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E. F. LOUGHRAN, JR

3,543,589

CAM WITH BALANCED SPRING-LOADED FOLLOWERS

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2 Sheets-Sheet 1

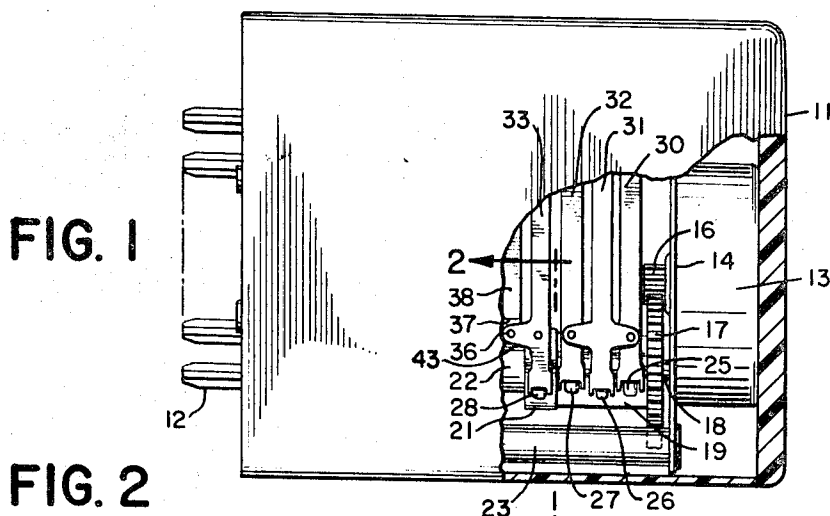


FIG. 2

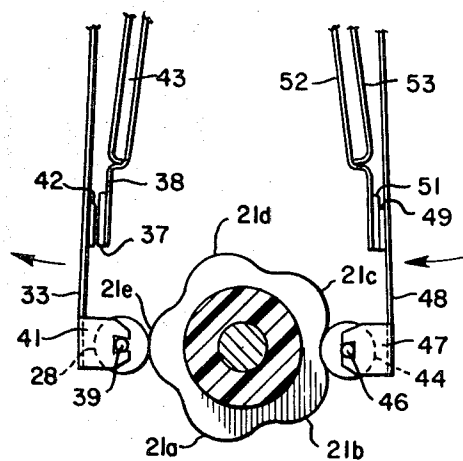
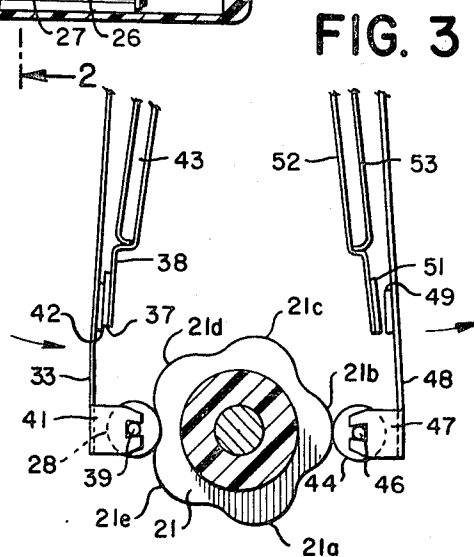
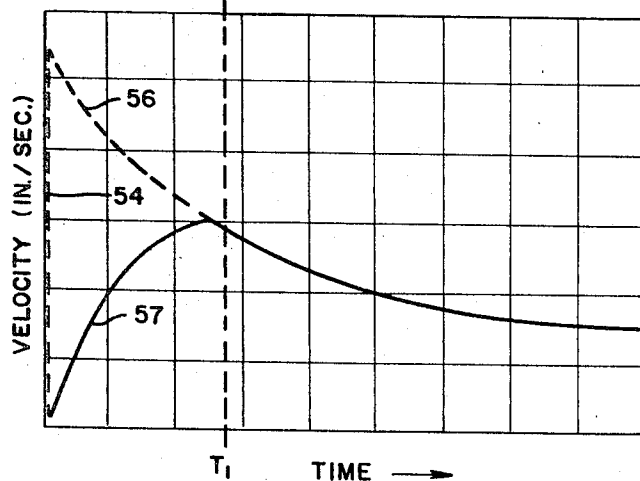


FIG. 4

INVENTOR
EUGENE FRANCIS LOUGHRAN

BY

Donald P. Dickhoff

ATTORNEY

Dec. 1, 1970

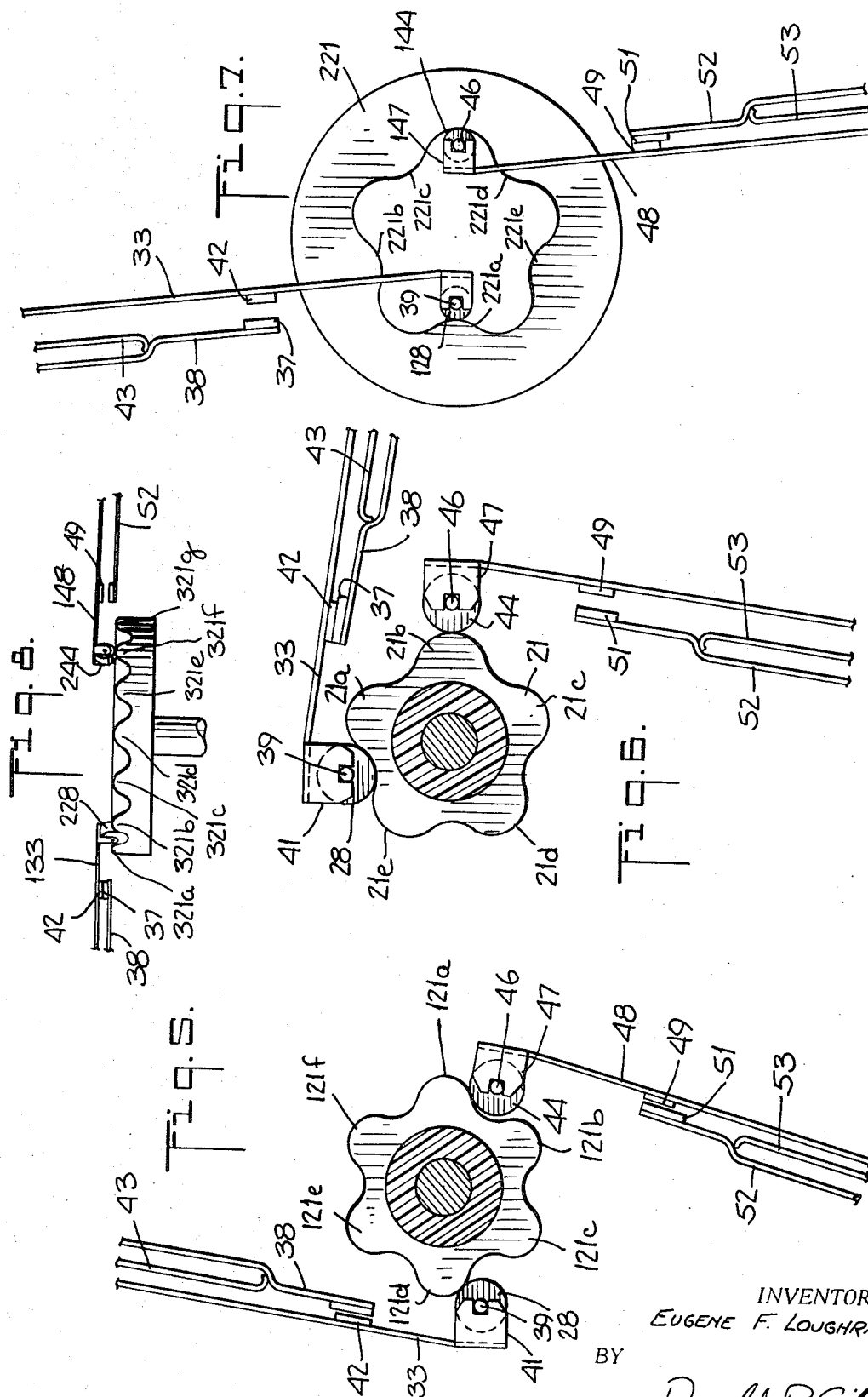
E. F. LOUGHRAN, JR

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INVENTOR.
EUGENE F. LOUGHRAN, JR.

BY

Donald P. Gillette
ATTORNEY

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CAM WITH BALANCED SPRING-LOADED FOLLOWERS

Eugene F. Loughran, Jr., Oakville, Conn., assignor to North American Philips Corporation, New York, N.Y., a corporation of Delaware
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11 Claims

ABSTRACT OF THE DISCLOSURE

A cam having a plurality of substantially equal lobes evenly spaced around an axis and having two cam followers spaced apart so that when one is on a rising portion of a lobe and thereby withdrawing energy from the mechanism that drives the cam, the other is on the falling portion of a lobe and is thereby returning energy to the cam in an amount of energy being withdrawn by the first cam follower.

This is a continuation-in-part of my co-pending application Ser. No. 466,963 filed June 25, 1965.

This invention relates to a cam with balanced spring-loaded followers and particularly to a cam usable in a cam-actuated switch assembly for a repeating interval timer or the like as shown and described in Kavanaugh Pat. 2,953,667 and Haydon Pat. 3,106,620.

In cam-actuated switches of the type described in the Kavanaugh and Haydon patents, supra, a small electric motor is required to supply sufficient power to drive a plurality of cams each of which actuates a number of switch contacts mounted on spring blades. Some of the switch blades are arranged so they bear against only one side of the cam while others are arranged in balanced pairs so that they provide substantially equal and opposite forces to offset each other so as not to create any side loading on the bearings for the cam. However, in all of the foregoing cam-actuated switches, each cam has either had its cam followers acting only on one side of it or, if it had balanced cam followers, the cam had an even number of equal lobes. Thus, in either case the motor had to supply sufficient power to rotate the cam and to accelerate the followers. The loading of the cam followers, where there are two of them operating on identical lobes and both moving in together and out together, is additive. The torque available from the motor could be effectively increased by gearing down the speed of the motor but where there is a minimum speed of operation of the cam and a maximum speed of operation of the motor, or perhaps a fixed synchronous speed of the motor, there is a limit to the number of gears that can be used. There is also some loss, although it may be very small, in each additional gear.

When a spring blade forces a cam follower against the surface of a cam, several forces are produced that must be overcome by the torque of the motor that drives the cam. For one thing the follower may exert a direct frictional drag on the cam. This can be reduced within limits by using roller followers having low inherent friction, or by suitable lubrication, or both. Even so, there is still some drag, and this is related to the force of the spring that presses the follower against the surface of the cam. In addition to supplying the pressure that produces the friction loading of the cam follower on the cam, the spring produces a force of its own that must be overcome by the torque of the motor, as will be discussed hereinafter. Another force arises from the product of the mass of the follower times the acceleration that the follower

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has to undergo. Thus if the cam has a rather steep incline that forces the follower against the pressure of its spring, there is a force which is proportional to the second derivative with respect to time of the movement of the cam follower along the inclined surface. This force is also proportional to the mass of the cam follower and can be reduced by reducing the mass, but again, in any design there is always a minimum mass for that particular design and once this has been reached, the only way of reducing this force is to reduce the acceleration of the follower, which is the same thing as reducing the rate of change of velocity of the follower with respect to time.

The present invention proposes an additional cam follower as a novel means of overcoming or, more properly, compensating part of the forces exerted on the motor that drives the cam. In accordance with the present invention a cam having an odd number of lobes is used with at least two cam followers acting on diametrically opposite points of the circumference. In this way, as one of the followers is being pushed outwardly away from the axis of the cam, energy is stored in it. Simultaneously the other follower is moving inwardly toward the axis of the cam and is returning its previously stored energy to the cam, thus providing an additional force that tends to assist the cam in rotating. This is opposite to the force that is required to thrust the other cam follower outwardly and thus tends to reduce the total amount of torque required of the electric drive motor. By proper formation of the lobes, the energy withdrawn from the cam by one follower can be nearly matched at any time by the energy returned to the cam from the other follower.

Further in accordance with the invention, the cam lobes are shaped so as to reduce the initial velocity of the cam followers. Since acceleration is proportional to the rate of change of velocity with respect to time, reduction in initial velocity also reduces the rate that the velocity changes initially and this means that the initial acceleration, which requires much of the torque of the motor, is reduced.

The invention will be described in greater detail hereinafter in connection with the drawings in which:

FIG. 1 shows a side view of a cam-actuated switch constructed according to the invention with part of the outer shell broken away to disclose the operating mechanism;

FIG. 2 is a cross-sectional view along the line 2—2 in FIG. 1 of a cam and follower mechanism in the switch of FIG. 1 constructed according to the invention;

FIG. 3 shows the apparatus of FIG. 2 at a different point in the operating cycle of the cam;

FIG. 4 is a graph of velocity versus time of the contacts in the switches of FIGS. 2 and 3;

FIG. 5 shows a different embodiment of the invention comprising a cam having an even number of lobes;

FIG. 6 shows an embodiment of the invention in which the cam followers are not diametrically opposite each other;

FIG. 7 shows an embodiment of the invention comprising an internal cam; and

FIG. 8 shows an embodiment of the invention comprising a disc cam.

The cam-actuated switch in FIG. 1 has an outer housing 11 and a plurality of contact pins 12 at one end to fit into a standard socket. The operating mechanism includes a motor 13, which may be governed or synchronous, constant speed motor mounted on a plate 14 and provided with a pinion 16 that meshes with a larger gear 17 rotatably mounted on an axle 18. The gear is rigidly connected to a first cam 19 and to a second cam 21 constructed according to the present invention. In addition the gear 17 is connected to a shaft 22 and through the latter to

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additional elements that play no part in the present invention and therefore are not shown. The plate 14 is attached by means of spacer rods, one of which is indicated by reference number 23, to other parts of the cam-actuated switch that must be supported rigidly with respect to the motor 13.

Several cam followers 25-28 are shown, each supported on its own resilient arm 30-33, respectively. The specific form of the cam followers and the means of mounting the followers is described and claimed in Kavanaugh Pat. 2,953,667, supra, and reference may be had to that patent for further description. In addition the relative spacings and arrangements of the cam followers 25-27 and their arms 30-32 may be constructed in accordance with the Haydon Pat. 3,106,620.

The arm 33 is provided with a contact that is attached to a spur 34 extending from one side of the arm. This contact may be welded in place or affixed by any other convenient means and is not visible in FIG. 1 although the weld mark 36 is shown there. This contact cooperates with a facing contact 37 on a resilient arm 38 located close to the arm 33.

In the design of switches of the type illustrated by the cam follower 28, its arm 33, the spur 34, and the contact 37 with its arm 38, the engineering specifications may include not only the spacing between the contacts when they are separated by a maximum amount but also the distance through which the cam follower 28 must move before disengagement of the two contacts is effected, as well as the pressure of both of the resilient contact arms 33 and 38 and even the velocity of the cam follower at the instant of separation of the two contacts from each other or at the instant of their coming together again. All of these requirements make the design of a satisfactory cam-actuated switch far from the simple matter it would appear to be on its surface.

FIG. 2 shows the cam 21 and the follower 28 in greater detail. As may be seen, the cam 21 has five lobes 21a-21e. The cam follower 28 is in the form of a roller having a stub axle 39 snapped into a recess formed in the end of a bent-over tab 41 at the end of the arm 33 and having an entrance smaller than the diameter of the axle 39. There are actually two such tabs, but the other is directly behind the tab 41 and therefore does not appear in this drawing.

The contact mounted on the spur 34 is indicated by reference number 42 and is directly facing another contact 37 supported by the arm 38. This arm is partly positioned by a more rigid arm 43 that determines the limit of motion of the contact 37 to the left, as the contact is shown in FIG. 2. The arm 38 is formed with a certain resilient force against the arm 43, although this resilient force may be less than the force applied by means of the contact 42 when follower 28 is farthest to the right. In the position shown in FIG. 2 there is no force of the contact 42 upon the contact 37 because the arm 33 is as far left as it will go in normal operation. Matching the cam follower 28 but on the other side of the cam 21 is a second follower 44 of similar dimensions. This follower has its own stub axle 46 held within a recess in the end of a bent-over tab 47 formed at the end of a resilient arm 48. The latter corresponds exactly to the arm 33 and has a contact 49 in juxtaposition to another contact 51 on the end of a resilient arm 52 that matches the arm 38. A relatively rigid arm 53 limits the movement of the contact 51 to the right.

FIG. 2 shows the cam 21 in a position such that the cam follower 28 is on the peak of the lobe 21e while the cam follower 44 is in the bottom of the pocket formed between the lobes 21b and 21c. The contact 49 is as firmly pressed against the contact 51 as the resilient forces in the arms 48 and 52 will permit while the contact 37 is as much separated from the contact 42 as the construction will allow. Any rotation whatsoever of the cam 21 from the position shown will cause the follower 28 to slide

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down from its peak and will correspondingly cause the follower 44 to move outwardly. Assuming that the rotation is clockwise the cam follower 28 will slide down that face of the lobe 21e toward the pocket between the lobes 21a and 21e while the follower 44 will start to rise up the slope of the lobe 21c.

In the absence of any other forces, the pressure of the arm 33 on the follower 28 and from the follower 28 onto the downward slope of the lobe 21e would cause the cam 21 to rotate until the follower 28 came to rest in the pocket between lobes 21a and 21e, as shown in FIG. 3. In doing so the spring arm 33 would give up the energy stored in it in moving from the pocket between the lobes 21d and 21e to the peak of lobe of 21e. Moreover, by proper design of the contour of the lobes of the cam 21, the amount of energy given up by the arm 33 to the cam at any instant would be substantially equal to the amount of energy withdrawn from the cam 21 by the arm 48 at the same instant.

Of course it is impossible to compensate the withdrawn energy by the returned energy precisely; there is always a small amount of energy that is lost and the shapes of the cam lobes are such that slightly more energy may be withdrawn at any given instant than is being replaced or vice versa. Even so, and taking into account that there will be a net loss overall, there is still a net gain with respect to the condition that would prevail in the absence of one of the cam follower systems. That is, if the cam follower 44 and the arm 48 to which it is attached were removed from any contact with the cam 21 so that only the cam follower 28 rode upon the surface of the cam 21, the torque required of the motor would be significantly greater than it is when there are two spring-loaded cam followers 28 and 44.

FIG. 4 is a graph of the velocity of one of the cam followers, for example, the follower 28 with respect to time. It is desired that the contacts 42 and 37 separate at a predetermined time T_1 . In addition the velocity of the contact 42 at the instant of separation should be relatively high so that there will be a clean break in the electrical circuit. Heretofore this has meant that the cam lobes would have to be shaped so as to start the motion of the cam follower suddenly as indicated by the dotted vertical line 54 at the left-hand part of the graph. Following the sudden start, the velocity of the cam follower would decrease along the dotted curve 56 to the desired velocity at the time T_1 . As stated hereinabove, the acceleration is the rate of change of velocity with respect to time and the force required to set the cam follower suddenly into motion is proportional to this acceleration. As may be seen by inspection of the line 54, its slope is quite steep and in fact is almost vertical, which means that the acceleration is very high and therefore the force required to produce this acceleration is correspondingly high. Since this force must be produced by the motor as torque, the minimum torque of the motor must be at least high enough to produce the initial acceleration of the follower, plus, of course, other loads in the rest of the device. However, the torque required to accelerate the followers is a significant part of the total torque required of the motor.

In accordance with the present invention, the lobes 21a-21e of the cam 21 have been shaped so that the velocity of each of the cam followers 28 and 44 changes rather slowly from zero to a maximum which is not much greater than the value at the time T_1 . This relatively slowly increasing velocity is indicated by the curve 57. The maximum slope of this curve is very much less than the line 54 and therefore the acceleration is also very much less. Thus, the force required to move even one of the cam followers 28 or 44 by means of the cam lobe shaped as shown in FIGS. 2 and 3 is minimized. In addition the lobes are so shaped that the acceleration of the cam follower 28, for example, toward the center of the shaft 18 to the peak of the lobe 28e, for example,

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is approximately the same as the acceleration of the cam follower 44 radially away from the axis of the shaft 18 along surface of the cam lobe 21c, for example. This permits the energy stored in the resilient arm 33 to be given back to the cam in about the same measure as energy is withdrawn from the cam.

In order to balance out radial forces on the cam, the cam followers should strike diametrically opposite points of the cam surface. This requires that the cam have an odd number of lobes so that one of the followers can be on the peak of one lobe while the diametrically opposite follower is in the center of a pocket between two lobes. If a radial force can be tolerated, as it frequently can, the cam may have an even number of lobes and one of the followers may be displaced so that it is not diametrically opposite the other follower. Such a structure is shown in FIG. 5 in which the cam 121 has six lobes 121a-121f. The followers are the same as in the embodiment in FIGS. 2 and 3 and have been given the same reference numerals, and except for the fact that the follower rollers 28 and 44 are not exactly diametrically opposed, the operation of this embodiment is the same as that in FIGS. 2 and 3. The follower rollers 28 and 44 are angularly disposed around the cam 121 so that they are 180 operating degrees out of phase with each other, that is, as the roller 28 is rolling up the inclined leading surface of one of the lobes, for example, lobe 121d, the roller 44 is rolling down the falling surface of one of the other lobes, in this case the lobe 121a. This permits the cam follower roller 44 to give energy that has been stored in the spring 48 back to the rotating cam mechanism simultaneously with and in approximately the same amount as the amount of energy being withdrawn from the cam operating mechanism by the roller 28 and being stored in the spring 33.

Another structure in which there is an even higher unbalanced radial load on the cam is shown in FIG. 6, which has the same five-lobed cam 21 as in FIGS. 2 and 3. However, the follower roller 44 and components connected to it have been moved so that it is no longer diametrically opposite the cam follower 28. Instead of being on top of the lobe 21c when the follower roller 28 is centered in the pocket between the lobes 21e and 21a, the follower roller 44 is shown at the instant that it rests on the peak of the lobe 21b. Again, the follower roller 44 is 180 operating degrees out of phase with respect to the follower roller 28.

It is not necessary that the rollers operate on external cam surfaces. FIG. 7 shows a similar operation utilizing an internal cam 221. The structure in FIG. 7 uses relatively small diameter follower rollers 128 and 144 which have relatively much smaller radii than the radius of curvature of the pockets between the inwardly-directed lobes 221a-221e in contrast to the rollers 28 and 44 in FIG. 2, which have radii only slightly smaller than the radius of curvature of the pockets between the lobes 21a-21e. The follower rollers 128 and 144 are shown diametrically opposed to each other and they are also 180 operating degrees out of phase.

The followers in the embodiments described hereinabove have all operated on cylindrical cam surfaces. However, the energy-balancing effect of the invention can also be realized in the case of a disk such as the cam 321 shown in FIG. 8. In this case, the cam has a multiplicity of lobes of which only the lobes 321a and 321 are shown. These lobes form an axially fluted surface on the cam 321. As may be seen, one of the follower rollers 228 is centered in the pocket between the lobes 321a and 321b, at the same time that the other follower roller 244 rests on the top of the lobe 321f. Except for the fact that the follower rollers press axially against the cam surface of the cam 321, the operation is the same as in the earlier embodiments and energy stored in the resilient member 133 will be returned to the cam 321

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at the same time that the resilient member 148 is extracting energy from the cam.

While this invention has been described in terms of a specific embodiment, it will be understood that modifications can be made therein without departing from the true scope of the invention.

What is claimed is:

1. Cam and follower mechanism comprising: a cam rotatably mounted on an axis and having a cam surface divided into a plurality of substantially identical, symmetrical, continuously rounded lobes separated from each other by the same number of pockets, each of said pockets having a predetermined contour; and a pair of followers disposed about the cam and separated by substantially 180 operating degrees, each of said followers having substantially identical convex portions bearing upon said cam surface, and separate and substantially equal resilient means supporting each of said followers and forcing said followers into contact simultaneously with said cam surface at all times whereby energy stored in one of said resilient means when the cam follower supported thereby is on a rising portion of one of said lobes produces a torque on the cam that is substantially equal and opposite to the torque resulting from the transmission of energy from the other of said resilient means through the cam follower supported thereby to the following portion of the lobe against which said last-named cam follower is pressed.

2. The cam and follower mechanism of claim 1 in which said cam surface is a cylindrical surface.

3. The cam and follower mechanism of claim 2 in which said convex portions of said followers are on diametrically opposite sides of said cam surface and in which the number of said lobes is odd and at least as great as five.

4. The cam and follower mechanism of claim 2 in which said cam surface is an external cylindrical surface of said cam.

5. The cam and follower mechanism of claim 2 in which said cam surface is an internal cylindrical surface of said cam.

6. The cam and follower mechanism of claim 1 in which there is an even number of said lobes.

7. The cam and follower mechanism of claim 1 in which said cam is an end cam and said cam faces in an axial direction.

8. The cam and follower mechanism of claim 1 in which each of said pockets has a predetermined minimum radius of curvature and each of said convex portions has a radius of curvature slightly less than the minimum radius of curvature of said pockets.

9. The cam and follower mechanism of claim 1 in which each of said pockets has the same predetermined minimum radius of curvature and each of said convex portions has a radius of curvature substantially less than the minimum radius of curvature of each of said pockets.

10. Cam and follower mechanism comprising: a radial disk cam rotatably mounted on its axis and having a cam surface divided into an odd number of substantially identical, symmetrical, continuously rounded, convex lobes separated from each other around the periphery of said cam by the same number of concave pockets, each of said pockets having a predetermined contour; and a pair of diametrically opposed convex followers bearing upon said cam, each of said followers having a contour substantially equal to said contour of said pockets; and separate substantially equal resilient means supporting each of said followers and forcing said followers into contact simultaneously with diametrically opposed portions of said cam surface at all times whereby the force of acceleration of one of said followers being urged radially outwardly by the inclined portion of one of said cam lobes is substantially equal and opposite to the force of acceleration of the other of said cam followers being urged radially inwardly by its resilient means against the diametrically

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opposed portion of the cam surface to minimize the net force opposed to the rotation of said cam due to acceleration forces of said followers.

11. The cam and follower mechanism of claim 10 in which said followers are rollers rotatably supported on said resilient means.

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FRED C. MATTERN, Jr., Primary Examiner

F. D. SHOEMAKER, Assistant Examiner

U.S. Cl. X.R.

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