes a silicon controlled rectifier **111**, which has its anode-cathode circuit connected through a weighting resistor **112** between the positive D.C. bus W and the common bus U. Means are coupled to the gate of the controlled rectifier **111** to fire it when the press phase position is leading and past its phase crossover point while the reference phase position is still short of its phase crossover point. The value of the weighting resistor **112** is selected so that when the controlled rectifier **111** is fired, the total current supplied by the summing bank **41** is increased by an amount proportional to 360° of angular rotation.

To permit the use of a simple and reliable means for firing the controlled rectifier **111**, the number of bits of the digital press and reference phase position signals relied on in determining whether the additional current flow available from the auxiliary circuit **105** is required or not is preferably minimized. Indeed, in the interest of minimizing the number of bits involved, it is permissible to sacrifice the ability to discriminate between leading and lagging press phase conditions in those situations in which the absolute error between the press and reference phase positions exceeds some relatively large angle, such as 100°. Of course, such a large error is unlikely to occur during normal operation and, if it does occur, the inability to accurately determine whether the press phase position is leading or lagging will only slightly affect the time consumed in bringing the press back into synchronism. For example, as here depicted, the controlled rectifier **111** is fired whenever the press and reference phase positions are within ranges of 0°–200° and 300°–360°, respectively, since the determination as to whether they are within such ranges or not requires that the levels of only three of the twenty bits of the digital press and reference phase position signals be monitored; i.e., the 200° bit of the press phase position signal and the 100° and 200° bits of the reference phase position signal. In particular, as here illustrated, the impedance between the gate-cathode circuit of the controlled rectifier **111** is regulated in dependence on the press phase position and the current flow through such impedance is regulated in dependence on the reference phase position, such that the combination of high impedance and high current required to develop a firing pulse for the controlled rectifier **111** exists only when the press and reference phase positions are within the aforementioned ranges of 0°–200° and 300°–360°, respectively.

More specifically, for regulating the impedance in the gate-cathode circuit of the controlled rectifier **111** in dependence on the press phase position, a gate-cathode resistor **113** is shunted by the collector-emitter circuit of a transistor **114**. The transistor **114** has its base connected via a current limiting resistor **115** and a blocking diode **116** to receive from the digital press phase position signal the bit representative of a press phase position of 200°. Thus, it will be seen that when the press phase position is between 0° and 200° the transistor **114** is held in a non-conductive state and the impedance appearing across the gate-cathode circuit of the controlled rectifier **111** is relatively high, whereas when the press phase posi-

tion is between 200° and 360° the transistor **114** is held in a conductive state and the impedance appearing across the gate-cathode circuit of the controlled rectifier **111** is then comparatively low.

On the other hand, for regulating the current flow through the impedance in the gate-cathode circuit of the controlled rectifier **111**, connected in series with the parallel combination of the resistor **113** and collector-emitter circuit of the transistor **114**, between the positive D.C. bus W and the common bus U, there is a pair of photoconductive diodes **117** and **118** and a current limiting resistor **119**. Further, aligned with each of the photoconductive diodes **117** and **118** there is a respective light source or lamp **121** and **122**. The energization circuits for the lamps **121** and **122** are completed, as indicated by the terminals F and G, in the summing bank **42** via silicon controlled rectifiers **123** and **124**, respectively, which are switched into and out of conduction in dependence on the logic levels of the 100° and 200° bits, respectively, of the digital reference phase position signal. The photoconductive diodes **117** and **118** are selected so that sufficient current flow is available to develop a firing pulse for the controlled rectifier **111** only when both of the photoconductive diodes are illuminated by their respective lamps **121** and **122** and, thus, only when the reference phase position is between 300° and 360°.

From the foregoing it will be understood that the present invention provides a relatively simple and compact digital control system for synchronizing the operation of a line of independently driven presses for operation thereof in a continuous mode, and that the control system does not impose any direct limitations on the sizes or number of the presses that may be included within the line.

I claim as my invention:

1. A control system for automatically synchronizing a plurality of independently and cyclically driven presses, each having an electrically responsive, variable speed drive; said system comprising

a cyclically rotating reference;

first means coupled to said reference for supplying a first digital signal representative of the instantaneous phase position of said reference; and, for each of said presses,

second means coupled to the press drive for providing a second digital signal representative of the instantaneous press phase position;

third means coupled to said first and second means and responsive to said first and second signals for differentially comparing the press phase position against the reference phase position and for converting any phase difference therebetween to an analog error signal having an amplitude and polarity respectively indicative of the amount and sense of said phase difference;

fourth means coupled to said first and second means and activated in response to said first and second signals only when the press and reference phase positions are in predetermined bands at opposite sides of but adjacent to their respective phase crossover points for supplying another analog signal having an amplitude and polarity representative of 360° of rotation of whichever one of said phase positions is leading;

means coupled to said third and fourth means for summing said analog error signal and said other analog signal to supply an analog control signal normally having an amplitude and polarity respectively representative of the amount and sense of a minimum difference between the press and reference phase positions; and

means for applying said control signal to correctively energize the press drive.

2. The control system of claim **1** wherein said reference is external of said presses whereby said first digital signal cycles at a rate independent of any variations in the operating speeds of said presses, and wherein said presses comprise a press line for performing successive operations on a workpiece.

3. The control system of claim **7** wherein said first and second digital signals are based on a binary coded decimal system such that each of them comprises a plurality of bits each of which has a first and second logic level to indicate the presence and absence, respectively, of a predetermined amount of angular rotation; said third means comprises a counter-converter having first and second pluralities of oppositely poled switching devices coupled to the press drive; each of said first switching devices having an input connected to receive a respective one of the bits of said first digital signal and an output connected through a respective weighting resistor in parallel with the outputs of the other of said first switching devices whereby said first switching devices are switched into and out of conduction in dependence on the logic levels of the bits of said first digital signal to supply a first analog signal which is of predetermined polarity and representative of the reference phase position; and each of said second switching devices having an input connected to receive a respective one of the bits of said second digital signal and an output connected through a respective weighting resistor in parallel with the outputs of the other of said second switching devices whereby said second switching devices are switched into and out of conduction in dependence on the logic levels of the bits of said second digital signal to supply a second analog signal which is of opposite polarity and representative of the phase position of said press.

4. The control system of claim **3** wherein said fourth means includes first and second auxiliary circuit means connected in parallel with said first and second switching devices, respectively; said first auxiliary circuit means being responsive to the logic levels of predetermined bits of said first and second digital signals for increasing said first analog signal by an amount proportional to 360° of rotation when the press phase position is lagging and within a predetermined range of positions short of its phase crossover point while the reference phase position is within a predetermined range of positions past its phase crossover point; and said second auxiliary circuit means being responsive to the logic levels of predetermined bits of said first and second digital signals for increasing said second analog signal by an amount proportional to **360°** of rotation when the press phase position is leading and within a predetermined band of positions past its phase crossover point while the reference phase position is within a predetermined band of positions short of its phase crossover point.

5. The control system of claim **4** wherein said reference is external of said presses whereby said first digital signal cycles at a rate independent of any variations in the operating speeds of said presses, and wherein said presses comprise a press line for performing successive operations on a workpiece.

* * * * *