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(54) Apparatus for decontaminating nuclear steam generators.

(57) Manipulator apparatus for cleaning a nuclear steam by sweeping a spray nozzle (32) about a pivot mechanism (20, 22) inside a spherical plenum (10) of the steam generator. The nozzle directs a water-grit mixture toward the inside surface (12, 14, 16) of the plenum in order to abrasively remove contaminates from the inside surface. The apparatus uses microprocessors (147, 159) to compute appropriate control parameters in order to maintain constant tangential velocity of the nozzle in relation to the inside surface. The microprocessors also compute, in one of the three modes of operation, appropriate control parameters for maintaining a predetermined distance between the nozzle and the surface to be cleaned so as to provide adequate cleaning of the surface but no damage thereto.

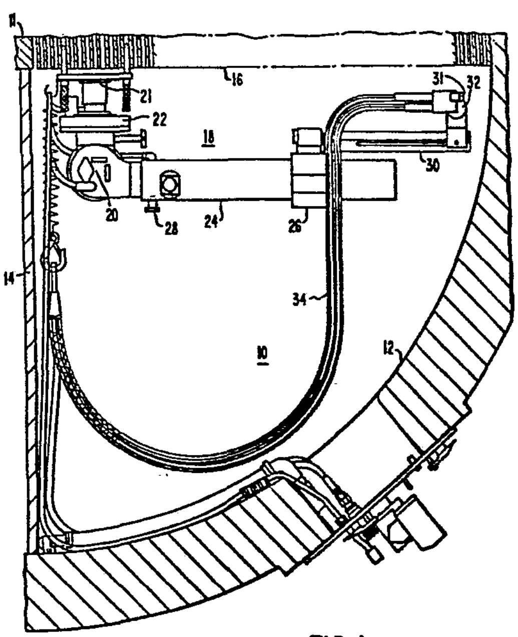

FIG. I

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APPARATUS FOR DECONTAMINATING NUCLEAR STEAM GENERATORS

This invention relates to decontamination apparatus and more particularly to apparatus for decontaminating components of nuclear power plants.

During the operation of nuclear power plants and similar apparatus, certain components become exposed to radiation and may develop a thin radioactive film on the surface of the component. From time to time, it is necessary to either inspect or repair these components of the nuclear reactor power plant. During the inspection or repair of the components, it is necessary for working personnel to enter the component or to be stationed in close proximity to the component whereby working personnel may be exposed to radiation emitted from the contaminated component. In some circumstances, the radiation field emitted from these components is such that a worker would receive the maximum permissible radiation dose in less than five minutes of working time. Such a situation means that a given worker may spend only a relatively short amount of time working on the inspection or the repair operation of the nuclear component. Having each worker spend a relatively short amount of time in the repair or inspection procedure, necessitates the use of many workers with each worker working a short time period in order to accomplish the desired procedure. While this may be an acceptable practice for minor inspections or repair procedures, this is not an acceptable practice where there is an extensive inspection or an extensive repair job to be performed. Where the procedure to be performed is a time-consuming procedure, it is likely that an unusually large number of highly trained personnel would be necessary to carry out the task. Such a situation may not only be unacceptable from a financial aspect, but may also be unacceptable from a manpower level aspect. Therefore, what is needed is a decontamination apparatus that reduces the radiation field in components of nuclear reactor power plants so that working personnel may perform operations thereon.

Apparatus has been described in copending U.S. patent application Serial No. 63,324 filed July 8, 1979 in the name of Wojcik et al. for remotely directing a water-grit mixture toward the component to be decontaminated through a nozzle, for example, suspended from the tube-sheet of a steam generator. However, the position and tangential velocity of the nozzle in relation to the surface component to be decontaminated must be controlled so that the force of the water-grit mixture is sufficient to provide adequate cleaning and decontamination but not enough to damage the surface of the component. Inadequate cleaning and decontamination may occur if the velocity of the nozzle is too high and/or if the nozzle is too far from the surface of the component to be decontaminated. Damage to the surface of the component to be decontaminated may also result if the nozzle velocity is too low or if the nozzle is too close to the surface of the component to be decontaminated.

In accordance with the teachings of the present invention, manipulator apparatus and a manipulator control system are provided for sweeping a nozzle about a pivot mechanism inside a spherical enclosure, for example, inside a primary inlet or outlet plenum of a nuclear steam generator. Means are attached to the nozzle for directing a water-grit mixture toward the inside surface of the inlet or outlet plenum in order to decontaminate the inside surface, that is, in order to abrasively remove contaminates from the inside surface.

The control system includes velocity means for governing the velocity of the nozzle so that the tangential velocity of the nozzle, that is, the velocity of the nozzle with respect to the inside surface, is maintained at a predetermined magnitude. The predetermined tangential velocity may be any velocity within a range of velocities chosen to be of a magnitude great enough so that the surfaces to be cleaned are not damaged by a prolonged exposure to the water-grit mixture but is of a magnitude low enough so that the exposure of the surfaces to be cleaned is long enough to provide adequate cleaning. Distance means are also included in the control system for adjusting the distance between the nozzle and the pivot mechanism according to certain command signals.

In one mode of operation, referred to as the bowl cleaning mode, the distance means operates so as to maintain a predetermined distance between the spherical center of the inlet or outlet plenum and the nozzle. In two other modes of operation, referred to as the divider plate cleaning mode and the tubesheet cleaning mode, the distance means operates to periodically adjust the distance between the spherical center and the nozzle by a fixed incremental distance.

In the bowl cleaning mode, the predetermined distance referred to may be any distance within a range of distances so that the distance between the surface to be cleaned and the nozzle is large enough so that the surface to be cleaned is not damaged by an exaggerated magnitude of pressure from the water-grit mixture directed by the nozzle but is a distance small enough so that the pressure exerted on the surface is great enough to adequately clean or decontaminate the surface to be cleaned. Likewise, in the tubesheet and divider plate cleaning modes the nozzle is maintained at a distance within a range of distances from the surfaces to be cleaned so that there is adequate cleaning of the surface to be cleaned but no damage thereto.

The invention will become readily apparent from the following description of an exemplary embodiment thereof when taken in conjunction with the accompanying drawings, in which:

Figure 1 shows apparatus contemplated for use in connection with the control system of the present invention;

Figures 2, 3, and 4 show broad block diagrams of the control system of the present invention in varying degrees of detail; and

Figures 5, 6, 7, and 8, show more detailed block diagrams of selected ones of the functional blocks in Figures 2 through 4.

Figure 1 shows a primary inlet plenum 10 of a nuclear steam generator (not shown) having a generally spherical shape. The inlet plenum 10 is characterized by a center 11, a curved inside (bowl) surface 12, a divider plate 14 and surface, and a tubesheet 16 and surface. As is well understood in the art, the tubesheet 16 is generally cylindrical having tube holes therein for attaching a tube bundle through which a fluid may flow. The dividing plate 14 defines the primary inlet and outlet plenums of the nuclear steam generator (not shown) of which only the primary inlet plenum 10 is shown in Figure 1.

Apparatus for cleaning the surfaces 12, 14, and 16 include a control arm 18 mounted inside the spherical enclosure 10 on a pivot mechanism 20, which pivot 20 is supported from the tubesheet 16 by a support apparatus 22. The illustrated embodiment of the control arm 18 includes a support arm 24 extending directly from the pivot mechanism 20. A nozzle support carriage 26 is slidably mounted on the support arm 24. A carriage stop 28 is mounted on the support arm 24 near the pivot mechanism 20 in order to prevent the support carriage 26 from coming too close to the pivot support mechanism 20. A nozzle extension arm 30 having a nozzle end 31 is slidably mounted on the nozzle support carriage 26. Means including a nozzle configuration 32 and flexible conduits 34 are provided mounted on the nozzle extension arm 30 for cleaning surfaces surrounding the plenum 10 by directing a water-grit mixture having a constant pressure onto the surfaces to be cleaned, i.e., surfaces 12, 14, and 16. The conduit 34 serves as a means to conduct the water-grit mixture from a source to the nozzle configuration 32.

Distances important in describing the manipulator of the present invention and its operation include the distance from the center 11 of the spherical enclosure to the point 21 of attachment of the pivot support mechanism 22, the distance from the point 21 of attachment to the center of the pivot mechanism 20, the distance from the center of the pivot mechanism 20 to the carriage 26, the distance from the carriage 26 to the nozzle end 31, and the offset distance from the nozzle end 31 to the support arm 24.

A geometrical sketch of the control apparatus of Figure 1 is shown in Figure 2 for defining important relationships. As shown in Figure 2, the following variables are defined:

a = the vertical distance from the center of the inlet plenum 10 to the center of the pivot mechanism 20;

b = the horizontal distance from the center 11 of the inlet plenum 10 to the center of the pivot mechanism 20;

c = the perpendicular distance from the center line of the control arm 18 to the nozzle end 31;

r' = the linear radius of the nozzle end 31 in relation to the pivot mechanism 20, i.e., the linear distance between the two;

r = the distance from the pivot mechanism 20 to a perpendicular line projected from the control arm 18 to the nozzle end 31;

R = the fixed distance in the bowl cleaning mode between the center 11 of the inlet plenum 10 and the nozzle end 31;

θ = the angle of horizontal movement of the control arm 18, in the case of Figure 2, going into and coming out of the paper;

ϕ = the angle of vertical movement of the control arm 18, in the case of Figure 2, in the plane of the paper;

$r'\cos\phi$ = the effective radius of the nozzle end 31.

The triangulation equations for computing the most important variables, r and $r'\cos\phi$ are:

$$r = -B + B^2 + C^2 \qquad (1)$$

where $B = a \sin \phi + b \cos\phi \sin \theta$

$$C = R^2 - a^2 - b^2 - c^2 - 2c[-a \cos\phi + b \sin \phi \sin \theta]$$

and

$$r'\cos\phi = r^2 + c^2 (\cos\phi) \qquad (2)$$

Figure 3 shows a manipulator 35 provided for controlling the speed and direction of movement of the control arm 18 about the pivot mechanism 20 via a control signal 51 and for adjusting the position of the nozzle support carriage 26 on the control arm 24 via a control signal 39 in response to initiation signals 61 and 62. As shown in Figure 3, the manipulator 35 includes a carriage feedback control within the lines at 36 for adjusting the position of the nozzle support carriage 26 and also includes a control arm feedback control within the lines at 38 for controlling the speed and direction of movement of the control arm 18 about the pivot mechanism 20. The initiation signals 61 and 62 are only for the purpose of initiating motion of the carriage 26 and the control arm 18.

Once motion is initiated by the initiation signals 61 and 62, the direction, velocity, and extent of motion is predetermined by parameters in the control arm control 38 and the carriage control 36. The carriage control means 36 and the support arm control means 38 may be suitably operated by initiation signals 61 and 62 to systematically clean or decontaminate any of the three surfaces surrounding the primary inlet plenum 10, that is, the surfaces 12, 14, and 16.

The carriage controller 36 includes a carriage position motor 40 suitably mounted on the nozzle support carriage 26 for adjusting the position of the nozzle support carriage 26 on the support arm 24 in order that the nozzle configuration 32 is not too close to nor too far from the bowl surface 12. Any adjustment by the motor 40 causing the nozzle configuration 32 to be too close to the bowl surface 12 may damage the surface 12 by exposing the bowl surface 12 to an extreme pressure from the water-grit mixture. Conversely, any adjustment by the motor 40 causing the nozzle configuration to be too far from the bowl surface 12 may not expose the surface 12 to sufficient pressure from the water-grit mixture to adequately clean the surface 12. A position control means 41 is responsive to feedback signal 42 from the motor 40 and to the initiation signal 61 for providing a control signal 43 for controlling the speed and direction of movement of the motor 40.

The support arm feedback control means 38 includes a motor means 50 suitably mounted relative to the pivot mechanism 20 for providing an output signal 51 for controlling the speed and direction of pivotal movement of the control arm 18 about the pivot mechanism 20. In particular, the pivotal movement of the control arm 18 occurs in the horizontal plane as measured by an angle θ and in the vertical plane as measured by an angle ϕ. Position control means 52 and velocity control means 53 are responsive to a feedback signal 54 from the output of the motor 50 and to the initiation signal 62 for providing position control signals 55 and velocity control signal 56, respectively, in order to control the speed and direction of movement of the motor means 50. The support arm velocity control means 53 is significant in that it controls the angular velocity of the control arm 18 to be within a range of angular velocities neither too fast nor too slow. Any angular velocity too slow may cause damage to the surfaces to be cleaned, i.e., surfaces 12, 14 and 16, by exposing the surfaces to an extreme pressure from the water-grit mixture. Contrariwise, any angular velocity too fast may not expose the surface 12 to sufficient pressure from the water-grit mixture to adequately clean the surface 12.

Initiation means 60 provides the initiation signals 61 and 62, generally simultaneously, and may include means for manually providing the initiation signals 61 and 62, for example, a control console or panel having controls manually adjusted by an operator. The initiation means 60 may alternatively or additionally include means for automatically providing the initiation signals 61 and 62, for example, a microprocessor having programmed therein instructions for providing signals 61 and 62 in a proper sequence.

The initiation means 60 is operative whether manually or automatically to provide at least three possible modes of cleaning operation, one for each of the surfaces to be cleaned, i.e., the divider plate surface 14, the bowl surface 12, and the tubesheet surface 16. In a first mode of operation referred to as the bowl-cleaning mode, the nozzle configuration 32 is swept along horizontal and vertical paths for cleaning the bowl surface 12. In a second mode of operation, referred to as the tubesheet cleaning mode, the control arm 18 is positioned horizontally and the nozzle configuration 32 is pointed upward in order to direct the water-grit mixture onto the tubesheet surface 16. The control arm 18 sweeps about the pivot mechanism 20 in a horizontal direction and the support carriage 26 incrementally adjusts along the control arm 18 in order to completely expose the tube sheet surface 16 to the water-grit mixture. In a third mode of operation, referred to as the divider plate cleaning mode, the control arm 18 is fixed in position at the end of a horizontal angular path such that the nozzle configuration

32 is close to and pointing in the direction of the divider plate surface 14. In order to completely expose the divider plate surface 14 to the water-grit mixture, the control arm 18 is swept through a vertical angular path and the support carriage 26 is incrementally adjusted along the total length of the support arm 18. Means may be included in the initiation means 60 for automatically or manually selecting one of the three modes, i.e., either the divider plate cleaning mode, the tubesheet cleaning mode, or the bowl-cleaning mode. Manually operated switches may be provided so as to allow manual control by an operator of the sequence of movement of the control arm 18 and the support carriage 26, or, automatic sequencing may be performed by a microprocessor having therein appropriate instructions.

In Figure 4, the carriage feedback control 36 of Figure 3 includes, more specifically, a proportional feedback control 68, a function generator 69 and a set point module 70. The proportional feedback control 68 provides the control signal 39 to the control arm 18 and an output signal 74 to the function generator 69 in response to an output signal 75 from the set point module 70. Also in Figure 4, the support arm feedback control 38 of Figure 2 includes proportional feedback controls 77 and 78, the function generator 69, and the set point module 70. The proportional feedback control 77 is responsive to the signal 75 for providing a horizontal position signal 82 to the function generator 69 and a horizontal (θ axis) control signal 80 to the control arm 18 for controlling the speed of movement in the control arm 18 in a horizontal direction. The proportional feedback control 78 provides in response to the signal 75 a vertical position signal 84 to the function generator 69 and a vertical (ϕ axis) control signal 86 to the control arm 18 for controlling the speed of movement of the control arm 18 in a vertical direction. The function generator 69 provides an output signal 88 to the set point module 70 proportional to the computed commanded position of the nozzle end 31.

Figure 5 shows the manipulator 35 of Figure 3 in still greater detail. In Figure 5, the motor means 50 of Figure 3 includes horizontal and vertical pivot electric motors 91 and 92, respectively. Means 93 and 94 are included for sensing the horizontal angular velocity and the horizontal angular position, respectively, of the horizontal pivot motor 91. Means 95 and 96 are included for sensing the vertical angular (ϕ) velocity and the vertical angular position (ϕ), respectively, of the vertical pivot motor 92. The angular velocity sensing means 93 can be, for example, means for measuring the back emf of the horizontal pivot motor 91 and the angular velocity sensing means 95 can be, for example, a tachometer. Means including a potentiometer 97 are included for sensing the linear position of the carriage 26 on the support arm 24 as determined by the carriage position motor 40. The linear velocity of the carriage position motor 40 is not controlled externally.

Referring to Figure 6, the movement and speed of movement of the horizontal pivot motor 91 are controlled by a horizontal position (θ) control signal 101 from a horizontal proportional controller module 103 in response to feedback from horizontal sensing means 93 and 94 and from a horizontal position (θ) sweep or command signal 105 and an angular velocity command signal 107. The horizontal controller module 103 in conjunction with the horizontal pivot motor 91 governs the movement of the control arm 18 in the horizontal (θ) direction essentially in response to the horizontal command signals, that is, horizontal velocity signal 107 and horizontal position (θ) signal 105. The horizontal angular velocity feedback signal 93 and the horizontal angular position (θ) feedback signal 82 provide an indication of the actual horizontal angular velocity and actual horizontal angular position θ of the horizontal pivot motor 91. The controller module 103 is operative to adjust the horizontal angular velocity and horizontal angular position (θ) of the horizontal pivot motor 91 in order to cause the appropriate horizontal feedback and command signals to match each other.

The horizontal position (θ) signal 105 can be, for example, a step function signal in the bowl and tube sheet cleaning modes having one state indicative of the command that the horizontal angular position (θ) of the horizontal pivot motor 91 be such that $\theta = 0°$ and having another state indicative of the command that the horizontal angular position (θ) of the horizontal pivot motor 91 be such that $\theta = 180°$. Means for providing the horizontal angular position (θ) signal 105 may include, for example, means 161 for providing a step function in response to a horizontal initiation signal 169 from the initiation means 60.

The vertical movement and the angular velocity of the vertical movement of the vertical pivot motor 92 are controlled by a vertical position control signal 111 of a vertical proportional controller module 113 in response to feedback from vertical sensing means 95 and 96 and from a vertical position sweep signal 115 and the angular velocity command signal 107. The vertical controller module 113 in conjunction with the vertical pivot motor 92 governs the movement of the control arm 18 in the vertical (ϕ) direction essentially in response to the vertical command signals, that is, angular velocity command signal 107 and vertical (ϕ) position signal 115. The vertical angular velocity feedback signal 90 from the tachometer 95 and the vertical angular position (ϕ) feedback signal 84 from the potentiometer 96 provide an indication of the actual vertical angular velocity and actual vertical angular position (ϕ) of the vertical pivot motor 92. The controller module 113 is operative to adjust the vertical angular velocity and the vertical angular position of the vertical pivot motor 92 in order to cause the appropriate vertical feedback and command signals to match each other.

The vertical position signal (ϕ) 115 can be, for example, a step function signal in the divider plate cleaning mode having one state indicative of the command that the vertical angular position (ϕ) of the vertical pivot motor 92 be such that $\phi = 0°$ and having another state indicative of the command that the vertical angular position (ϕ) of the vertical pivot motor 92 be such that $\phi = 180°$. Alternatively, the vertical position (ϕ) signal 115 can be, for example, a staircase signal in the bowl-cleaning mode having a plurality of discrete increments in magnitude such that the vertical angular position (ϕ) of the vertical pivot motor 92 sweeps through a 90° path from $\phi = 0°$ to $\phi = 90°$ in fixed predetermined angular increments. Means for providing the vertical angular position signal 115 may include, for example, means 163 for providing a step function and for providing a staircase function in response to a vertical movement initiation signal 168 from the intitiation means 60.

Referring to Figure 7, the linear movement of the carriage position motor 40 is controlled by a carriage position control signal 121 from a proportional controller module 123 in response to feedback from the carriage position sensing means 97 and inputs from a carriage command signal 125. The carriage controller module 123 in conjunction with the carriage position motor 40 governs the movement of the support carriage 26 on the support arm 24 essentially in response to the carriage command signal 125. The carriage position feedback signal 74 from the potentiometer 97 provides an indication of the actual position of the carriage motor 40. The controller module 123 is operative to adjust the position of the carriage motor 40 in order to cause the carriage feedback and command signals to match each other.

A radius computation bus signal 137 is provided by a relay means 133 in response to a relay control signal 135. The radius computation bus signal 137 will be the same as one of carriage radius computation signals 173 or 174 depending upon the position of the relay means 133 determined by the relay control signal 135. The carriage radius computation signal 174 used in the blowl-cleaning mode is proportional to the distance between the center 11 of the primary inlet plenum 10 and the nozzle configuration 32. Carriage radius computation means 143 are included for providing the carriage radius computation signal 174 and may include a potentiometer appropriately adjusted to provide the proper carriage radius computation signal 174.

The carriage radius computation signal 173 used in the tubesheet and divider plate cleaning modes is proportional to a fixed predetermined incremental distance which the nozzle support carriage 23 is desired to be moved. Referring to Figure 8, the carriage radius computation means 141 includes increment means 184 for providing a predetermined distance of linear radius adjustment for the support carriage 26. The incremental adjustment is performed essentially by a ramp generator 186. Means 187 are included for adding to or subtracting from the output of the ramp generator 186 the fixed increment derived from the instruction means 184, in response to a feedback signal 188 from the output of the ramp generator 186. The output of the means 187 referred to as an "update" signal is always the same as that of the ramp generator 186 plus or minus the fixed increment provided by the increment means 184. In fact, the output of the means 187 is the current linear radius or position of the support carriage 26 on the control arm 18 plus or minus the fixed increment. A track/store means 189 operates the ramp generator in response to a signal from a logic means 190.

In operation of the instruction means 141, a linear movement initiation signal 170 from the initiation means 60 causes the logic means 190 to provide an increment initiation signal to the track/store module 189 thereby causing the track/store module 189 to "hold" the "update" signal at its input--the "update" signal being the output of the means 187. The "update" signal is also provided as input to the ramp generator 186. The ramp generator 186 operates to adjust "increase or decrease" its output so that its output, that is signal 188, matches the output of the track/store module 189.

The ramp generator 186 provides a signal to logic means 190 for removing the increment initiation signal in response to the matching of the output signals of the ramp generator 186 and the track/store module 189. The removing of the increment initiation signal from the input of the track/store module 189 causes the track/store module 189 to "track-up" or "track-down" to the output of the means 187, that is to the output of the ramp generator 186 plus or minus the fixed increment from the increment means 184. Means 191 are included for causing the input of the ramp generator 186 to float, that is to cause the ramp generator input to be disconnected from the track/store output, in response to the removing of the increment initiation signal.

A part 147 of a microprocessor provides the carriage command signal 125. In the bowl-cleaning mode, the relay means 133 is positioned in response to the relay control signal 135 such that the carriage radius computation signal 174 is coupled to the microprocessor 147 via the radius computation bus signal 137. In this mode, the microprocessor 147 provides the carriage command signal 125 in response to the position feedback signals 82 and 84 and the radius computation bus signal 137 in order to adjust the position of the support carriage 26 such that the nozzle 32 is maintained at the distance R from the center 11 of the primary inlet plenum 10 of Figure 1. The microprocessor 147 accepts as inputs the position feedback signals 82 and 84 and the radius computation bus signal 137 and performs the triangulation computation shown in equation (1).

In the tube-shaped and divider plate cleaning modes, the relay means 133 is positioned in response to the relay control signal 135 such that the carriage radius computation signal 173 is coupled to the microprocessor 147 via the radius computation bus signal 137. In these two modes of operation, the position feedback signals 82 and 84 are essentially unused. The carriage command signal 125 is effective to cause the support carriage 26 to move incrementally along the support arm 18 in response to the carriage radius computation signal 173.

The angular velocity command signal 107 is provided as an output by a divider means 151. A potentiometer means 176 provides a tangential velocity signal 155 proportional to a predetermined tangential velocity of the nozzle 32. As discussed hereinbefore, the predetermined tangential velocity provided by the potentiometer means 176 must be within a range of tangential velocities such that the nozzle configuration 32 moves in relation to the surface to be cleaned at a speed fast enough so that the surface to be cleaned is not damaged, but at a speed slow enough so that the surface can be adequately cleaned by the water-grit mixture directed thereon through the nozzle 32. A microprocessor 159 provides an effective radius signal 157 as an input to the divider means 151. The divider means 151 is operative to form a quotient having the effective radius signal 157 as a divisor and having the tangential velocity signal 155 as a dividend. The angular velocity command signal 107 is proportional to the quotient formed in the dividing means 151.

In the bowl-cleaning mode, the microprocessor 159 accepts as inputs vertical position feedback signal 74 and carriage position feedback signal 84. The effective radius in this mode is determined as a function of the position feedback signals 74 and 84 according to the equation (2). In the tubesheet and divider plate cleaning modes, the vertical position feedback signal 74 is essentially unused and the effective radius signal 157 is essentially the same as the carriage position feedback signal 84. In the bowl cleaning mode, vertical angular movement of the control arm 18 is suspended and the motor 91 sweeps the control arm 18 in a horizontal direction in response to the horizontal sweep signal 168. In the process of the horizontal sweep, the control arm 18 covers an angular path measured by th angle θ of Figure 2, where θ can range from 0° to 180°. At the end of the horizontal path, that is where θ = 0° or where θ = 180°, vertical movement is enabled and horizontal movement discontinues. The control arm 18 is then swept vertically along an incremental angular vertical path measured by the angle ϕ of Figure 2. In this mode of operation, the angular coverage of the vertical path is, for example, on the order of ϕ =2°. After this incremental vertical sweep, vertical movement is suspended and the control arm 18 is caused to sweep horizontally in the opposite direction. The incremental vertical sweep occurs at the end of each horizontal path until the total angular coverage by the multiple incremental vertical sweeps equals 90°. Throughout the operation of the control arm in the bowl-cleaning mode, the nozzle configuration 32 of Figure 1 is caused to remain a predetermined distance from the center 11 of the spherical enclosure 10. This is performed by the proportional controller module 123 in response to the position control signal 125 and feedback from the linear position signal 74. The signal 174 is proportional to the predetermined distance R of Figure 1 which is provided by the instruction means 143. Relay means 133 in response to the signal 135 operates such that the signal 137 is the same as the signal 174. The horizontal angular velocity of the motor 91 and the control arm 18 is adjusted such that the tangential velocity of the nozzle configuration 32 with respect to the bowl surface 12 of the primary inlet plenum 10 is maintained at a predetermined tangential velocity V_T derived from potentiometer means 176. The proper angular velocity to achieve the predetermined tangential velocity is performed by the dividing means 151 in response to the tangential velocity signal 155 and the effective radius signal 157. The angular velocity of the incremental vertical sweep occurring at the end of each horizontal path is adjusted in a similar manner to achieve the predetermined tangential velocity at the nozzle configuration 32 with respect to the bowl surface 12.

In the tubesheet cleaning mode, the vertical position of the control arm 18 is such that the angle ϕ is $\phi = 0$ and vertical movement is suspended. The control arm 18 sweeps about the pivot mechanism 20 in a horizontal direction along a path such that the angle θ ranges from 0 to 180°. The nozzle configuration 32 is pointed toward the tubesheet surface 16. The horizontal angular velocity of the control arm 18 is adjusted in the same manner discussed above such that the nozzle configuration 32 is maintained at the predetermined tangential velocity with respect to the tubesheet 16. At the end of each horizontal sweep path, that is where $\theta = 0°$ or $\theta = 180°$, the support carriage 26 is caused to move incrementally on the order of a distance of 2 inches. The incremental linear movement of the support carriage 26 is effected by the signal 173 from the instruction means 141. In the second mode of operation, the relay means 133 operates in response to the signal 135 such that the signals 137 and 173 are the same.

In the divider plate cleaning mode, the horizontal position of the control arm 18 is fixed such that the angle $\theta = 180°$ or such that the angle $\theta = 0°$ and horizontal movement is suspended. The control arm 18 sweeps through a vertical angular path such that the angle ϕ ranges from 0° to 90°. At the end of each vertical sweep path, that is where the angle ϕ is 0° or where the angle ϕ is 90°, the support carriage 26 moves incrementally along the support arm 18 a distance on the order of 2 inches such that the total of the incremental linear movements of the carriage 26 causes it to move from end of the support cathode arm 18 to the other as a result of the incremental movements at the end of each vertical sweep path. The linear incremental movement of the support carriage 26 is performed in the same way as discussed above with respect to the second mode of operation.

Figure 6 shows a block diagram of a preferred embodiment of the proportional controllers 103 and 113 of Figure 5. For purposes of simplicity, only the proportional controller 103 is described in Figure 6. The controller 103 includes operational amplifiers 172 and 173 having feedback signals 82 and 93 coupled to respective inverting inputs. A programmable limit circuit 174 is coupled between the amplifiers 172 and 173 and includes as an input the velocity set point signal 107. The limit circuit 174 may be, for example, a circuit of the type included in Action Pack 4300-112 manufactured by the Action Instrument Co. The position set point signal 105 is coupled to the non-inverting input of the amplifier 172.

Figure 7 shows a block diagram of a preferred embodiment of the proportional controller 123. The proportional controller 123 is similar in design to the controllers 103 and 113 as shown in Figure 6 except that there is no velocity feedback signal. The motor 40 is free to move at its inherent speed, however fast or slow that speed is. The proportional controller 123 includes essentially an operational amplifier 181 having as inputs position feedback signal 74 coupled to the inverting input and position set point signal 125 coupled to the non-inverting input.

The computation means 147 and 159 can be, for example, a circuit 194 as shown in Figure 9 including an appropriately programmed microprocessor, for example, an INTEL 8748 or 8741 having associated multiplexers (MUX) and A/D and D/A converters for providing outputs 125 and 157 in response to inputs 82, 84, and 137, and inputs 74 and 84, respectively.

What we claim is:

1. Apparatus for decontaminating a nuclear steam generator by directing a cleaning mixture onto the surfaces (12, 14, 16) in a plenum (10) of the steam generator, said plenum (10) being surrounded by a divider plate surface (14), a tubesheet surface (16), and a bowl surface (12), said plenum having a spherical center (11) with respect to said bowl surface (12), said apparatus comprising: a pivot mechanism (20) fixed in position a first predetermined distance from said spherical center (11); nozzle means (32) from which said cleaning mixture is directed onto said bowl, dividing plate, or tubesheet surface; motion means (18) for angularly moving said nozzle means (32) about said pivot mechanism (20); adjusting means (26, 30) for adjusting the linear radius of said nozzle means with respect to said pivot mechanism (20), characterized in that the apparatus includes control means (35) operable on said motion means (18) and said adjusting means (26, 30) to move said nozzle means (32) about said pivot mechanism (20) at a predetermined tangential velocity while maintaining said nozzle means (32) at a distance from the surface to be cleaned so as to provide adequate cleaning of the surface but no damage thereto.

2. Apparatus according to Claim 1 characterized in that said nozzle means (32) includes: a control arm (18) having a pivot end, said pivot end having freedom of movement in vertical and horizontal directions; a nozzle support carriage (30) slidably mounted on said control arm (18); a nozzle configuration (32) slidably mounted on said

nozzle support carriage (30) for directing said cleaning mixture toward the surfaces to be cleaned; and flexible hosing (34) attached to said nozzle configuration (32) for providing a conduit for said cleaning mixture to reach said nozzle configuration (32).

3. Apparatus according to Claim 2 characterized in that said control means (35) includes: potentiometer means (176) for providing a first signal (155) proportional to a predetermined tangential velocity; means (97) for determining the actual linear radius of said nozzle configuration; first position feedback means (52) for determining an angular position of said nozzle configuration (32); means (159) for providing a second signal (157) proportional to the effective radius of said nozzle configuration (32) as a function of said actual linear radius (74) and of said angular position (84); means (151) responsive to said first and second signals for providing a third signal (107) proportional to an instructed angular velocity of said control arm (18) varying so as to maintain said predetermined tangential velocity of said nozzle configuration (32) in relation to said bowl surface (12); and first velocity feedback means (95) for providing a fourth signal (90) proportional to the actual angular velocity of said control arm (18); said motion means including first electric motor means (50) for angularly sweeping said control arm (18) about said pivot mechanism (20) at said instructed angular velocity, said control means (35) further including first feedback control means (38) including first proportional controller means (103, 113) responsive to said third and fourth signals for controlling the movement of and the angular velocity of said electric motor means (50); means (147) for providing a fifth signal (125) proportional to an instructed linear radius of said nozzle configuration; and means (97) for providing a sixth signal (74) proportional to the actual linear radius of said nozzle configuration (32).

4. Apparatus according to Claim 3 characterized in that said adjusting means includes: second electric

motor means (40) for adjusting the linear radius of said nozzle configuration (32), said control means further including a second feedback control means (41) including second proportional controller means (123) responsive to said fifth signal (125) and said actual linear radius (74) for controlling the movement of said second electric motor means (40).

5. Apparatus according to Claim 4 characterized in that said means (147) for providing a fifth signal comprises a microprocessor which operates to maintain a predetermined distance between said spherical center (11) and said nozzle configuration (32).

6. Apparatus according to Claim 5 characterized in that said first electric motor means (50) includes: a first electric motor (91) for sweeping said control arm in a horizontal direction, and a second electric motor (92) for sweeping said control arm in a vertical direction; and said first proportional controller means includes: a first feedback controller (103) coupled to said first electric motor, first potentiometer means (94) coupled to said first electric motor (91), a second feedback controller (113) coupled to said second electric motor; a second potentiometer means coupled to said second electric motor (92); means coupled to said first electric motor (91) for sensing the back emf of said first electric motor, and tachometer means (95) coupled to said second electric motor (92); and wherein said second electric motor means includes: a third electric motor (40) for adjusting the linear radius of said nozzle configuration (32); and wherein said second proportional controller means (123) includes: a third feedback controller coupled to said third electric motor (40); and third potentiometer means (97) coupled to said third electric motor (40).

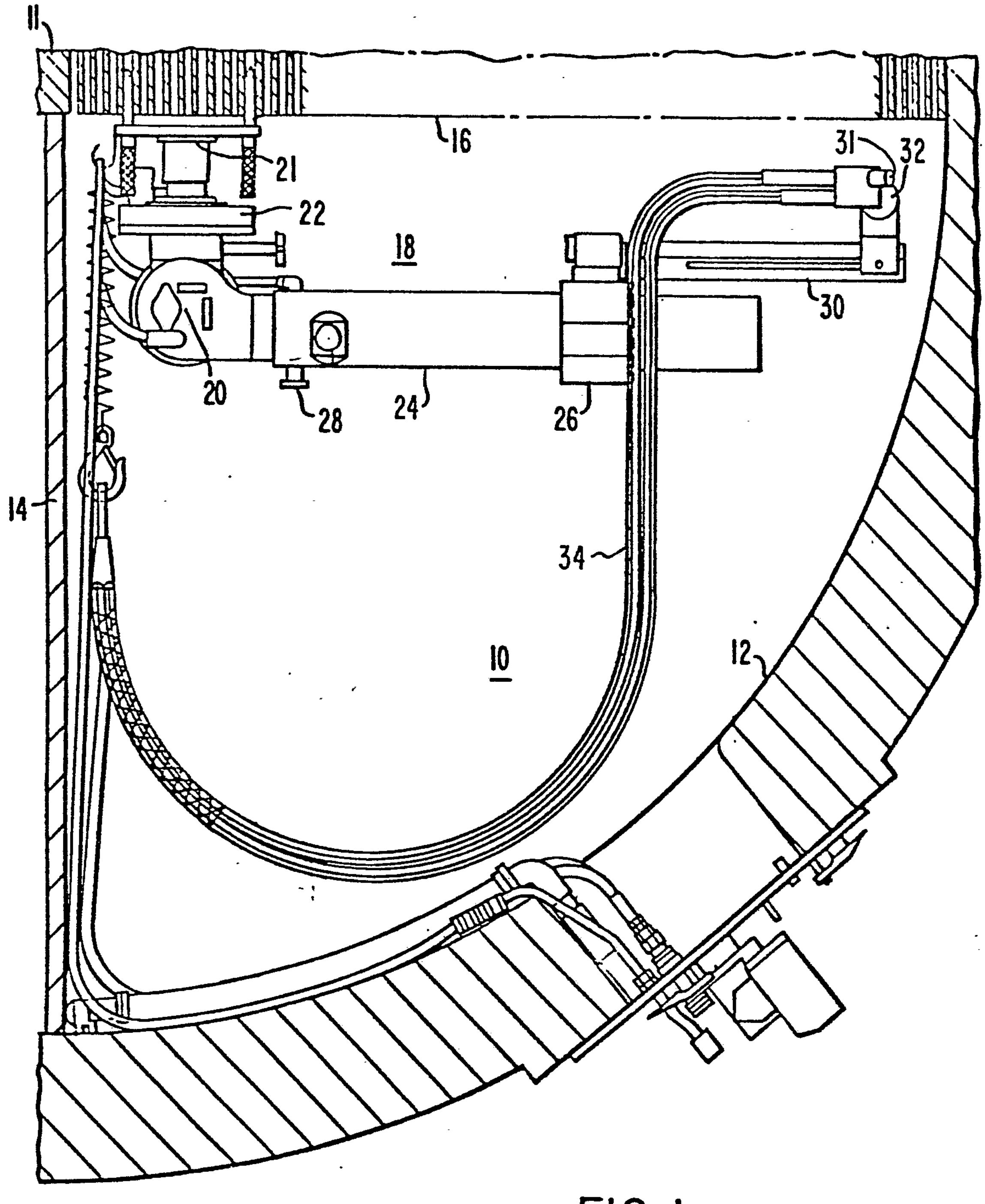

FIG. 1

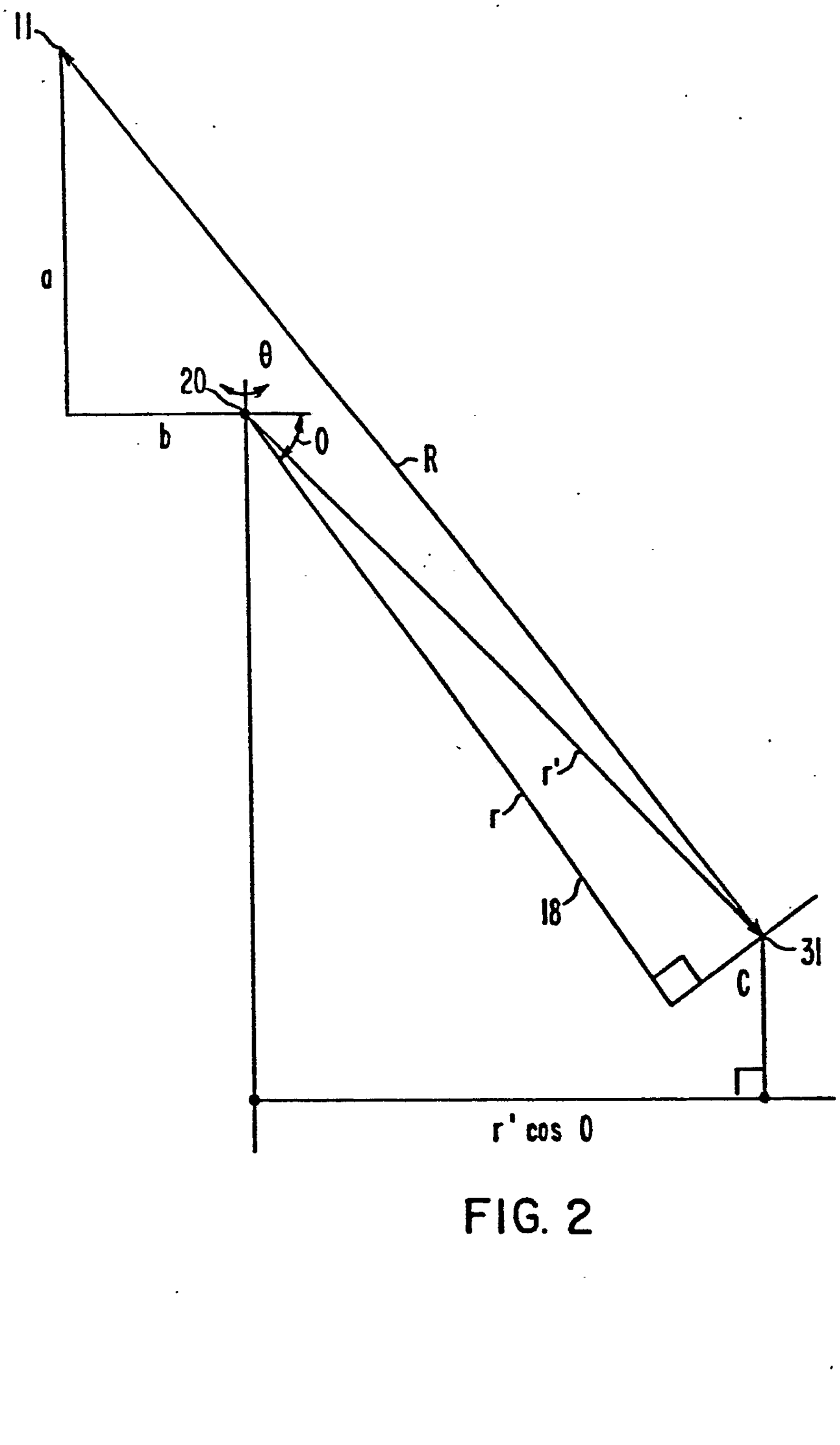

FIG. 2

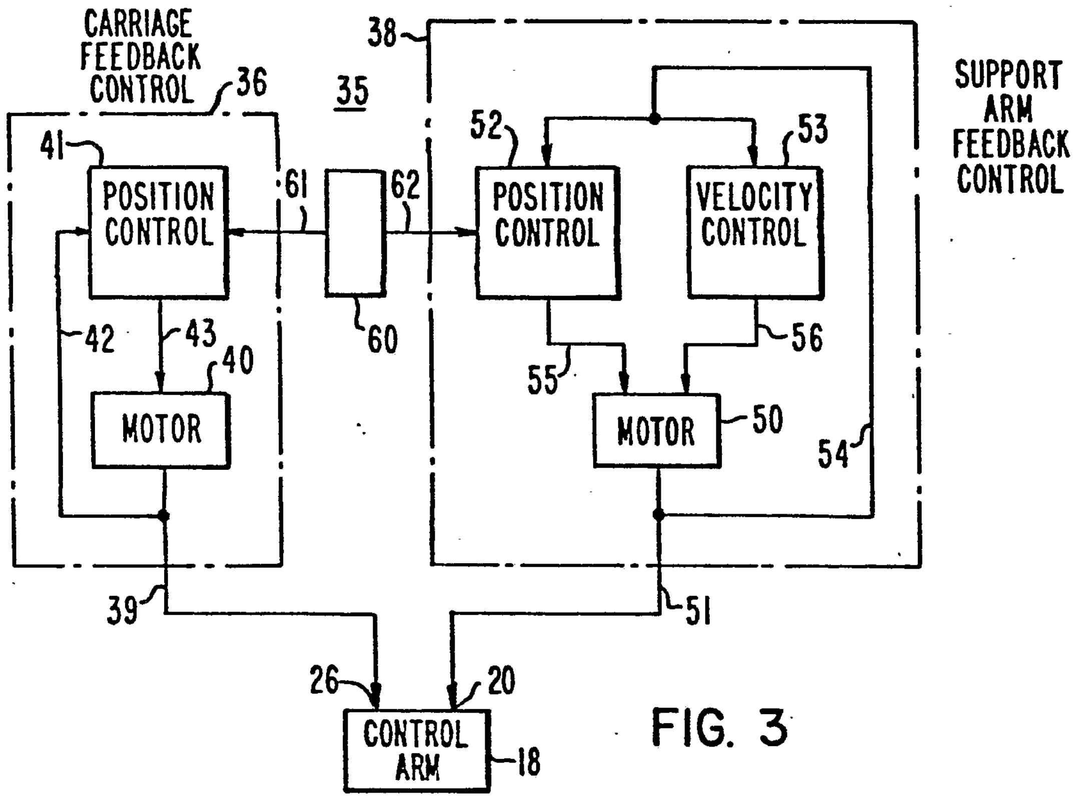
CARRIAGE FEEDBACK CONTROL
36
35
38
SUPPORT ARM FEEDBACK CONTROL
41
POSITION CONTROL
61
62
52
POSITION CONTROL
53
VELOCITY CONTROL
42
43
40
MOTOR
60
55
56
MOTOR
50
54
39
51
26
20
CONTROL ARM
18

FIG. 3

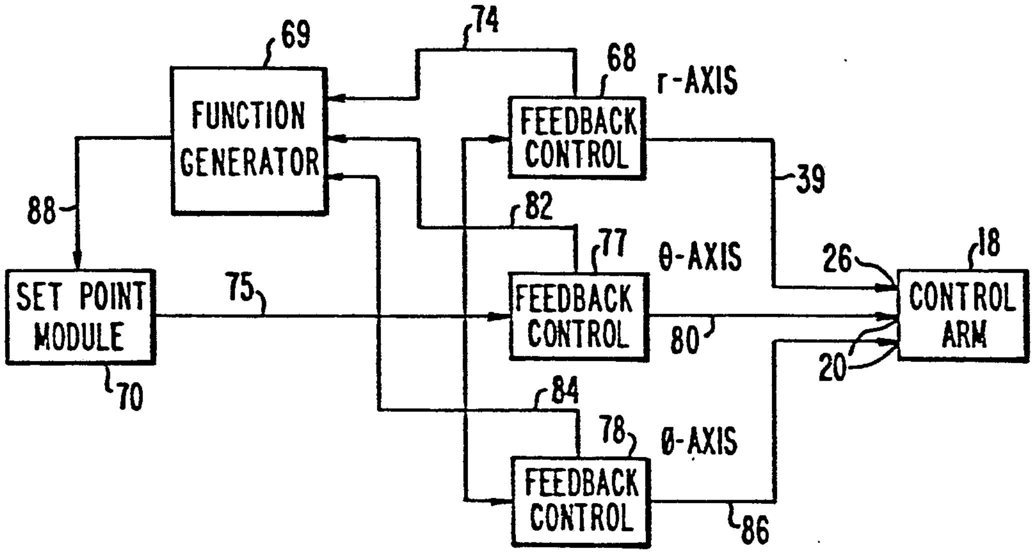
69
FUNCTION GENERATOR
74
68
r-AXIS
FEEDBACK CONTROL
39
88
82
77
θ-AXIS
26
18
SET POINT MODULE
75
FEEDBACK CONTROL
80
CONTROL ARM
70
20
84
78
Ø-AXIS
FEEDBACK CONTROL
86

FIG. 4

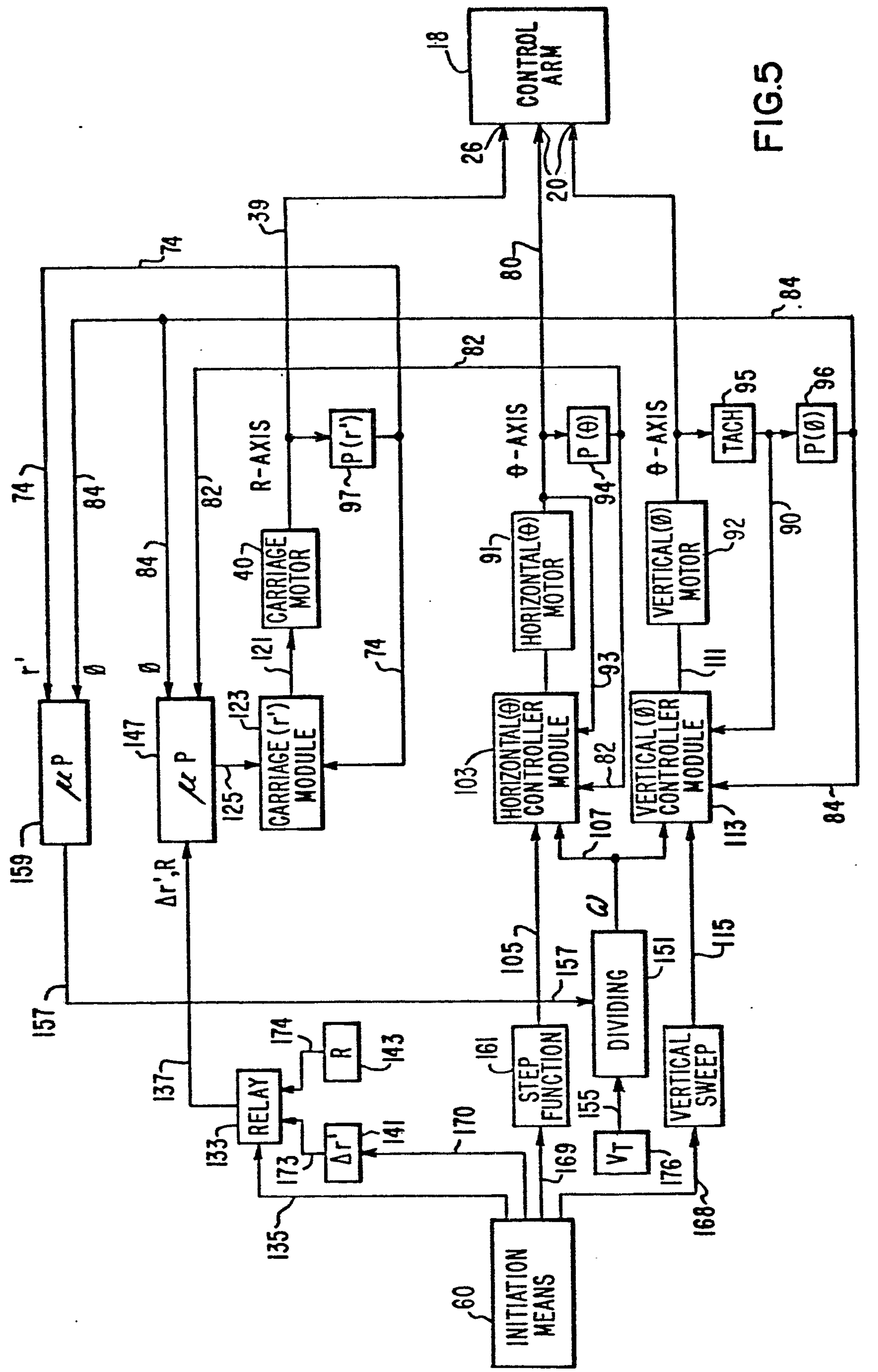
CONTROL ARM
INITIATION MEANS
RELAY
R
Δr'
STEP FUNCTION
DIVIDING
V_T
VERTICAL SWEEP
μP
μP
CARRIAGE (r') MODULE
HORIZONTAL(θ) CONTROLLER MODULE
VERTICAL(Ø) CONTROLLER MODULE
CARRIAGE MOTOR
HORIZONTAL(θ) MOTOR
VERTICAL(Ø) MOTOR
R-AXIS
θ-AXIS
Ø-AXIS
P(r')
P(θ)
TACH
P(Ø)
Δr',R
ω

FIG.5

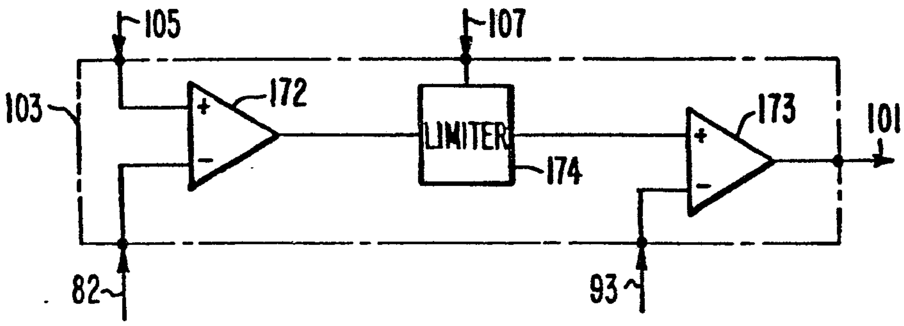

FIG. 6

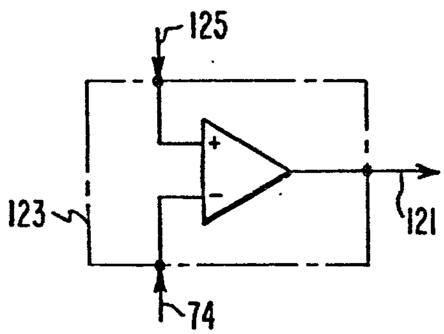

FIG. 7

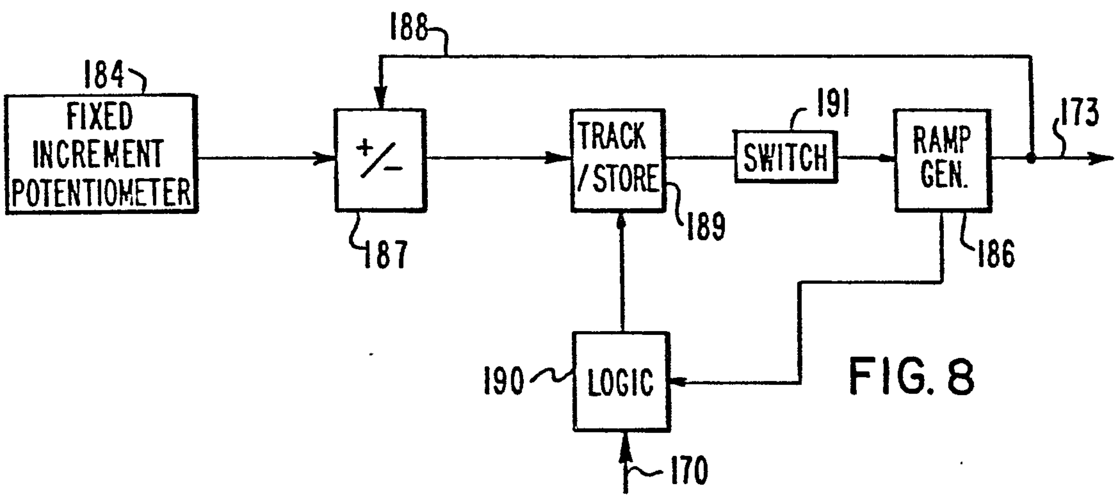

FIG. 8

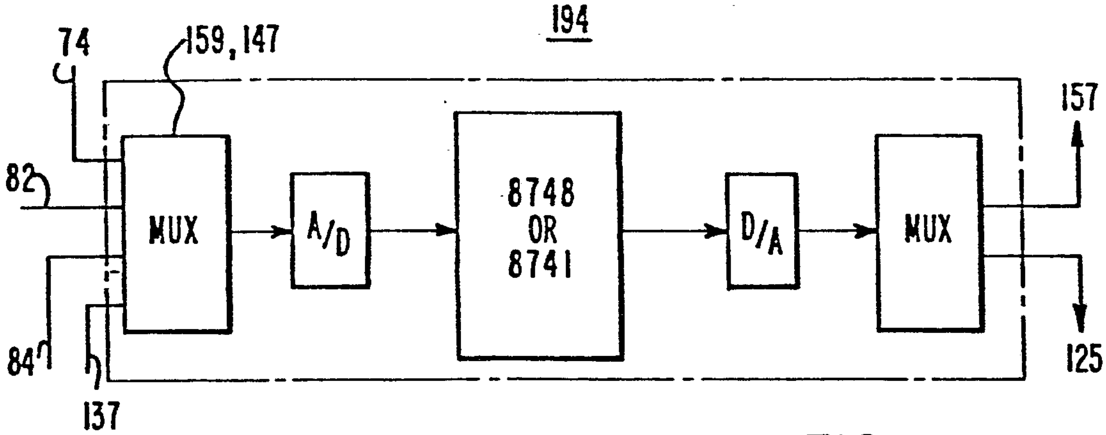

FIG. 9