July 13, 1965 J. KUNKEL 3,195,111
MECHANICAL STORAGE APPARATUS FOR CONTROLLING
PERIODIC PROCESSES
Filed May 22, 1962 4 Sheets-Sheet 1

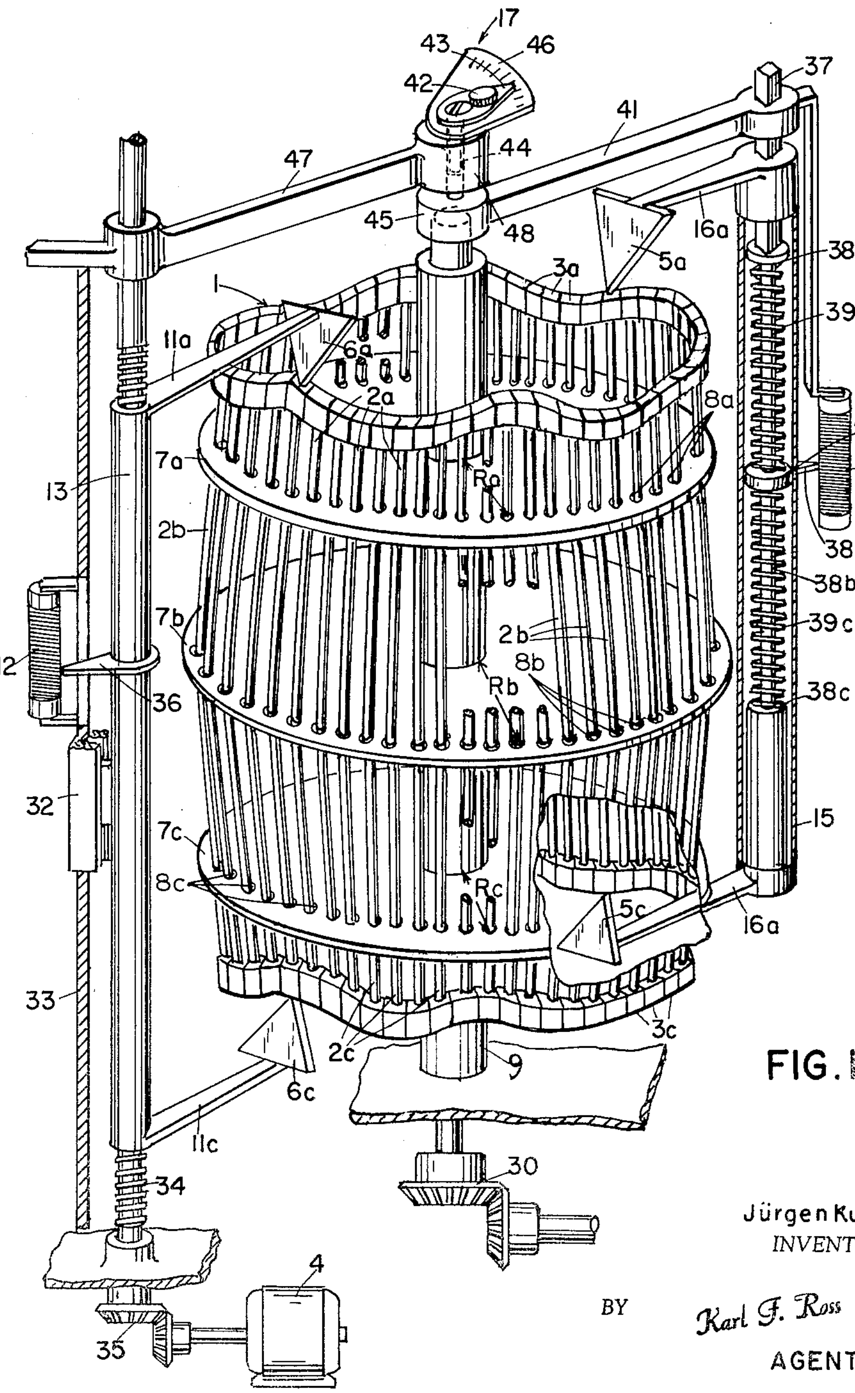

FIG. 1

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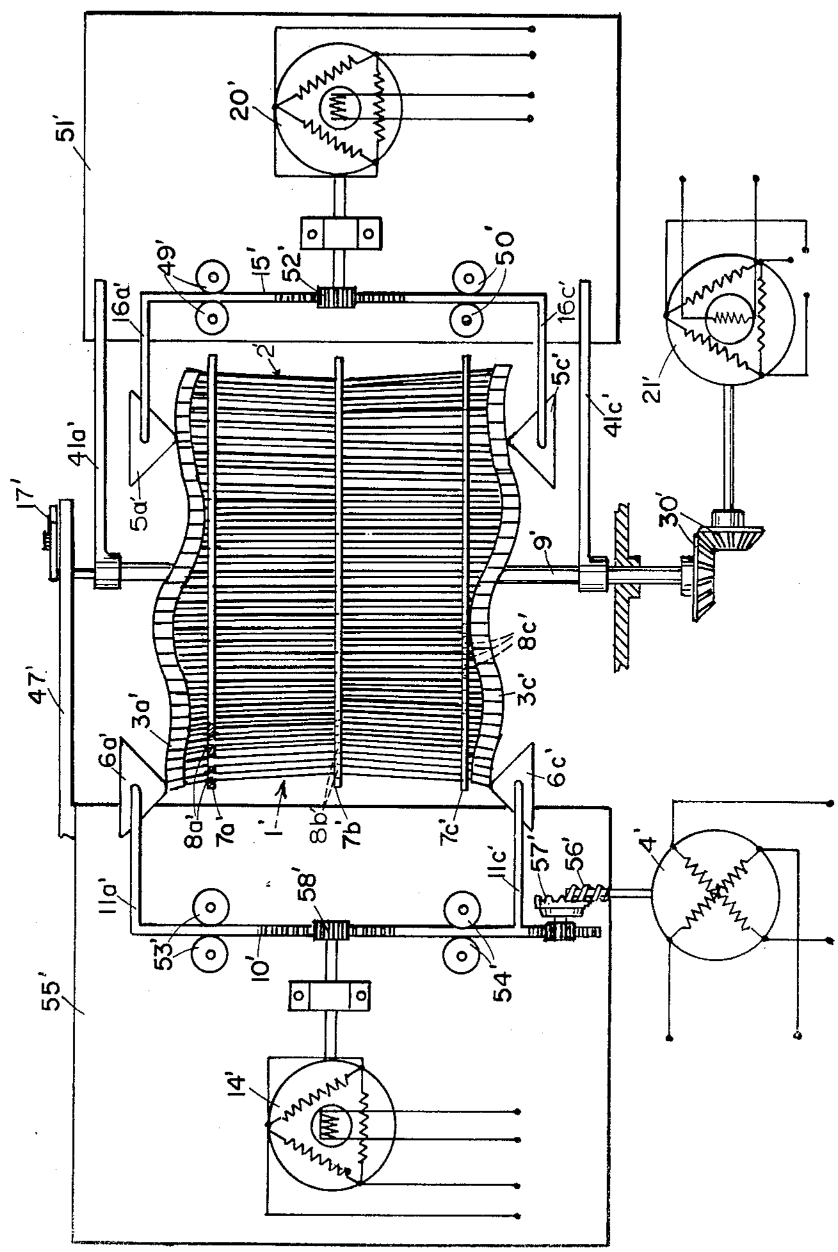

FIG. 2

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FIG. 4

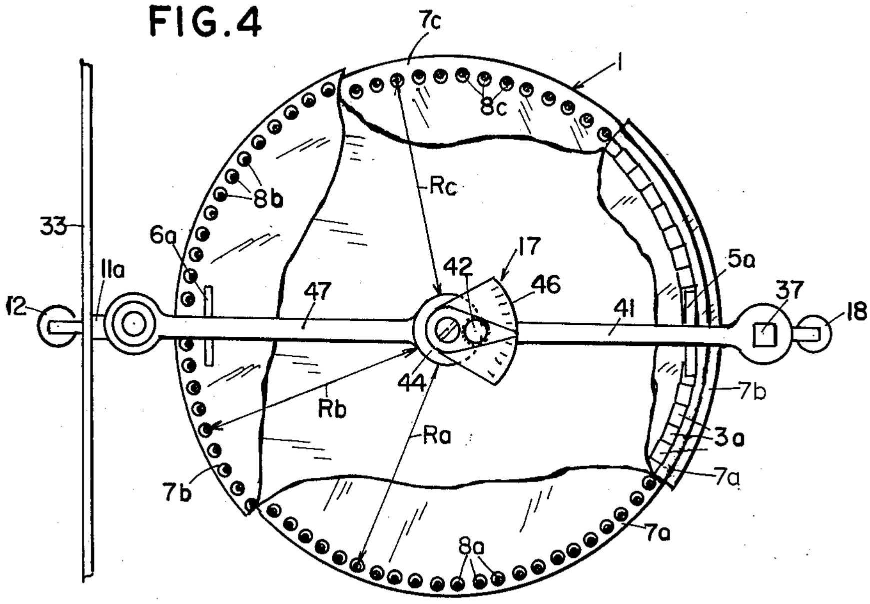
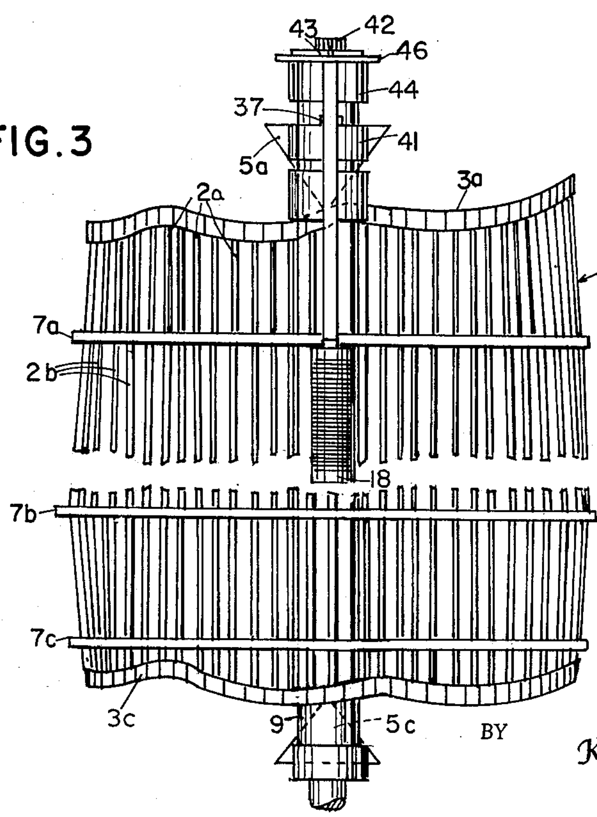


FIG. 3



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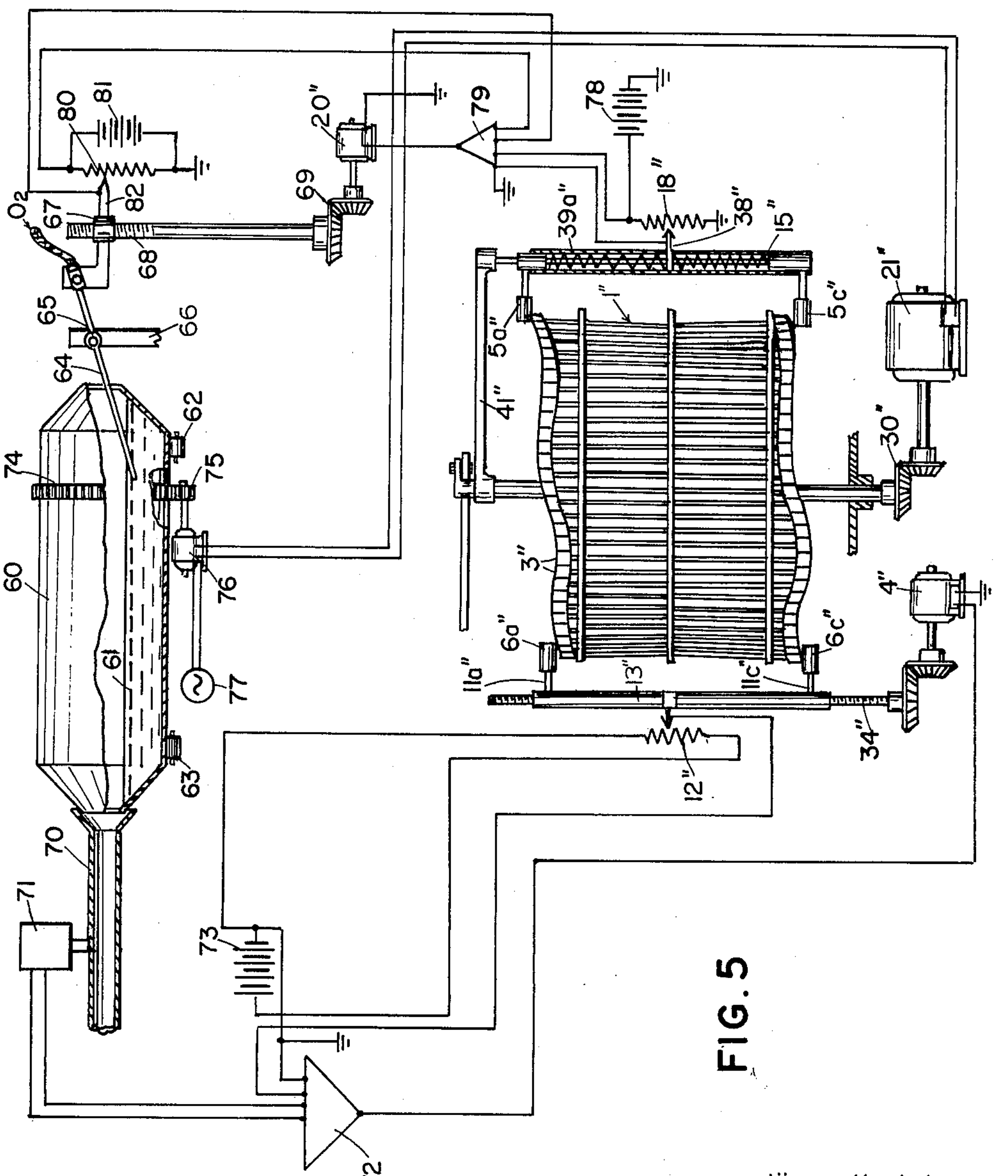

FIG. 5

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MECHANICAL STORAGE APPARATUS FOR CONTROLLING PERIODIC PROCESSES

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Claims priority, application Germany, May 24, 1961, H 42,689
13 Claims. (Cl. 340—173)

My present invention relates to apparatus for controlling periodic processes and, more particularly, to a control system including mechanism for recording a periodically variable parameter.

In the commonly assigned copending application Ser. No. 55,347, now Patent No. 3,100,699 filed September 12, 1960, Von Bogdandy et al. have disclosed a feedback-operated control system for periodic processes, especially for the operation of a refining furnace, wherein an output variable subject to both long-term and short-term variations is stabilized.

As pointed out in that application, a rotary refinery furnace, containing a melt below the surface of which air or oxygen is introduced via lances or the like, requires that the depth at which the oxygen is introduced be regulated precisely and be maintained at a substantially constant level. Since the oxygen introduced below the level of the bath oxidizes the carbon contained in the melt to carbon monoxide, which is evolved by the bath and burned above the surface thereof, the exhaust gases of the furnace may be analyzed in order to determine the proper distance of the air of the oxygen lance or nozzle below this level in the bath upon rotation of the furnace. As the furnace rotates, however, the bath level fluctuates periodically in consequence of slight eccentricities of the furnace wall and/or surface irregularities resulting from uneven wear. These unavoidable fluctuations, which change the effective depth of the submersed oxygen blast, superimpose upon the measured output variable, e.g., the exhaust-gas composition, a pattern of rhythmic variations which must be compensated by the control system if the desired stability is to be maintained.

Patent No. 2,977,217, issued March 28, 1961, to Graef et al., points out the relationship between the exhaust-gas composition and the depth of the air-blast nozzle. A further commonly assigned copending application, Ser. No. 825,428, now patent No. 3,043,668 filed July 7, 1959, by Von Bogdandy et al., discloses apparatus for analyzing the waste gases emanating from a furnace of the type referred to and producing an electrical output proportional to the composition of the waste gases analyzed and, consequently, to the depth of immersion of the nozzle.

In the above-mentioned copending application Ser. No. 55,347, the control system disclosed comprises a pair of magnetic tapes adapted to record a control signal for adjusting the depth of immersion of an oxygen-introducing nozzle and means for compensating for the inherent lag within the control system by increasing the effective length of the tape between a recording and a reading head. It is common knowledge that tape-operated control systems have a relatively high noise level and are susceptible to maladjustment owing to the nature of the magnetic storage medium.

An object of the present invention, therefore, is to provide an improved control system including mechanical means for recording and reproducing a control parameter, thereby obviating the disadvantages of magnetic recording systems.

It is another object of this invention to provide a mechanism for the continuous recording of a variable suitable for use in analog control installations.

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According to a feature of the present invention, the magnetic recording medium disclosed in copending application Ser. No. 55,347 is replaced by a mechanical storage device adapted to be formed with a curve corresponding to the variations of an independent variable with a dependent variable and a reading device mechanically scanning the curve for converting the variations of this independent variable into suitable control action. The storage device advantageously comprises a drum rotatable about an axis and formed with a plurality of axially shiftable elongated members extending along generatrices of the drum, the corresponding ends of these members defining the afore-mentioned control curve. The mechanical read-out device may comprise a cam follower bearing upon the ends of the drum members and displaceable in accordance with the contours of the curve formed thereby.

According to a more specific feature of the invention, the drum is formed with a plurality of axially spaced transverse support disks which are perforated around their periphery to receive the elongated members, which may be frictionally received in the peripheral perforations. The disks may include a central disk and a pair of outer disks flanking the central disk. The outer disks which may engage the terminal quarters of the length of the elongated members, have their peripheral apertures lying at a distance from the axis of the drum different from the distance between the axis and the peripheral apertures of the central disk. Thus, the members will be slightly bowed inwardly or outwardly, respectively, at their central region depending upon whether the distance between the peripheral apertures of the central disk is less or greater than the distance between the peripheral apertures of the outer disks and the axis.

The members are, preferably, resilient (e.g. made from spring steel) so that their concave or convex bowing results in frictional engagement with the support disks. To insure that the curve formed by the end faces of the members is substantially continuous, the members have a relatively small width and a large number are provided to form the surface of the drum. The slight rounding of the end faces of the members also facilitates the formation of a smooth curve. A setting device adapted to cam the members into their proper positions upon rotation of the drum is also provided. It should be noted that the frictional engagement of the members by the support disks should be insufficient to prevent displacement of the members by the setting device but sufficient to withstand the pressure of the read-out mechanism.

According to another aspect of the invention, a drum of the aforementioned type is employed in conjunction with a system having a discernible time lag or dead time between the detection of a fluctuation in a measurable output variable and the cause of such fluctuation. Thus, in a rotary refinery furnace wherein the drum is to control the depth of immersion of an air-blast nozzle in response to fluctuations in the composition of furnace exhaust gases, the drum is rotated synchronously with the furnace and a control signal, corresponding to changes in the level of the bath, is fed by the gas-analyzing means to the setting device. The latter shifts the elongated members of the drum axially to form a control curve which is followed by the read-out means and converted into an adjustment of the position of the nozzle upon a successive rotation of the furnace. Advantageously, the setting and read-out means are angularly offset about the axis of the drum by approximately 180° and the drum is coupled with the furnace for rotation at a rate one half that of the latter. The furnace, therefore, makes two revolutions for each revolution of the drums. Since the detection of a change in gas composition does not correspond to a simultaneous alteration in the effective depths of the nozzle owing to the aforementioned time lag or dead time, it is necessary to advance the read-out means relative to the setting means by an amount corresponding to the duration of the lag.

According to another specific feature of the invention, I provide means for relatively angularly displacing the setting and read-out stations about the axis of the drum in order to compensate for the lag. Such means may include a support or carrier for, say, the read-out means which is manually or automatically swingable about the axis of the storage drum by an angle corresponding to the lag. An indicator may be provided for denoting the relative angular positions of the setting and read-out stations and, more particularly, for showing the deviations of the read-out station from its normal position diametrically opposite the setting station when the drum and the furnace are rotated with speeds in the ratio of 1:2.

The above and other objects, features and advantages of the present invention will become more readily apparent from the following description, reference being made to the acompanying drawing in which:

FIG. 1 is a somewhat diagrammatic perspective view of a storage drum according to the invention;

FIG. 2 is a front-elevational view of a drum showing modified setting and read-out means therefor;

FIG. 3 is a side-elevational view of the apparatus of FIG. 1;

FIG. 4 is a plan view of the apparatus of FIG. 1; and

FIG. 5 is a diagrammatic view of a control system embodying a storage mechanism according to the invention.

In FIGS. 1, 3 and 4 I show a storage drum 1 whose shaft 9 carries three axially spaced transverse disks *7a*, *7b*, *7c*. The central support disk *7b* is provided with peripheral apertures *8b* which lie along a circle centered upon the axis of shaft 9 and whose radius R_b is greater than the identical radii R_a, R_c of the corresponding circles of disks *7a*, *7c*. The apertures *8a*, *8c* lie along circles having the radii R_a and R_c, respectively. A plurality of elongated members 2 form the periphery of the drum and are received in respective bores *8a*–*8c* aligned along generatrices of the generally cylindrical drum. Since, however, the apertures *8b* of the central disk *7b* are farther from the axis of the drum than the corresponding apertures *8a*–*8c* of the outer disks *7a*, *7c*, each of the members 2 is slightly bowed outwardly at its central portion. These members are, advantageously, resilient and may be made, say, of spring steel so that their bowed configuration results in a frictional engagement of the members with the inner edges of the apertures *8b* and with the outer edges of the apertures *8a* and *8c*. The members are thus restrained from spontaneous movement in axial direction by the frictional forces at these edges. Each member 2 is formed with terminal portions *2a*, *2c* which contiguously abut corresponding portions of the adjacent members so that their end faces form substantially continuous annular curves *3a*, *3c* at the upper and lower ends of the drum. The intermediate portion *2b* of each member 2 is of reduced cross-section and is received in the bores *8a*–*8c*.

The shaft 9 of drum 1 is driven synchronously with the rotary furnace, as will be described in greater detail hereinafter, via a bevel-gear transmission 30. The setting means for longitudinally adjusting the members or rods 2 comprises a servomotor 4 and a mechanism designed to convert the rotary output of this servomotor into an axial displacement of a pair of triangular cams *6a*, *6c* constituting the setting elements. Cams *6a* and *6c* are carried by respective, radially extending arms *11a*, *11c* at opposite ends of the drum so that the cams *6a* and *6c* bear simultaneously upon both end faces of each rod 2 as the drum rotates past the setting station. Arms *11a* and *11c* are rigid with a threaded sleeve 13 whose rotation is prevented by an axially extending guide slot 32 in a wall 33 of the support structure for drum 1. A screw 34 threadedly engages sleeve 13 and is journaled in the support structure for rotation by the servomotor 4 via bevel gears 35. A feedback resistor 12 has a wiper 36 mounted on sleeve 13 and extending through slot 32. This resistor provides a feedback voltage proportional to the actual displacement of sleeve 13 to the amplifier 72 (FIG. 5) of servomotor 4 and results in an accurate positioning of the cams *6a*, *6c* in response to an input signal.

The read-out device comprises a pair of similar cams *5a*, *5c* mounted upon radially extending arms *16a*, *16c* of a sleeve 15 which is axially displaceable relatively to a bar 37 passing through the sleeve. The prismatic configuration of bar 37 prevents relative rotation between the latter and sleeve 15 which carries a wiper 38 of a variable resistor 18 whose function will be described subsequently. Bar 37 is formed with a pair of axially spaced shoulders *38a*, *38c* against which a pair of compression springs *39a*, *39c* are seated. Springs *39a*, *39c* bear against a ring *40b* which surrounds the shank *38b* of bar 37. Ring *40b* is rigid with sleeve 15 so that the springs *39a*, *39c* tend to maintain this sleeve in an intermediate position and to return it to this position upon axial displacement of the sleeve by the curves *3a*, *3c* via followers *5a*, *5c*. It should be noted that springs *39a* and *39c* apply less force to the rods 2 than is required to overcome the frictional forces acting thereon and thus avoid dislodging the rods once they have been set by cams *6a* and *6c*. Bar 37 is carried by a radially extending arm 41 journaled on shaft 9 for rotation about the axis of the latter. Thus, arm 41, bar 37 and the read-out follower elements *5a*, *5c* may be swung angularly about the axis of drum 1 by a distance sufficient to compensate for the duration of the time lag.

While the angular displacement of arm 41 can be effected by means of a servomotor such as a mechanism employed to deflect the tape in the Bogdandy et al. application Ser. No. 55,347, I prefer to position it manually after experimental determination of the duration of the time lag or dead time to compensate for the latter. As locking means I provide a knurled screw 42 which is threadedly received in a pointer 43 secured to a stud 44 extending axially from boss 45 of arm 41. The pointer 43 sweeps a scale 46 of indicator means 17 denoting the relative positions of the setting and read-out means. Scale 46 is held stationary by an arm 47, which is provided with a boss 48 rotatably receiving a stud 44 rigid with the support structure.

In FIG. 2, there is shown a modified arrangement of a control device wherein the drum 1′ is provided with support disks *7a′*, *7b′* and *7c′*. The peripheral apertures *8b′* are located along a circle whose radius is somewhat less than the radii of the corresponding circles along which the apertures *8a′* and *8c′* of disks *7a′* and *7c′* lie. Thus the rods 2′, which are shown schematically in FIG. 2 and actually have a configuration similar to that shown in FIG. 1, are slightly concave outwardly so that they frictionally bear against the outer edges of apertures *8b′* and the inner edges of apertures *8a′* and *8c′*. In this embodiment, however, the sensing cams *5a′*, *5c′* and the setting cams *6a′*, *6c′* are rounded off at their surfaces in contact with the curves *3a′*, *3c′* formed by rods 2′. The arms *16a′*, *16c′* carrying the sensing cams *5a′*, *5c′* are rigid with a rack 15′ guided between pairs of rollers 49′, 50′ journaled in a support plate 51′. A pinion 52′ engages the rack 15′ for rotation by the latter to drive an electromechanical transducer such as servomotor 20′ and operate a control element. Plate 51′ is carried by arms *41a′*, *41c′* for swinging movement about the shaft 9′ of drum 1′. Arm *41a′* is provided with indicating means 17′ similar to the indicator 17 previously described.

The setting cams *6a′*, *6c′* are mounted upon arms *11a′*, *11c′* rigid with a rack 10′ guided between the rollers 53′, 54′ journaled in a stationary plate 55′. A servomotor 4′ rotates a worm 56′ to drive a pinion 57′ which, in turn, displaces the rack 10′. The feedback signal is, in this instance, derived from a servomotor 14′ which is driven by pinion 58′ from rack 10′. Servomotor 21′ drives shaft 9′ via the bevel gears 30′.

FIG. 5 illustrates a control system embodying a mechanical storage device of the character previously described. For convenience, prime numerals have been employed in FIG. 2 and double-prime numerals in FIG. 5 to indicate elements equivalent to those designated with identical but unprimed reference characters in FIG. 1. In FIG. 5 I show a rotary furnace **60** containing a bath **6**, of a metal (e.g. iron) to be refined. Through one end of furnace **60**, which is rotatable on rollers **62**, **63** about a substantially horizontal axis, an oxygen lance **64** is introduced below the surface of the bath. The lance **64** is fulcrumed at **65** to a support **66** and is provided with a nut **67** threadedly engaged by a lead screw **68**. The latter is driven via bevel gears **69** by a servomotor **20''**.

At the output end of furnace **60** a duct **70** is provided to carry away the exhaust gases. The carbon-monoxide content of these gases is analyzed by a device **71** of the type disclosed in the above-mentioned Bogdandy et al. application Ser. No. 825,428 filed July 7, 1959. The voltage output of the gas analyzer **71** is fed to a servo-amplifier **72** which also receives a voltage indicative of the position of the setting elements **6a''**, **6c''**. These elements are, in the device shown in FIG. 5, rollers mounted upon arms **11a''**, **11c''** extending from sleeve **13''** of a setting device such as that shown in FIG. 1. The reference voltage is derived from a potentiometer **12''** and a battery **73**. Amplifier **72** controls a servomotor **4''** which reversably drives a screw **34''** of the setting device whenever the input to amplifier **72** from the analyzer **71** differs from that derived from the feedback potentiometer **12''**. Consequently, setting elements **6a''** and **6c''** are always positioned in response to the gas composition and, therefore, the effective depth of immersion of the lance **64**.

The drum **1''** is rotated by its follower servo **21''** at half the speed of rotation of furnace **60**. The latter is driven by a motor **76**, constituting a servo transmitter, whose pinion **75** meshes with the ring gear **74** of furnace **60**. Motor **76** is fed with alternating current in the usual manner from a source **77**. As the furnace **60** rotates, the effective level of the bath **61** fluctuates periodically, thereby alterning the depth of immersion of the lance **64**. Changes in the carbon-monoxide concentration of the gas resulting from variations in the depth of the immersion of lance **64** are sensed by the analyzer **71** with a lag proportional to the volume of the furnace. The previously recorded curve **3''** of the storage device **1''**, however, now displaces the follower rollers **5a''**, **5c''** of the read-out means and shifts their support body **15''** so that the wiper **38''** of the associated potentiometer **18''** produces a control-voltage output representative of the required correction of the position of lance **64**. Potentiometer **18''** bridges a battery **78** and feeds its control voltage to a servo-amplifier **79** which is also supplied with an input from a feedback potentiometer **80** bridged across another battery **81**. The slider **82** of potentiometer **80** is connected to nut **67** and thus indicates the actual position of lance **64**. Consequently, an imbalance between the two inputs is established whenever the support body **15''** is shifted by the storage drum **1''** in a manner tending to adjust the position of the lance. In the usual manner, amplifier **79** produces an error signal which drives the servomotor **20''** to operate screw **68** and reposition the lance **64** at the point at which the two inputs are again in balance. Advantageously, the swingable arm **41''** carrying the read-out means has previously been locked relatively to the setting device so as to compensate for the time lag.

The invention as described and illustrated is believed to admit of many modifications and variations within the ability of persons skilled in the art; all such variations and modifications are deemed included within the spirit and scope of the invention recited in the appended claims.

I claim:

1. A mechanism for analog recording of a variable of a cyclical progress, comprising support means displaceable

about an axis; a plurality of elongated members shiftably mounted on said support means for displacement in generally axial direction and extending along respective generatrices of a surface surrounding said axis, said elongated members being formed with corresponding faces defining an annular curve characteristic of said variable; axially shiftable setting means cammingly engageable with said members for axially displacing them in accordance with fluctuations in said variable upon displacement of said members on said support means along a closed path; and read-out means along said path cammingly displaceable by said faces upon said displacement of the said support means; servo means operatively connected with said setting means for shifting same; position-sensing means responsive to axial displacement of said setting means; and circuit means forming a feedback path between said position-sensing means and said servo means.

2. A mechanism for analog recording of a variable of a cyclical process, comprising support means rotatable about an axis; a plurality of substantially contiguous elongated members shiftably mounted on said support means for displacement in generally axial direction and extending along respective generatrices of a surface of revolution centered on said axis, said elongated members being formed with corresponding faces defining an annular curve characteristic of said variable; axially shiftable setting means cammingly engageable with said members for axially displacing them in accordance with fluctuations in said variable upon displacement of said members on said support means along a closed path; and read-out means along said path cammingly displaceable by said faces upon said displacement of said support means; at least one of said setting and read-out means being provided with a carrier swingable about said axis relatively to the other for adjusting the mutual angular spacing between said setting and read-out means.

3. A mechanism according to claim **2** wherein said support means comprises at least three axially spaced disks including a central disk and a pair of outer disks flanking said central disk, each of said disks being provided with peripheral apertures for receiving said members, the peripheral apertures of said central disk being located at distances from said axis different from the distances between the peripheral apertures of said outer disks and said axis whereby each of said members is frictionally entrained with apertures of said disks lying along a respective generatrix of said surface.

4. A mechanism according to claim **3** wherein the peripheral apertures of each of said disks lies along respective circles centered on said axis, the radius of the circle of said central disk being different from the radii of the circles of said outer disks.

5. A mechanism according to claim **2** wherein said elongated members are of identical length and are each formed with a pair of end faces lying along parallel annular curves at opposite extremities of said surface, said setting means comprising a pair of setting elements axially spaced by a distance equal substantially to the length of said members and engageable with the opposite end faces thereof.

6. A mechanism according to claim **5** wherein said setting means comprises an axially shiftable body carrying said setting elements and servo means operatively connected with said body for shifting same.

7. A mechanism according to claim **6** wherein said setting means further comprises position-sensing means responsive to axial displacement of said body, and circuit means forming a feedback path between said position-sensing means and said servo means.

8. A mechanism according to claim **5** wherein said read-out means comprises a pair of follower elements axially spaced by a distance equal to the length of said members and engageable with respective end faces thereof.

9. A mechanism according to claim **8** wherein said read-out means further comprises an axially displaceable body carrying said follower elements and electromechanical transducer means coupled with said body for providing a control signal upon displacement thereof in accordance with the contours of said curves.

10. A mechanism according to claim 2 wherein said setting and read-out means are spaced angularly apart by approximately 180°, further comprising drive means for said support synchronized with said cyclical process for rotating said support means one revolution for each two cycles of the process.

11. A mechanism according to claim 2 further comprising indicator means coupled to said carrier for denoting the relative angular positions of said setting and read-out means.

12. A mechanism according to claim 2, further comprising locking means for securing said carrier against displacement in a selected angular position about said axis.

13. In a control system for a rotating reaction vessel having output means adapted to produce an output signal representative of the progress of a reaction in said vessel and input means adjustable for changing an operating parameter to influence the reaction with an inherent time lag between the adjustment of said input means and a resulting change in said output signal, the improvement which comprises a mechanical storage device for analog recording of said output signal, said storage device comprising support means rotatable about an axis, and a plurality of elongated members shiftably mounted on said support means for displaceemnt in generally axial direction and extending along respective generatrices of a surface of revolution centered on said axis, said elongated members being formed with corresponding faces defining an annular curve characteristic of said variable; axially shiftable setting means cammingly engageable with said members for axially displacement them in accordance with fluctuations in said variable upon displacement of said members on said support means along a closed path; read-out means along said path cammingly displaceable by said faces upon said displacement of said support means, and circuit means connecting said read-out means and said input means for adjusting the latter in accordance with the contours of said curve, said read-out means comprising a carrier swingable about said axis relatively to said setting means for conpensating for said time lag.

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