

June 4, 1963

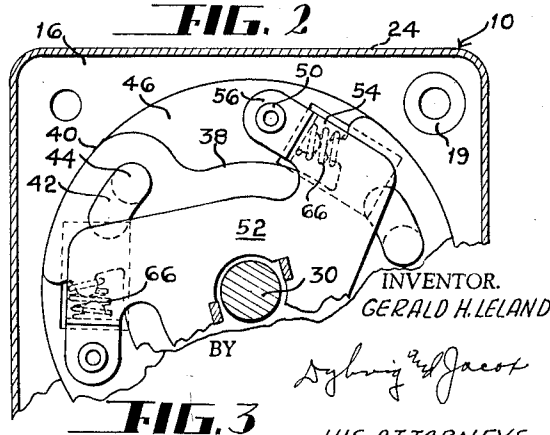
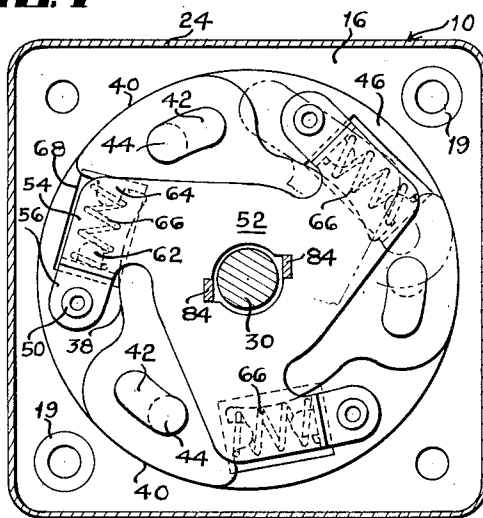
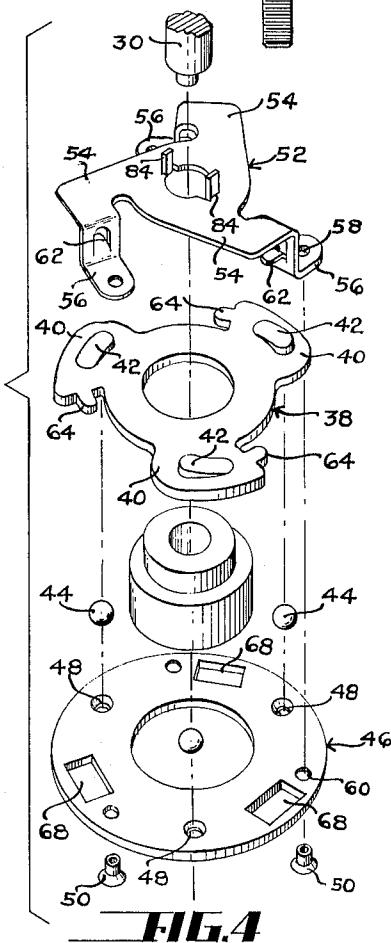
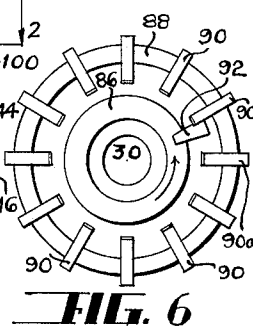
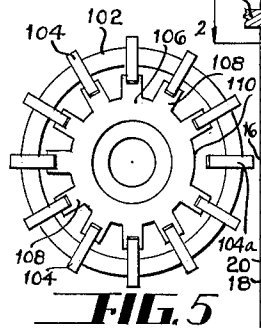
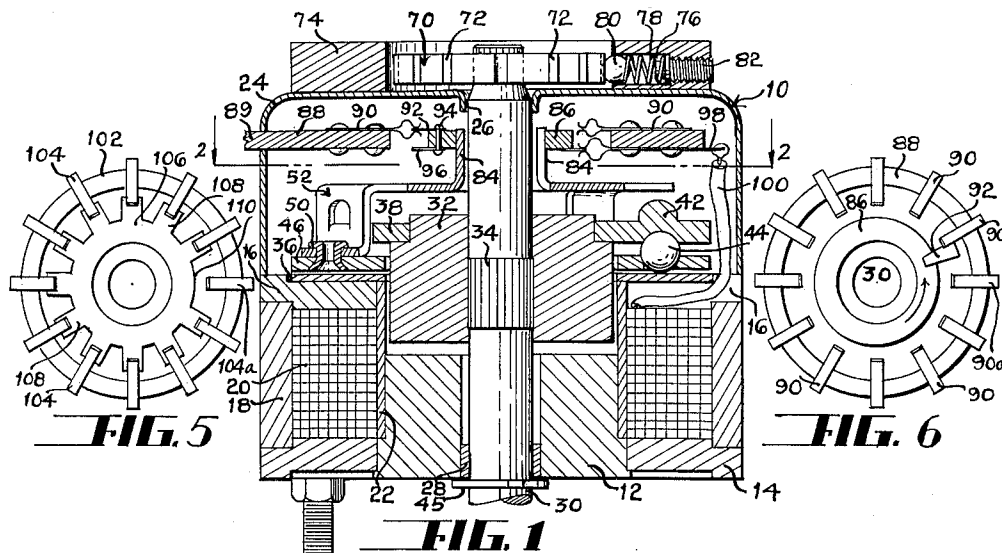
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3,092,740

ROTARY STEPPING MOTOR

Filed Jan. 12, 1959

2 Sheets-Sheet 1



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ROTARY STEPPING MOTOR

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2 Sheets-Sheet 2

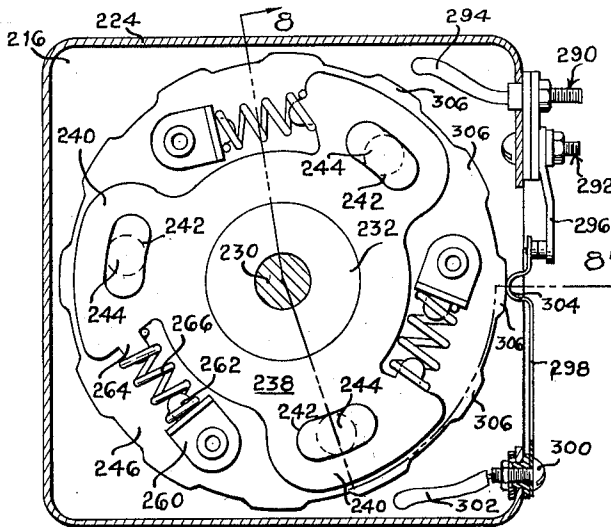


FIG. 7

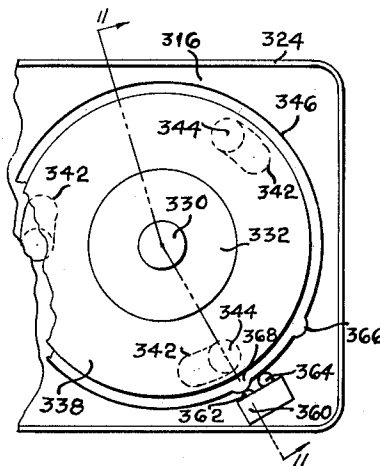


FIG. 10

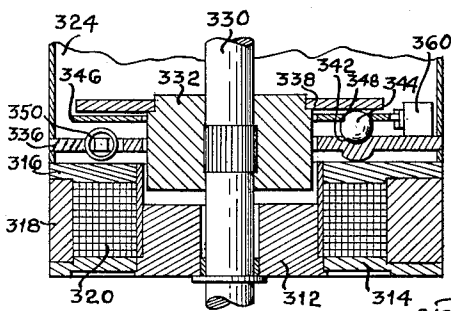


FIG. 11

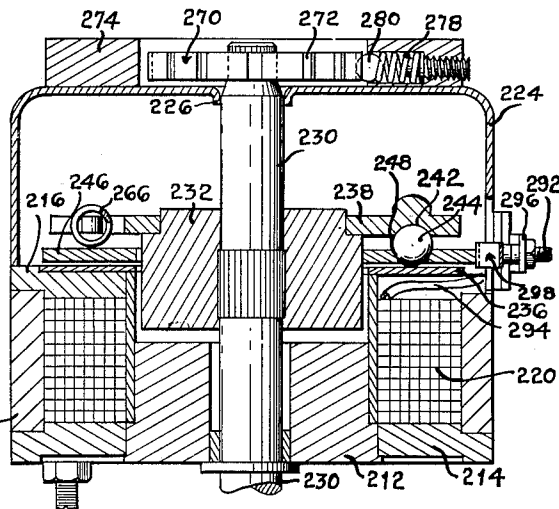


FIG. 8

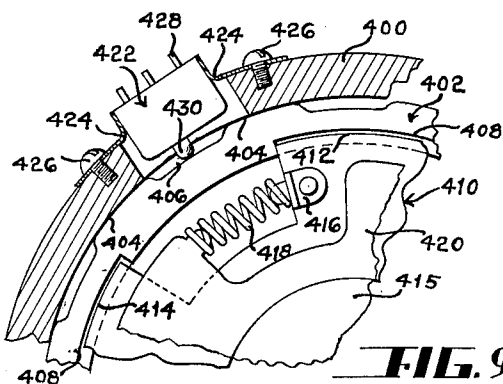


FIG. 9

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3,092,740

ROTARY STEPPING MOTOR

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18 Claims. (Cl. 310-23)

This invention relates to a stepping motor, and more particularly to a rotary stepping device having commutating characteristics, however, the invention is not necessarily so limited.

An object of the present invention is to provide a new and improved electromagnetically operated stepping device, wherein axial movement of a magnetically energized armature is converted to rotary movement through coaction between roller elements and inclined surfaces or the equivalent.

Another object of this invention is the provision of a rotary stepping device having a number of discrete rotary positions and, in combination therewith, a master-slave switching circuit for directing the stepping device to any one of its rotary positions.

Still another object of this invention is to provide, in an electromagnetically operated rotary stepping device comprising an electromagnet, an armature driven axially thereby, and conversion means for changing the axial movement of the armature to rotary movement, new and improved means for resetting the conversion mechanism.

Other objects and advantages reside in the construction of parts, the combination thereof, the method of manufacture and the mode of operation, as will become more apparent from the following description.

In the drawing, FIGURE 1 is an elevational view in section illustrating the stepping device of the present invention.

FIGURE 2 is a sectional view taken substantially along the line 2-2 of FIGURE 1.

FIGURE 3 is a sectional view analogous to that in FIGURE 2 illustrating the stepping device in a different operative position.

FIGURE 4 is a fragmentary perspective view in exploded detail illustrating the rotary conversion mechanism for the stepping device.

FIGURE 5 is a schematic plan view of a master switch for controlling the stepping device.

FIGURE 6 is a schematic plan view of a slave switch responsive to the master switch of FIGURE 5.

FIGURE 7 is a plan view with parts shown in section of a modification.

FIGURE 8 is a sectional view taken substantially along the line 8-8 of FIGURE 7.

FIGURE 9 is a fragmentary plan view of another modification with portions shown in section.

FIGURE 10 is a fragmentary plan view of still another modification.

FIGURE 11 is a sectional view taken substantially along the line 11-11 of FIGURE 10.

Referring to the drawing in greater detail, the rotary stepping motor of this invention is designated by the reference numeral 10. With reference to FIGURE 1 the rotary stepping motor 10 is seen to include a cylindrical electromagnet core element 12 upon which is press fitted a generally rectangular base plate 14. A like plate 16 having a rectangular periphery is supported in spaced relation to the plate 14 by a rectangular annular upright wall 18. As best seen in FIGURES 2 and 3, rivets 19 draw the plates 14 and 16 upon the wall portion 18.

The plates 14 and 16 and the wall portion 18 define an annular cavity encircling the core element 12 into which is fitted a coil 20. The coil 20 together with the core element 12 comprise an electromagnet. An insulating layer 22 separates the core element from the coil.

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A generally rectangular housing 24 is fitted upon the plate 16. Centrally located in the top of the housing 24 is an inwardly flared annular wall 26 providing bearing support for a shaft 30 passing axially through the core element 12. The shaft 30 is supported within the core element 12 by a bushing 28. A cylindrical armature 32 is press fit upon the shaft 30 in spaced relation to the core element 12. Knurling 34 on the shaft 30 secures the armature 32 against rotation relative to the shaft 30. The arrangement is such that the electromagnet formed by the core element 12 and the coil 20 may be energized to draw the armature 32 axially to the core element 12. This axial movement is converted to rotary movement by a mechanism described in the following.

An annular plate 36, hereafter designated a stator, encircling the armature 32 is fixedly secured to the upper surface of the plate 16. The stator 36 is hardened so that it may function as a ball race. An opposing ball race 38, hereafter designated a rotor, is press fit on the armature 32 in spaced parallel relation to the stator 36. As best illustrated in FIGURE 4, the rotor 38 is provided with three equally spaced outwardly projecting arms 40, each of which is stamped to provide an inclined surface 42 therein opposing the stator element 36. Three ballbearing elements 44 are interposed between the rotor 38 and the stator 36, one engaging each of the inclined surfaces thereof. As is apparent in FIGURE 4, the inclined surfaces engaged by the ball elements 44 are recessed into the face of the rotor 38 and the spacing between the rotor 38 and the opposing stator 36 is so arranged that the ball elements 44 are trapped in the recessed portions. To this end, movement of the rotor 38 axially away from the stator 36 is limited by a collar 45 secured to the shaft 30 and engaging the core element 12 at the base of the stepping device.

It is to be observed that the inclined surfaces 42 each provide an elevation gradient in the surface of the rotor whereby the rotor may engage the ball elements at varying elevations relative to the stator. For convenience of description, the opposite ends of each inclined surface, i.e. elevation gradient, in the rotor 38 are identified as proximal and distal respectively relative to the stator 36. Clearly, if the ball elements 44 are initially placed at the proximal ends of the inclined surfaces and then the electromagnet is energized electrically to pull the armature 32 toward the core element 12, the ball elements 44 will be urged to the distal ends of the inclined surfaces thereby inducing the rotor 38 to rotate relative to the stator 36. Thus, the axial armature motion is converted to rotary movement of the rotor 38. Upon subsequent deenergization of the electromagnet the ball elements 44 may be reset by returning them to the proximal ends of the inclined surfaces. Means for resetting the ball elements 44 is described in the following.

The three ball elements 44 are caged by an annular cage member 46, the ball elements 44 being situated in complementary apertures 48 in this cage element. Rivets 50 secure a bracket 52 to the cage element 46. This bracket 52 includes three equispaced outwardly projecting arms 54 each terminating in angularly bent lugs 56. Holes 58 in the lugs 56 are aligned with holes 60 in the cage member 46 to receive the rivets 50. The relative locations of the holes 60 and the ball element receiving apertures 48 and the cage member 46 are such that the arms 54 of the bracket 52 nestle between the arms 40 of the rotor 38.

A tongue 62 is struck out of each of the lugs 56 of the bracket 52. A complementary tongue 64 projects from each of the arms 40 of the rotor 38. With reference to FIGURES 2 and 3 coil springs 66 are seated between the tongues 62 and 64. There are three coil springs 66, one for each of the spaced pairs of arms 40 and 54 asso-

ciated with the rotor 38 and the bracket 52, respectively. Apertures 68 in the cage member 46 provide clearance for the springs. These springs 66 operate to bias the cage member 46 rotatably relative to the rotor 38, the direction of bias being such as to urge the ball elements 44 to the proximal ends of the inclined surfaces of the rotor.

It is to be noted that the cage member 46 confines the movement of the ball elements 44 to a rotary path and, accordingly, the inclined surfaces 42 of the rotor 38 are arcuate, these being concentric to the axis of relative rotation between the rotor 38 and the cage member 46. In other words, the elevation gradient established by the inclined surfaces 42 extends in the direction of relative movement between the rotor and the stator.

In light of the foregoing discussion, it is clear that, with the electromagnet deenergized, the springs 66 operate on the bracket 52 to bias the ball elements 44 to the proximal ends of the inclined surfaces of the rotor 38, thereby indirectly biasing the armature 32 away from the core element 12 of the electromagnet. The relative positions of the bracket 52, the rotor 38, and the ball elements 44 at such time are illustrated in FIGURE 2. Upon electrical energization of the coil 20, magnetic pull exerted on the armature 32 in opposition to the springs 66 forces the ball elements 44 to the distal ends of the inclined surfaces 42 thereby imparting rotation to the rotor 38 relative to the stator 36. The relative positions of the bracket 52, the rotor 38, and the ball elements 44 at the end of the power stroke are illustrated in FIGURE 3.

It is to be noted that the rotation of the rotor 38 is in a counterclockwise direction as viewed in FIGURES 2 and 3. The amount of rotation is that amount required to accommodate movement of the ball elements 44 from the proximal to the distal ends of the inclined surfaces 42. Since the ball elements 44 are simultaneously rolling upon the surface of the stator 36, the angular rotation of the rotor 38 will be approximately twice the central angle subtended by each of the inclined surfaces 42 of the rotor 38.

The movement of the ball elements 44 relative to the rotor 38 is merely from the proximal to the distal ends of the inclined surfaces 42 and accordingly the angular rotation of the cage element 46 and bracket 52 relative to the stator 36 is just one-half that of the rotor 38 relative to the stator 36. Thus, on the power stroke of the armature 32, the rotation of the rotor 38 relative to the cage member 46 and the bracket 52 is approximately one-half the total angular rotation of the rotor 38 relative to the stator 36. To illustrate this difference in the rotation of the bracket 52 and the rotor 38 on the power stroke, FIGURE 3 is partially superimposed on FIGURE 2 in broken line detail.

Upon deenergization of the electromagnet after each power stroke, the springs 66 operate to restore the cage element 46 and the bracket 52 to their initial positions relative to the rotor 38. Thus, with respect to the stator 36, energization of the electromagnet moves the rotor 38 a full rotational increment and the bracket 52 a half rotational increment. As a result of this differential in rotational movement, the springs 66 are compressed. If the rotor element 38 is thereafter secured against further rotation upon deenergization of the electromagnet, the springs 66 will operate on the bracket 52 to advance that member another half rotational increment realigning the bracket with the rotor 38. In consequence of this movement, the armature 32 is drawn away from the core element 12 of the electromagnet.

From the foregoing it is apparent that the net effect of a single energization of the electromagnet followed by deenergization of the electromagnet will be to advance the rotor through a whole increment of rotation and to advance the bracket 52 through two half increments of rotation. As noted hereinabove, this operation requires that the rotor 38 be restrained while the electromagnet is deenergized. In typical operations, restraint of the rotor

38 is provided naturally by friction associated with the load driven by the shaft 30. Where the load on the shaft 30 is insufficient to restrain rotation when the electromagnet is deenergized, suitable detent means must be employed.

In order to provide a complete description of the operation of the present stepping motor, detent means for restraining the shaft 30 are illustrated in FIGURE 1. This detent means includes a cylindrical disc 70 splined to the shaft 30 in such a manner that the shaft 30 may move axially independent of the disc 70. The disc 70 is provided with a plurality of spaced notches 72 in the periphery thereof and is surrounded by an annular member 74 fixedly secured to the housing 24. The member 74 is provided with a recess 76 housing a spring 78 which biases a ball element 80 radially inwardly into engagement with the notches 72. The tension on the spring 78 is adjustable through operation of a set screw 82 forming an end wall for the recess 76.

The spacing between the notches 72 corresponds to the angular movement of the rotor 38 relative to the stator 36 during the power stroke of the armature 32. The inclined surfaces 42 in the rotor 38 are so designed that a whole number of power strokes will produce 360° of rotation of the rotor 38. In the embodiment illustrated, the inclined surfaces 42 are designed to advance the rotor in 30° increments. The notches 72 in the disc 70 cooperate with the ball element 80 to maintain uniformity in the rotational increments.

A master-slave switching circuit for controlling the operation of the stepping device is illustrated in FIGURES 1, 5 and 6. With reference to FIGURE 1, the bracket 52 is provided with a pair of upstanding posts 84 which engage and support a rotor wafer 86. The rotor wafer 86 encircles the shaft 30 for rotation thereabout. Encircling the rotor wafer 86 is a stator wafer 88 mounted fixedly with respect to the housing 24 by means of an arm 89. A plurality of contacts 90 are distributed at 30° intervals along the upper surface of the stator wafer. A single contact 92 is provided on the upper surface of the rotor wafer for engagement with the contacts 90. The arrangement of the contact 92 and the contacts 90 is illustrated schematically in FIGURE 6.

An annular slip ring 96 is secured to the under surface of the rotor wafer 86 by rivets 94. A rivet 94 provides an electrical path between the contact 92 and the slip ring 96. The slip ring 96 also makes electrical connection with a contact 98 secured to the underside of the stator wafer. A wire 100 connects from the contact 98 to the coil 20. Through rotation of the rotor wafer 86, an electrical path may be established between the coil 20 and any one of the contacts 90 on the stator wafer 88.

The stepping device is assembled with the single contact 92 of the rotor wafer in engagement with one of the contacts 90 of the stator wafer when a notch 72 is engaged by the ball element 80 of the detent assembly and simultaneously the ball elements 44 are at the proximal ends of the inclined surfaces of the rotor 38. With this initial alignment, if all of the contacts 90 on the stator wafer are connected to a common electrical input for the coil 20 the stepping device will operate continuously as a commutating motor.

Thus, upon supplying electrical energy to the contacts 90 the electromagnet will be energized, commencing a power stroke of the armature 32. This power stroke will produce counterclockwise rotation of the rotor 38 and of the bracket 52 causing the rotor wafer 86 to move in a counterclockwise direction as viewed in FIGURE 6. This will cause the contact 92 of the rotor wafer to separate from the then engaged contact 90 of the stator wafer deenergizing the electromagnet. Thereafter the springs 66 return the bracket 52 to its original position relative to the rotor 38 resetting the ball elements 44 and bringing the contact 92 of the rotor wafer into engagement with the next adjacent contact 90 of the stator wafer. This re-

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energizes the electromagnet commencing a new cycle of operation. The stepping device will operate cyclicly in the described manner so long as electrical energy is supplied to all of the contact fingers of the stator wafer 88.

As illustrated in FIGURE 6, the contact 92 of the rotor wafer is preferably set in lagging relation to the contacts 90 of the stator wafer. Furthermore, the contact 92 is dimensioned to subtend a central angle slightly less than one-half the central angle subtended by adjacent contacts 90 on the stator wafer. With this construction the delivery of electrical energy to the electromagnet is maintained substantially throughout the power stroke, and the initiation of a new power stroke is delayed until the ball elements 44 have been returned substantially to the proximal ends of the inclined surfaces of the rotor 38.

Illustrated in FIGURE 5 is a master control switch constructed for use in combination with the switch of FIGURE 6, hereinafter designated a slave switch. The master switch includes a stator wafer 102 having contacts 104 spaced at 30° intervals, there being one contact 104 for each contact 90 of the slave stator wafer 88. With conductors, not illustrated, each of the contacts 104 of the master stator wafer 102 is connected electrically to the corresponding contacts 90 of the slave stator wafer 88. A rotor wafer 106 of the master switch carries a plurality of contacts 108 arranged at 30° intervals for engaging the contacts 104 of the stator wafer 102. The rotor wafer 106 is further provided with an open space 110 such that, at all times, all but one of the contacts 104 of the stator wafer 102 are engaged by contacts 108. The contacts 108 are all interconnected and serve as an electrical input for the stepping device. It is to be understood, of course, that the contacts 108 can be replaced by a continuous annular slip ring having a single gap therein corresponding to the opening 110.

With the rotor wafer 106 connected to a source of electrical energy for the electromagnet, all of the contacts 104 on the stator wafer 102 will be in contact with the source of electrical energy except the single contact opposite the opening 110. For convenience that contact is given the reference numeral 104a. The corresponding contact on the slave stator wafer 88 is given the reference numeral 90a.

With power supplied, the stepping device will operate cyclicly in the counterclockwise direction until the contact 92 of the slave rotor wafer 86 engages the contact 90a of the slave stator wafer 88. Whenever the master rotor wafer 106 is rotated to a new position, the stepping device will operate again in the counterclockwise direction seeking out the new position of the master switch and stopping only when that new position is found. The switch of FIGURE 5 may thus be used to remotely direct the stepping motor to any of its positions.

Sometimes it is desired to have a continuously commutating stepping motor rather than one which obeys a master slave switching circuit such as disclosed in the preferred embodiment. FIGURES 7 and 8 illustrate a modification wherein continuous commutation is obtained. With reference particularly to FIGURE 8 this modification includes an electromagnet core element 212 upon which is press fitted a generally rectangular base plate 214. A like plate 216 having a rectangular periphery is supported in spaced relation to the plate 214 by a rectangular annular upright wall 218. Rivets, not shown, secure the plates 214 and 216 with respect to the wall 218.

The plates 214 and 216 and the wall 218 define an annular cavity encircling the core element into which is fitted a coil 220. The coil 220 together with the core element 212 comprise an electromagnet.

A generally rectangular housing 224 is fitted upon the plate 216. Centrally located in the top of the housing 224 is an inwardly flared wall 226 providing a bearing

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for a shaft 230 supported for rotation within the core element 212. A cylindrical armature 232 is press fitted upon the shaft 230 in spaced relation to the core element 212. The arrangement is such that the electromagnet may be energized to draw the armature 232 axially to the core element. The following mechanism is employed to convert such axial movement to rotary movement.

An annular plate 236, hereafter designated a stator, encircles the armature 232 and is fixedly secured to the upper surface of the plate 216. The stator 236 is hardened so that it may function as a ball race. An opposing ball race 238, hereinafter designated a rotor, is press fitted on the armature 232 in spaced parallel relation to the stator 236. As best illustrated in FIGURE 7, this rotor is provided with three axially spaced outwardly projecting arms 240, each of which is stamped to provide an inclined surface 242 opposing the stator element 236. Three ball bearing elements 244 are interposed between the rotor 238 and the stator 236, one engaging each of the inclined surfaces 242. The three ball elements are caged by an annular cage member 246 provided with apertures 248 receiving the ball elements.

The cage member 246 supports three equispaced lugs 260 having outwardly projecting tongues 262. Complementary tongues 264 are provided in the outwardly projecting arms 240 of the rotor. Springs 266 seated on the pairs of tongues 262 and 264 bias the cage member 246 to an extreme rotary position relative to the rotor 238. This bias is such as to draw the ball elements 244 to the proximal ends of the inclined surfaces 242.

Rotation of the shaft 230 is controlled by a detent means including a disc 270 provided with equispaced notches 272 in the periphery thereof and surrounded by an annular member 274 fixedly secured to the housing 224. A spring 278 biases a ball element 280 against the periphery of the disc 270 so as to seat the ball element in one of the notches 272. The spacing between notches 272 corresponds to the central angle of the inclined arcuate surfaces 242.

The mechanical operation of the embodiment of FIGURES 7 and 8 is as follows. Upon energization of the electromagnet the armature 232 is drawn toward the core element 212. This axial movement of the armature 232 pulls the rotor 238 toward the stator 236 forcing the ball elements 244 to roll to the distal ends of the inclined surfaces 242. The rolling action of the ball elements 244 causes the rotor to rotate relative to the stator a distance which is twice the effective length of the inclined surfaces 242. As was the case with the preferred embodiment, the cage member 246 rotates just half this distance. When the ball elements 244 have reached the distal ends of the inclined surfaces the ball element 280 drops into one of the notches 272 of the detent means. Upon deenergization of the electromagnet the springs 266 return the ball elements 244 to the proximal ends of the surfaces 242. Since the rotor is secured by the detent means, the action of the springs 266 results in rotary movement of the cage member 246 relative to the rotor. Thus, the cage member rotates an additional half increment, catching up with the rotor.

As best seen in FIGURE 7, electrical energy is supplied to the electromagnet through terminals 290 and 292. The terminal 290 connects through a lead 294 through one end of the coil 220. The terminal 292 connects through switch arms 296 and 298 with a lead 302. The lead 302 connects with the opposite side of the coil 220.

The switch arms 296 and 298, the latter supported by a screw assembly 300, are employed as an interruptor switch for regulating the energization of the electromagnet. Control of the interruptor switch is effected through a projection 304 formed in the switch arm 298 which bears against the periphery of the cage member 246. As best illustrated in FIGURE 7 this periphery is in the nature of a cam provided with spaced outwardly projecting bosses 306.

The function of the interruptor switch is as follows. In the position shown in FIGURE 7, a boss 306 on the cage member 246 biases the switch arm 298 into contact with the switch arm 296. Thus, the electrical circuit for energizing the electromagnet is complete. In the position illustrated, the armature 232 is half way through its power stroke and accordingly the ball elements 244 are centrally located with respect to the inclined surfaces 242. The direction of rotary movement is such as to compress the springs 266.

At termination of the power stroke the projection 304 on the switch arm 298 will drop off the boss 306 engaged thereby and such movement will break contact with the switch 296, deenergizing the electromagnet. This will permit the springs 266 to advance the cage member 246 another half rotational increment placing the projection 304 of the switch arm 298 on the next adjacent boss 306 of the cage member. This reenergizes the electromagnet causing a new power stroke of the armature in a new operating cycle. So long as electrical energy is supplied to the terminals 290 and 292 the described stepping motor will operate continuously to rotate the shaft 230 in discrete rotational increments.

FIGURE 9 illustrates a modification analogous to the device of FIGURES 7 and 8. In this modification the essentially rectangular housing structure of the previous embodiments is replaced with a circular housing 400. Mounted for rotation within the housing 400 is an annular ring 402 having spaced cam bosses 404 and intermediate indentations 406. The dimensions of the ring 402 are such that it fits snugly within the housing 400 with a minimum of lateral play, but is freely rotatable relative to the housing 400. To insure a low coefficient of friction between the ring 402 and the housing, the ring may be made of sintered nylon, as one example.

Spaced notches 408 located in the inner periphery of the annular ring 402 receive lobes such as illustrated at 412 and 414 integral with a cage member 410. This cage member cages the ball bearings of the rotary conversion mechanism in a manner analogous to the cage member 246 of the embodiment of FIGURES 7 and 8, and is mounted rotatably relative to an armature 415 analogous to the armature 232 of the embodiment of FIGURES 7 and 8.

Secured to the lobe 412 of the cage member is a lug 416 engaging one end of a spring 418. The opposite end of the spring 418 is engaged by an armature plate 420 fixedly secured to the armature 415 in parallel relation to the cage member. The space between the lobes 412 and 414 provides clearance for the body of the spring 418.

A microswitch 422 is mounted in the wall of the housing 400 by means of brackets 424 secured by screws 426. The microswitch has terminals 428 with which it may be connected in the electrical circuit for energizing the electromagnet. An actuator button 430 operates the microswitch. The position of this actuator button is such that it opens (or closes) the microswitch contacts when it projects into an indentation 406 and closes (or opens) the contacts when it rides on a cam boss 404.

It is apparent that the cam bosses 404 and actuator button 430 of the embodiment of FIGURE 9 are capable of regulating operation of this embodiment in the same manner that the cam bosses 306 and the switch arm 298 of the embodiment of FIGURES 7 and 8 are capable of regulating the operation of that embodiment. The chief difference between the two embodiments is that, in the embodiment of FIGURE 9, the cam bosses 404 may be located with much greater precision than is possible in the embodiment of FIGURES 7 and 8. In each embodiment, a certain amount of play must be provided in the cage member to allow for variations in the locations of the ball elements of the rotary conversion mechanism. Where the cam bosses which operate the switch for the stepping motor are integral with the cage

member, the position of these cam bosses cannot be held with precision. This sometimes leads to erratic operation of the interruptor switch. By separating the cage member into two pieces, namely, the annular ring 402 and the cage member 410, and by providing for play between those pieces, the position of the cam bosses 404 can be held with precision.

FIGURES 10 and 11 illustrate still another modification wherein a continuously commutating stepping motor is obtained. With particular reference to FIGURE 11, the stepping motor comprises a core element 312 to which is press fitted a base plate 314. Spaced from the base plate 314 is a like plate 316. An annular wall portion 318 extends between the plates 314 and 316. These plates and the wall portion define an annular cavity into which is positioned a coil 320. The coil and the core element cooperate to form an electromagnet. Secured to the plate 316 is a rectangular housing portion 324 which, as was the case with the previous embodiments, provides a bearing, not shown, for a shaft 330.

Press fitted to the shaft 330 is an armature 332 and press fitted to the armature 332 is a rotor plate 338. A corresponding stator plate 336 is fixedly mounted to the housing 324 adjacent the plate 316. The stator 336 is stamped to provide inclined arcuate surfaces 342 therein analogous to the arcuate surfaces employed in the previous embodiments. Contacting these surfaces 342 are ball elements 344 caged by a cage member 346. Apertures 348 in the cage member receive the ball elements. As in the previous embodiments three ball elements 344 and three equispaced inclined surfaces 342 are employed.

Springs such as illustrated at 350 in FIGURE 11 operate to bias the cage member 346 to an extreme rotary position relative to the stator 336, the springs operating in much the same way as those illustrated in the embodiment of FIGURES 7 and 8. These springs bias the ball elements 344 to the proximal ends of the inclined surfaces 342. Upon energization of the coil 320 the armature 332 is drawn toward the core 312 of the electromagnet. This causes the rotor plate 338 to press the ball elements 344 against the inclined surfaces 342 such that these ball elements will roll to the distal ends of the inclined surfaces. As with the previous embodiments, detent means, not shown, is employed to arrest movement of the shaft 330 when the ball elements 344 have arrived at the distal ends of the inclined surfaces.

At this point the rotor plate 338 will have rotated a full rotational increment relative to the stator plate 336 while the cage member 346 will have rotated a half rotational increment, the springs 350 being compressed. Upon deenergization of the coil 320 the springs 350 will operate to rotate the cage member 346 in reverse restoring the ball elements 344 to the proximal ends of the inclined surfaces in the stator 336.

The operation of the embodiment of FIGURES 10 and 11 may be distinguished from the operation of the embodiment of FIGURES 7 and 8 in the following. In the embodiment of FIGURES 7 and 8, the cage member 246 rotates in half rotational increments continuously in one direction following the rotary movement of the rotor 238. In the embodiment of FIGURES 10 and 11 the cage member 346 reciprocates to and fro in half rotational increments relative to the stator 336 while the rotor 338 rotates in successive increments always in the same direction.

In the modification of FIGURES 10 and 11 a toggle switch 360 is employed to obtain continuous commutating action. The toggle switch includes a pair of spaced actuator buttons 362 and 364. The operation of the toggle switch is conventional. When the button 362 is depressed, electrical circuit to the coil 320 is made and is held until the button 364 is depressed breaking the circuit. The button 364 then remains depressed until button 362 is depressed. Actuation of the buttons 362 and

364 is accomplished with outwardly projecting bosses 366 and 368 on the periphery of the cage member 346.

In the position shown in FIGURE 10 the boss 368 has depressed the toggle switch button 362 energizing the coil 320. On the power stroke the rotor plate 338 will be rotated in the clockwise direction as viewed in FIGURE 10 a whole rotational increment. The cage member 346 will move a half rotational increment bringing the boss 366 into engagement with the toggle switch button 364. This will deenergize the coil 320 permitting the springs 350 to return the cage member 346 to its initial position relative to the stator 336. When the cage member 346 reaches its home position the button 362 is again depressed by the boss 368 initiating a new power stroke. Thus, the stepping motor of FIGURES 10 and 11 will commutate continuously so long as electrical energy is supplied to the coil 320 through the toggle switch 360.

Although the preferred embodiment and various modifications of the device have been described, it will be understood that within the purview of this invention various changes may be made in the form, details, proportion and arrangement of parts, the combination thereof and mode of operation, which generally stated consist in a device capable of carrying out the objects set forth, as disclosed and defined in the appended claims.

Having thus described my invention, I claim:

1. In a stepping device, first and second relatively movable members having opposing surfaces, roller means interposed between said surfaces for rolling engagement therewith, the surface of said first member engaging said roller means at varying elevations relative to the surface of said second member, there being a continuous elevation gradient on said surface, yielding means biasing said roller means to a proximal extreme of said gradient with respect to the opposing surface, motive means for actuating said members one relative to the other to compress said roller means between said opposing surfaces thereby inducing said roller means to roll to a distal extreme of said gradient relative to the opposing surface, said motive means thereby inducing said members to move one relative to the other in the direction of said elevation gradient, structure for supporting said members one for movement along a path coincident with said elevation gradient and the other stationary relative to said path, and a switch including a first operator element operatively connected to said roller means and a second operator element mounted to engage said first operator element when said roller means is at one extreme of said elevation gradient and to disengage said first operator element when said roller means is at the opposite extreme of said elevation gradient.

2. The stepping device according to claim 1 wherein said structure supports said members for relative rotation, the elevation gradient in the surface of said first member extending concentric to the axis of relative rotation, said members, upon operation of said motive means to compress said roller means between the opposing surfaces thereof, being induced to rotate one relative to the other.

3. A rotary stepping device comprising, in combination, motive means, first and second relatively rotatable members having opposing surfaces, one of said members being a stator secured against rotation relative to said motive means, the other of said members being a rotor mounted for rotation relative thereto, said members being relatively movable axially along the axis of relative rotation thereof, roller means interposed between said opposing surfaces for rolling engagement therewith, the surface of said first member engaging said roller means at varying elevations relative to the surface of said second member, there being a continuous elevation gradient on the surface of said first member extending concentric to the axis of relative rotation of said members, said elevation gradient having opposite ends proximal and distal respectively relative to the opposing surface of said second member, yielding means biasing said roller means to the proximal end of

said elevation gradient, said motive means being operable to actuate said members axially to compress said roller means between the opposing surfaces thereof, the construction and arrangement being such that the pressure of said roller means against the elevation gradient in the surface of said first member induces said roller means to roll to the distal end of said elevation gradient thereby imparting rotation to said rotor, and a switch comprising a first operator element operatively connected with said roller means, and a second operator element mounted to engage said first operator element when said roller means is at one end of said elevation gradient and to disengage said first operator element when said roller means is at the opposite end of said elevation gradient.

4. A rotary stepping device comprising, in combination, motive means having an axial stroke, a rotatably journaled shaft, means mounted on said shaft for actuation by said motive means for converting the axial motion of said motive means to rotary motion of said shaft, said means including first and second members mounted for relative rotation upon said shaft, one of said members being secured against rotation and the other being operatively connected to said shaft for rotation therewith, said members having opposing axially spaced surfaces, a roller interposed between said surfaces for rolling engagement therewith, said first member having a plane surface, the surface of said second member engaging said roller at varying elevations relative to the opposing plane surface of said first member, there being an elevation gradient on the surface of said second member concentric with the axis of said shaft, the opposite ends of said gradient being proximal and distal relative to the opposing surface of said first member, a cage element for said roller, resilient means acting on said cage element to bias said roller to the proximal end of said gradient, said motive means being operable to compress said members axially against said roller thereby urging said roller to the distal end of said gradient and inducing said members to rotate, and switch means comprising a first operator element secured fixedly with respect to said cage element and a second operator element positioned to engage said first operator element when said roller is at one end of said elevation gradient, and to disengage said first operator element when said roller means is at the opposite end of said elevation gradient.

5. A rotary stepping device comprising, in combination, motive means having an axial stroke, a rotatably supported shaft, means mounted on said shaft for actuation by said motive means for converting the axial movement thereof to rotary motion of said shaft, said means including a pair of members mounted for relative rotation upon said shaft, one of said members designated a stator being secured against rotation and the other of said members designated a rotor being operatively connected to said shaft for rotation therewith, said members having opposing axially spaced surfaces, a roller interposed between said surfaces for rolling engagement therewith, one of said members having a plane surface, the surface of the other of said members engaging said roller at varying elevations relative to the opposing surface of said one member, there being elevation gradient on the surface of said other member extending concentric to the axis of said shaft, the opposite ends of said gradient being proximal and distal, respectively, relative to the opposing surface, a cage element for said roller interposed between said rotor and stator members, resilient means acting on said cage element to bias said roller to the proximal end of said gradient, said motive means being operable to compress said members axially against said roller urging said roller to the distal end of said gradient thereby inducing relative rotation of said members, said shaft being thereby rotated, and switch means comprising a first operator element operatively connected to said cage element and a second operator element fixedly secured with respect to said stator, said operator elements successively

engaging and disengaging as said roller element reciprocates between the opposite ends of said elevation gradient.

6. A rotary stepping device comprising, in combination, motive means having an axial stroke, a rotatably supported shaft, means mounted on said shaft for actuation by said motive means for converting the axial motion thereof to rotary motion of said shaft, said means including a pair of members mounted for relative rotation on said shaft, one of said members designated a stator being secured against rotation and the other of said members designated a rotor being operatively connected to said shaft for rotation therewith, said members having opposing axially spaced surfaces, a roller interposed between said surfaces for rolling engagement therewith, said stator having a plane surface, the surface of said rotor engaging said roller at varying elevations relative to the opposing plane surface of said stator, there being an elevation gradient on said rotor surface extending concentric with the axis of said shaft, the opposite ends of said gradient being proximal and distal, respectively, relative to the stator surface, a cage element for said roller interposed between said members, resilient means acting on said cage element to bias said roller to the proximal end of said gradient, said motive means being operable to compress said members axially against said roller urging said roller to the distal end of said gradient thereby inducing rotation of said rotor and said shaft through an increment determined by the angle between the proximal and distal ends of said elevation gradient, and switch means comprising a first operator element operatively connected to said cage element, and a plurality of second operator elements secured fixedly with respect to said stator, there being one second operator element for each increment of rotor rotation, said first operator element successively engaging and disengaging said second operator elements as said roller is reciprocated between the opposite ends of said elevation gradient through successive strokes of said motive means.

7. The rotary stepping device according to claim 6 wherein said motive means comprises an armature mounted on said shaft for axial movement and an electromagnet for imparting axial movement to the armature, and wherein said switch is connected electrically in series relation with said electromagnet and with a source of electrical energy for energizing said electromagnet.

8. In combination, a rotary stepping device and an electrical circuit including a master switch and a slave switch for controlling the operation of said stepping device, said stepping device comprising an electromagnet, an armature mounted for axial movement toward said electromagnet, means mounted for actuation by said armature for converting the axial motion thereof to rotary motion, said means including a pair of members mounted for relative rotation, one of said members designated a stator being secured against rotation and the other of said members designated a rotor being mounted for rotation, said members having spaced opposing surfaces, a roller interposed between said surfaces for rolling engagement therewith, the surface of said rotor engaging said roller at varying elevations relative to the opposing surface of said stator, there being an elevation gradient on said rotor surface extending concentric with respect to the axis of relative rotation of said rotor and stator, the opposite ends of said gradient being proximal and distal, respectively, relative to the stator surface, a cage element for said roller, and resilient means acting on said cage element to bias said roller to the proximal end of said gradient, said armature upon energization of said electromagnet compressing said members against said roller urging said roller to the distal end of said gradient and inducing rotation of said rotor through an increment determined by the angle between the proximal and distal ends of said elevation gradient, said slave switch comprising a first contact, means connecting said first contact electrically to said electromagnet, means connecting said

first contact mechanically to said cage element, and a plurality of second contacts secured fixedly with respect to said stator, there being one second contact for engagement with said first contact at each increment of rotor rotation, said master switch comprising a rotor and a stator member, said stator member having a plurality of third contacts, there being one third contact on the stator member of said master switch connected electrically to each second contact of said slave switch, said rotor element having a fourth contact for connection to a source of electrical energy for energizing said electromagnet and engaging simultaneously all but a selected one of said third contacts, the construction and arrangement being such that said first contact engages one of said second contacts when the ball element is at the proximal end of said elevation gradient and disengages all of said second contacts when the ball element is at the distal end of said elevation gradient.

9. In combination, a rotary stepping device and an electrical circuit including a master switch and a slave switch for controlling the operation of the stepping device, said stepping device comprising an electromagnet, a shaft rotatably journaled therein, an armature mounted on said shaft for axial movement toward said electromagnet, means mounted for actuation by said armature for converting the axial motion of said armature to rotary motion of said shaft, said means including a pair of members mounted for relative rotation on said shaft, one of said members designated a stator being secured against rotation, and the other of said members designated a rotor being operatively connected to said shaft for rotation therewith, said members having opposing axially spaced surfaces, a roller interposed between said surfaces for rolling engagement therewith, said stator having a plane surface, the surface of said rotor engaging said roller at varying elevations relative to the opposing plane surface of said stator, there being an elevation gradient on said rotor surface extending concentric with the axis of said shaft, the opposite ends of said gradient being proximal and distal respectively relative to the stator surface, a cage element for said roller interposed between said members, and resilient means acting on said cage element to bias said roller to the proximal end of said gradient, said armature upon energization of said electromagnet compressing said members axially against said roller urging said roller to the distal end of said gradient and inducing rotation of said rotor through an increment determined by the angle between the proximal and distal ends of said elevation gradient, said slave switch comprising a first contact operatively connected to said cage element, a plurality of second contacts secured fixedly with respect to said stator, there being one second contact for engagement with said first contact at each increment of rotor rotation, and means connecting said first contact with the electrical input to said electromagnet, said master switch comprising a stator element having a plurality of third contacts thereon, each third contact being connected electrically to a different one of the second contacts of said slave switch, and a rotor element having a fourth contact thereon for simultaneously engaging all but a selected one of the contacts on said stator element, the construction and arrangement being such that said first contact engages one of said second contacts whenever said ball element is at the proximal end of said elevation gradient and disengages all of said second contacts whenever said ball element is at the distal end of said gradient.

10. A rotary stepping device comprising, in combination, motive means having an axial stroke, a rotatably supported shaft, means mounted on said shaft for actuation by said motive means for converting the axial motion thereof to rotary motion of said shaft, said means including a pair of members mounted for relative rotation on said shaft, one of said members designated a

stator being secured against rotation and the other of said members designated a rotor being operatively connected to said shaft for rotation therewith, said members having opposing axially spaced surfaces, a roller interposed between said surfaces for rolling engagement therewith, said stator having a plane surface, the surface of said rotor having an arcuate inclined recess therein extending concentric with the axis of said shaft, the opposite ends of said recess being proximal and distal respectively relative to the stator surface, a cage element for said roller interposed between said members, resilient means acting on said cage element to bias said roller to the proximal end of said recess, said motive means being operable to compress said members axially against said roller urging said roller to the distal end of said recess thereby inducing rotation of said rotor through an increment determined by the angle between the proximal and distal ends of said recess, and switch means comprising a first operator element operatively connected to said cage element, and a plurality of second operator elements secured fixedly with respect to said stator, there being one second operator element for engagement with said first operator element at each increment of rotor rotation, said first operator element successively engaging and disengaging said second contacts as said roller is reciprocated between the opposite ends of said recess through successive strokes of said motive means.

11. In a stepping device, first and second relatively movable members having opposing surfaces, roller means interposed between said surfaces for rolling engagement therewith, the surface of said first member engaging said roller means at varying elevations relative to the surface of said second member, there being a continuous elevation gradient in the surface of said first member, yielding means biasing said roller means to a proximal extreme of said gradient with respect to the opposing surface, motive means for actuating said members one relative to the other to compress said roller means between said opposing surfaces thereby inducing said roller means to roll to a distal extreme of said gradient relative to the opposing surface, said motive means thereby inducing said members to move one relative to the other in the direction of said elevation gradient, structure for supporting said members one stationary and the other for movement relative thereto, and means controlled by movement of said roller means relative to said first member for actuating said motive means when said roller means is at one end of said elevation gradient and for deactuating said motive means when said roller means is at the opposite end of said gradient.

12. In a stepping device, first and second relatively movable members having opposing surfaces, a roller interposed between said surfaces for rolling engagement therewith, the surface of said first member engaging said roller at varying elevations relative to the surface of said second member, there being a continuous elevation gradient in the surface of said first member, an element caging said roller between said opposing surfaces, yielding means operating between said caging element and said first member to bias said roller to a proximal extreme of said gradient with respect to the opposing surface, motive means for actuating said members one relative to the other to compress said roller between said opposing surfaces thereby inducing said roller to roll to a distal extreme of said gradient with respect to the opposing surface, said motive means thereby inducing said members to move one relative to the other in the direction of said elevation gradient, structure for supporting said members one stationary and the other for movement relative thereto, and switch means operative to regulate the operation of said motive means, said switch means including a first operator element carried by said caging element and a second operator element mounted separate from said caging

ing element for engagement with said first operator element.

13. A rotary stepping device comprising, in combination, an electromagnet, a shaft rotatably journaled therein, an armature mounted on said shaft for axial movement toward said electromagnet, means mounted for actuation by said armature for converting the axial motion of said armature to rotary motion of said shaft, said means including first and second members mounted for relative rotation upon said shaft, one of said members being secured against rotation and the other being operatively connected to said shaft for rotation therewith, said members having opposing axially spaced surfaces, a roller interposed between said surfaces for rolling engagement therewith, said first member having a plane surface, the surface of said second member engaging said roller at varying elevations relative to the opposing plane surface of said first member, there being an elevation gradient on the surface of said second member concentric with the axis of said shaft, the opposite ends of said gradient being proximal and distal relative to the opposing surface of said first member, a cage element for said roller, resilient means acting on said cage element to bias said roller to the proximal end of said gradient, said armature upon energization of said electromagnet compressing said members axially against said roller thereby urging said roller to the distal end of said gradient and inducing said rotor to rotate, and means controlled by movement of said cage element relative to said second member for energizing said electromagnet when said roller is at the proximal end of said gradient and for deenergizing said electromagnet when said roller is at the opposite end of said gradient.

14. A rotary stepping device comprising, in combination, motive means having an axial stroke, a rotatably supported shaft, means mounted on said shaft for actuation by said motive means for converting the axial movement thereof to rotary motion of said shaft, said means including a pair of members mounted for relative rotation upon said shaft, one of said members designated a stator being secured against rotation and the other of said members designated a rotor being operatively connected to said shaft for rotation therewith, said members having opposing axially spaced surfaces, a roller interposed between said surfaces for rolling engagement therewith, said rotor having a plane surface, the opposing stator surface being inclined along a path concentric with said shaft between extremes proximal and distal relative to the rotor surface, a cage element for said roller interposed between said rotor and stator members, resilient means acting on said cage element to bias said roller to the proximal end of said gradient, said motive means being operable to compress said members axially against said roller urging said roller to the distal end of said gradient thereby inducing relative rotation of said members, and switch means including a first operator element operatively connected to said cage element and a second operator element fixedly secured with respect to said stator, said operator elements cooperating to make switch contact during the time said cage element rotates in one direction relative to the stator and to break switch contact during the time said cage element rotates in the opposite direction.

15. A rotary stepping device according to claim 14 wherein said second operator is a toggle action switch and wherein said first operator comprises a cam having lost motion for actuating said switch oppositely at extremes of the rotary movement of said cage element.

16. A rotary stepping device comprising, in combination, motive means having an axial stroke, a rotatably supported shaft, means positioned for actuation by said motive means for converting the axial motion thereof to rotary motion of said shaft, said means including a pair of members mounted for relative rotation on said shaft, one of said members designated a stator being secured against rotation and the other of said members designated

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a rotor being operatively connected to said shaft for rotation therewith, said members having opposing axially spaced surfaces, a roller interposed between said surfaces for rolling engagement therewith, said stator having a plane surface, the surface of said rotor engaging said roller at varying elevations relative to the opposing plane surface of said stator, there being an elevation gradient on said rotor surface extending concentric with the axis of said shaft, the opposite ends of said gradient being proximal and distal, respectively, relative to the stator surface, a cage element for said roller interposed between said members, resilient means acting on said cage element to bias said roller to the proximal end of said gradient, said motive means being operable to compress said members axially against said roller urging said roller to the distal end of said gradient thereby inducing rotation of said rotor through an increment determined by the angle between the proximal and distal ends of said elevation gradient, and an interruptor switch secured fixedly with respect to said stator, said cage element having a substantially circular periphery with a plurality of equispaced cam bosses thereon for operating said switch, there being one cam boss for each increment of rotor rotation, each cam boss having a length along the periphery of said cage corresponding substantially to the length of said elevation gradient.

17. A rotary stepping device comprising, in combination, a housing, a shaft rotatably supported therein, motive means having an axial stroke disposed within said housing, means positioned for actuation by said motive means for converting the axial motion thereof to rotary motion of said shaft, said means including a pair of members mounted for relative rotation on said shaft, one of said members designated a stator being secured against rotation with respect to said housing and the other of said members designated a rotor being operatively connected to said shaft for rotation therewith, said members having opposing axially spaced surfaces, a roller interposed between said surfaces for rolling engagement therewith, said stator having a plane surface, the surface of said rotor engaging said roller at varying elevations relative to the

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opposing plane surface of said stator, there being an elevation gradient on said rotor surface extending concentric with the axis of said shaft, the opposite ends of said gradient being proximal and distal, respectively, relative to the stator surface, a cage element for said roller interposed between said members, resilient means acting on said cage element to bias said roller to the proximal end of said gradient, said motive means being operable to compress said members axially against said roller to the distal end of said gradient thereby inducing rotation of said rotor and said shaft through an increment determined by the angle between the proximal and distal ends of said elevation gradient, and switch means comprising an interruptor switch secured fixedly relative to said stator, a substantially annular cam member supported for rotation in said housing, and means interengaging said cam member and said cage element for unison rotation, said cam member having a plurality of equispaced bosses on the periphery thereof for actuating said interruptor switch, there being one boss for each increment of rotor rotation, said bosses each having a length along the periphery of said cam element corresponding substantially to the length of said elevation gradient.

18. The rotary stepping device according to claim 17 wherein said housing has a circular inner wall in the plane of said cage element concentric to the axis of rotation of said shaft, said bosses slidably engaging the inner wall to support said cam member for rotation about the axis of rotation of said shaft, and wherein the means interengaging said cage element with said cam member includes a lobe projecting outwardly from said cage element, said cam member having a notch in the inner periphery thereof loosely receiving said lobe.

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