

[54] **WANKEL ENGINE CYLINDER
GENERATING MACHINE**

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[51] Int. Cl. **B24b 19/00, B24b 17/00**

[58] Field of Search **51/DIG. 245, 100 R**

[56] **References Cited**

UNITED STATES PATENTS

2,870,578 3/1957 Baier 51/DIG. 32
3,494,388 6/1970 Sandels et al. 51/DIG. 32

FOREIGN PATENTS OR APPLICATIONS

957,922 5/1964 Great Britain 51/DIG. 32

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[57] **ABSTRACT**

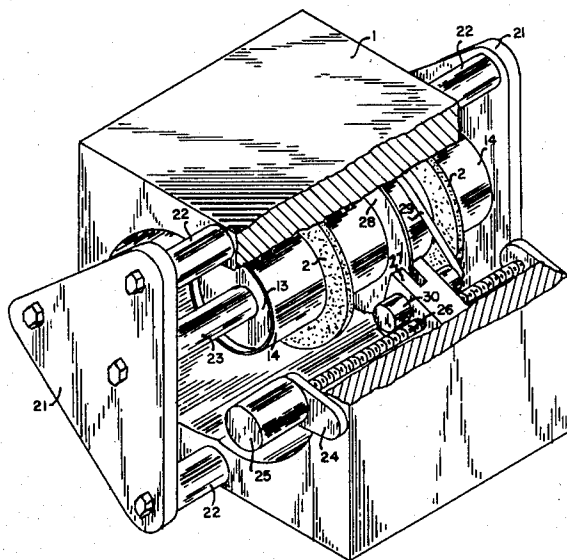
The generating machine comprises complementary tools called the lobe generator and the neck generator, together capable of machining the cylinder con-

tour for a Wankel engine. An inside-out machine structure is disclosed wherein the tools are supported and guided by the workpiece. Compatible structural rigidity and freedom of motion is provided by hydrostatic bearing spindles and slides.

The lobe generator operates somewhat like the conventional cylindrical grinder or boring machine with the important provision of an articulated arm comprising the cutter center itself and an eccentric bearing. Said bearing is a Wankel type stator-rotor pair which produces a third harmonic radial compensation and is also used to produce torque to swing the cutter around the eccentric pivot point. Key to the generating concept is natural transfer of the cutting center to the region of the cusps of the evolute of the arch, without radial change or change in tangential direction of the cutter edge.

The neck generator is a mechanical analogue of the Wankel rotor, having two edges which ride the arches completed by the lobe generator and a third edge which is the cutting tool. Said tool machines the cusp region of the epicycloidal cylinder to where it joins the arches already produced by the lobe generator. Key to the invention is capability of the lobe generator to complete enough of the cylinder surface to guide the neck generator.

7 Claims, 6 Drawing Figures



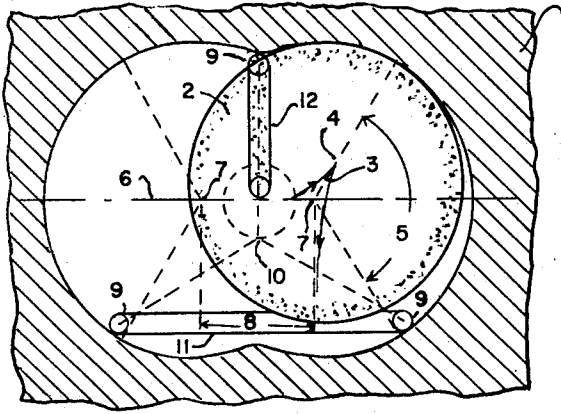


Fig. 1.

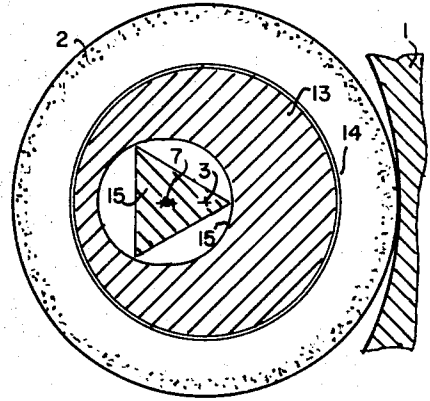


Fig. 2.

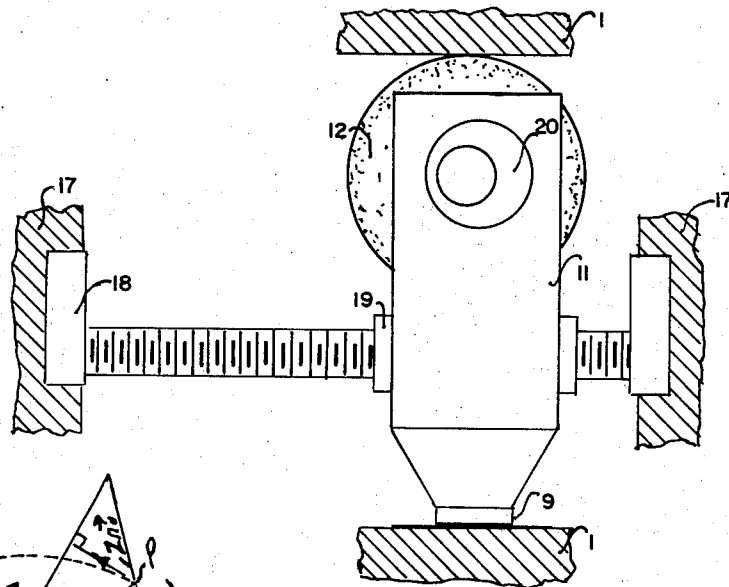


Fig. 3

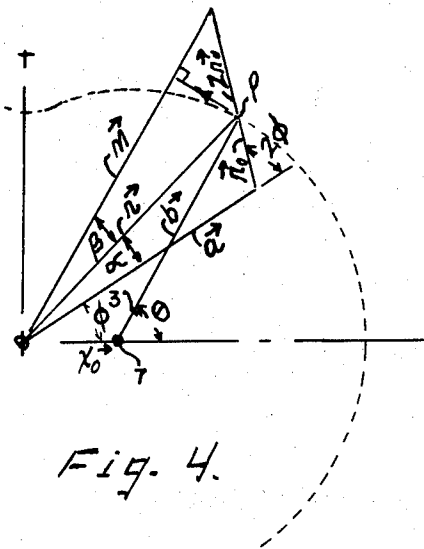


Fig. 4.

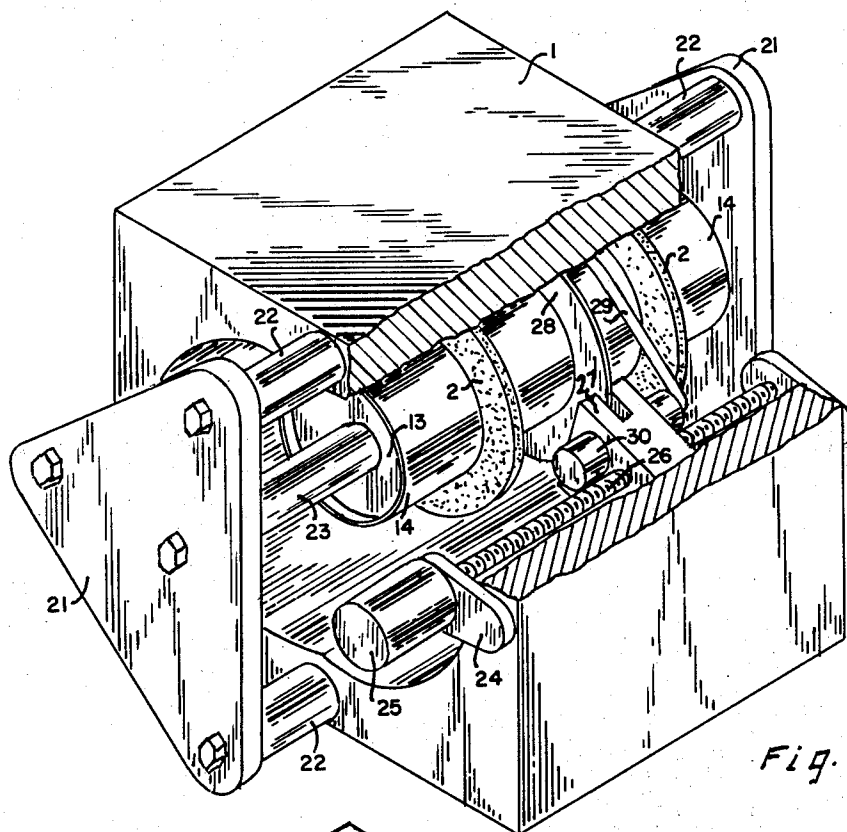


Fig. 5.

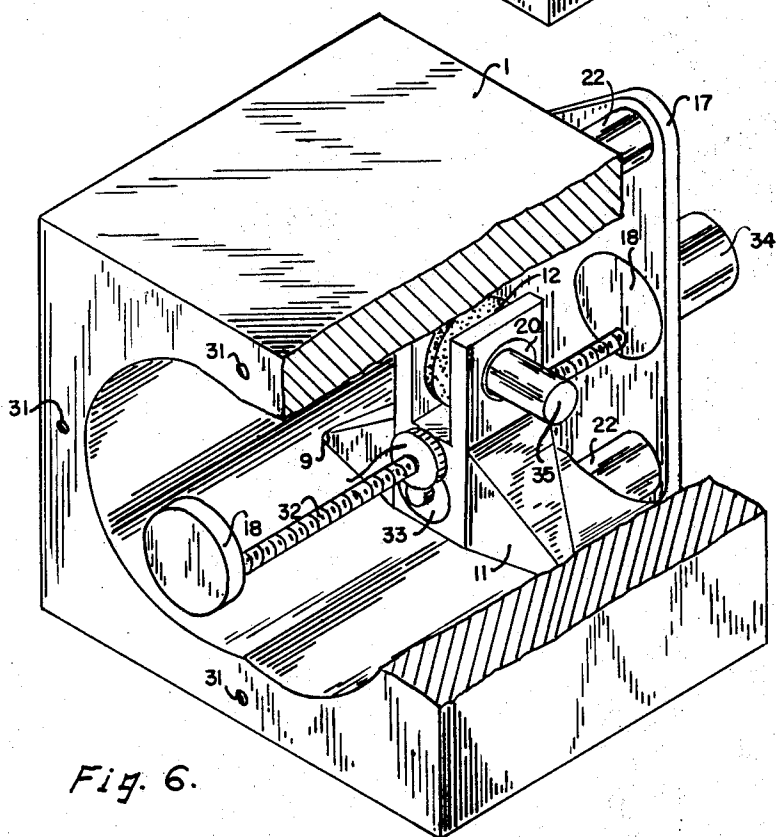


Fig. 6.

WANKEL ENGINE CYLINDER GENERATING MACHINE

BACKGROUND OF THE INVENTION

Advent of the Wankel engine brings into focus characteristics of a curtate epicycloid of two arches, known also as a nephroid. The engine cylinder resembles a figure eight in cross section and the rotor an equilateral triangle with rounded edges. The rotor edges just fit the cylinder in any angular position while the center of the triangle follows a circular path. The basic curtate epicycloid is traced by the centers of curvature of the rotor edges as the rotor is turned within the cylinder on a crank arm. The cylinder surface extends beyond the basic curve in a normal direction and in an amount equal to the radius of curvature of the rotor edges.

Contours like the Wankel engine cylinder can be produced by a variety of numerically controlled contouring machines. Large boring mills, jig grinders, contouring machines, and the like represent a major capital investment outside the reach of the local shop or garage. Even for the automotive industry expensive large machines present a bottleneck to production because one wishes to invest in a minimum number and so has to route parts through in a serial fashion. Less expensive machines like that disclosed here can be set up in parallel in the large shops and are even in reach of the smaller facilities.

Being an internal combustion engine, the Wankel has many characteristics in common with the ordinary engine with circular cylinders. For instance seals like the piston rings must fit the cylinder, providing means for minimizing friction and wear, and preventing blowby of the exhaust or unburned fuel. The rotor and cylinder combination must withstand high temperature gradients, corrosive atmosphere, and high pressure differentials. Pollution controls demand that these characteristics be maintained during the useful life of the engine. The machine disclosed here is ideally suited for rebor-ing or regrinding the Wankel cylinder in a manner suitable for ordinary overhaul as it is known today.

Although the curtate epicycloid of two arches does resemble a pair of intersecting circles, its evolute shows appreciable shift of the center of curvature. The principle of the lobe generator is based on the fact that the evolute has three cusps associated with an arch region where sufficiently good approximation may be made to stationary centers of curvature when minor compensations are provided. The degree of compensation depends on the ratio of the crank arm to the size of the rotor.

BRIEF DESCRIPTION OF THE INVENTION

In the description of my invention, reference is made to the curve which describes the contour of the cylinder of a Wankel engine and two complementary tools used to generate the complete curve, one the lobe sections and the other the neck sections of the curve. The generating machine disclosed here comprises the lobe generator and the neck generator with the necessary appurtenances for driving and controlling the cutters which generate the curve. In the text of this disclosure one is to understand the terms curve, lobe generator, and neck generator in the foregoing sense, and further to understand that both generators are necessary to the concept for the complete machine.

The curve may be described mathematically as the envelope of a family of small circles carried by a pair of crank arms so linked that one arm rotates about a fixed center carrying the second arm at its end with a fixed ratio of rotation between them. For a practical Wankel engine, the smaller arm rotates at three times the angular rate of the longer arm, the ratio of the arm lengths is greater than 5 to 1, and the radius of the small circle is less than 5 percent of the length of the longer arm. Other ratios of rotation and length may be produced by the generating machine with different tolerances than those used to describe the preferred embodiment which resembles the Wankel engine.

It is to be understood that the curves so described are a cross section of the engine cylinder which also has depth, described by elements of the cylinder which are elements of the cylinder parallel to the axis. In applications like the Wankel engine it is also important that these elements be straight and smooth to conform to the rotor seals. It is important too that the cylinder walls have a good finish to improve the sealing and wear characteristics of the engine. The generating machine described in this disclosure is especially adapted to fulfill these needs for a good cylinder surface. Tolerances are well within the range of deformations which may be expected from thermal gradients set up by combustion during engine operation.

In the sequence of operations the lobes are generated first to establish a reference surface against which the necks may be formed. First of course the desired curve for the cylinder cross section must be defined dimensionally. This may be done by mathematical formula or point by point either in terms of the curve or its evolute. The evolute is most descriptive since it defines the centers of curvatures of the osculating circles to the curve. The primary generating circle has its center on the major axis and intersects the curve at points 30° from said axis measured around this center. The proper generating circle lies at equal distances outside and inside the curve respectively at angles of zero and plus or minus 60° .

The error between the primary generating circle and the curve may be approximated closely by the third harmonic cosine function for the generating angle. Thus a cutter swung about this center and compensated by the third harmonic cosine will trace the curve accurately between $+ \text{ or } - 60^\circ$. In the region of 60° another set of circumstances come into play. The evolute shows that the osculating circles between sixty and ninety degrees have a relatively constant center with minimum radius of curvatures in this region. If one chooses a circle with center on a radius of the primary generating circle near 60° , this new circle passing through the closest point of the curve in the region of 100° , he finds that this new circle closely fits the curve between 60° and 90° .

Therefore the lobe generator comprises a circle with radius close to the minimum radius of curvature in the lobe, an arm which swings around the center of the primary generating circle, and a third harmonic generator which varies the center of the arm slightly with respect to the center of the primary generating circle. In the case of the preferred embodiment chosen, for example, in this disclosure, it is seen that the envelope described by the secondary circle, as the arm is swung between plus or minus 59° , conforms to the curve for a practical

Wankel engine to one part in 4,000 between + and - 100°.

In the preferred embodiment, the outer circle consists of a cutting wheel such as a diamond grinder or boring spindle. At the center of the primary generating circle is a triangular shaft on which is rotated a circumscribing curve like the one being generated. This curve is produced by the intersection of two circles whose centers are separated by four times the amplitude of the third harmonic error. One vertex of the triangle lies outward on the major axis in the direction of the lobe being generated. The outer surface of the body in which the compensating curve is bored forms a journal for the bearing on which the outer circle, or cutter, is rotated. The cutter may slide along the journal bearing as well as turn on it to generate the desired lobe along the elements of the cylinder.

A preferred means for rotating the eccentric journal on the triangular shaft is to differentially vary the pressure in a fluid between the cavities separated by the vertices of the triangle. This method utilizes the principles of the Wankel engine to produce torque. In cases where the third harmonic correction is too small to provide an adequate crank arm, the journal may be turned through a mechanical coupling. Stops are provided between the triangular shaft and the journal to prevent angular motion beyond the 60° region.

The preferred journal bearing is an hydrostatic bearing of the outlet restrictor type. If a flexible membrane bearing is used, one can take advantage of the feature of varying pressure behind the membrane to slightly displace the axis of rotation. This may be desirable to produce fine compensation in curves where extreme accuracy is required. The rotor is a cylindrical sleeve which carries a pair of cutting wheels separated by half the depth of the Wankel cylinder. The sleeve itself is half again as long as the depth of the cylinder. Alternatively a single cutting wheel can be used on a bearing sleeve whose length is twice the depth of the cylinder.

In the preferred embodiment the cutter wheel assembly is turned and fed by a friction drive mounted within the cavity of the opposite lobe. Although more sophisticated driving and control means may be devised in a specific machine design, it is only the purpose here to show a practical means which makes the invention practical. These and other features of the lobe generator are apparent from the drawings outlining the preferred embodiment.

The lobe generator is reversed in the cylinder block to produce the lobe on the opposite side. Positioning is accomplished by mating mounting points on the ends which carry the triangular shaft to corresponding holes in the block. An interesting aspect of the tool disclosed is that the work supports the tool. This provides for extreme rigidity between the tool and the work with the attendant benefits of fine finish. More than 90 percent of the Wankel cylinder surface can be prepared with the lobe generator.

The remaining surface is prepared by the neck generator which is the complementary tool for the generating machine. The remaining surface undergoes wild variations in curvature and so can hardly be approximated by arcs of circles. The neck generator is essentially a Wankel rotor carrying a cutting tool at one vertex of the equilateral triangle. The other two vertices follow the surface of the lobe already prepared. Sufficient

surface has been formed between + and - 90° on each side to completely define the neck portion by the edge of the cutter at the third vertex of the rotor.

In the simplest embodiment, the neck generator comprises a base which rides on 2 feet conforming to two vertices of the desired rotor profile. Said base carries a cutting tool with edged conforming to the third vertex. The base is held aligned to elements of the cylinder by a lead screw passing through the geometrical center of the rotor. Said lead screw is supported by bearings in plates at either cylinder end and is rotated around the geometric center of the cylinder on an eccentric crank arm corresponding to the Wankel rotor crank arm. Suitable feeds and drives are provided to turn the cutter, rock the base back and forth, and to move the base axially in the cylinder. The cutter drive is provided with an eccentric mount which permits adjustment of cutter height corresponding to the amount of wear.

It is presumed that those who may benefit by my invention are skilled in the art of preparing fine surface by grinding, boring, lapping and honing. They will also be familiar with the features of the Wankel Engine and understand the need for preparing surfaces for good wear and seal. It will be clear from the detailed description of the preferred embodiment which follows how my invention can be used to accomplish the desired ends simply.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic drawing showing the important surfaces and curves as viewed axially into the Wankel cylinder. The lobe generator and the neck generator are superimposed. Grinding wheels are shown as the preferred cutting tools.

FIG. 2 is the cross section of the lobe generator showing the triangular shaft, compensating hole which circumscribes the shaft, flexible membrane bearing, and grinding wheel.

FIG. 3 is the side view of the neck generator showing the grinder and sliding base.

FIG. 4 is a diagram showing the generating vectors and defining their lengths and arguments as required to demonstrate the degree of fit to the true curve.

FIG. 5 is a perspective view of a Wankel cylinder being prepared by the lobe generator.

FIG. 6 is a perspective view of the neck generator preparing the neck section of a Wankel cylinder.

DETAILED DESCRIPTION OF THE DRAWINGS

Referring now to the drawings and particularly to FIG. 1, the curve to be generated is shown as a cavity in the cylinder block 1. The grinding cutter 2 is shown in a position where it most nearly fits the lobe section of the curve. The cutter center 3 lies near the cusp of the evolute 4 which is the locus of the centers of curvature of the curve being generated. The cutter 2 generates the lobe by swinging its center 3 between the angular limits 5 around a point on the major axis 6, said limits being of the order of + or - 60° or a total of 120°. Said point is called the generating center 7 for the lobe generator.

The neck section of the curve is generally defined as the region 8 which is the spacing between the centers 7 of the lobe generator in the two positions necessary to produce both lobes of the curve. The lobe sections are defined as the portions of the curve which lie outside the neck section. When the lobes are formed, the

necks may be defined by one of the three small circles 9 which are symmetrically disposed at the vertices of an equilateral triangle with center 10 when the other two are in contact with the lobes. The circles 9 correspond to the edges of the Wankel rotor which would be used in the cylinder 1.

In the neck generator, two of the circles 9 correspond to the edges of a base 11 and the third to the edge of a grinding cutter 12 shown here in cross section. When the edges of the base are moved contiguously along the finished lobe sections of the curve, the cutter edge will generate the desired contour for the neck section. At the same time, the center 10 will swing in a circle around the geometric center of the curve. One revolution of the center 10 corresponds to one third revolution of the equilateral triangle defined by the circles 9. The circle which is the locus of 10 is the locus of the crank arm of the Wankel rotor.

Geometry of the lobe generator is defined more fully in FIG. 2 which shows the grinding cutter 2 free to rotate on a journal 13 whose outer surface is the preferred embodiment is a flexible membrane hydrostatic bearing. A flexible membrane bearing is described in my copending U.S. Pat. application Ser. No. 159,608 filed July 6, 1971. The mating surface 14 of the rotor is a sleeve which is free to slide axially along the journal as well as to turn on the journal. The cutter center 3 is defined by the cylindrical bearing surfaces and any run-out; i.e. wobble error which may occur between them.

The equilateral triangular shaft 15 extends in an eccentrically disposed hole 16 of the journal 13 for the full length of the journal 13 and may be sealed at the ends by caps which allow rotation of the journal around the shaft. Fluid under pressure may be applied differentially to the three cavities defined in the hole 16 by the vertices of the shaft 15 for purposes of reducing friction and producing torque between the journal and shaft. The hole 16 is not exactly round because it is bored on at least two slightly displaced centers. In the preferred embodiment shown in FIG. 2 said centers lie along the horizontal axis and are separated by twice the diameter of the small circle described by the mean center of hole 16 around the generating center 7 for the lobe generator, as the journal 13 is rotated on the shaft 15. Thus, the center of the equilateral triangular shaft 15 lies off the mean center of the two circles. Pressure on any face of the shaft acts through the shaft center. Therefore, a differential pressure between the two faces of the shaft results in a torque around the mean center of the two circles. This is a basic operating principle of the Wankel engine.

Those skilled in the art who follow the teachings of this invention will see that the hole 16 resembles an epicycloid sufficiently for the shaft 15 to behave as a Wankel rotor. With the orientation of parts shown in FIG. 2, the mean center of the hole 16 is slightly offset from the center of the shaft 15 in a direction away from the contact area between the wheel 2 and the work 1, thereby slightly reducing the amount of material removed in that position. When the journal is rotated counterclockwise, the center 7 relatively rotates clockwise around the center of the shaft 15 on the small circular locus. When the journal has turned 60°, the center has moved around through twice the angle to become in line with the cutter center 3 thereby moving the cutter toward the work in an amount equal to the

diameter of the small circular locus. In the process of rotation of the journal, the cutter center has moved to keep the line through 3 and 7 in line with the normal to the curve as marked by the evolute 4 in FIG. 1, in essence producing the same evolute for the curve traced by the center 3 as for the cylinder contour.

When the journal has been rotated approximately sixty degrees to the position shown in FIG. 1, the cutter center 3 lies in the region of the cusp of the evolute 4. For the next 30°, the center of curvature remains in the vicinity of the cusp. Proper choice of the radius of the cutter provides a close fit between the cutter and the curve in the 60° to 90° region of the arch. In the preferred embodiment chosen for illustration, the cutter edge tracks the curve accurately for the total arch as the journal is rotated through the limits 5 marked out in FIG. 1.

The lobe generator may be used to produce both arches preparatory to using the neck generator outlined in FIG. 3. The neck generator is supported axially by end supports 17 firmly attached to the workpiece 1 at either end of the cylinder. The crank 18 extends between the end supports through the base 11 of the neck generator. Said crank is free to turn and to be driven in bearings in the end supports and in the base. The crank comprises a machine screw held eccentrically between the end bearings. A ball nut 19 matching the machine screw supports the crank along the geometrical center of the base 11. A bearing is located on the same center with sufficient displacement from the ball nut to assure alignment between the axis of the machine screw and the plane of the base, as well as the plane of the cutter wheel 12.

The cutter wheel bearing is provided with an eccentric bushing 20 to adjust the height of the wheel for wear. Means for driving the crank 18, driving the ball nut 19, and adjusting the eccentric bushing 20 are necessary but not shown in FIG. 3. Operation of the neck generator may be explained better with respect to FIG. 1 which shows the axis of the machine screw and ball nut as point 10. When the crank is turned through an angle of + or - 120°, the vertices 9 follow the Wankel cylinder contour. The edges of the base follow the completed lobes, and the edge of the wheel follows one of the incomplete neck regions to remove material from the workpiece. The cutter wheel may be fed into the work by the eccentric bushing 20 described with respect to FIG. 3. The wheel is fed back and forth in the cylinder by rotating the ball nut 19. For completing the opposite neck region, the neck generator is withdrawn from the cylinder, the cylinder is inverted and the neck generator is reinserted.

In FIG. 4 is a diagram showing the generating vectors which define the Wankel cylinder contour relative to the machine geometry. The Wankel cylinder curve is related to the locus of the point p at the end of vector r . Vector r is the vector sum of a and r whose positions are defined by the argument ϕ . Vector n defines the direction of the normal to the curve through the point p . The lobe generating machine is described by point at x along the major axis and the vector b whose argument is θ . Vector b carries the cutter center 3 and is slightly adjusted in accordance with the small circle around x , its end starting on the axis toward the origin when θ is zero and moving in an amount -2θ in the range of + or - 60° for θ .

Errors are measured by projecting all other vectors along n . The argument θ is related to θ by the closest approach of the wheel to the work at any point p . Since the vector b is not always exactly parallel to n , the closest approach may not be exactly at p . In the preferred embodiment disclosed here, an improved alignment between b and n is maintained by the method of compensation which involves a choice of b that in turn permits a third harmonic correction in terms of the argument θ by the small circle around 7. For the case chosen to support the disclosure, $a/r = 5$. The residual error between the limits of $+ \text{ or } - 60^\circ$ for θ is one thousandth of r and is mainly a sixth harmonic in θ .

Other parameters of interest include $x = 1.595r$, radius of the circle around 7 is $0.019r$, distance of point 3 from the small circle is $0.625r$, and the cutter radius is $3.798r$. The best fit of the wheel in the 60° to 90° region of θ is about 50 percent greater than in the $+ \text{ or } - 60^\circ$ range. The fit may be optimized by minor adjustments in the wheel diameter, position of the cutter center 3 along b , and the maximum rotation of b around point 7. The curve may be enlarged to accommodate a radius on the rotor vertices by enlarging the cutter wheel radius.

Compensation for the sixth harmonic error in the $+ \text{ or } - 60^\circ$ region may be made simply by modifying the boring procedure for the hole 16 shown in FIG. 2. Two small circles with radii twice the peak residual sixth harmonic error are drawn around the centers chosen for compensation of the third harmonic error. A pentagon is inscribed in each circle with one vertex on the line between points 3 and 7, said vertex being away from the contact between the wheel and the work. Hole 16 is bored with centers on the vertices of said pentagons. Size of the triangular shaft is adjusted to fit the hole.

Means for rotating the journal 13 around the shaft 15 is best seen in FIG. 2. For example, if hydraulic pressure is applied to the cavity in which the number 16 appears, the journal will be forced clockwise with respect to the shaft until their centers fall in a line normal to the triangular face under pressure. In the preferred embodiment, the same effect is obtained by maintaining the cavity with the number 15 under pressure and bleeding fluid from the cavity with the numbers 7 and 3. This has the additional effect of maintaining close contact between the shaft and the journal at the vertex toward the workpiece while allowing for some clearance tolerance for the shaft and hole.

In FIG. 5 is shown a perspective view of the lobe generator mounted in the cylinder block 1 with the necessary mounting fixtures and driving motors. The cutter assembly already described with respect to FIG. 2 mounts between two end plates 21 positioned and spaced by mounting feet 22 located by accurately placed holes in the cylinder body. The shaft extensions 23 bolt to the end plates at either end and to the triangular shaft 15 with sufficient overlap and clearance at the shaft to seal off the cavities between the shaft and the journal 13 as described for FIG. 2 previously. The seal between members 13 and 23 allows for free rotation between said members while at the same time restricting the flow of fluid from the cavities.

A feed and drive mechanism is mounted in the free set of holes on the block. The two pivot arms 24 carry a drive motor 25 and a lead screw 26. The lead screw is free to turn in bearings in said pivot arms. The motor

drives the lead screw through a gear unit which provides the proper speed and reversal to feed the floating base 27 back and forth axially along said lead screw. Said base is threaded to match the lead screw and is slotted to match the disk 28 carried by the rotor sleeve 14. There is a bearing surface between the disk and slot allowing the disk to turn freely as well as move in a radial direction.

The rotor sleeve is driven by a flat belt 29 coupled to a drive motor 30 mounted in the base 27. Tension in the belt holds the base in position for the slot to properly follow the disk as the cutter assembly is rotated around its shaft. Weight of the floating base maintains proper tension in the belt while allowing relative motion between the centers defined by the shaft extensions 23 and the lead screw 26, the slack being taken up by the base 27 as it drops under the pull of gravity.

In the preferred embodiment shown here, the cutters are shown as a pair of grinding wheels 2 mounted on the rotor sleeve 14. Said wheels are spaced at a distance of one-half the Wankel cylinder length. The bearing journal 13 is also one half the cylinder length and the bearing sleeve 14 is as long as the cylinder. In operation, the bearing journal 13 is rotated substantially $+ \text{ and } - 60^\circ$ as already described, while at the same time the rotor sleeve is turned by the belt 29 and is fed back and forth axially by the feed mechanism comprising the motor 25, the lead screw 26, the base 27, and the disk 28.

The other lobe is finished by reversing the rotor and the drive mechanisms in the cylinder block. Mounting holes 31 are shown with one end plate left off in FIG. 6 where the neck generator is shown in operating position. The same holes are used to mount the end plates for the lobe generator and the neck generator. The mounting feet 22 for the end plates 17 may be of different length than for the lobe generator. The neck generator end plates 17 are spaced to provide bearings for the crank 18 which is a rigid assembly comprising two ends separated by a threaded shaft 32. The neck generator and its operation have been described with respect to FIG. 3 which did not show the driving means or mounting. A perspective of the base 11 is shown in FIG. 6 with the neck generator in the central position. Two feet 9 ride against the finished lobe region of the Wankel cylinder. Said feet may have hydrostatic pads to reduce friction and improve accuracy in the presence of coolant and debris.

The base 11 carries a motor and pinion 33 which engages a gear on the ball screw 19 to feed the base assembly back and forth axially over the full length of the cylinder. When the crank 18 is rotated by the drive motor 34, the base assembly rotates in the cylinder as a Wankel rotor. The cutter 12 is rotated by a drive motor 35 to complete the neck portion of the cylinder. Said motor and cutter are mounted on an eccentric 20 to compensate for wheel wear.

Together the lobe and neck generating tools may be used to prepare a complete Wankel cylinder. Either one of the tools may be used to refurbish a used cylinder. The drive and feed mechanisms described for the preferred embodiment are examples of practical mechanism, they and their appurtenances not being essential to the basic invention in the exact form described. Said

auxiliary devices are described as means in the claims which follow.

I claim:

1. Apparatus adapted to be supported with respect to the block of a rotary engine for finishing a lobe surface of a cylinder wall therein which in cross-section has the shape of a curtate epicycloid of two arches, comprising

- a. a circular rotatable cutting wheel having a radius substantially equal to the minimum radius of curvature of the lobe surface,
- b. means for rotating said cutting wheel about a center of rotation thereof,
- c. an arm for swinging the center of rotation of said cutting wheel around the center of a primary generating circle which intersects the desired curve of the lobe surface at points approximately 30° on either side of the major axis of the epicycloid measured around the circle center, said circle center lying on said major axis, and d. third harmonic error compensating means for varying the displacement of the wheel center with respect to said circle center in accordance with the cosine of three times the angle through which said arm is swung around said circle center, whereby the envelope described by the circular periphery of the cutting wheel as said arm is swung between about plus and minus 60° conforms to said desired curve of the lobe surface.

2. Apparatus according to claim 1, wherein the cutting wheel is a grinding wheel.

3. Apparatus according to claim 1, wherein said arm and said third harmonic error compensating means comprise a fixed shaft having an equilateral triangular cross-section whose center coincides with the center of said primary generating circle, said shaft being fitted within a cavity whose circumscribing wall is engaged by the vertices of the shaft, said cavity wall having a shape similar to that of said curtate epicycloid and produced by the intersection of two circles whose centers are separated by four times the amplitude of the third harmonic error to be compensated, one vertex of said shaft lying on said major axis in the direction of said lobe sur-

face, said cavity being eccentrically disposed in a rotatable body which forms a journal for a bearing on which said cutting wheel is mounted for rotation about said center of rotation of said cutting wheel, said cutting wheel being slidable in the axial direction of said journal for finishing said lobe surface throughout the length of said cylinder wall.

4. Apparatus according to claim 3, wherein said journal may be rotated on said fixed shaft by differentially varying the pressure in a fluid supplied to the portions of said cavity separated by said vertices of the triangular shaft.

5. Apparatus according to claim 3, wherein said cutting wheel is one of a pair of like cutting wheels carried by a cylindrical sleeve forming the rotor of said bearing, said wheels being separated along the axis of said sleeve by half the length of the engine cylinder to be finished, said sleeve itself being half again as long as the engine cylinder length and being connected to means for sliding it in said axial direction of said journal.

6. Apparatus adapted to be supported with respect to the block of a rotary engine for finishing a lobe surface of a cylinder wall therein of curtate epicycloidal shape, comprising a circular grinding wheel having a center of rotation, means for rotating said grinding wheel about said center of rotation, and means for swinging the center of rotation of said grinding wheel between first and second angular limits around a generating center located on the major axis of the curtate epicycloid while simultaneously varying the distance between said centers as a function of the angle of swing, the outer peripheral surface of said grinding wheel engaging and most nearly matching the curvature of the lobe surface at each angular limit of the swing of the wheel's center of rotation around said generating center, the angular limits being approximately 60° on either side of said major axis.

7. Apparatus according to claim 6, wherein the center of rotation of said grinding wheel, when said wheel surface most nearly matches the curvature of the lobe surface, lies near the cusp of the evolute which is the locus of the centers of curvature of said lobe surface.

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