Nov. 9, 1937. E. STUBBS 2,098,438

GRINDING MACHINE FOR GRINDING NONCIRCULAR SHAPES

Filed May 19, 1932 5 Sheets-Sheet 1

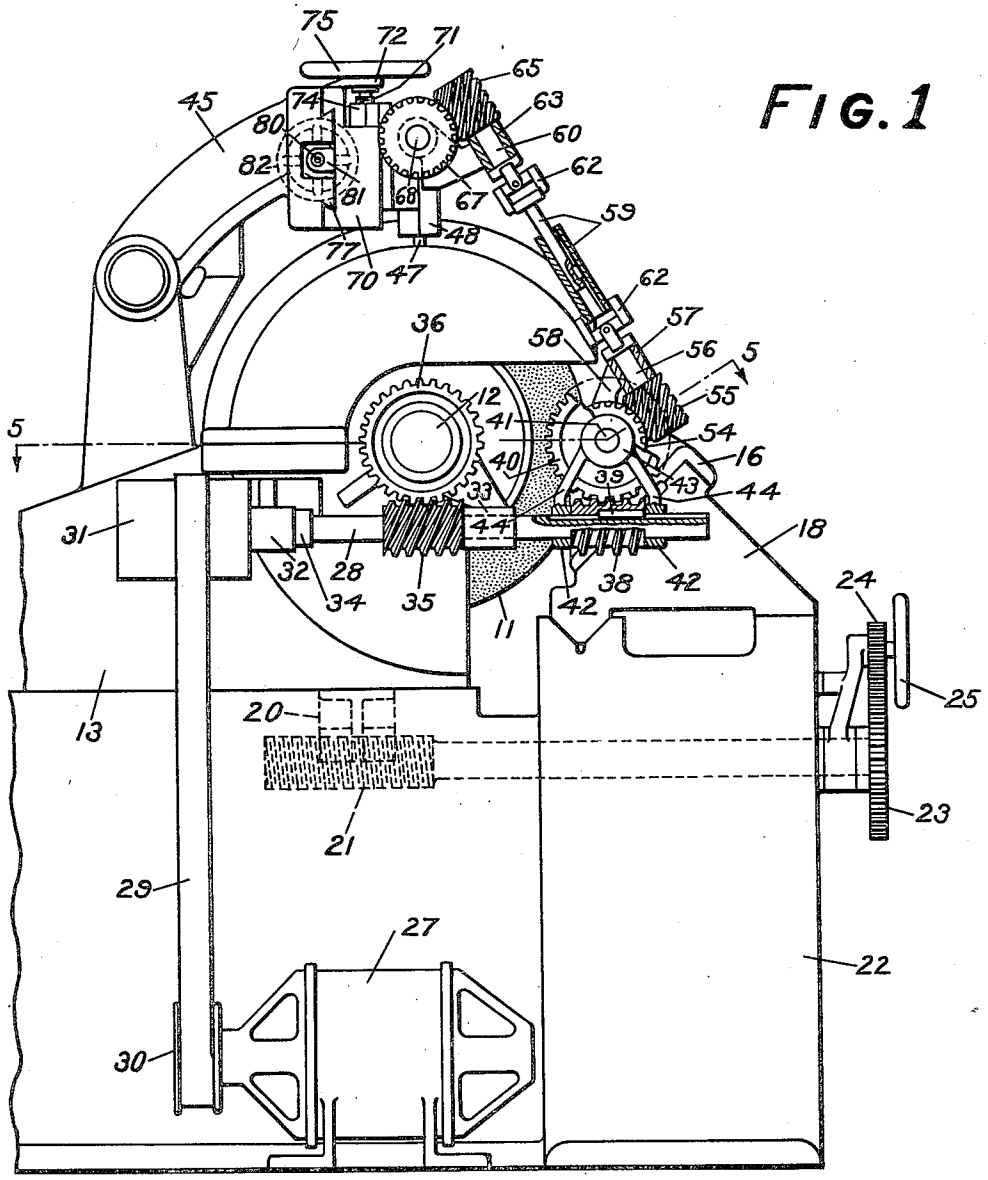


FIG. 1

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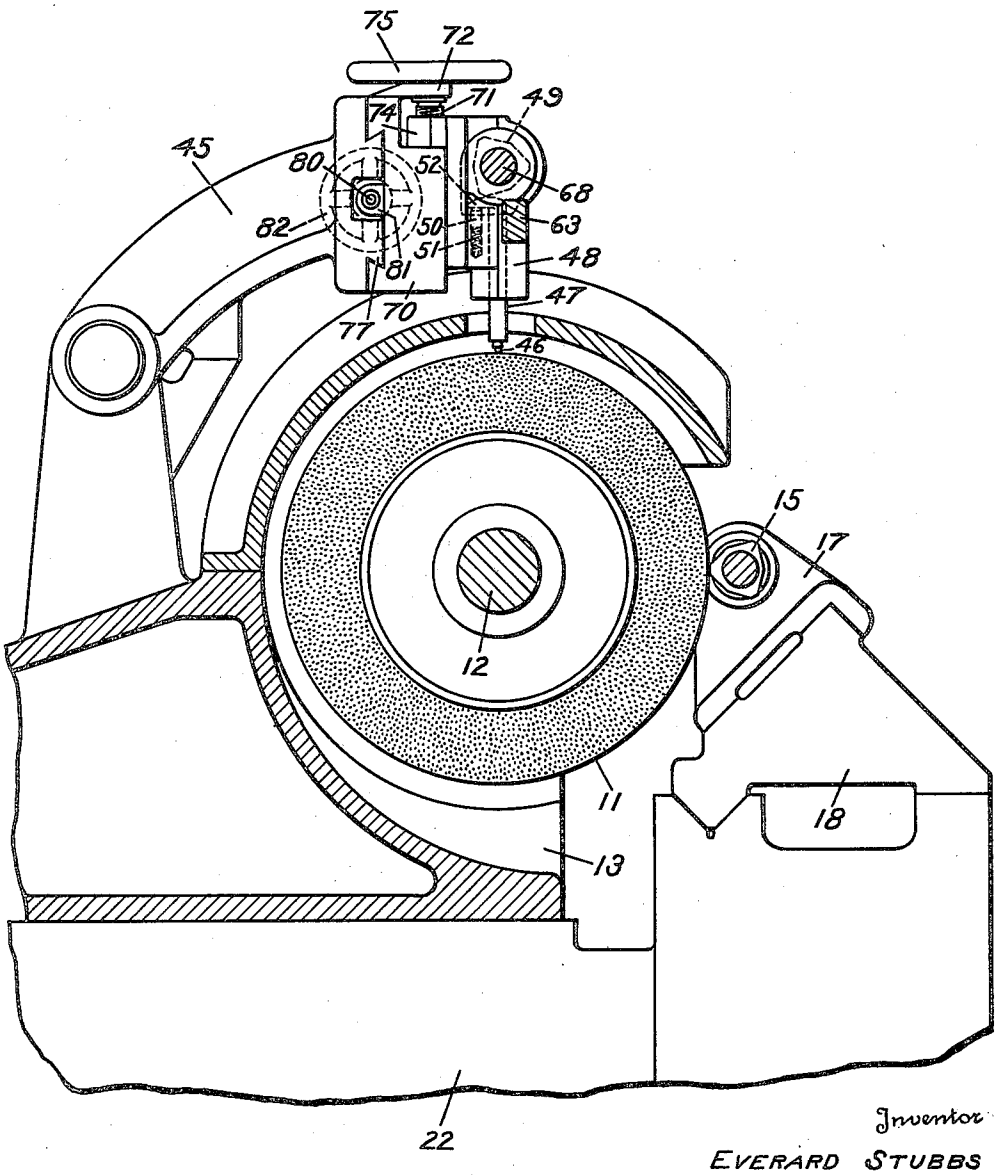
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GRINDING MACHINE FOR GRINDING NONCIRCULAR SHAPES

Filed May 19, 1932 5 Sheets-Sheet 2

FIG. 2



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GRINDING MACHINE FOR GRINDING NONCIRCULAR SHAPES

Filed May 19, 1932 5 Sheets-Sheet 3

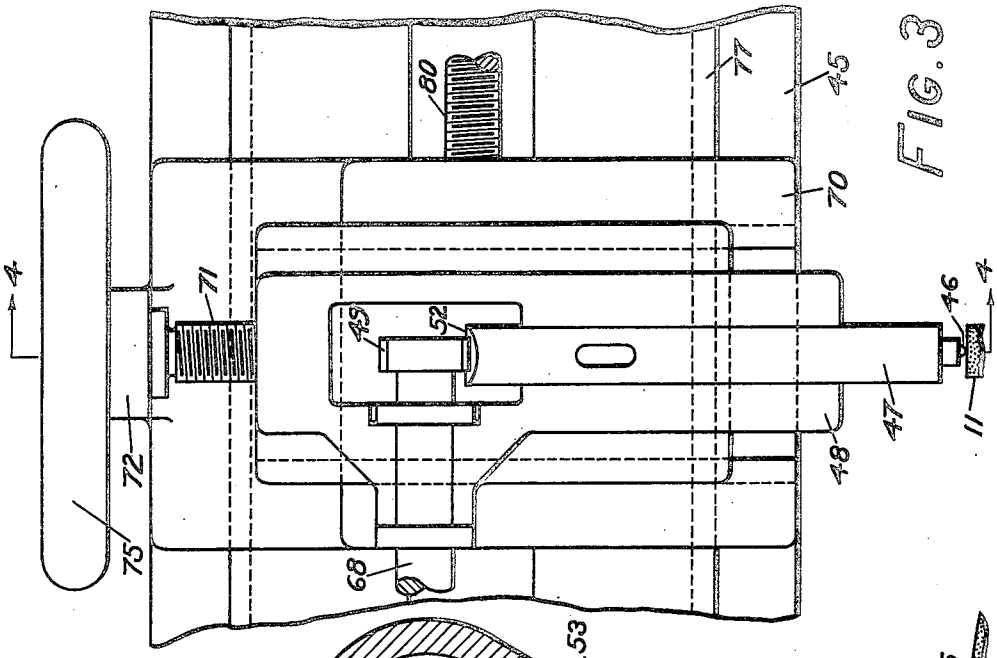


FIG. 3

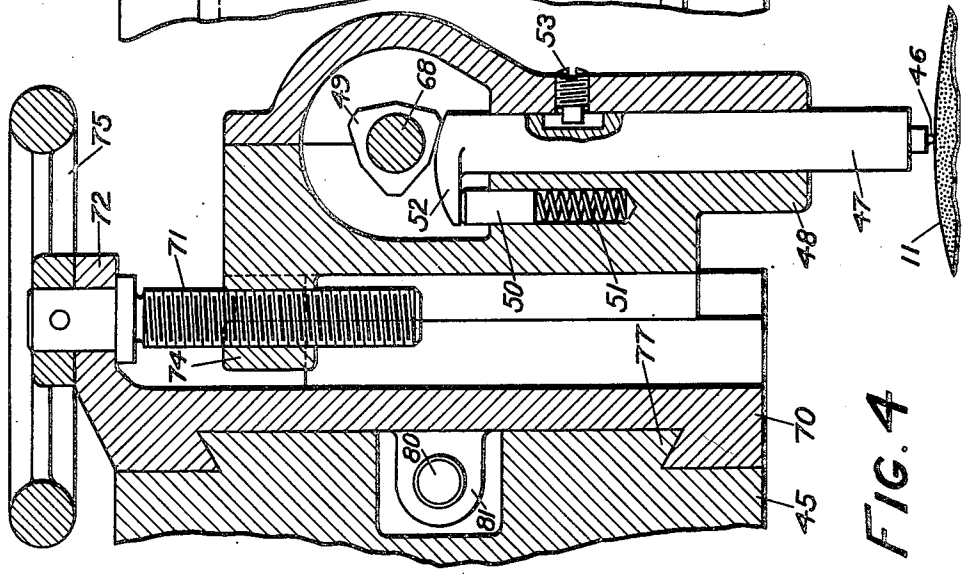


FIG. 4

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GRINDING MACHINE FOR GRINDING NONCIRCULAR SHAPES

Filed May 19, 1932 5 Sheets-Sheet 4

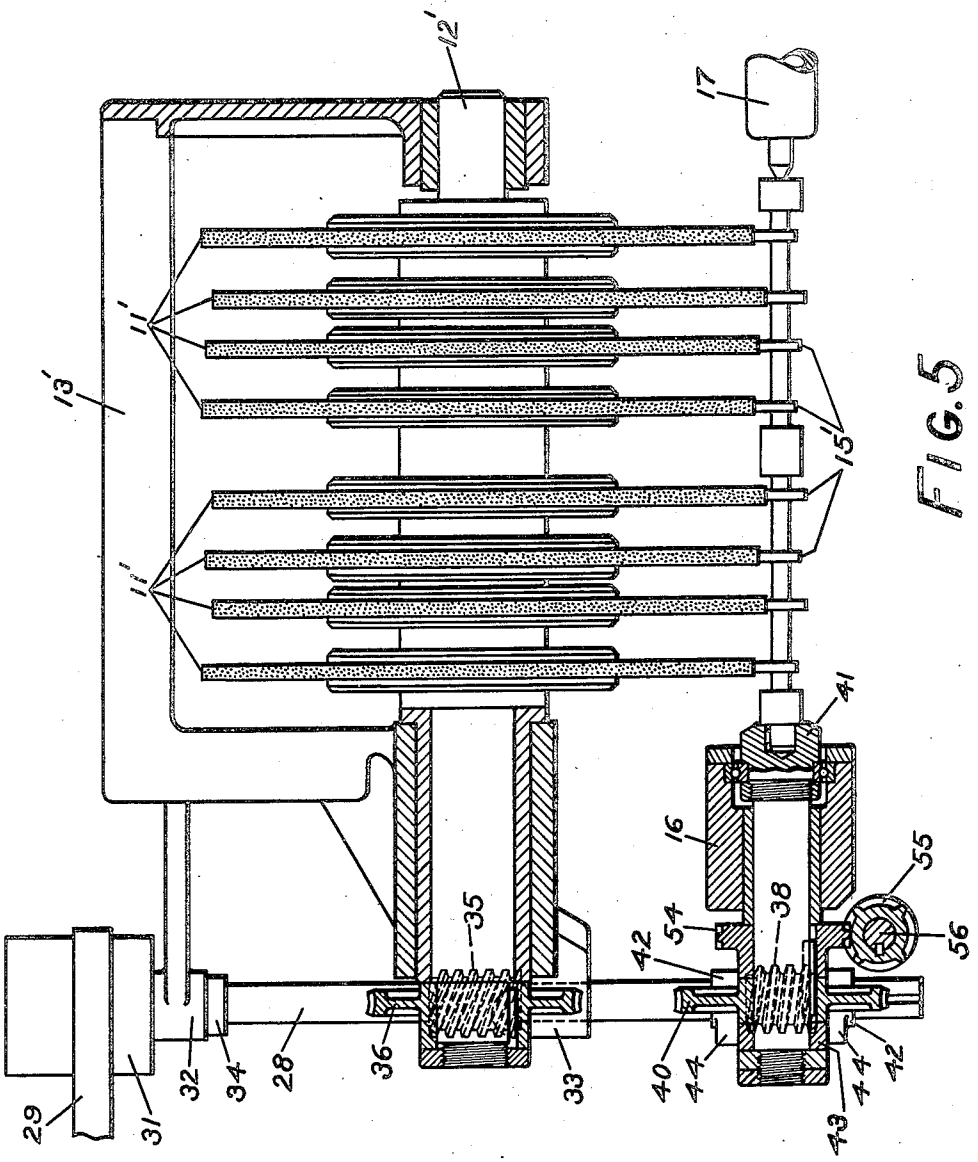


FIG. 5

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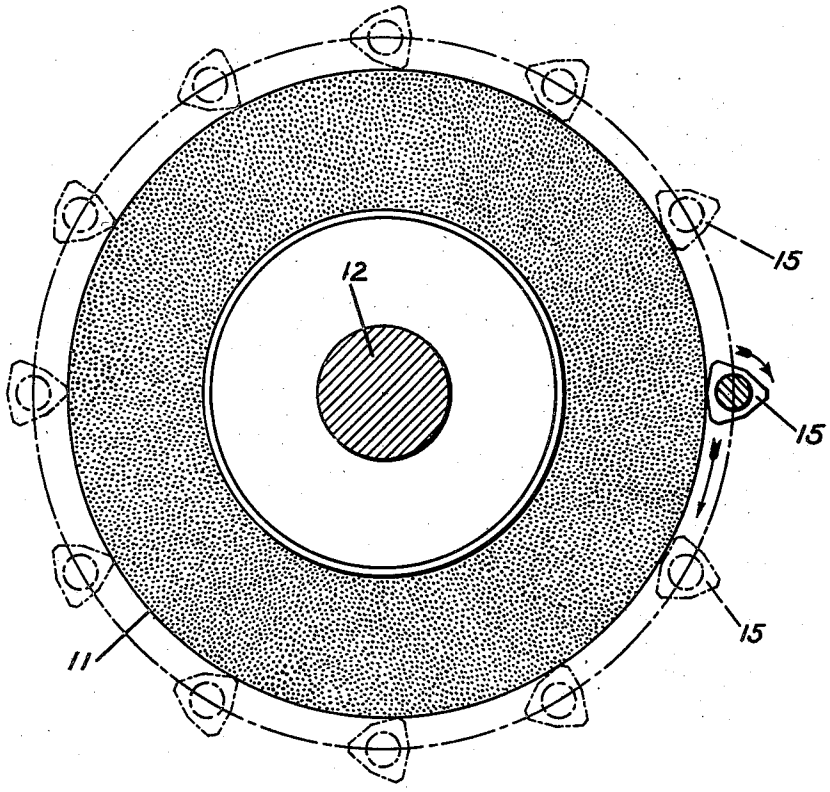
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GRINDING MACHINE FOR GRINDING NONCIRCULAR SHAPES

Filed May 19, 1932 5 Sheets-Sheet 5

FIG. 6



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Patented Nov. 9, 1937 2,098,438

UNITED STATES PATENT OFFICE

2,098,438

GRINDING MACHINE FOR GRINDING NON-CIRCULAR SHAPES

Everard Stubbs, Springfield, Vt., assignor to Norton Company, Worcester, Mass., a corporation of Massachusetts

Application May 19, 1932, Serial No. 612,232

6 Claims. (Cl. 51—105)

This invention relates to a grinding machine and more particularly to a machine adapted to finish work having an irregular contour.

In prior grinding machines as heretofore used to form non-circular shapes such as cams, it has been the practice to utilize a grinding wheel of circular shape; and in order that the wheel may engage with the work throughout the entire work surface to be finished, the work support has been arranged to move towards and from the wheel center in timed relation with the work rotation while both the wheel and the work are rotated. Such machines are often unsatisfactory due to their complicated construction and owing to the complex movement impressed on the work by moving it towards and from the wheel as it rotates. With grinding machines of this type the wheels may be used only within certain narrow limits of diameter if a satisfactory grinding operation is to be produced. Furthermore, it is difficult to grind certain other types of non-circular work, such as splined shafts, by utilizing the mechanisms as heretofore proposed.

It is, therefore, one object of my present invention to provide a machine for shaping bodies of various irregular non-circular contours which makes it possible to produce duplicate work pieces on a mass production basis.

A further object of my invention is to provide a grinding machine which is constructed and arranged to produce work of irregular contour accurately and repeatedly in duplicate sizes and which may be utilized to produce various shaped bodies by varying the shape of the cutting wheel.

A further object of my invention is to provide a grinding machine having a plurality of grinding wheels arranged to simultaneously grind a plurality of work blanks, the shape of each blank being wholly determined by the abrading action of its respective grinding wheel.

Another object is to provide a new type of grinding wheel which is so shaped and constructed that it may be rotated in contact with the surface of a work piece of non-circular cross section while the wheel and work rotate at predetermined rates about fixed axes and cause the wheel to generate the desired curves on the work.

With these and other objects in view as will be apparent to one skilled in the art, my invention resides in the combination of parts and the steps of a method set forth in the following description and appended claims.

In the drawings illustrating a grinding machine embodying my invention:

Fig. 1 is an end elevation of a grinding machine showing the drive for the wheel and the work;

Fig. 2 is a fragmentary elevation, partly in section, showing the relation of the grinding wheel, work blank and forming attachment for truing the wheel;

Fig. 3 is a fragmentary detail showing the mechanism for turning or truing the wheel;

Fig. 4 is a cross sectional view of the truing mechanism, taken approximately on lines 4—4 of Fig. 3;

Fig. 5 is a sectional view taken along the line 5—5 of Fig. 1 showing this invention as adapted for grinding a plurality of work blanks simultaneously;

Fig. 6 is a diagrammatic view showing the relation of the wheel and work in various angular positions during the grinding operation.

In accordance with my invention, I have provided a grinding machine wherein the grinding wheel is given a particular shape that is the conjugate of the desired work contour, such as a cam or an eccentrically mounted cylindrical work piece. The wheel and the work are rotated in a definite angular timed relation but at different linear speeds at the point of grinding contact, so that a given portion of the wheel will always contact with a given portion of the work during the grinding operation. For instance, a grinding wheel is conjugate to an irregular work piece in the sense of this invention when the cutting portion of the wheel projects or recedes in complement to the receding or projecting parts of the work with which said cutting parts contact and the wheel and work rotate in substantially continuous contact but at different linear speeds. In a grinding machine of this type, certain fixed points in the work and the wheel are withheld from recession or oscillation towards and from the work axis during the grinding operation, the only movement thereof resulting from the feeding action required to grind the work to the desired extent as it reduces in size. In other words, if the operative faces of the grinding wheel and work constitute their peripheries, then their axes are fixed and the sum of the radii of the work and the wheel at the point of grinding contact always remains constant except as the grinding wheel is fed towards the work axis to reduce the work to the required size. If the side face of either wheel or work is utilized, then one may consider

a fixed plane therein perpendicular to the axis of rotation as the position from which measurements may be made.

One form of my machine which embodies this principle, has the grinding wheel and work arranged to rotate in angular synchronism about relatively fixed parallel axes with their peripheries in operative contact, the wheel and work being relatively movable towards each other so that the wheel may be fed into the work to grind it to the desired size. It should be noted, however, that the shape or contour of the work is wholly controlled by the shape of the grinding wheel and not by the infeed thereof, as is the case in the standard type of cam grinding machines now on the market. The work and grinding wheel are rotated in angular synchronism, either at the same number of revolutions per minute or with the wheel rotating at a definite angular rate which may be a multiple of the angular rate of the work rotation.

The grinding wheel may be given its required grinding shape by a truing tool which is moved toward and from the wheel axis by a master cam or form shaped in accordance with the work contour to be produced. This cam for controlling the truing tool movement is rotated in angular synchronism with the grinding wheel and the work. If a long piece of work is to be ground, the work and the grinding wheel may be axially reciprocated relative to each other by any suitable type of reciprocating mechanism, such as is standard in a Norton grinding machine as shown in the patent to Norton No. 762,838, so that the wheel may be traversed throughout the length of the work while the irregularly shaped noncylindrical surfaces of the grinding wheel and the work remain in operative abrading contact, as is the usual practice in cylindrical grinding. A suitable cross feed mechanism may be utilized to feed the grinding wheel toward the work as it wears away and thereby reduce the work to a predetermined size. It is to be understood, however, that the work and the wheel axes are substantially immovable and are not oscillated toward and from each other during the grinding operation as is common practice in prior machines. Hence, the only movement of these substantially fixed axes is the small relative feeding movement between the wheel and work required to reduce the work in size.

The preferred embodiment of my invention, as illustrated in the drawings, comprises a machine base carrying the grinding wheel 11 mounted upon a rotatable spindle 12 which in turn is supported on a wheel slide 13. The work piece 15, which is illustrated as a special type of splined shaft or integral key shaft covered by my U. S. Patent No. 1,912,412 issued June 6, 1933, is rotatably mounted between a headstock 16 and footstock 17 which are in turn supported on the work table 18. The axes of the grinding wheel and the work are fixed relative to each other during the grinding operation, except for the relative feeding of the work and grinding wheel to reduce the work to the required size.

A cross feed mechanism is provided to move the wheel slide and grinding wheel toward and from the work, to reduce the work to a predetermined size. This mechanism may be of any suitable construction, such as that shown in the patent to Wilcox #1,197,700 of September 12, 1916, to which reference may be had for a detailed disclosure thereof. This wheel feeding mechanism comprises a half nut 20 mounted on the under side of the wheel slide 13 and adapted to engage the feed screw 21 which is rotatably mounted on suitable bearings in a base 22. The outer end of the feed screw 21 is provided with a gear 23 fixed thereon and engaging a pinion 24 which is operatively connected to a hand wheel 25. By rotating the hand wheel 25, a rotary movement is transmitted through the gears 24 and 23, to the feed screw 21 which, operating through a half nut 20 moves the grinding wheel slide and thereby causes a relative feeding movement between the grinding wheel and the work. This feeding movement is utilized only to compensate for wheel wear or to feed the wheel and thereby reduce the work to the required size.

It is essential that the rotation of the grinding wheel and the work be angularly synchronized so that the specially shaped operative face of the grinding wheel will produce a conjugate surface on the work. To rotate these parts, a motor 27 is mounted either adjacent to the machine as shown in Figure 1 or on or within the base 22. This motor serves to drive a cross shaft 28 by means of a belt 29 passing over a motor pulley 30 and over the wide driven pulley or drum 31 fixed on the outer end of shaft 28 which serves to impart a synchronous rotation to the wheel and work. Shaft 28 is mounted in suitable bearings 32 and 33 on the wheel slide 13 and held in position by collar 34 and worm 35 engaging the ends of the bearings, whereby it is arranged for endwise movement with the wheel slide during the wheel feeding movement. The worm 35 is fixedly mounted on the shaft 28 and meshes with a worm gear 36 on the grinding wheel spindle 12. The other end of shaft 28 is provided with a worm 38 slidably fastened thereon by means of a key 39 and maintained in fixed driving relation with a worm gear 40 on the work driving spindle 41 which is mounted in the headstock. A yoked bearing support comprising the spaced bearings 42 rotatably engaging shaft 28 and mounted on opposite sides of the worm 38, together with a head 43 connected by arms 44 to the bearings 42, is rotatably suspended from the work driving spindle 41. This construction serves to permit the grinding wheel to be moved towards and from the work without changing the angular relation of the wheel and the work, since the forward or rearward axial movement of shaft 28 is not imparted to worm 38 slidably keyed to the driveshaft 28. It will readily be seen from this construction that any rotation of shaft 28 will be transmitted to rotate the grinding wheel and the work in synchronism.

As illustrated in the drawings I have provided a triple worm 35 to engage the worm wheel 36 on the grinding wheel spindle 12, while on the other end of shaft 28 the worm 38 is of the single thread type. By employing this arrangement, the grinding wheel will be rotated three times for each rotation of the work with the wheel and work both rotated in the same angular direction as shown in Fig. 6.

This ratio and rotation of the grinding wheel and work is applicable only for grinding a body, such as the cam illustrated in the drawings, in which the three lobes of the work are symmetrical. In the case of the ordinary camshaft, such as commonly used in internal combustion engines, it is necessary to employ a one to one ratio, wherein both the wheel and the work are rotated synchronously at the same angular rate. If desired,

the wheel and the work may be rotated in opposite angular directions, so that their adjacent faces at the point of grinding contact will travel in the same direction, although at different speeds.

A special feature of my machine involves a mechanism for truing the face of the grinding wheel to an irregular shape so that it will grind to produce the required conjugate work shape. As illustrated in the drawings, a truing apparatus 45 mounted on the wheel slide is adapted to support a truing tool such as a diamond 46 in operative relation with the face of the grinding wheel. The diamond 46 is mounted in the lower end of a holder 47 which is slidable in a vertical sliding support 48, as shown in Figs. 3 and 4. To shape the face of the grinding wheel so that it will produce a conjugate surface on the work of the desired size and shape, a master form or cam 49 is rotatably mounted on the slide 48 as illustrated. The rotation of the master form 49 will be transmitted to cause a movement of the truing tool 46 towards and from the surface of the grinding wheel. A straight plunger 50 actuated by a spring 51 is provided to maintain the follower 52 in operative engagement with the master cam 49. A stud 53 threaded into the support 48 rides in a slot in the holder 47 and serves to prevent angular movement of the diamond holder and follower 52.

It is essential that the master cam 49 be rotated in angular synchronism with the work spindle. As illustrated in the drawings, a spiral gear 54 is fixed on the work driving spindle and meshes with a spiral gear 55 on the lower end of a shaft 56 which is provided with a suitable bearing 57 secured on the headstock 16 by arm 58. A telescopic shaft 59 is connected with shafts 56 and 60 through universal joints 62 which permit the shafts to be out of alignment as the diamond is traversed across the face of the wheel and fed into the wheel as the wheel is reduced in size. The shaft 60 is supported in a bearing 63 fixed on the support 46 and has at its upper end a spiral gear 65 meshing with a spiral gear 67 secured on the end of the master camshaft 68.

It will now be apparent that any rotation of the headstock spindle 41 will be transmitted to produce a corresponding rotation of the master form 49 which in turn transmits a movement to the diamond or truing tool 46 towards or from the periphery of the grinding wheel, thereby producing a surface on the grinding wheel which is the conjugate of the master cam. In the present instance, the master cam 49 as shown in the drawings is of identical size and shape as the final required work size and is, therefore, rotated in synchronism with the work piece 15 at the same angular rate. It is to be understood that other shapes of master cams and other constructional arrangements may be employed, but the master cam must be rotated in synchronism with the work spindle and it must be of such form as to cause the truing tool to shape the grinding wheel the exact conjugate of the final desired work shape.

In order that the diamond may be fed towards the periphery of the wheel, as the wheel wears away, the truing tool is mounted on a vertical sliding support 48, which is slidably mounted on a horizontal slide member 70, so that the truing tool may be moved vertically towards and from the periphery of the wheel. As illustrated in the drawings, a nut and screw mechanism is provided to produce the desired adjustment of the vertical slide. This preferably comprises a screw 71 rotatably fixed in a suitable bearing 72 in the member 70 and threaded into a projection 74 of the vertical support 48. The upper end of the screw 71 is fixed to a hand wheel 75 so that it may be readily turned to position the truing tool 46 relative to the periphery of the wheel.

In order that the truing tool 46 may be traversed across the face of the wheel, any suitable mechanism may be employed, such as a cross slide 77 adapted to mate with a dovetailed sliding surface on member 70 and positioned so that the sliding movement is parallel with the grinding wheel axis. A screw 80 is mounted in suitable bearings (not shown) in the cross slide 77 of the truing mechanism engaging a nut or suitable projection 81 of the member 70 so that any rotation of the screw 80 will be transmitted to move the truing tool 46 across the face of the grinding wheel parallel to its axis. The screw 80 is provided with a hand wheel 82 so that the screw may be readily turned to produce the desired traversing action of the truing tool across the work.

As illustrated in Fig. 5, a modification of my invention has been illustrated whereby the wheel spindle 12' suitably mounted on the slide 13' may carry a plurality of grinding wheels 11' in spaced relation and arranged thereon to correspond with the positions of cams 15' on an automotive camshaft or the like. By employing a construction of this type, a plurality of cams or irregularly shaped objects on the same shaft may be simultaneously ground. The various constructional features on a machine utilizing more than one wheel are in general the same as above described, but will be duplicated as required for the grinding operation and for truing each wheel. The camshaft to be ground is rotated through the work drive spindle 41 and synchronized with the wheel by means of drive shaft 28, which connects them as previously described. Likewise the gear 54 driven with the work serves to rotate the shaft 56 and thus rotates the master camshaft 68 in synchronism with the work and the grinding wheel, whereby the latter may be properly trued. It will be readily seen from this construction that the grinding wheels will not only be formed as the conjugate of the respective cams on a shaft, but they will be trued so as to produce the correct grinding of various cams of the work piece to be finished irrespective of the shape and the angular position of each cam on the shaft.

In the operation of my machine a master form or cam of the required shape is mounted in operative relation with the truing mechanism. The grinding wheel of suitable characteristics is then set in rotation and the hand wheel 75 is rotated to feed the diamond truing tool 46 into operative relation with the face of the grinding wheel 11. The hand wheel 82 is then turned to traverse the diamond across the face of the wheel after which the hand wheel 75 is turned to produce a further feed of the diamond into the face of the wheel. This operation is continued until the grinding wheel has been trued so that its shape is the conjugate of the master form or cam, thereby forming the grinding wheel as the conjugate of the required work shape. During the truing operation, the rotation of the grinding wheel and the master cam 49 in angular synchronism causes the truing tool 46 to move towards and from the wheel axis in a definite phase relation with the wheel rotation in order to true the wheel face to the desired contour. The work blank is then

mounted on centers between the headstock 16 and footstock 17. After the work and wheel have been angularly located and put into synchronous rotation, the grinding wheel is fed forward by rotating hand wheel 25, which serves to rotate the feed screw 21, thereby causing a movement of the slide 13 and grinding wheel 11. The work blank will be rotated in synchronism with the grinding wheel so that any high spots on the wheel will produce correspondingly low spots on the work and vice versa as shown diagrammatically in Fig. 6. The grinding operation continues as the operator feeds the wheel into the work until the work blank has been reduced to a predetermined shape and size which is the conjugate of the peripheral surface of the grinding wheel.

It is to be understood that the term "conjugate" as used in this specification and in the claims is associated with those curves which are so related as to be produced by the rotation of the connecting surfaces of the tool and the work about fixed axes with their angular velocities equal or in a simple ratio where these surfaces are in part irregular in shape and their peripheries are of unequal extent. If the work and wheel were rotated in opposite directions and their circumferences were the same in length and their angular velocities were the same, the two surfaces would have a pure rolling contact; but with the dissimilarity of length of the two peripheries a slipping or cutting action between the wheel and work serves to grind the latter to size. If the wheel and the work are rotated in the same direction, the cutting conditions are the same as in a normal cylindrical grinding operation. They may be rotated in opposite directions if desired. It is essential, however, that the work and the grinding wheel rotate in fixed angular synchronism and that the wheel be so shaped that for each revolution thereof it will reproduce a conjugate shape on the work.

It is to be understood that the present invention applies to forming eccentrically revolved cylindrical surfaces, such as crankpins, as well as non-circular peripheral surfaces, the cross section or contour of which do not form geometric circles, such as cams, and to the forming of irregular surface contours on the side faces of rotary bodies; hence the expression "work of non-circular contour" and similar wordings found in the claims are to be interpreted as covering such shapes. The invention applies equally to the art of grinding internal surfaces, where the length of the surface being ground is greater than that of the circumference of the wheel. Likewise, a work piece of a suitable shape may be mounted on the bed of a plane oscillative grinder or a rotary surface grinder for the purposes of my invention. For example, a ring shaped piece having a wave shape contour may be mounted concentrically with the axis of the rotary circular bed of a rotary surface grinder and the latter may be rotated about a vertical or horizontal axis with the peripheral conjugate face of a grinding wheel in operative contact with the work. The rotary bed will be rotated in angular synchronism with the wheel. The work and the wheel are said to be in "angular synchronism" when their angular velocities are in simple ratio of one to one, one to two, one to three or one to any finite number. In other words, the wheel and work are always rotated through a proportionate angular displacement.

This application of conjugate grinding or forming of a work piece has been illustrated as applicable to grinding the outer surface of a body but this invention is not limited to this type of grinding. It is equally applicable to grinding holes of an irregular shape by forming the grinding wheel so that when it rotates in synchronism with the work blank, it will produce a conjugate surface in a periphery of the work aperture. These principles apply to various types of grinding machines, in which the wheel grinds on its peripheral or on its side face, and they apply also to the production of many different shapes of work. Various other applications of this invention are clearly within the scope of the appending claims.

This case is a continuation in part of my copending application Serial No. 459,922 filed June 9, 1930.

Having thus described my invention, what I claim as new and desire to secure by Letters Patent is:

1. A grinding machine for grinding a rotatable work piece having the line of grinding contact at varying distances from the axis of rotation of the grinding wheel comprising a rotatable grinding wheel shaped as the conjugate of the desired work contour and a support for the rotatable work which are relatively movable for feeding the wheel into the work, power operated driving means to simultaneously rotate the wheel and work in a definite cyclic phase relation but at different surface speeds at the line of grinding contact, and driving mechanism including a slidable connection between the wheel and the work drive, which permits a relative feeding movement of the wheel and work without disturbing the phase relation of the wheel and work.

2. A grinding machine for shaping the periphery of a rotatable work piece having the line of grinding contact at varying distances from its axis of rotation comprising a machine base, a grinding wheel rotatably supported thereon and preshaped as the conjugate of the desired work contour, means to support a work piece for rotation on the base, means to prevent relative oscillation of the wheel and work towards and from each other during grinding, means to simultaneously rotate the wheel and work in angular synchronism but at different peripheral rates, and a driving connection between the wheel and the work which is so arranged that the wheel and work may be subjected to a relative feeding movement without changing their angular synchronism.

3. A machine for grinding work of irregular contour comprising a rotatable support for the work, a grinding wheel having a plurality of symmetrical surface portions thereon, each of which is the conjugate of the entire work surface, and the length of each of said surface portions of the wheel being sufficiently greater than that of the corresponding conjugate work surface so as to cause a grinding action, means for rotating the work and the grinding wheel about substantially fixed axes in which the ratio of the angular rate of rotation of the wheel to that of the work is a multiple of the number of said symmetrical surfaces on the wheel, and means for relatively feeding the wheel and the work towards each other to reduce the latter to the required size.

4. A machine for grinding the periphery of a rotatable work piece in which the elements of its surface lie at different distances from its axis of rotation comprising a grinding wheel having a continuously curved peripheral face of materially different length from that of the work periphery and shaped to the conjugate form of the final re-

quired contour thereof, said operative wheel face serving as the sole means to determine the work contour, means for simultaneously rotating the wheel and work in predetermined angular synchronism, means to cause a relative feeding movement between the wheel and the work to compensate for wheel wear and to reduce the work to a desired size, and mechanism arranged to maintain the wheel and work in said predetermined angular relation at all times irrespective of the extent of feeding movement.

5. A machine for grinding a rotatable curved work surface in which the elements of said surface lie at different distances from the axis of work rotation comprising a grinding wheel support and a work support relatively movable towards and from each other, a grinding wheel having a continuously curved peripheral face of materially different length from that of the work surface being shaped, said operative wheel face being preshaped to the conjugate form of the desired finished work contour and serving as a sole means to determine the work shape, mechanism for simultaneously rotating the wheel and work in a predetermined angular phase relation, means arranged to provide a relative feeding movement between the wheel and work to bring the operative wheel face into grinding engagement with the work from a relatively remote position and to compensate for wheel wear and thereafter reduce the work to the desired size, and means including driving and driven gears and connections therebetween which maintain said angular phase relation between the wheel and work during the entire feeding movement.

6. A machine for grinding a non-circular rotatable work piece to a predetermined contour comprising a grinding wheel having a preshaped peripheral grinding face composed of a plurality of uniformly spaced arcuate portions of the same radius connected by similar arcuate portions of a different radius which tangentially blend therewith and provide a plurality of spaced symmetrical lobed surface portions forming a grinding face which is shaped as the conjugate form of and has a longer contour than that of the work surface being ground so as to cause a grinding action, means for rotating the work, means to rotate the grinding wheel at a greater angular speed than that of the work but with the ratio of wheel speed to work speed as a multiple of the number of symmetrical portions on the work surface, means for providing a relative feeding movement between the wheel and work to bring them into grinding engagement and thereafter reduce the work to a desired size, and mechanism associated with the said wheel and work rotating means which is arranged to maintain the wheel and work in angular phase relationship at all times during the feeding movement.

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