United States Patent

[11] 3,602,615

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[21] Appl. No. **13,544**
[22] Filed **Feb. 24, 1970**
[45] Patented **Aug. 31, 1971**
[73] Assignee **The Bendix Corporation**

[54] **ACTUATOR WITH IMPROVED TOOTH PROFILE**
6 Claims, 5 Drawing Figs.

[52] **U.S. Cl.** **418/61, 74/804**
[51] **Int. Cl.** **F01c 1/02**
[50] **Field of Search** 418/61; 74/804

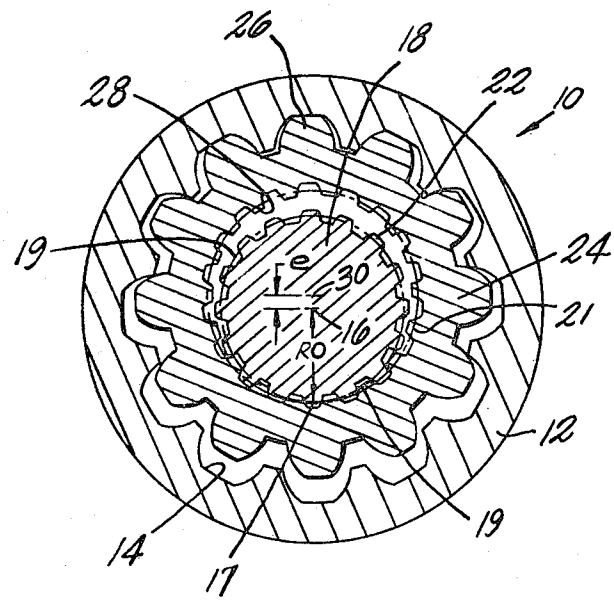
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ABSTRACT: An actuator of a type which includes a stationary member having a plurality of gear tooth cavities arranged in an approximately circular formation about an axis, an output gear arranged in a coaxial relation with the stationary member axis, a free floating ring gear having a pitch center of internal teeth which is spaced a predetermined distance from said axis, the ring gear having its internal teeth arranged in an engaged driving relation with the output gear and having a plurality of external teeth corresponding in number to the number of cavities in the stationary member wherein the ring gear teeth and the gear tooth cavities in the stationary member are of arcuate shape to thereby provide the actuator with rotation constraint of the ring gear such that uniform rotation of the ring gear internal teeth pitch circle center about the output gear center will result in uniform rotation of the output gear. A form of the actuator is also disclosed in which the arcuate teeth are on the stationary member and the gear tooth cavities are in the ring gear.



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SHEET 1 OF 2

FIG. 1

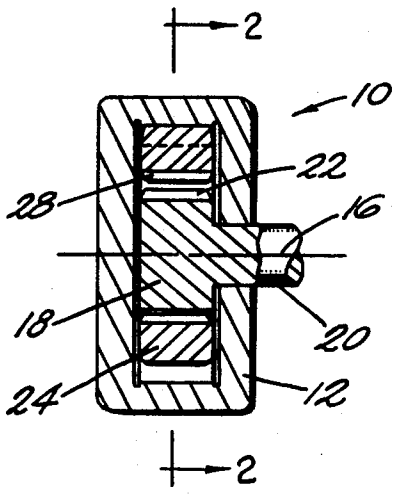


FIG. 2

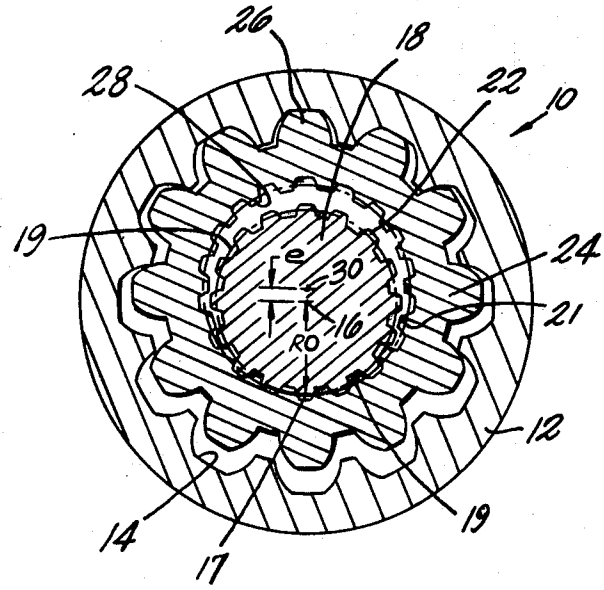
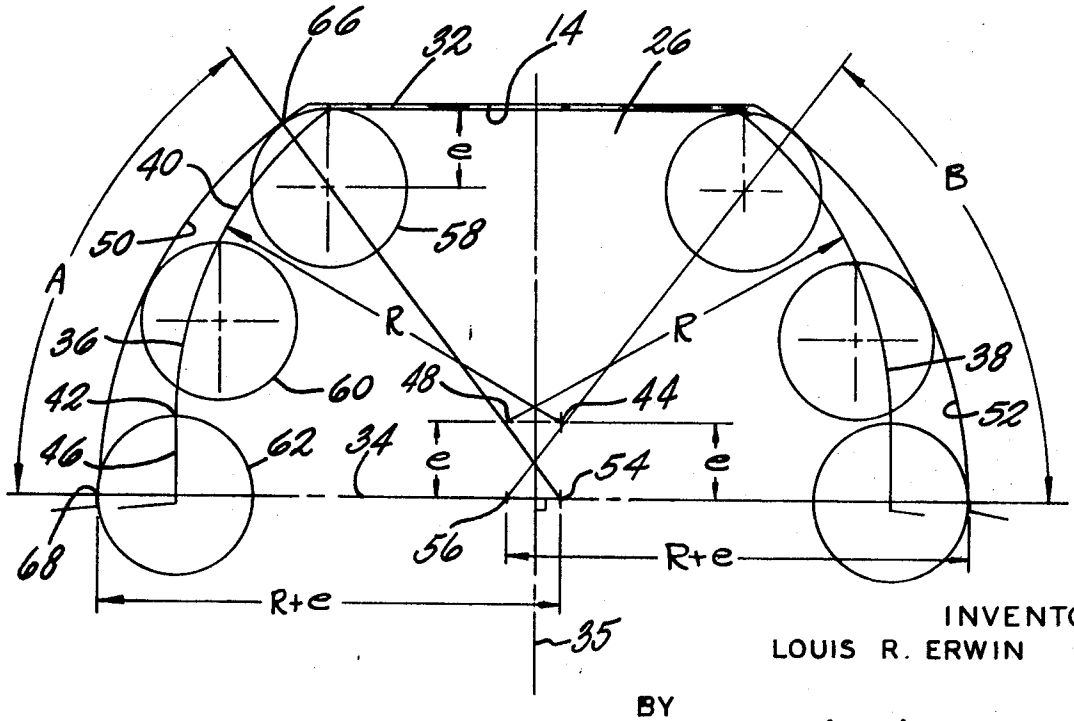


FIG. 3



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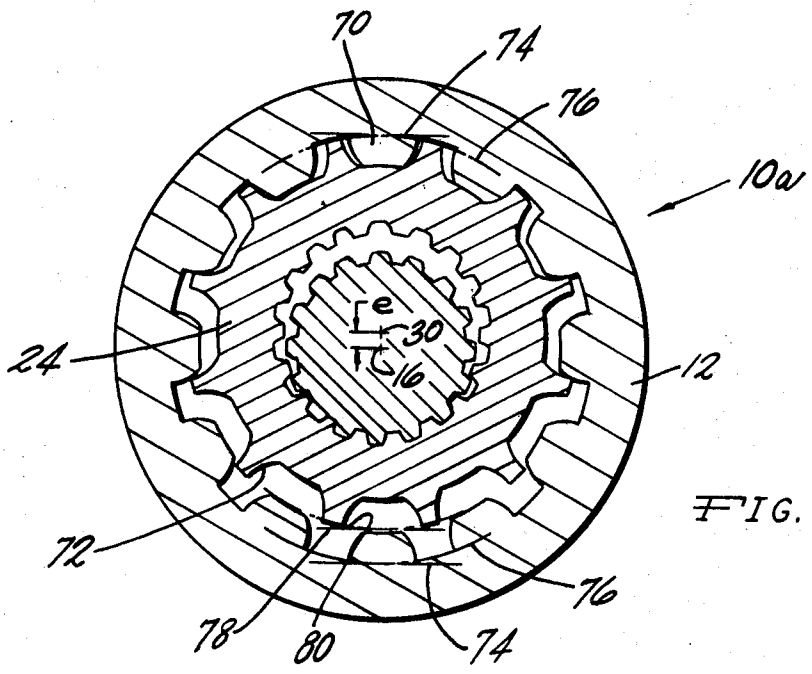


FIG. 4

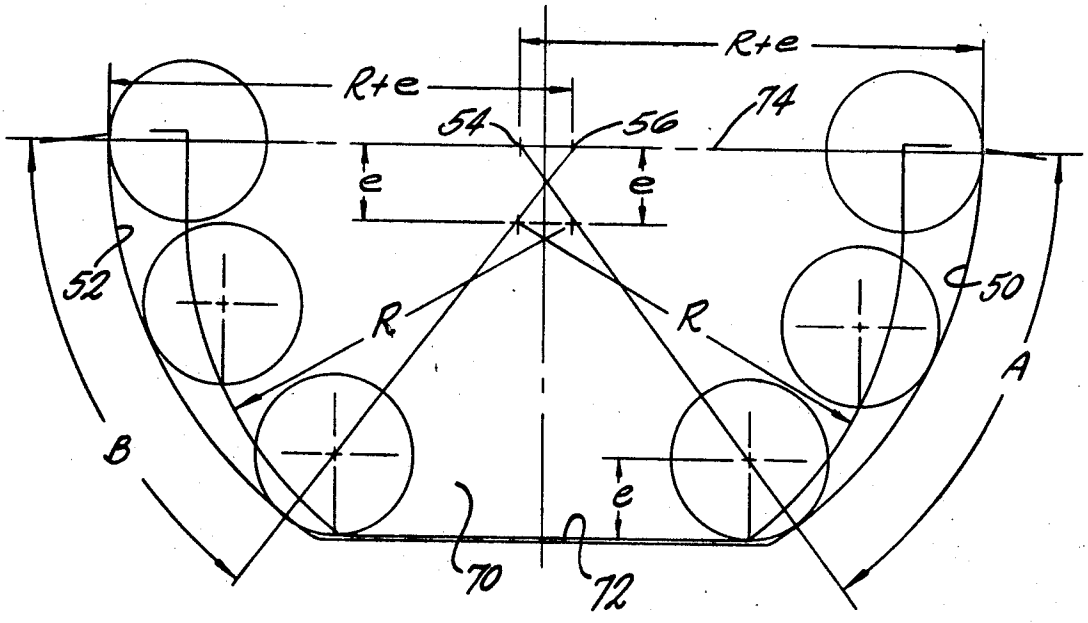


FIG. 5

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ACTUATOR WITH IMPROVED TOOTH PROFILE

CROSS REFERENCE TO COPENDING APPLICATIONS

The actuator of this invention is an improvement on the actuators shown in copending application Ser. No. 667,459 filed Sept. 13, 1967 and application Ser. No. 678,951 filed Oct. 30, 1967, now Pat. No. 3,516,765, owned by the assignee of this application.

SUMMARY OF THE INVENTION

This invention relates generally to an actuator of the general type described in the aforementioned copending patent applications in which a free floating eccentric ring gear is moved in an orbital path by a rotating force so that it coacts with a stationary member and an output member to drive the output member. In particular, this invention relates to an actuator of this type in which there is a 1:1 gear ratio relationship between the stationary member and the ring gear. When the ring gear external teeth are of the conventional involute shape in this general type of actuator, ratios other than 1:1 can be designed with resulting well defined contact ratios. Contact ratio is the ratio of the arc of action to the circular pitch. The arc of action is the arc of the pitch circle through which a tooth travels from the time it first makes contact with a mating tooth until contact with the mating tooth is discontinued. In the 1:1 ratio case, the contact ratio computed by the involute formulas becomes undefined and it can be shown that motion of the ring gear center about the output gear center without ring gear rotation is not accompanied by continuous contact with the stationary member. Since contact with the stationary member is required to provide a reaction point for the ring gear, motion in the 1:1 ratio case cannot be simple circular motion of the ring gear center about the output gear center but must necessarily involve ring gear rotational movement. This rotational movement is undesirable as it causes nonuniform output gear torque and speed, even if the torque on the ring is completely uniform. Also, due to the very complex ring gear motion, tooth loads and contact point sliding velocities are very difficult to compute, which leads to difficulty with design for adequate wear. This invention constrains ring gear rotation about the internal teeth pitch circle center while allowing that center to move around the output gear center.

According to one form of this invention, the teeth on the ring gear, and the corresponding tooth cavities formed in the stationary member, are formed with arcuate surfaces which provide for a continuous contact of a gear tooth on the ring gear with the adjacent wall of the stationary member and for a smooth transfer of contact with the stationary member from one ring gear tooth to the next. Each tooth on the ring gear which meshes with the stationary member is shaped so that it has a terminal end, a base line, and a pair of side surfaces extending from the base line to the terminal end, with each of the side surfaces being of a generally arcuate shape. When one of the ring gear teeth is positioned symmetrically within a tooth cavity in the stationary member, the cavity sidewalls which are also arcuate, are shaped so that the spacing between each cavity sidewall and the adjacent tooth sidewall progressively decreases in a direction toward the tooth end. The axis of revolution for each arcuate tooth sidewall is positioned between the tooth baseline and the tooth end and is spaced from the baseline a distance corresponding substantially to the spacing between the center of the pitch circle of the internal teeth of the ring gear and the axis of the output gear. The axis of revolution of each tooth cavity sidewall is located substantially on the tooth base line when the tooth is positioned symmetrically within the cavity.

This particular tooth construction provides for continuous contact of a tooth with a cavity sidewall when the ring gear is in a positions to make that tooth the working tooth. When the ring gear has orbited to a position in which the next successive tooth is the working tooth, there is a smooth transfer of contact from the first working tooth to the second since the teeth

can be designed to maintain contact for an arc of ring gear internal teeth pitch circle center movement greater than one rotation divided by the number of teeth on the outside of the ring gear. There is therefore overlap to the extent desired in the working arcs of the individual teeth so that the second tooth actually starts its working arc (effective contact arc) before the first working tooth loses contact. This results in a smooth transfer of contact from each tooth to the next tooth. The result is a regular motion of the output gear with simply defined contact point loads and sliding velocities relative to ring gear center velocity and the torque being carried. This allows systematic design for desired life. In another form of the invention, the same desirable results are obtained by forming the arcuate teeth on the stationary member and forming the cavities therefore in the ring gear.

Further objects, features and advantages of this invention will become apparent from a consideration of the following description, the appended claims, and the accompanying drawings in which:

FIG. 1 is a sectional view of an actuator constructed according to this invention;

FIG. 2 is a sectional view of the actuator shown in FIG. 1 as seen from substantially the line 2—2 in FIG. 1;

FIG. 3 is a diagrammatic illustration of one of the gear teeth in the actuator shown in FIG. 2 and shaped according to this invention;

FIG. 4 is a sectional view, like FIG. 2, of a modified form of the actuator of this invention; and

FIG. 5 is a diagrammatic view, like FIG. 3 of one of the gear teeth in the actuator shown in FIG. 4 and shaped according to this invention.

With reference to the drawing, the actuator of this invention, indicated generally at **10**, is shown in FIGS. **1** and **2** as including a housing or stationary member **12** formed with a plurality of gear tooth cavities **14** arranged in an approximately circular formation about an axis **16**. An output gear **18**, illustrated as being attached to an output shaft **20** rotatably supported on the member **12**, has teeth **22** arranged on a pitch circle **19**. The gear **18** is mounted on the stationary member **12** so that it is in a coaxial relation with the axis **16**. A free floating ring gear **24** has a plurality of external teeth **26** corresponding in number to the number of tooth cavities **14** and a plurality of internal teeth **28** arranged on a pitch circle **21**. The teeth **28** mesh with the output gear teeth **22**. By "free floating" is meant that the ring gear **24** is free of any support in the actuator **10** other than for its engagement with the stationary member **12** and the output gear **18**. The ring gear teeth **26** always have at least one engagement point with the stationary member **12** and the teeth **28** always have at least one engagement point with the output gear teeth **22**. The ring gear **24** is configured so that it has a center point **30** (which is the center of the pitch circle of teeth **28**) which is spaced at all times from the axis **16** by a distance "*e*." (The geometric center is also the center of mass if the ring gear is completely symmetrical, but this is not an essential feature.)

The aforementioned copending applications show how a force vector can be caused to shift in angle as point **30** moves about point **16**. Assume that this force vector can be so positioned that a component will keep teeth **28** and teeth **22** in tight mesh so that center distance "*e*" is essentially constant, as it will be for tightly meshed involute profile teeth. Then only that component of the force vector which is at right angles to a line from point **16** to the point **17** where the pitch circle **19** of teeth **28** touches the pitch circle **21** of teeth **22** will be effective in causing torque to be imposed on member **18**. This force vector is hereinafter called F_1. If member **16** is stationary, a reaction force will be generated equal but opposite in direction to the initial force F_1. The torque required to hold the member **18** stationary will be force F_1 times RO, where RO represents the distance between points **16** and **17**, and this will be the available output torque on the output member **18**. Further discussion of the force vector will not be attempted here, since the means of developing the force vector are not

shown except to note that under the assumption of tight meshing of members **18** and **24** and the geometry of the teeth **26** and cavities **14**, the only possible motion of point **30** is along a circle of radius "*e*"about point **16**. Since there are more teeth **28** than teeth **22**, a complete rotation of point **30** counterclockwise about point **16** results in a partial clockwise rotation of member **18** about point **16**. The ratio of rotations of point **30** about point **16** to rotations of member **18** about point **16** is the number of teeth **22** divided by the number of teeth **28** less the number of teeth **22**. This is the same as RO/*e*.

The improvement in the actuator **10** of this invention is in the shape of the ring gear teeth **26** and the cavities **14** in which the teeth **26** are located. The shapes of a tooth **26** and a cavity **14** are illustrated in FIG. **3** wherein the tooth **26** is shown in a position located symmetrically within the cavity **14** and with point **30** directly above axis **16**. As shown in FIG. **3**, the tooth **26** has a terminal end **32**, an imaginery base line **34** perpendicular to a radius **35** from point **30** and side surfaces **36** and **38**. Since the shapes of the side surfaces **36** and **38** are substantially identical, being only right- and left-hand versions of each other, but not necessarily symmetrically located relative to the radius **35** to which the base. line **34** is perpendicular, only the surface **36** is described in detail hereinafter.

The major portion **40** of the surface **36**, extending from the tooth end **32** to a point **42** adjacent the base line **34** is arcuate in shape having an axis **44** of revolution spaced from the base line **34** a distance "*e*"corresponding to the eccentricity "*e*"of the ring gear **24** relative to the axis **16**. The surface portion **40** is located on a radius R having its center at the axis of revolution **44**. A portion **46** of the surface **36**, extending from the point **42** to the base line **34** and equal in length to the distance "*e*, " can be substantially straight. This portion **46** of the tooth is noncontacting and therefore can be any shape which will clear the corner **68** of the cavity **14** as each point on the tooth surface moves along the arc of a circle of radius "*e*" whose center is directly below the subject point.

The tooth surface **38** is similarly shaped having an axis **48** of revolution spaced from the axis **44** a distance which determines the width of the tooth **26**. Design considerations in each particular instance will determine the desired width of the tooth **26** and do not form a part of the present invention. It is to be understood, therefore, that the tooth can be of any desired width and can also be of any desired length, the tooth end **32** being also located a distance from the base line **34** determined by design considerations in each instance.

The cavity **14** has sidewalls **50** and **52** which are also arcuate in shape, and since they are right- and left-hand versions of each other, only the shape of the surface **50** will be described in detail. The surface **50** has an axis **54** of revolution located on the base line **34** and spaced from the axis **44** a distance equal to the eccentricity of the ring gear **24** relative to the output gear axis **16**. Similarly, the surface **52** has an axis **56** of revolution located on the base line **34**. As shown in FIG. **3**, the surface **50** is tangent to imaginary circles **58**, **60** and **62** each of which has a radius "*e*." The centers of the circles **58**, **60** and **62** are determined by locating imaginary radii which intersect the tooth surface **36** and are perpendicular to the base line **34**. The "contact angle, " namely the angle of rotation of the ring gear center **30** about the axis **16** during which each tooth **26** is in engagement with the stationary member **12** is indicated at A in FIG. **3** for counterclockwise orbiting movement of the ring gear **24** and at B in FIG. **3** for clockwise orbiting movement of the ring gear **24** relative to the axis **16**. Since the tooth surfaces **36** and **38** are right- and left-hand versions of each other, the angles A and B are equal. Thus, for counterclockwise orbiting movement of the ring gear **24**, contact of the tooth **26** with the cavity surface **50** will commence at point **66** on the surface **50** and continues as the ring gear center **30** moves counterclockwise about the axis **16** until point **42** on tooth **26** engages the point **68** on the surface **50**. At such time, or sooner, the next tooth **26**, moving in a counterclockwise direction about the ring gear **24** will contact the next surface **50** in the counterclockwise adjacent cavity **14** in the stationary member **12**. Thus, well defined tooth contact is obtained which is geometrically consistent with the desired motion restraint. During motion from the position shown until initial contact at point **66**, the load bearing contact would be on the tooth next clockwise from the one shown.

It is to be understood that the tooth **26** need not be wide enough to contain the axes of revolution **44**, **48**, **54** and **56**, as shown in FIG. **3**, but that the tooth **26** can be narrower if desired and can also terminate in a pointed or in a semicircular end **32** if desired. The number of teeth **26** required on the ring gear **24** is determined by dividing 360° by the contact angle A. By the use of sufficient teeth, a contact overlap which is acceptable can be arbitrarily set. A meaningful contact ratio is defined by the angle of contact per tooth divided by the minimum contact angle required per tooth to achieve ideal ring gear motion restraint.

It is to be understood that while the actuator **10** is illustrated with all cavities **14** symmetrically placed about the axis **16** of the stationary gear and the teeth **26** symmetrically placed about the center **30** of the pitch circle of teeth **28**, this is not a required condition. Each tooth and cavity pair can be designed and spaced independently provided only that adjacent pairs have at least continuity and preferable overlap of their arcs of action when related to the motion of point **30** about axis **16**. This can be of considerable practical importance when the means for achieving a torque on the ring gear **24** is developed in a particular application of the invention since a considerable number of slots and/or passages in stationary part **12** might of necessity need to be accommodated.

In the modified form of the actuator of this invention, indicated generally at **10*a*** in FIG. **4**, components corresponding to the actuator components described above in the actuator **10** are utilized. Consequently, corresponding numerals are employed to indicate like parts in the actuators **10** and **10*a***. The actuator **10*a*** differs from the actuator **10** in that in the actuator **10*a*** teeth **70**, shaped like the teeth **26** in the actuator **10**, are formed on the stationary member **12** and cavities **72** for the teeth **70**, shaped like the cavities **14** in the actuator **10**, are formed in the ring gear **24**. As shown in FIG. **5**, each tooth **70** is shaped like the teeth **26** previously described, the base line **74** of the tooth **70** being tangent to a circle **76** having its center located on the axis **16**. Similarly, the cavities **72** are shaped so that the base line **78** for each cavity **72** is tangent to a common circle **80** having its center located at the point **30**. It is to be understood that this arrangement of having the base lines tangent to common circles and having the teeth **70** and cavities **72** symmetrical about radii perpendicular the base lines, is not essential. It is only necessary that the radius length to the base line **74** for the tooth **70** from the axis **16** be equal to the radius length plus the eccentricity "*e*" to the mating cavity base line **78** and that the tooth and cavity each have axes corresponding to the points **54** and **56** in FIG. **3** displaced the same amount and direction from the radius perpendicular to the base line. In operation, the actuator **10*a*** operates like the actuator **10** previously described.

From the above description it is seen, therefore, that this invention provides improved actuators **10** and **10*a*** by virtue of the geometric configuration of the ring gear teeth **26** and the associated cavities **14** in the stationary member **12** in the actuator **10** and the corresponding stationary member teeth **70** and ring gear cavities **72** in the actuator **10*a***. This configuration is essentially arcuate having predetermined axes of revolution which determine the precise tooth shape in each instance.

I claim:

1. In an actuator which includes a stationary gear having an axis, an output member arranged in a coaxial relation with said axis and a free floating ring gear having a center which is spaced a predetermined distance from said axis, said ring gear being arranged in an engaged driving relation with said output member, said stationary and ring gears having a plurality of coacting teeth and tooth cavities corresponding in number

and arranged in substantially circular formation about said axis and said center respectively, at least some of said teeth being positioned in said cavities whereby said center is movable in an orbital path about said axis and said ring gear is restrained against rotation, the improvement wherein each of said teeth is shaped so that it has an end, a base line and a pair of side surfaces extending from said base line to said end, each of said side surfaces having an arcuate surface portion the axis of revolution of which is located between said base line and said end and is spaced from said base line a distance substantially equal to said predetermined distance.

2. In an actuator having the structure set forth in claim 1 wherein said arcuate portion constitutes the major portion of each of said side surfaces.

3. In an actuator having the structure set forth in claim 2 wherein each of said cavities has sidewalls shaped so that when one of said teeth is positioned symmetrically therein said sidewall is spaced from said tooth at said base line a distance equal to said predetermined distance, said cavity sidewall being curved so that the spacing between said cavity sidewall and the adjacent tooth sidewall progressively decreases in a direction toward said tooth end.

4. In an actuator having the structure set forth in claim 3 wherein said cavity sidewall is substantially arcuate having an axis of revolution disposed substantially on said base line.

5. In an actuator having the structure set forth in claim 3 wherein said tooth cavities are formed in said stationary gear and are arranged in a substantially circular formation about said axis.

6. In an actuator having the structure set forth in claim 3 wherein said teeth are formed in said stationary gear and are arranged in a substantially circular formation about said axis.