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(54) IMPROVEMENTS IN AND RELATING TO SERVO CONTROL APPARATUS

(71) We, RICOH COMPANY, LTD., a Japanese Body Corporate of 3-6, 1-chome Naka Magome, Ohta-ku, Tokyo, Japan, do hereby declare the invention, for which we pray that a patent may be granted us, and the method by which it is to be performed, to be particularly described in and by the following statement:-

The present invention relates to a servo control apparatus for incorporation into a facsimile transceiver, an impact printer, or a magnetic disc head drive for example.

According to the invention there is provided servo control apparatus comprising a servo motor having a shaft, sensor means arranged to produce position signals in response to rotation of the shaft, differentiating means for differentiating the position signals to produce a velocity signal, computer means for computing and generating a position error signal from the position signals and a position command signal, a reference signal generator for generating a reference signal corresponding to the amplitude of the position signals, control means for varying the magnitude of the reference signal in dependence upon the magnitude of the position error signal to produce a velocity command signal, and comparison means for comparing the velocity signal with the velocity command signal to produce a motor drive signal in dependence upon the difference, the reference signal generator means comprising an integrator for integrating the position signals and summing means for summing the integrated position signals to produce the said reference signal.

According to the invention there is further provided servo control apparatus comprising a servo motor having a shaft, means responsive to rotation of the shaft to generate two sinusoidal position signals in quadrature each having a frequency related to the rotary speed of the shaft, differentiating means for differentiating the two sinusoidal position signals and producing a dc velocity signal having an amplitude related to the shaft velocity, computer means responsive to a position command signal and one of said position signals to provide an error signal indicative of the difference between the actual position of the shaft and the desired position, means for combining said position signals to produce a dc reference signal related to the average amplitude of the position signals, means for varying the amplitude of the dc reference signal in dependence upon the magnitude of the error signal to produce a control signal and comparison means for comparing the velocity signal with the control signal and controlling the motor speed in response thereto.

Servo control apparatus embodying the invention, will now be described, by way of example, with reference to the accompanying drawings, in which:

Figure 1 is a perspective view of a servo motor and sensor assembly of the apparatus;

Figure 2 is a fragmentary section through the sensor of the assembly of Figure 1;

Figure 3 is a plan view of an occluder disc of the sensor of Figure 2;

Figure 4 is a plan view of a mask of the sensor of Figure 2;

Figure 5 is a graph illustrating position signals produced by the sensor of Figure 2;

Figure 6 is a block diagram of the servo control apparatus;

Figure 7 is a graph illustrating the generation of a velocity signal by the apparatus of Figure 6;

Figure 8 is a graph of voltage versus motor shaft position for the apparatus of Figure 6;

Figure 9 is a graph illustrating a position signal as a function of time for the apparatus of Figure 6;

Figure 10 is a graph illustrating a reference signal as a function of time for the apparatus of Figure 6;

Figure 11 is a circuit diagram of a reference signal generator of the apparatus of Figure 6; and

Figure 12 is a graph illustrating an alternative method of producing a velocity signal.

The servo control apparatus 11 shown in Figures 1 and 6 includes a servo motor 12 having a shaft 13 used to position a movable element 10 such as a type element in an impact printer, or an element in a facsimile system which needs to be positioned by a rotary shaft.

A transducer or sensor array 14 is arranged to sense the position and velocity of the shaft 13. In operation rotation of the shaft 13 causes the sensor array 14 to produce electrical position signals A′ and B′ which are in the form of quasisinusoidal signals superimposed on a positive dc level. The frequency of the position signals A′ and B′ is directly proportional to the speed of rotation of the shaft 13, as will be described in detail below. The position signals A′ and B′ are 90° out of phase relative to each other.

Amplifiers 16 and 17 respectively amplify the position signals A′ and B′ and remove the dc components to produce position signals A and B. Inverting amplifiers 18 and 19 invert the position signals A and B at an amplification factor of unity to provide inversions of the position signals A and B which are designated $\bar{A}$ and $\bar{B}$. As is shown in Figure 7, the four position signals, A, B, $\bar{A}$ and $\bar{B}$ are in quadrature, the signals B, $\bar{A}$ and $\bar{B}$ being progressively shifted in phase by 90° relative to the signal A.

The position signals $\bar{A}$, $\bar{B}$, A and B are applied to respective ones of four differentiators 21, 22, 23 and 24 which produce differentiated position signals $\dot{\bar{A}}$, $\dot{\bar{B}}$, $\dot{A}$ and $\dot{B}$, respectively. Whereas the amplitude of the position signals A, B, $\bar{A}$ and $\bar{B}$ is independent of the velocity of the motor shaft 13 and thereby the frequency of the position signals, the amplitude of the differentiated position signals $\dot{\bar{A}}$, $\dot{\bar{B}}$, $\dot{A}$ and $\dot{B}$ increases with shaft velocity and corresponding position signal frequency. More specifically,

$$\frac{d}{dt}\,[A(\sin \omega t)] = A\omega(\cos \omega t)........(1)$$

where A is amplitude, ω is frequency of oscillation and t is time. In other words, the amplitude of each differentiated position signal $\dot{\bar{A}}$, $\dot{\bar{B}}$, $\dot{A}$ and $\dot{B}$ is directly proportional to the frequency of oscillation and velocity of rotation of the motor shaft 13.

The differentiated position signals $\dot{\bar{A}}$, $\dot{\bar{B}}$, $\dot{A}$ and $\dot{B}$ are fed to a commutator 26 which commutates them to produce a velocity signal VS. The commutator 26 operates to sample the most positive portions of the differentiated position signals $\dot{\bar{A}}$, $\dot{\bar{B}}$, $\dot{A}$ and $\dot{B}$ to produce a composite signal which consists of these most positive portions. The velocity signal VS is shown in Figure 7 as being in the form of a ripple signal having an average positive dc value, this average dc value increasing in magnitude in the positive direction in proportion to the speed of the motor shaft 13 and the frequency of the position signals. The velocity signals VS is fed to a comparator 27.

The signals A, B and $\bar{B}$ are also fed to inputs of a commutator signal generator 25, which produces and feeds to the commutator 26 commutator signals D, E, F, G and H in response thereto. The commutator signals are used to commutate the positive peaks of the differentiated position signals. More specifically, the commutator signal generator 25 comprises circuitry including Schmitt triggers and gates which are not shown in detail. The signal D is produced by applying the signal A to an inverting Schmitt trigger with a trigger point of zero volts (OV). The signal E is produced by applying the signal B to an inverting Schmitt trigger having a trigger point equal to $1/\sqrt{2}$ of the peak amplitude of the signal B or shifted in phase by 45° from the sine wave peak. The signal F is produced from the signal $\bar{B}$ in the same manner as the signal E. The signal G is produced by performing a logical NAND operation on the signals D and F and the signal H is produced by performing a logical NAND operation on the signals $\bar{D}$, E and F. The speed signal VS is produced by utilizing the commutator signals D to H at their negative levels as gate signals for the differentiated position signals $\dot{\bar{A}}$, $\dot{\bar{B}}$, $\dot{A}$ and $\dot{B}$ in accordance with the following Boolean algebraic equations.

$$VS = \dot{\bar{A}}E + \dot{A}F + \dot{\bar{B}}G + \dot{B}H..........(1)$$

or

$$VS = \dot{\bar{A}}E + \dot{A}F + \dot{\bar{B}}\,\overline{DEF} + \dot{B}\,\overline{\bar{D}EF}......(2)$$

The commutator signal generator 25 also detects the zero crossings of the inverted position signal $\bar{B}$ and produces position pulses PP in response thereto. The position pulses PP are fed to a computing circuit 28 in addition to a reference signal VR which is produced by a reference signal generator 30. The reference signal VR is a dc signal of positive polarity.

The computing circuit 28 comprises a position error and direction computing unit 40 including a digital counter (not shown). A psoition command signal PCS indicating a new desired command position of the motor shaft 13 is fed into the computing circuit 28 from a position command unit 35 to the unit 40 which computes the number of steps that the shaft 13 must rotate to move from its initial position to the new position. This number of steps is set into the counter. When the motor 12 is energised the shaft 13 is driven towards the new position, and the position pulses PP are fed to the input of the counter to cause the counter to count down. When the down counter has reached zero indicating that the shaft 13 has reached the new position, the motor 12 is de-energised.

The computing circuit 28 also has a level control unit 45 including a plurality of decoders (not shown) which decode the count in the counter. The decoders control the switching of an attenuation network (not shown) which selectively attenuates the reference signal VR in accordance with the count in the corner. As illustrated in Figure 8, the attenuation factor increases as the motor shaft 13 approaches its new position, or as the count in the counter decreases. The attenuated reference signal constitutes a velocity command signal VCS which is fed from the level control unit 45 to the comparator 27. It will be appreciated that the velocity command signal VCS decreases in magnitude as the motor shaft 13 approaches the new position so that the motor shaft 13 which is initially driven at high speed is progressively slowed down as it approaches the new position. The unit 40 controls a direction switching unit 50 to select the reference signal VR or an inverted reference signal $\overline{VR}$ from an invertor 55 depending on the direction of the position error.

The comparator 27 compares the velocity command signal VCS from the computing circuit 28 with the actual velocity signal VS from the commutator 26 and produces an error signal ES in response to the difference therebetween. The error signal ES is amplified by a motor driver 29 and fed to the motor 12 to speed up or slow down the shaft 13 depending on the polarity of the error signal ES.

In summary, the sensor array 14 produces position signals which are used to produce position pulses indicating the position of the motor shaft 13, or more particularly the angular distance through which the motor shaft 13 has rotated. The position signals are differentiated and commutated to produce a velocity signal indicating the actual velocity of the motor shaft 13. The computing circuit 28 receives the position pulses and produces a velocity command signal indicating the desired velocity of the motor shaft 13. The comparator 27 compares the velocity command signal with the actual velocity signal and controls the excitation of the motor 12 so that the shaft 13 rotates at the desired speed. The velocity command signal is gradually reduced from a high initial value to zero as the motor shaft 13 approaches the desired new position.

The sensor array 14 has an occluder disc 31 (see Fig. 14) which is rotated by the motor shaft 13. The disc 31 is provided with a plurality of equi-angularly spaced light transmitting apertures 32, only one aperture 32 being labelled in the drawing for simplicity of illustration. The disc 31 also has a transparent annular portion 33. The disc 31 is advantageously in the form of a circular glass plate coated with an opaque material, and the apertures 32 are etched in the opaque material.

The array 14 also has an opaque mask 34 (see Fig. 4) provided with a first series of three apertures 36 and a second series of three apertures 37. The spacing between the apertures 36 and between the apertures 37 is the same as the spacing between the apertures 32 in the occluder disc 31.

As viewed in Figure 2 the occluder disc 31 and the mask 34 are coaxial but lie only a small distance apart. In operation the disc 31 is rotated by the motor shaft 13, while the mask 34 is held stationary. When the disc 31 is rotated to a position where the apertures 36 are aligned with some of apertures 32, none of the apertures 37 is aligned with any of the apertures 32.

The sensor array 14 has a light emitting diode (LED) 38 which acts as a light source and a monolithic array 39 of three photodiodes 41, 42 and 43 which act as photosensors. The LED 38 is located on the opposite side of the disc 31 and mask 34 to the array 39.

The photodiodes 41 and 42 (See Fig. 2) are located below the apertures 36 and 37 respectively. The photodiode 43 is located radially inwardly of the apertures 36 and 37 and is continuously illuminated by the LED 38 through the transparent annular portion 33 of the disc 31 and a transparent window 34*a* in the mask 34.

The cathodes of the photodiodes 41, 42 and 43 are grounded. The position signals A′ and B′ appear at the anodes of respective photodiodes 41 and 42. A positive dc signal C appears at the anode of the photodiode 43, which is used to stabilize the sensor array 39 against variations in temperature.

Since the photodiode 43 is continuously illuminated by the LED 38, the signal C is produced continuously. However, the position signals A′ and B′ are produced by the respective photodiodes 41 and 42 only upon rotation of the disc 31 relative to the mask 34. In the position shown in Figure 2, the apertures 32 and 36 are aligned so that the photodiode 41 is illuminated by the LED 38. This causes the photodiode 41 to conduct to a maximum extent and the instantaneous voltage of the position signal A′ reaches a maximum positive value. At the same time the apertures 32 and 37 are out of alignment so that the photodiode 42 is masked and prevented from being illuminated by the LED 38. The conduction of the photodiode 42 is therefore low and so the instantaneous value of the position signal B′ will drop to a minimum positive value, or approach ground potential. Due to the arrangement of the apertures 32, 36 and 37 the photodiodes 41 and 42 produce quasisinusoidal position signals A′ and B′ upon rotation of the motor shaft 13 and disc 31. As the apertures begin to align the corresponding photodiode begins to conduct until a maximum value of alignment and conduction occurs. As the apertures move out of alignment conduction decreases to a minimum value.

Figure 8 shows the relationship between the signals VS, VCS and ES. During the initial movement of the motor shaft 13, the shaft 13 rotates at a speed lower than the command speed. VCS is maximum but the shaft 13 must accelerate so that VS is lower than VCS. The motor 12 is energised by a positive error signal ES. In the drawing of Figure 8 the area under the curve of ES is hatched.

When the shaft 13 reaches maximum speed ES becomes zero and the shaft 13 and load 10 are allowed to coast. At a position K before the desired command or final position L, the magnitude of the signal VCS falls to cause the shaft 13 to decelerate. In this case ES becomes negative and a reverse torque is applied to the shaft 13. When the shaft 13 has decelerated sufficiently, ES drops to zero and the shaft 13 again coasts. This is repeated in several steps until the shaft 13 reaches the final position L and where it is accurately stopped.

Figure 9 shows the inverted position signal $\overline{A}$. This signal is used to stop the shaft 13 at exactly the required position. More specifically, when the shaft 13 is $\frac{1}{8}$th step before the final position, designated as L-$\frac{1}{8}$, the signal $\overline{A}$ is applied to the motor 12. This causes a reverse torque to be applied to the shaft 13 which decreases to zero just at the final position L. Also designated for reference is a position L-1 which is one step before the final position L.

Figure 10 illustrates the reference signal VR as a function of shaft position. It will be noted from a comparison of Figure 9 and 10 that the amplitude of the inverted position signal $\overline{A}$ decreases with the motor shaft speed VS. This is due to high frequency attenuation in the sensor array 14. It will be noted that the magnitude of the signal VR is minimum at the central portion of the curve which corresponds to maximum shaft speed. The amplitude of the signal $\overline{A}$ decreases in exactly the same manner. Thus, where the reference signal VR is voltage-divided to produce the velocity command signal VCS, the signal VCS is effected in the same manner as the signal VS and errors caused by fluctuation in the output of the sensor array 14 are cancelled out.

The reference signal generator 30 which produces the reference signal VR is illustrated in more detail in Figure 11. The signals A, B, $\overline{A}$ and $\overline{B}$ are applied to an inverting input of an operational amplifier 75 through respective ones of diodes 71, 72, 73 and 74 and respective ones of summing resistors 76, 77, 78 and 79. The signals A, B, $\overline{A}$ and $\overline{B}$ are applied to the anodes of the diodes 71, 72, 73, and 74. The cathodes of the diodes 71, 72, 73 and 74 are grounded through respective capacitors 86, 87, 88 and 89 which act as integrators.

In operation, the signals A, B, $\overline{A}$ and $\overline{B}$ are half wave rectified by respective ones of diodes 71, 72, 73 and 74 and integrated by respective ones of capacitors 86, 87, 88 and 89. More specifically, the signals A, B, $\overline{A}$ and $\overline{B}$ charge each capacitor 86, 87, 88 and 89 to an extent which is determined by the time constant of the capacitor in combination with its corresponding resistance to ground through the associated circuitry. This time constant is selected to be longer than one position signal period, and preferably equal to a number of periods. The optimum time constant is calculated or determined empirically so that the voltages across the capacitors 86, 87, 88 and 89 will vary in proportion to the respective amplitudes of the signals A, B, $\overline{A}$ and $\overline{B}$.

The operational amplifier 75 is connected as an inverting summing amplifier and produces at its output an inversion $\overline{VR}$ of the reference signal VR. An inverter (not shown) follows the amplifier 75 to produce the signal VR.

A feedback resistor 91 is connected between the output and inverting input of the operational amplifier 75 and an offset bias compensation resistor 92 is connected between the non-inverting input of the operational amplifier 75 and ground.

The operational amplifier 75 sums the signals across the capacitors 86, 87, 88 and 89 to produce the signal VR in the form of a dc signal which is substantially free of any ripple component or cusps. Furthermore, this summing operation minimizes the effects of variations in the amplitudes of the signals A, B, $\overline{A}$ and $\overline{B}$. In applications where low cost is more important than accuracy, only the signals A and $\overline{A}$ or B and $\overline{B}$ need be processed to produce the reference signal VR. The decrease in accuracy is not excessive and the amount of circuitry is substantially reduced.

In order to compensate for thermal drift of the diodes described heretofore, diodes 94 and 96 are connected in series with a resistor 93 between ground and a positive dc rail +V1. The junction between the diodes 94 and resistor 93 is connected through a resistor 97 to the inverting input of the operational amplifier 75. The signal at the anode of the diode 94 is summed with the signals applied through the resistors 76, 77, 78 and 79. The diodes 94 and

96 are of the same type as the other diodes described hereinbefore and are connected in such a manner that variations in voltage drop as a function of temperature across the diodes 94 and 96 are fed to the operational amplifier 75 in a sense such as to cancel the variations in voltage drop across the other diodes. In other words, the diodes 94 and 96 provide temperature compensation for the circuit.

A bias voltage VB (see Figure 10) is applied to the capacitors 86, 87, 88 and 89 from a positive dc rail +V2 through diodes 101, 102, 103 and 104 respectively. The value of the bias voltage VB is determined by the time constant of the circuitry, and is selected to correspond to the value of VR when VS is zero. The variations in amplitude of the signals A, B, $\overline{A}$ and $\overline{B}$ are in effect added to the bias voltage VB through the integrating action of the capacitors 86, 87, 88 and 89.

Thus, it will be seen that the reference signal generator 30 produces a very precise reference voltage in the form of a varying dc signal which compensates for variations in the output of the sensor array 14, due, for example, to high frequency attenuation, wow, flutter and temperature variations.

Figure 12 illustrates an alternative method of forming the velocity signal VS using only the two signals A and $\overline{A}$. A Schmitt trigger (not shown) produces a pulse M at every negative to positive transition of the signal $\overline{A}$. These correspond to the positive peaks of the signal $\overline{A}$. In a similar manner, pulses N are produced at the negative to positive transitions of the signal A which correspond to the positive peaks of the signal $\overline{A}$. These signals are integrated by a capacitor (not shown) and combined with a signal 0 to produce the velocity signal VS as illustrated.

WHAT WE CLAIM IS:-

1. Servo control apparatus comprising a servo motor having a shaft, sensor means arranged to produce position signals in response to rotation of the shaft, differentiating means for differentiating the position signals to produce a velocity signal, computer means for computing and generating a position error signal from the position signals and a position command signal, a reference signal generator for generating a reference signal corresponding to the amplitude of the position signals, control means for varying the magnitude of the reference signal in dependence upon the magnitude of the position error signal to produce a velocity command signal, and comparison means for comparing the velocity signal with the velocity command signal to produce a motor drive signal in dependence upon the difference, the reference signal generator means comprising an integrator for integrating the position signals and summing means for summing the integrated position signals to produce the said reference signal.

2. Apparatus according to claim 1, wherein the sensor means produces two position signals in the form of two phase displaced generally sinusoidal signals and wherein the integrator comprising rectifying means for rectifying the position signals.

3. Apparatus according to claim 2, wherein the integrator comprises an invertor for inverting the two position signals to produce two inverted position signals, and wherein the rectifying means comprising four diodes for half wave rectifying both the position signals and inverted position signals.

4. Apparatus according to claim 3, wherein the integrating means comprises four capacitors for integrating respective ones of the two position signals and the two inverted position signals.

5. Apparatus according to any preceding claim, wherein the summing means comprises an operational amplifier.

6. Apparatus according to claim 5, wherein the summing means further comprises resistors connected to a common input of the opertional amplifier, the position signals being applied to the said common input of the operational amplifier through a corresponding one of the resistors.

7. Apparatus according to claim 3, wherein the summing means comprises an operational amplifier having an input and four resistors connected to the input, the position signals and inverted position signals being fed to the input through respective ones of the four resistors.

8. Apparatus according to claim 4, wherein the integrating means further comprises bias means for applying a bias voltage to the four capacitors.

9. Apparatus according to claim 8, wherein the bias means comprises four diodes each connected between a dc power source and a respective one of the four capacitors.

10. Apparatus according to claim 3, wherein the integrating means further comprises temperature compensation means for the four diodes.

11. Servo control apparatus comprising a servo motor having a shaft, means responsive to rotation of the shaft to generate two sinusoidal position signals in quadrature each having a frequency related to the rotary speed of the shaft, differentiating means for differentiating the two sinusoidal position signals and producing a dc velocity signal having an amplitude related to the shaft velocity, computer means responsive to a position command signal and one of

said position signals to provide an error signal indicative of the difference between the actual position of the shaft and the desired position, means for combining said position signals to produce a dc reference signal related to the average amplitudes of the position signals, means for varying the amplitude of the dc reference signal in dependence upon the magnitude of the error signal to produce a control signal and comparison means for comparing the velocity signal with the control signal and controlling the motor speed in response thereto.

12. Apparatus according to claim 11, wherein the combining means comprises an integrator and rectifier for integrating and rectifying each of the position signals and summing means for summing the integrated position signals.

13. Servo control apparatus substantially as hereinbefore described with reference to the accompanying drawings.

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1590428 COMPLETE SPECIFICATION

5 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 1

Fig. 1

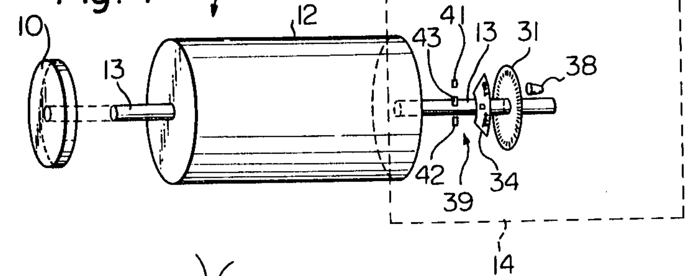


Fig. 2

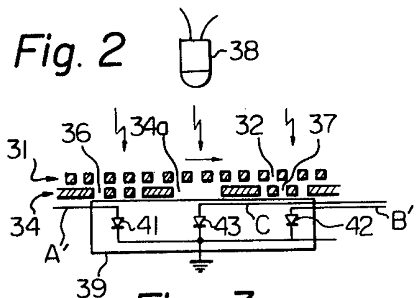


Fig. 3

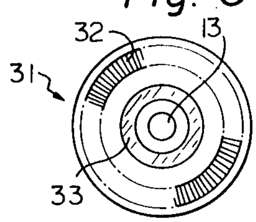


Fig. 4

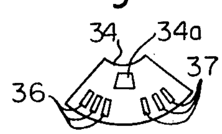
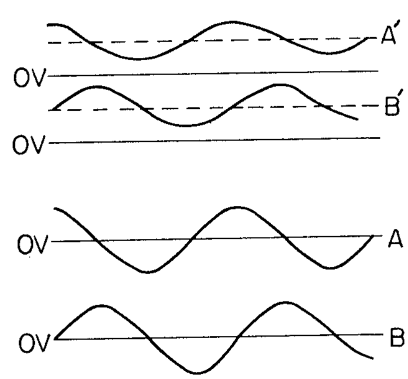


Fig. 5



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Sheet 2

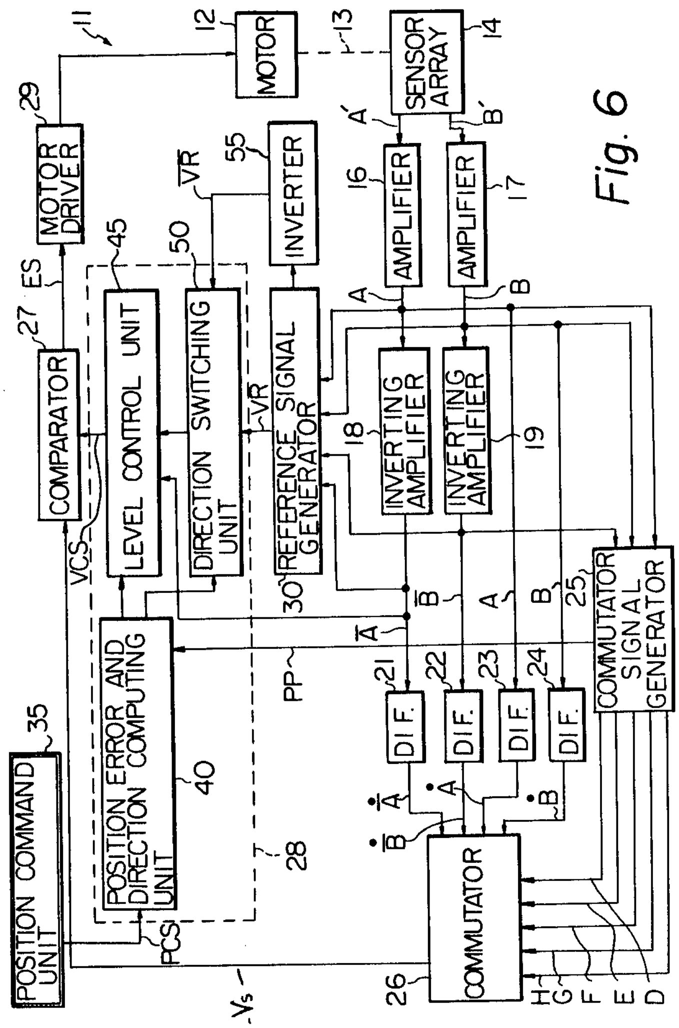

Fig. 6

Fig. 7

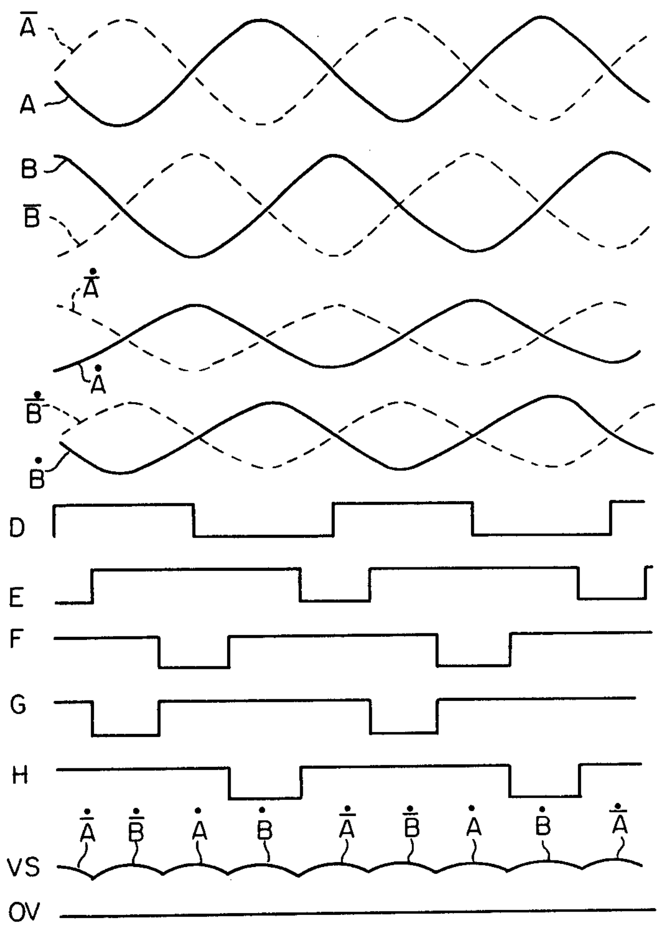

Fig. 8

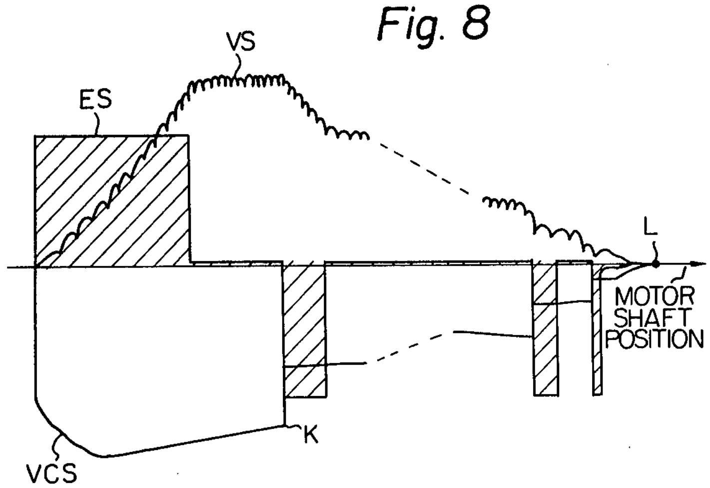

Fig. 9

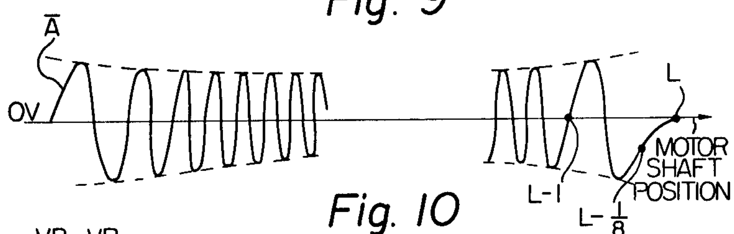

Fig. 10

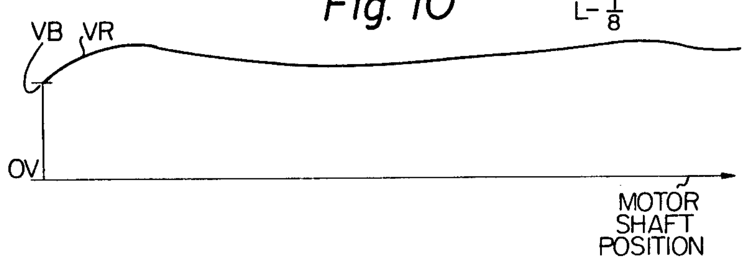

Fig. 11

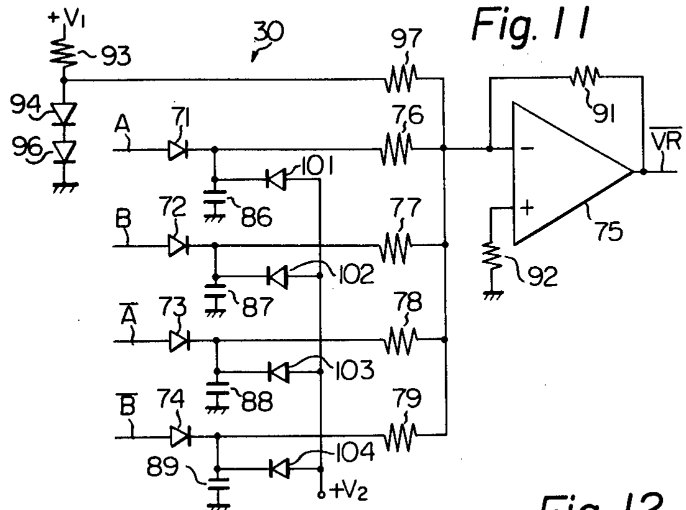
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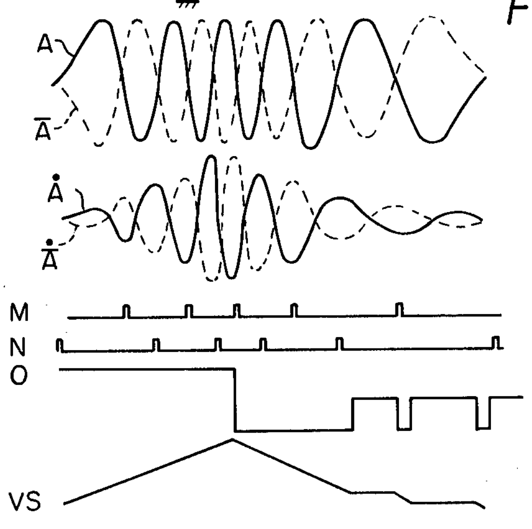
Fig. 12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