

May 30, 1933.

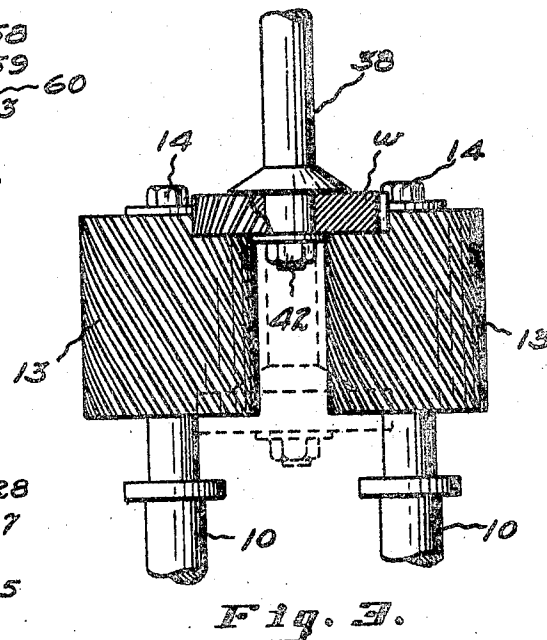
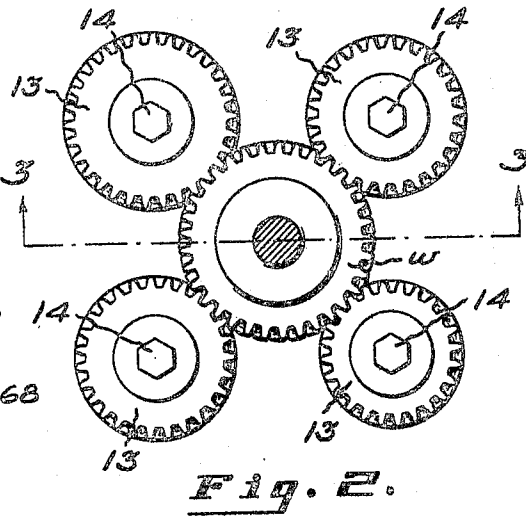
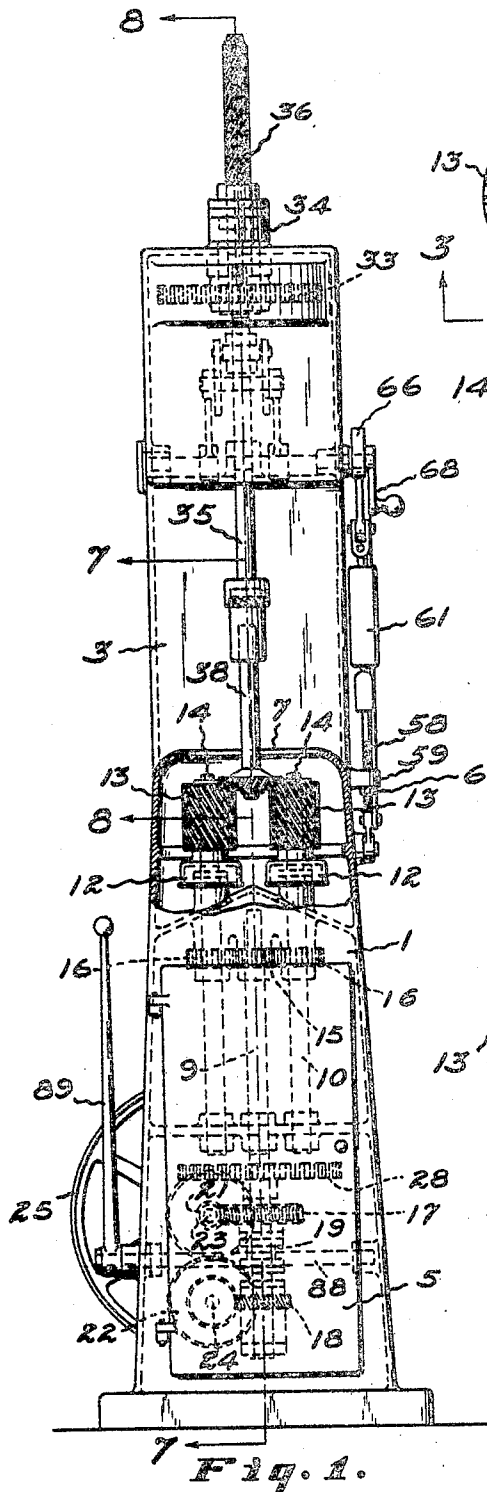
A. C. PAGE

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METHOD AND APPARATUS FOR LAPPING GEARS

Filed March 1, 1929

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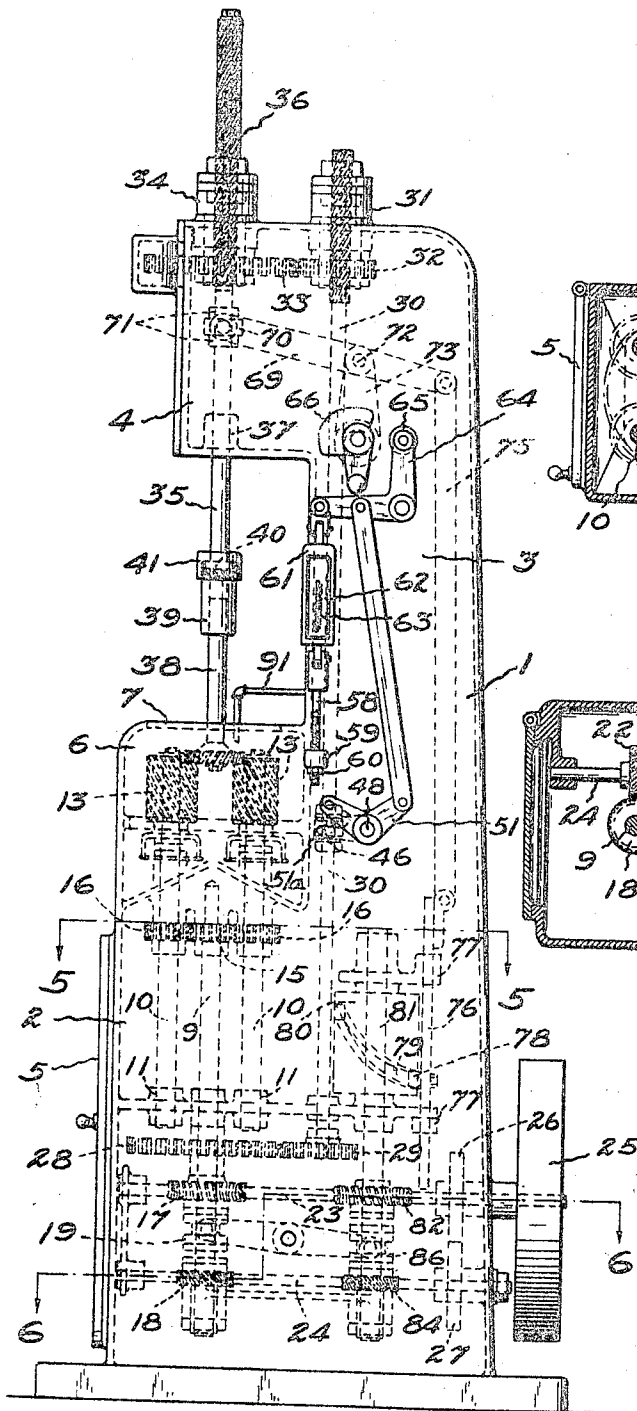


Fig. 4.

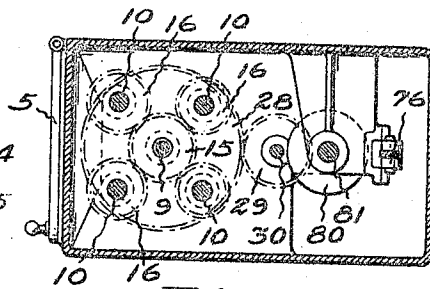


Fig. 5.

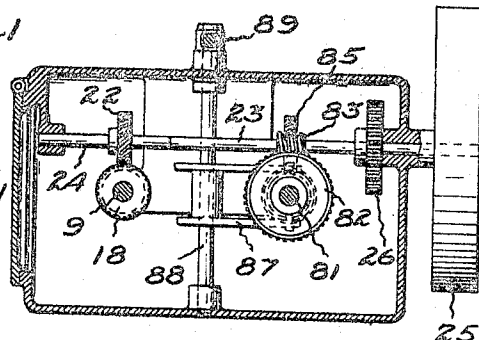


Fig. 6.

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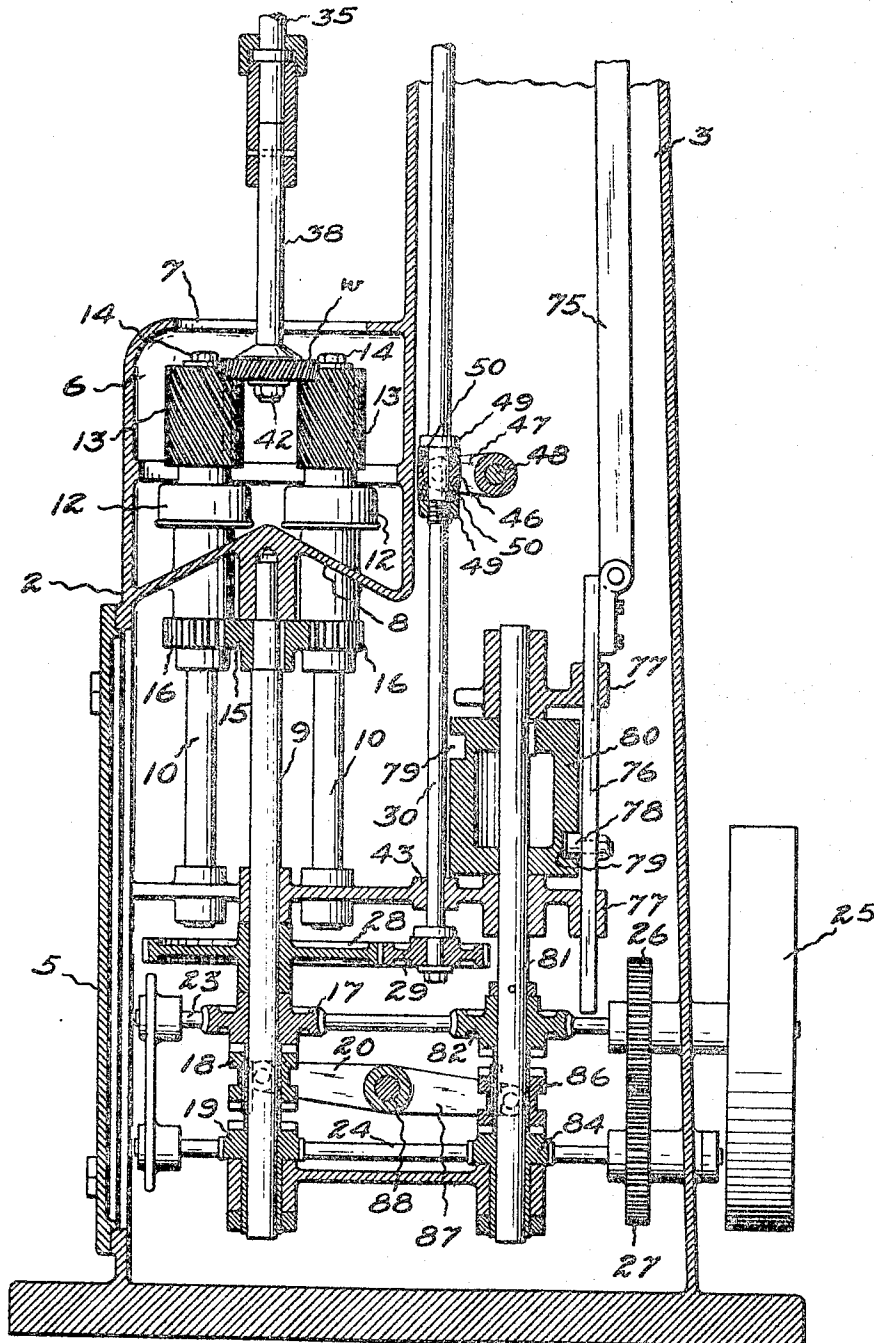


Fig. 7.

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METHOD AND APPARATUS FOR LAPPING GEARS

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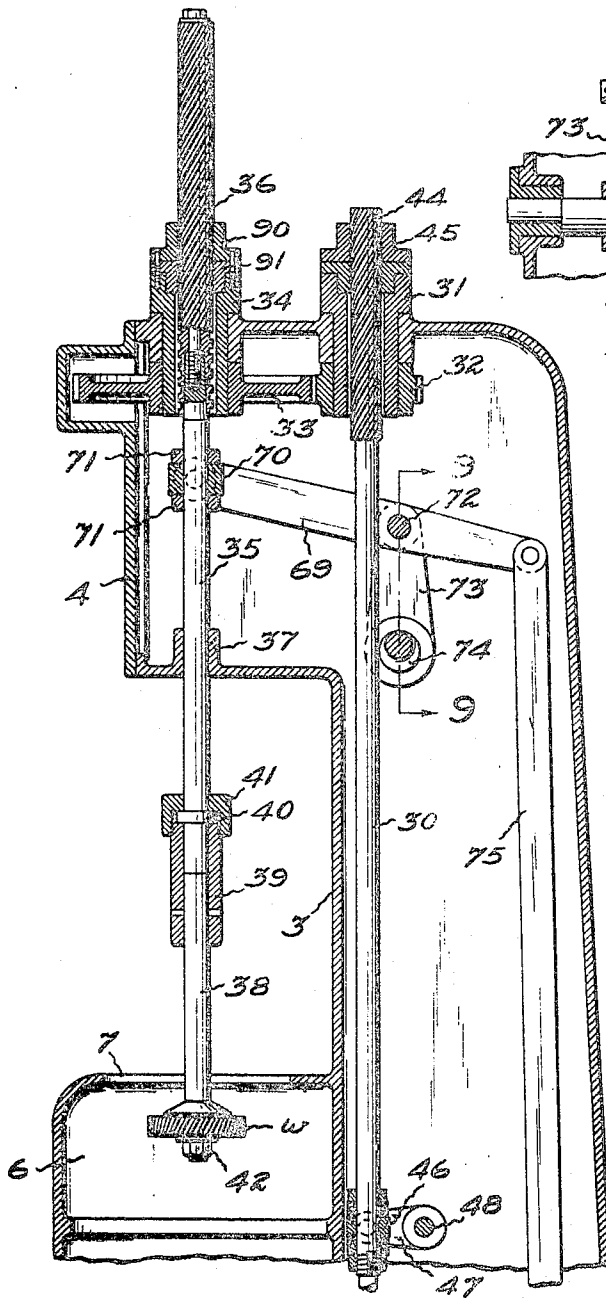


Fig. 8.

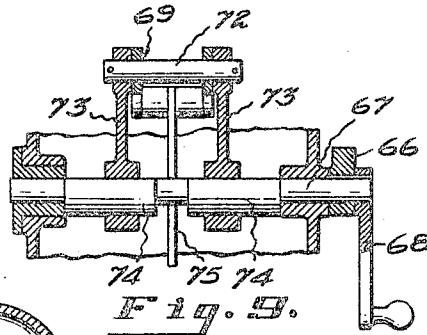


Fig. 9.

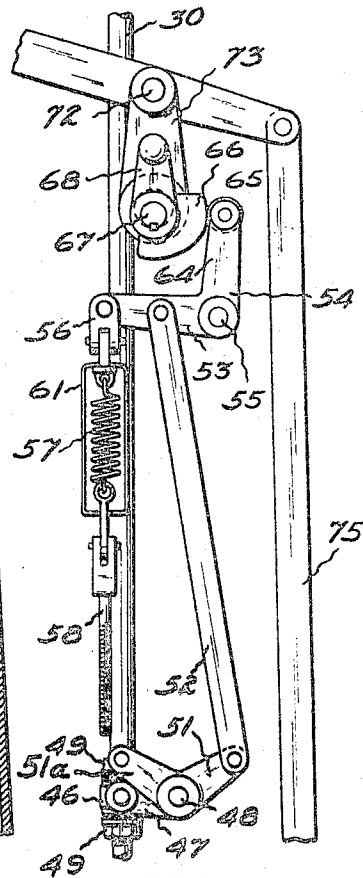


Fig. 10.

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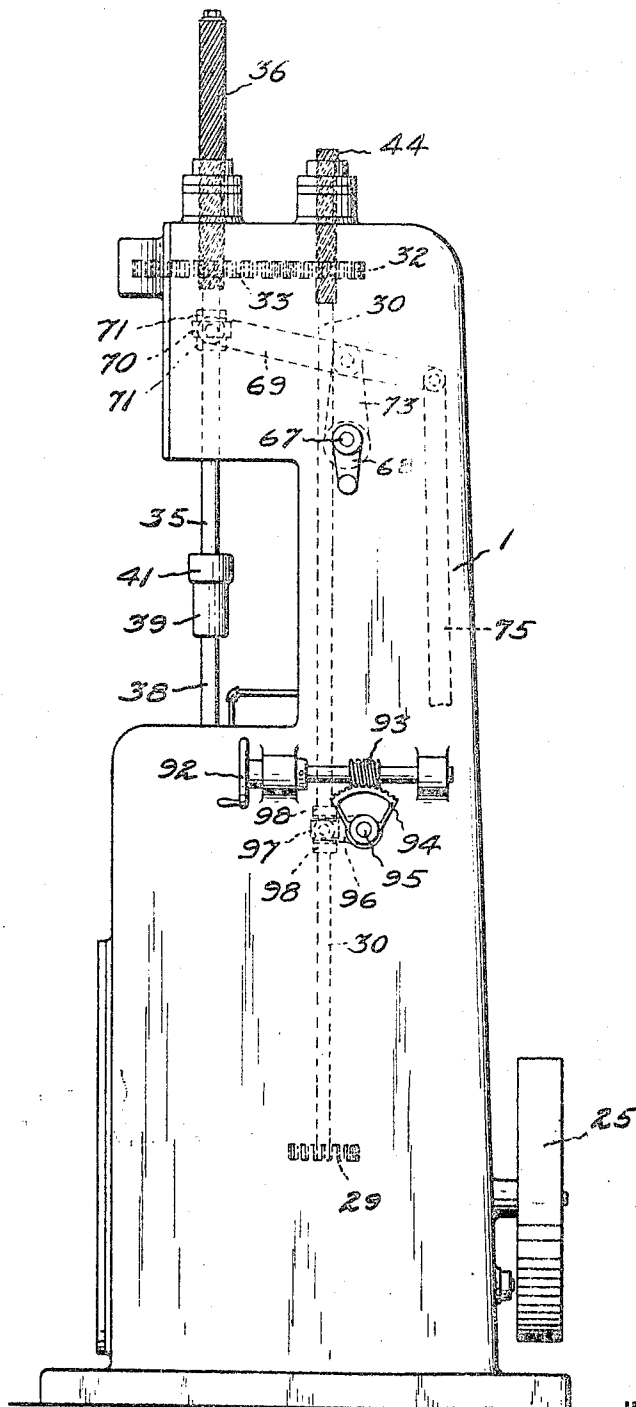


Fig. 11.

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METHOD AND APPARATUS FOR LAPPING GEARS

Application filed March 1, 1929. Serial No. 343,606.

The present invention relates to a method of and apparatus for finishing gears or other articles having the form of gears and more particularly to a method of and apparatus for correcting errors of tooth spacing, tooth contour and tooth curvature and for obtaining concentricity of the teeth with respect to the axis of rotation of the gear.

By present commercial methods of gear cutting, gears may be cut quite rapidly with but slight errors in spacing in contour and of eccentricity. However, in order to obtain gears having the required wearing qualities, it is necessary to harden the gears by heat treatment after they have been cut and the heat treatment develops irregularities in contour and may cause additional errors in spacing and of eccentricity. The errors, due to the original cutting operation and due to the subsequent heat treatment are in most instances sufficiently great to prevent smooth and silent operation of the gears running at high speeds.

Where accuracy of the gears is highly important and the cost a minor consideration, the gears may be accurately finished by grinding the tooth surfaces with an abrasive disc or wheel in a gear generating machine; or where accuracy is not so important mating gears or gears of a gear train may be made to run together more smoothly by a lapping process in which the gears of the pair or train are run in mesh with each other and abrasive material is supplied between the interengaging tooth faces so that some of the irregularities causing excessive friction between teeth are worn away.

Both of the above methods are laborious, slow and expensive methods. The gear grinding requires complicated and expensive gear generating machinery and a high degree of skill upon the part of the operators. Both the grinding and lapping methods, as heretofore practised, are slow and laborious processes and the lapping process has the disadvantage that a lapped gear will mesh satisfactorily only with the gear with which it has been lapped.

In various standardized machines such

as automobiles of which large numbers of identical construction are manufactured, quiet and smooth running gearing is very important, and the present invention has for its object to provide a method of finishing gears by which gears which are uniform and accurate within extremely small limits of error may be produced without materially increasing the cost of manufacture so that in assembling the gearing in individual machines, the proper gears may be selected indiscriminately from the stock and will run quietly and smoothly with the gear or gears with which they mesh.

Heretofore, in the assembling of gearing which is required to run with reasonable smoothness, it has been necessary to maintain a large stock of gears and to carefully test and select the particular gears which are to be meshed with each other in each machine with the result that quite a large percentage of the gears must be discarded for the reason that they will not mesh properly with any of the other gears.

The present invention has for an object to provide a method of finishing gears by which gears are made so uniform that the testing of the gears during assembly of machines is not necessary and the loss due to rejected gears is eliminated.

A further object of the present invention is to provide a method of grinding gears which is very rapid, which involves but little expense and by which the gears are finished with a very near approach to perfect accuracy and uniformity.

A further object of the invention is to provide apparatus for practicing the method in the form of a machine of simple and rugged construction which may be constructed and operated at relatively small cost.

A further object is to provide a machine in which the gears are rapidly ground to correct contour in which the spacing of the teeth is made uniform and in which the teeth are accurately centered with respect to the axis of rotation of the gear by means of a series of continuously rotating laps which are positively driven at the proper

speed by gearing separate from that driving the gear being finished.

A further object is to provide a machine in which a series of laps are caused to simultaneously mesh with the gear being finished, in which the gear is reciprocated axially with respect to the laps to obtain an abrasive action between the teeth of the gear and the teeth of the laps in which the laps are driven by gearing separate from the gearing driving the gear being finished and in which means is provided for maintaining contact between the tooth faces of the gear and the tooth faces of the laps.

A further object is to provide means for simultaneously driving the laps at the speeds at which they would be driven by the gear in its rotation and for rigidly supporting the lap spindles so that the gear, engaging lap teeth at spaced points on its circumference, is kept accurately centered with respect to the laps, and the correct spacing between gear and teeth engaged by the laps is obtained.

A further object is to provide a machine of the character above referred to capable of finishing helical gears as well as straight tooth gears in which means is provided for maintaining the correct peripheral speed ratio between the gear and the laps during relative axial reciprocation of a helical gear in mesh with a series of helical tooth laps.

A further object is to provide a machine in which the speed of rotation of the gear and laps may be varied and in which the speed of reciprocation of the gear relative to the laps may be also varied.

A further object is to provide means in connection with the gear and lap spindles for automatically changing the speed of one of the spindles to compensate for the axial movements of a helical gear in mesh with a helical lap.

A further object is to provide a gear and lap spindles with means by which the gears being finished and the laps may be quickly and easily applied to the spindles, or removed therefrom, and further, to provide removable and interchangeable means by which the machine may be adapted for finishing straight tooth gears or gears of any helix angle.

A further object is to provide a spring actuated mechanism for maintaining a predetermined driving torque on the work spindle so that a substantially uniform pressure is maintained at all times between the teeth of the gear and laps.

A further object is to provide means by which the gear may be quickly and easily shifted into and out of engagement with the laps and by which the yielding means for applying torsional thrust to the work spindle is automatically released when the gear is disengaged from the laps.

A further object is to provide a machine in which the laps or tools and the gear being ground are driven by separate gearing and in which the gear is yieldably supported with respect to the laps so as to prevent excessive pressures between the interengaging teeth of the gear and laps which would impair the effectiveness of the abrading action and would tend to set up objectionable vibrations in the machine.

With the above and other objects in view, the invention may be said to comprise the method and apparatus as illustrated in the accompanying drawings hereinafter described and particularly set forth in the appended claims, together with such variations and modifications thereof as will be apparent to one skilled in the art to which the invention appertains.

Reference should be had to the accompanying drawings forming a part of this specification in which:

Figure 1 is a front elevation of the machine for practicing the method of the present invention.

Fig. 2 is a plan view showing the gear being finished and the laps in intermeshing engagement therewith.

Fig. 3 is a section taken on the line indicated at 3—3 in Fig. 2.

Fig. 4 is a side elevation of the machine.

Fig. 5 is a section taken on the line indicated at 5—5 in Fig. 4.

Fig. 6 is a section taken on the line indicated at 6—6 in Fig. 4.

Fig. 7 is a fragmentary vertical section through the lower portion of the machine taken on the line indicated at 7—7 in Fig. 1.

Fig. 8 is a fragmentary vertical section through the upper portion of the machine taken on the line indicated at 8—8 in Fig. 1.

Fig. 9 is a section taken on the line indicated at 9—9 in Fig. 8.

Fig. 10 is a fragmentary detail view showing the spring actuated linkage through which spring pressure is applied to the shaft which drives the work spindle.

Fig. 11 is a side elevation showing a normally operable device for imparting an angular feed movement to the gear to create pressure between the intermeshing teeth of the gear and laps.

In finishing a gear by the method of the present invention, the gear is placed in mesh with a series of tools or laps, each of which is in the form of a gear conjugate to the gear to be finished, as shown in Figs. 2 and 3, the gear to be finished being indicated by the reference letter "a" and the tools or laps with which the gear is meshed being designated by the reference numeral 13.

The tools or laps are preferably of considerably greater axial length than the gear, and the gear, while being rotated in mesh with the laps is given an axial reciprocating

movement with respect to the laps so that there is a frictional abrading action between the interengaging tooth faces.

The laps may be in the form of gears made of cast iron or other suitable metal or may be gear shaped hones formed of a composition containing finely divided carborundum, alundum, emery or other suitable abrasive material. When cast iron or other metal laps are employed, a suitable liquid containing finely divided particles of abrasive material is preferably caused to flow over the intermeshing teeth so that particles of abrasive material entering between the interengaging tooth faces cause a more rapid abrading action.

In prior gear lapping processes, insofar as I am aware, one of the mating gears only is driven and this gear, in turn, drives the other gear. In the method of the present invention, however, the gear being finished and the tools or laps are driven through separate gearing, preferably from a common drive shaft, and the gearing is so proportioned that the gear and the laps are rotated with equal peripheral speeds at their pitch circles. In other words, the speeds or rotation are the speeds at which the gear and laps would be driven if the gear were driving the laps or vice versa. The laps are positively driven at equal peripheral speeds at their pitch circles so that a definite spaced relationship is maintained between the tooth faces of the several laps simultaneously engaged by the tooth faces of the gear.

If the tooth curves, tooth spacing and concentricity of the gear and laps were perfect, and if the gearing through which the gear and tools or laps were driven were also perfect, and the gear and laps were positively driven, there would be no pressure between the tooth faces of the intermeshing teeth. These conditions are, of course, impossible from a practical standpoint, since perfect uniformity cannot be obtained and since it is necessary in practice to provide a certain amount of backlash between intermeshing driving gears and between the gear and the laps. Furthermore, in order to obtain an abrading action on the gear teeth to correct errors in contour in spacing and of eccentricity, it is necessary that there be a certain amount of pressure between the teeth of the gear and the teeth of the laps.

In order to maintain a pressure between the inter-engaging tooth faces of the gear and laps, a thrust applying means is interposed between the gear being ground and the gearing through which it is driven, by which a torsional thrust is exerted on the gear tending to move the gear in the direction of rotation or in the opposite direction from the position in which it would normally be held by its driving means, thereby causing the teeth of the gear to be continuously

pressed against the teeth of the laps. If there is a high point on the surface of one of the teeth of the gear, this high point engaging a tooth of the lap will tend to hold the surface of the other lap engaging teeth of the gear out of contact with the mating teeth of the laps, the thrust applying means will yield and the pressure will be localized on this high spot, causing rapid abrasion at the high point during engagement with the tooth on which the high point is located with a lap tooth. During the rotation and reciprocation of the gear in mesh with the laps, the teeth of the gear are successively engaged by different teeth of the laps and the high points are gradually worn down until the teeth are of uniform contour.

Errors in tooth spacing in the gear are corrected in a similar manner since a tooth surface which is too far forward in the direction of rotation of the gear will receive the entire torsional thrust during its engagement with a lap tooth and will be quickly worn back to its proper position by engagement with successive lap teeth.

Errors of eccentricity in the gear will cause localization of pressure on the tooth surfaces of the gear farthest from the center of rotation thereof and these surfaces will be abraded during the initial portion of the grinding operation.

Regardless of whether the errors are of irregularity of tooth contour, of tooth spacing, of eccentricity or a combination of these errors, the abrading action is first localized and gradually progresses, until the abrading action is distributed uniformly throughout the gear teeth at which time the gear teeth will be of uniform contour, uniformly spaced and centered with respect to the axis of rotation within extremely narrow limits of error.

The laps which are in the form of gears conjugate to the gears to be finished by them may be manufactured at relatively small cost and may be formed by means of gear generating machinery to within very minute limits of error with respect to the proper tooth curvature, the proper tooth spacing and the concentricity of the teeth with respect to the axis of rotation.

It should be noted that the total area of the tooth faces of the tools or laps which engage with the tooth faces of the gears being finished are many times greater than the total area of the tooth faces of the gear. Consequently, the abrasive wearing action on the tooth faces of the laps or tools is very much slower than the abrasive action on the teeth of the gear.

Each lap is preferably formed with a number of teeth different from that of the gear to be finished so that there will be many revolutions of the lap and gear between successive engagement of the same

gear and lap tooth faces, so that there will be a more uniform distribution of the wear on the lap teeth. The laps are also preferably of different pitch diameters and provided with different numbers of teeth, so that the teeth of each lap has a different rolling and sliding action on the teeth of the gear and so that there are a great many successive simultaneous engagements of the same teeth of the laps with the gear, this also serving to insure greater uniformity in the distribution of the abrasive wearing action on the lap teeth, as well as to insure a nearer approach to perfect uniformity of tooth spacing and to perfect concentricity.

In addition to being positively driven, the lap spindles are rigidly supported against relative lateral movements by means of bearings closely adjacent the laps. The support for the gear, however, while comparatively rigid, is not as rigid as the support for the laps, the gear being supported at the free end of the sliding spindle which has a bearing spaced a considerable distance from the free end thereof to which the gear is attached. Errors of tooth spacing or eccentricity of the gear might subject the teeth of the gear to heavy stresses, if the support for the gear were as rigid as the support for the laps. These errors, of course, are always comparatively slight and the work spindle can readily flex to permit the gear to center itself with respect to the teeth of laps with which it engages and prevent the exertion of objectionably heavy pressures between the teeth of the gear and the teeth of the laps which would make the wear on the lap teeth less uniform and would tend to set up objectionable vibrations in the machine.

It is to be understood, however, that flexibility in the work spindle is not essential to the method of the present invention, since the errors to be corrected in gears are ordinarily not sufficient to prevent the gears from running in mesh with the laps and the work spindle may, if desired, be supported as rigidly as the lap spindles.

The method of the present invention is applicable to helical gearing as well as to straight spur gears, laps with helical teeth being provided for operation on a helical gear, the speed of either the gear or of the laps being increased during movement of the gear in one direction and decreased during movement of the gear in the opposite direction, a relative speed of rotation being maintained at all times corresponding to that which would be maintained if the gear alone were positively driven and reciprocated axially between laps meshing therewith.

During the finishing operation, the gear is continuously rotated and reciprocated while

it remains in intermeshing engagement with all the laps. The wearing action is therefore continuous and a number of teeth of the gear are simultaneously acted upon at all times. The abrading action is continued until the entire surface of one side of each tooth of the gear has been ground, whereupon the direction of the torsional thrust on the gear is reversed causing the opposite side faces of the gear teeth to bear against the lap teeth and continued rotation and reciprocation of the gear will cause the opposite faces of the gear teeth to be ground in the same manner as the tooth faces first acted upon.

As above explained, the high points of the gear tooth faces, the improperly spaced tooth faces and the tooth faces farthest from the axis of rotation are first abraded and when the abrading action has become substantially uniform over all of the tooth faces, these tooth faces will be uniformly spaced circumferentially, will be concentric with the axis of rotation and will conform substantially to the theoretically correct tooth curvature, all errors being reduced to within extremely narrow limits.

The uniform distribution of wear on the lap tooth surfaces permits the laps to be used for relatively long periods of time without seriously affecting the concentricity of the teeth, the angular spacing of the tooth faces or the curvature of the tooth faces. The action of the gear tooth faces upon the lap tooth faces tends to correct any irregularity developed in the lap tooth faces and to maintain the lap tooth faces concentric and uniformly spaced, as well as to maintain the correct tooth curvature.

As shown in the accompanying drawings, the machine employed in practicing the method of the present invention is provided with a frame or casing 1 which serves as a housing for the gear and lap spindles and the operating mechanism, this casing having a base portion 2 and a hollow standard 3 extending upwardly from the rear end of the base portion and terminating in its upper end in a forwardly projecting portion 4 which overhangs the base portion 2.

The base portion 2, which houses the major portion of the operating mechanism is provided at the front with a door 5 which provides access to the mechanism within the casing.

Immediately beneath the overhanging portion 4 of the casing, the base portion 2 is provided with a chamber 6 at the top thereof which has an opening 7 directly beneath the overhanging portion 4 of the casing. The chamber 6 has a bottom 8 of substantially conical form and journaled at its upper end in the apex of the conical bottom 8, there is a vertical drive shaft 9. Grouped about the vertical shaft 9 are a series of ver-

tical spindles 10 which are journaled in bearings 11 at their lower ends and which extend through the bottom 8 into the chamber 6, these spindles being rigidly supported adjacent their upper ends by means of thrust bearings 12 secured in the bottom 8 of the chamber. The upper ends of the spindles 10 within the chamber 6 are adapted to receive the laps 13 which are keyed to the spindles and rigidly clamped thereto by means of nuts 14.

The shaft 9, which is centrally located with respect to the spindles 10 has fixed thereto a spur gear 15 which meshes with spur gears 16 fixed to the spindles 10. Each of the gears 16 is either of exactly the same pitch diameter as the lap carried by the same spindle or the pitch diameters of the laps 13 and gears 16 on the individual spindles are of equal ratio so that the laps are positively driven from the shaft 9 at equal peripheral speeds at their pitch circles.

The shaft 9 may be driven either through a worm gear 17 rotatably mounted thereon or through a spiral gear 18 also rotatably mounted thereon, the worm gear and spiral gear being provided with clutch teeth adapted to engage with corresponding teeth on a clutch collar 19 which is splined to the shaft 9 and adapted to be shifted by means of a movable arm 20 to clutch either the worm gear 17 or the spiral gear 18 to the shaft 9. The shaft 9 may be driven at a relatively low speed through the worm gear 17 and at a relatively high speed through the spiral gear 18. The worm gear 17 meshes with a worm 21 and the spiral gear 18 meshes with a spiral gear 22, the worm 21 being fixed to a transverse shaft 23 and the spiral gear 22 being fixed to a transverse shaft 24 parallel with the shaft 23. The shafts 23 and 24 are journaled in the front and rear walls of the casing 1 and the shaft 23 extends through the rear wall and has fixed thereto a suitable driving member such as a belt pulley 25 by means of which it may be driven from a suitable source of power. The shaft 24 is driven from the shaft 23 by means of intermeshing gears 26 and 27, one fixed to each of the shafts.

When the clutch collar 19 is in engagement with the worm gear 17, the shaft 9 will be driven at low speed and when the clutch collar 19 is in engagement with the spiral gear 18, the shaft 9 will be driven at a relatively high speed.

Beneath the lower ends of the spindles 10, the shaft 9 has fixed thereto a spur gear 28 which meshes with a spur gear 29 fixed to a vertical shaft 30 which is mounted for endwise sliding movement in the casing 1, the upper end of the shaft being splined in a sleeve 31 rotatably mounted in the casing at the top thereof.

Fixed to the sleeve 31, there is a spur

gear 32 which meshes with a spur gear 33 which is fixed to a second sleeve 34 rotatably mounted in the casing in front of the sleeve 31. The sleeve 34 forms a bearing for a work spindle 35 which is in axial alinement with the shaft 9. The work spindle has a detachable section 36 at its upper end which is grooved to provide a spline connection with the sleeve 34. The work spindle 35 extends through the overhanging portion 4 of the upper end of the casing and is slidably mounted in a bearing 37 formed in the lower wall of the portion 4.

At its lower end, the spindle 35 has a gear carrying section 38 which is detachably secured to the main portion of the spindle by means of a sleeve 39 which is rigidly secured to the upper end of the section 38 and which fits over the lower end of the intermediate section of the spindle. An internally threaded collar 40 has a sliding fit on the spindle above the flange or collar 40 and is adapted to screw onto the sleeve 39 to rigidly clamp the section 38 to the intermediate section of the spindle. The section 38 of the spindle projects through the opening 7 into the lapping chamber 6 and is provided at its lower end with means for rigidly securing thereon, a gear "w" to be ground, the gear being held in place on the spindle by means of a clamping nut 42.

The gears 33 and 28 on the sleeve 34 and shaft 9 are of the same pitch diameter and the gears 32 and 29 on the sleeve 31 and shaft 30 which mesh with the gears 28 and 33 are also of the same pitch diameter so that if the shaft 30 and spindle 35 be held against turning movements in the sleeves 31 and 34, the spindle 35 would be driven in the same direction and at exactly the same speed as the shaft 9. In other words, the gear "w" on the work spindle would be driven through the gears 28, 29, 32 and 33 at exactly the speed at which it would be driven by the gear shaped laps or tools 13.

In order, however, to obtain more effective grinding action on the tooth faces of the gear, it is desirable that contact be maintained between and pressure be exerted upon the interengaging tooth faces and, to obtain this result, means is provided for feeding the gear angularly with respect to the laps to maintain contact between the interengaging tooth faces by turning the work spindle with respect to the gearing through which it is driven. In order to cause this additional turning or feed movement of the work spindle, the shaft 30 is mounted in the casing for a slight vertical movement, the lower end of the shaft 30 adjacent the gear 29 being slidable in a bearing 43 so that the shaft is rigidly held against lateral movements. At its upper end, the shaft 30 is provided with a helical

spline 44 which slides in a nut 45 which is rigidly secured to the collar 31.

It will be apparent that if an endwise movement be imparted to the shaft 30, the helical spline which forms the driving connection between the shaft 30 and the sleeve 31 will cause the sleeve to turn with respect to the shaft 30 and if this endwise movement be imparted to the shaft while the shaft 30 is being driven, it will cause the sleeve 31 and gear 32 attached thereto to be advanced or retarded with respect to the shaft 30. An advancement or retardation of the gear 32 will cause a corresponding advancement or retardation of the work spindle 35. Assuming that the gear "w" on the work spindle is in mesh with the laps or tools 13 which are rotating at constant speed, the work spindle will be prevented from rotating at a speed higher than that at which it would be driven by the laps or tools. However, if an endwise pressure be maintained on the shaft 30 tending to slide the helical spline 44 through the nut 45, this pressure will be transmitted through the gears 32 and 33 to the work spindle causing the teeth of the gear "w" to press against the teeth of the laps or tools 13.

An end thrust is maintained on the shaft 30 during the operation of the machine through a collar 46 which is loosely mounted on the shaft and which is engaged by a rocker arm 47 fixed to a transverse rock shaft 48, the collar 46 is held against longitudinal movement on the shaft 30 by means of fixed collars 49 secured to the shaft above and below the collar 46 and ball thrust bearings 50 interposed between the collars 49 and the collar 46. The rock shaft 48 is actuated by means of either of two oppositely extending arms 51 and 51a and a link 52 which may be attached at its lower end to either of said arms and extends upwardly from the outer end of the arm to a laterally projecting arm 53 of a bell crank lever 54 which is carried by a rock shaft 55 journaled in the casing.

To the outer end of the arm 53, there is secured a clevis 56 to which is attached a coil spring 57 which is attached at its lower end to a threaded rod 58 which extends through a lug 59 formed integrally with one side of the casing 1 and which is anchored to the lug by means of a nut 60 on the rod 58 engaging the under side of the lug 59. The spring 57 is held under tension and tends to rock the arm 53 of the bell crank lever downwardly and through the link 52 and arms 51 and 47 to impart an upward or downward thrust to the shaft 30. This endwise thrust on the shaft 30 is converted by means of the helical spline 44 into a torsional driving thrust on the sleeve 31 which serves to yieldingly press the teeth of the gear "w" against the teeth of the rotat-

ing laps or tools 13. By adjusting the nut 60, the tension of the spring 57 may be regulated so that the desired pressure may be obtained between the teeth of the gear being ground and the gear shaped laps or tools with which the gear meshes.

The spring 57 may be enclosed in a housing 61 and the front wall of this housing may be provided with a scale 62 along which a pointer 63 attached to the spring is moved as the tension of the spring is increased or decreased. The scale may be graduated to indicate pressure exerted by the spring in pounds or other units of weight so that the nut 60 may be accurately adjusted to obtain the desired torsional thrust on the work spindle.

The bell crank lever 55 has an upwardly extending arm 64 which is provided at its upper end with a roller 65 which may be engaged by a cam 66 carried by a transverse shaft 67 extending through the casing. The shaft 67 has attached thereto a handcrank 68 by means of which the shaft may be turned to engage the cam 66 with the roller 65 and cause the thrust of the spring to be transmitted to the cam instead of to the shaft 30 so that the shaft 30 will be relieved of the spring pressure.

An endwise reciprocating movement is imparted to the work spindle during the grinding operation and this movement is imparted by means of a lever 69, the forward end of which engages a collar 70 loose on the spindle 35 and held against endwise movement on the spindle by means of collars 71 fixed to the spindle immediately above and below the collar 70. The lever 69 fulcrums intermediate its ends on a pivot pin 72 which is supported at the upper ends of a pair of arms 73 which are pivoted on eccentric portions 74 of the transverse shaft 67. The lever 69 is actuated by a vertical link 75 which is connected at its upper end to the rear end of the lever 69 and at its lower end to a slide 76 which is mounted for vertical movement in guides 77 in the lower portion of the casing. The slide 76 carries a roller 78 which engages in an endless cam groove 79 formed in a drum 80 fixed to a vertical shaft 81. The shaft 81 has loosely mounted thereon a worm gear 82 which meshes with a worm 83 fixed to the shaft 23 and a spiral gear 84 which meshes with a spiral gear 85 fixed to the shaft 22.

The opposing faces of the worm gear 82 and spiral gear 84 are provided with clutch teeth which are engageable with clutch teeth on a splined clutch collar 86 which may be moved into engagement either with the worm gear 82 or with the spiral gear 84 by means of an actuating arm 87. The worm gear 82 serves to drive the cam drum 80 at a slow

speed and the spiral gear 84 to drive the cam drum at a relatively high speed.

The arm 87 actuating the clutch collar 86 and the arm 20 actuating the clutch collar 18 controlling the speed of rotation of the shaft 9 are both fixed to a transverse rock shaft 88 which extends through a side wall of the casing and has a hand lever 89 attached to its outer end. By swinging the lever 89 in one direction, the clutch collar 18 will be engaged with the worm gear 17 to drive the laps or tools 13 at a relatively slow speed and the clutch collar 86 will at the same time be engaged with the spiral gear 84 to drive the cam drum 81 at a relatively high speed to reciprocate the spindle 35 at a relatively rapid rate. By swinging the lever 89 in the opposite direction, the clutch collar 18 will be engaged with the spiral gear 19 to cause the laps or tools 13 to be driven at a relatively high speed and the clutch collar 86 will be engaged with the worm gear 82 to cause the work spindle to be reciprocated at a relatively low speed.

In some instances, it may be desirable to impart a positive angular feed movement to the work spindle instead of advancing the spindle by the yielding torsional thrust exerted by the spring 57 above described.

A manually operable device for positively turning the work spindle in either direction relative to its driving means is illustrated in Fig. 11 of the drawings in which the shaft 30 may be positively shifted in either direction to move the work spindle forwardly or backwardly with respect to its normal position by means of a hand wheel 92 which operates a worm 93 journaled in fixed bearings and meshing with a worm gear segment 94 fixed to a shaft 95 journaled in the frame and having an arm 96 pivotally connected to a collar 97 within which the shaft 30 rotates and which is interposed between collars 98 fixed to the shaft. By turning the hand wheel 92 the shaft 30 may be raised or lowered in the helical spline 45 to impart a turning movement to the work spindle 35 through the gears 32 and 33, advancing or retarding the spindle with respect to the speed of rotation of the shaft 30 from which it is driven and pressing the teeth of the gear against the teeth of the laps. During the operation of the machine, the gear may be fed angularly in one direction to effect the desired grinding action on one face of each of the gear teeth and in the opposite direction by actuating the hand wheel in the reverse direction to grind the opposite faces of the gear teeth.

In grinding helical gears, the laps or tools must be in the form of helical gears conjugate to the gear to be ground and when an endwise movement is imparted to the work spindle, there must be an increase or decrease in the speed of rotation of the spindle

depending on its direction of movement due to the helical form of the teeth. In other words, during the axial movement of the gear in one direction, the speed of the spindle must be increased an amount corresponding to the movement of rotation which would be imparted to the gear by the laps or tools if the laps or tools were stationary during the reciprocating movement and in movement of the gear in the opposite direction, the speed of rotation of the spindle must be correspondingly decreased. To automatically obtain the required variation in the speed of the work spindle, the spline section 36 is provided with helical grooves of the proper pitch to impart turning movements to the spindle in the sleeve 34 corresponding to the turning movements which would be imparted to the spindle if the gear were reciprocated between the laps and the laps held against rotation. Thus the rotation of the gear "w" being ground is maintained at exactly the same speeds at which the gear would be driven by the laps during its reciprocating movements if the separate gearing for driving the spindle were omitted. The torsional thrust on the spindle 35 is thus maintained substantially uniform due to the fact that the proper speed ratio is maintained at all times between the work spindle and the lap spindles.

The splined section 36 is made easily detachable so that different splined sections may be substituted for gears of different helix angles and a replaceable key collar or nut 90 is detachably secured to the sleeve 34 for engagement with the spline section 36. For gears of small helix angles, a spline of very steep pitch will be required and, for gears with straight teeth, the grooves of the spline section will be straight.

During the grinding operation, a stream of liquid carrying finely divided abrasive material in suspension is delivered into the chamber 6 through a pipe 91 so that particles of abrasive material are continuously supplied between the interengaging tooth faces of the gear and laps.

When it is desired to secure a gear to the work spindle, the shaft 67 is turned by means of the handle 68 to engage the cam 66 with the roller 65 and relieve the shaft 30 of the spring pressure. At the same time, the arms 73 are lifted by the eccentrics 74 moving the fulcrum pin 72 upwardly and swinging the forward end of the lever 69 unwardly to lift the work spindle sufficiently to move a gear at the lower end of the spindle out of engagement with the laps. Another gear may then be attached to the lower end of the spindle, whereupon the shaft 67 is again turned to lower the spindle 35 and engage the gear with the laps 13, simultaneously releasing the bell crank lever 54 so that the spring 67 will exert a thrust

on the shaft 30 which, as above explained, is converted by means of the helical spline 44 into the torsional driving thrust on the gear engaging the laps. The handle 89 is then actuated to engage the clutch collar 18 with the worm gear 17 to impart a relatively slow rotation to the laps or tools 13 and to simultaneously engage the collar 86 with the spiral gear 84 to impart a relatively fast reciprocation to the work spindle 35.

The faster reciprocation and slow rotation may in some instance be desirable during the initial portion of the grinding operation for quickly grinding off the high spots on the gear tooth surfaces and for grinding the tooth surfaces to approximately the proper spacing and concentricity.

In other instances, it may be desirable that the gear and laps be rotated at a relatively rapid rate and that the reciprocating movement be relatively slow, and the lever 89 may be shifted to engage the clutch columns 18 and 86 with the spiral gear 19 and worm gear 82 to impart relatively rapid rotation to the gear and laps and a relatively slow reciprocating movement to the work spindle.

The above operations serve to finish the teeth of the gear on one side and the opposite sides of the gear teeth may be finished by disconnecting the link 52 from the arm 51 or 51a to which it is attached and connecting it to the other arm to reverse the direction of the thrust of the spring 57 on the shaft 30 and thereby reverse the direction of the torsional thrust on the work spindle.

It will be apparent that by reason of the relatively rapid abrading action, the present invention provides a method by which the teeth of the gear may be very quickly ground to the proper contour, to the proper spacing and to the proper concentricity within very narrow limits of error.

Furthermore, it will be apparent that by reason of the yielding mounting of the work spindle and rigid mounting of the lap spindle, the machine may be operated quite rapidly without vibration and that the abrading action will be very uniform.

It will be apparent that by reason of the changes in speed of rotation and reciprocation of the work that abrading action suitable for the initial or roughing cut and also for the final or finishing cut are obtained with the result that the tooth surfaces of the finished gears are very smooth and accurate.

It will also be apparent that the cost of operation will be relatively small due to the rapidity of operation, due to the fact that the laps may be manufactured at small cost and due to the fact that a very large number of gears may be finished with a single set of laps.

Furthermore, it is to be understood that the particular form of apparatus shown and described, and the particular procedure set forth, are presented for purposes of explanation and illustration and that various modifications of said apparatus and procedure can be made without departing from my invention as defined in the appended claims.

What I claim is:

1. The herein described method of grinding gears, which consists in meshing the gear to be ground simultaneously with a series of laps having the form of gears adapted to intermesh with the gear to be ground and spaced circumferentially with respect thereto, driving the gear and imparting thereto an axial reciprocating movement with respect to the laps, driving the laps by means other than the gear, and causing a relative angular feed movement between the gear and laps to maintain contact between the intermeshing teeth thereof.

2. The herein described method of grinding gears, which consists in meshing the gear to be ground simultaneously with a series of laps having the form of gears conjugate to the gear to be ground and spaced circumferentially with respect thereto, driving the gear and imparting thereto an axial reciprocating movement with respect to the laps, driving the laps by means other than the gear, and applying abrasive material between the interengaging tooth faces of the gear and laps.

3. The herein described method of grinding gears, which consists in meshing the gear to be ground simultaneously with a series of laps having the form of gears conjugate to the gear to be ground and spaced circumferentially with respect thereto, driving the gear and imparting thereto an axial reciprocating movement with respect to the laps, driving the laps by means other than the gear with equal peripheral speeds at their pitch circles, and causing a relative angular feed movement between the gear and laps to maintain contact between the intermeshing teeth thereof.

4. The herein described method of grinding gears, which consists in meshing the gear to be ground simultaneously with a series of laps having the form of gears conjugate to the gear to be ground and spaced circumferentially with respect thereto, driving the gear and imparting thereto an axial reciprocating movement with respect to the laps, driving the laps by means other than the gear with equal peripheral speeds at their pitch circles, causing a relative angular feed movement between the gear and laps to maintain the teeth to maintain contact between the intermeshing teeth thereof and applying abrasive material between the interengaging lap and gear tooth faces.

5. The herein described method of grind-

ing helical gears, which consists in meshing the gear to be ground simultaneously with a series of laps having the form of helical gears conjugate to the gear to be ground and spaced circumferentially with respect thereto, rotating the gear and imparting thereto an axial reciprocating movement with respect to the laps, and driving the laps by means other than the gear at the speeds of rotation which would be imparted to them by the gear.

6. The herein described method of grinding helical gears, which consists in meshing the gear to be ground simultaneously with a series of laps having the form of helical gears conjugate to the gear to be ground and spaced circumferentially with respect thereto, rotating the gear and imparting thereto an axial reciprocating movement with respect to the laps, driving the laps by means other than the gear at the speeds of rotation which would be imparted to them by the gear, and causing a relative feed movement between the gear and laps to maintain contact between the intermeshing teeth thereof.

7. The herein described method of grinding helical gears, which consists in meshing the gear to be ground simultaneously with a series of laps having the form of gears conjugate to the gear to be ground and spaced circumferentially with respect thereto, the laps being of different pitch diameters and having different numbers of teeth, driving the gear and imparting thereto an axial reciprocating movement with respect to the laps, driving the laps by means other than the gear at the speeds at which the laps would be driven by the gear, and causing a relative angular feed movement between the gear and laps to maintain contact between the intermeshing teeth thereof.

8. The herein described method of grinding helical gears, which consists in meshing the gear to be ground simultaneously with a series of laps having the form of helical gears conjugate to the gear to be ground and spaced circumferentially with respect thereto, rotating the gear and imparting thereto an axial reciprocating movement with respect to the laps, driving the laps by means other than the gear at the speeds of rotation which would be imparted to them by the gear, and supplying abrasive material between the interengaging lap and gear tooth faces.

9. The herein described method of grinding helical gears, which consists in meshing the gear to be ground simultaneously with a series of laps having the form of helical gears conjugate to the gear to be ground and spaced circumferentially with respect thereto, rotating the gear and imparting thereto an axial reciprocating movement with respect to the laps, driving the laps by means

other than the gear at the speeds of rotation which would be imparted to them by the gear, applying pressure to interengaging tooth faces of the gear and laps, and supplying abrasive material between the interengaging lap and gear tooth faces.

10. The herein described method of grinding helical gears, which consists in meshing the gear to be ground simultaneously with a series of laps having the form of gears conjugate to the gear to be ground and spaced circumferentially with respect thereto, the laps being of different pitch diameters and having different numbers of teeth, driving the gear and imparting thereto an axial reciprocating movement with respect to the laps, driving the laps by means other than the gear at the speeds at which the laps would be driven by the gear, applying pressure to the interengaging tooth faces of the gear and laps, and supplying abrasive material between the interengaging lap and gear tooth faces.

11. The herein described method of grinding helical gears, which consists in meshing the gear to be ground simultaneously with a series of laps having the form of gears conjugate to the gear to be ground and spaced circumferentially with respect thereto, the number of the teeth of each of the laps differing from the number of teeth of the gear, driving the gear and imparting thereto an axial reciprocating movement with respect to the laps, driving the laps by means other than the gear at the speeds at which the laps would be driven by the gear, and causing an angular feed movement of the gear with respect to the laps to apply pressure to interengaging gear and lap tooth faces.

12. The herein described method of grinding helical gears, which consists in meshing the gear to be ground simultaneously with a series of laps having the form of helical gears conjugate to the gear to be ground and spaced circumferentially with respect thereto, the number of teeth of each of the laps differing from the number of teeth of the gear, rotating the gear and imparting thereto an axial reciprocating movement with respect to the laps, and driving the laps by means other than the gear at the speeds of rotation which would be imparted to them by the gear.

13. The herein described method of grinding helical gears, which consists in meshing the gear to be ground simultaneously with a series of laps having the form of helical gears conjugate to the gear to be ground, said laps being spaced circumferentially with respect to the gear and arranged in diametrically opposed pairs, the number of teeth of each of the laps differing from the number of teeth of the gear, rotating the gear and imparting thereto an axial reciprocating movement with respect to the laps,

and driving the laps by means other than the gear at the speeds of rotation which would be imparted to them by the gear, while maintaining mutually abrasive contact between tooth faces of the gear and laps.

14. The herein described method of grinding helical gears, which consists in meshing the gear to be ground simultaneously with a series of laps having the form of helical gears conjugate to the gear to be ground and spaced circumferentially with respect thereto, the number of teeth of each of the laps differing from the number of teeth of the gear, rotating the gear and imparting thereto an axial reciprocating movement with respect to the laps, driving the laps by means other than the gear at the speeds of rotation which would be imparted to them by the gear, causing teeth of the gear to press against the faces of lap teeth, and supplying abrasive material between the interengaging lap and gear tooth faces.

15. The herein described method of grinding gears, which consists in meshing the gear to be ground simultaneously with a series of laps having the form of gears conjugate to the gear to be ground and spaced circumferentially with respect thereto, the gear and each of the laps having a different number of teeth, driving the gear and imparting thereto an axial reciprocating movement with respect to the laps, driving the laps by means other than the gear at the speeds at which the laps would be driven by the gear, and applying torsional thrust to the gear to create pressure between tooth faces of intermeshing gear and lap teeth.

16. The herein described method of grinding gears, which consists in meshing the gear to be ground simultaneously with a series of laps having the form of gears conjugate to the gear to be ground and spaced circumferentially with respect thereto, the gear and each of the laps having a different number of teeth, driving the gear and imparting thereto an axial reciprocating movement with respect to the laps, driving the laps by means other than the gear at the speeds at which the laps would be driven by the gear, applying pressure to interengaging gear and lap tooth faces, and supplying abrasive material between the interengaging tooth faces of the gear and laps.

17. The herein described method of grinding helical gears, which consists in meshing the gear to be ground simultaneously with a series of laps having the form of helical gears conjugate to the gear to be ground and spaced circumferentially with respect thereto, the number of teeth of each lap differing from the number of teeth of the gear and from the number of teeth of each of the other laps, rotating the gear and imparting thereto an axial reciprocating move-

ment with respect to the laps, and driving the laps by means other than the gear at the speeds of rotation which would be imparted to them by the gear.

18. The herein described method of grinding helical gears, which consists in meshing the gear to be ground simultaneously with a series of laps having the form of helical gears conjugate to the gear to be ground and spaced circumferentially with respect thereto, the number of teeth of each lap differing from the number of teeth of the gear and from the number of teeth of each of the other laps, rotating the gear and imparting thereto an axial reciprocating movement with respect to the laps, driving the laps by means other than the gear at the speeds of rotation which would be imparted to them by the gear, and causing a relative angular feed movement between the gear and laps to create pressure between intermeshing teeth thereof.

19. The herein described method of grinding helical gears, which consists in meshing the gear to be ground simultaneously with a series of laps having the form of helical gears conjugate to the gear to be ground and spaced circumferentially with respect thereto, the number of teeth of each lap differing from the number of teeth of the gear and from the number of teeth of each of the other laps, rotating the gear and imparting thereto an axial reciprocating movement with respect to the laps, driving the laps by means other than the gear at the speed of rotation which would be imparted to them by the gear, applying a torsional thrust to the gear, and supplying abrasive material between the interengaging tooth faces of the gear and laps.

20. The herein described method of grinding gears, which consists in meshing the gear to be ground simultaneously with a series of laps having the form of gears conjugate to the gear to be ground and spaced circumferentially with respect thereto, constraining the laps to rotation about fixed parallel axes, yieldably supporting the gear to permit slight lateral movements with respect to the laps, driving the gear and imparting thereto an axial reciprocating movement with respect to the laps, and positively driving the laps by means other than the gear at the speeds at which the laps would be driven by the gear.

21. The herein described method of grinding gears, which consists in meshing the gear to be ground simultaneously with a series of laps having the form of gears conjugate to the gear to be ground and spaced circumferentially with respect thereto, constraining the laps to rotation about fixed parallel axes, yieldably supporting the gear to permit slight lateral movements with respect to the laps, driving the gear and im-

parting thereto an axial reciprocating movement with respect to the laps, driving the laps by means other than the gear at the speeds at which the laps would be driven by the gear, and causing a relative angular feed movement between the gear and laps to create pressure between intermeshing teeth thereof.

22. The herein described method of grinding gears, which consists in meshing the gear to be ground simultaneously with a series of laps having the form of gears conjugate to the gear to be ground and spaced circumferentially with respect thereto, constraining the laps to rotation about fixed parallel axes, yieldably supporting the gear to permit slight lateral movements with respect to the laps, driving the gear and imparting thereto an axial reciprocating movement with respect to the laps, driving the laps by means other than the gear at the speeds at which the laps would be driven by the gear, applying a torsional thrust to the gear, and supplying abrasive material between the interengaging tooth faces of the gear and laps.

23. The herein described method of grinding gears which consists in meshing the gear to be ground with a series of laps having the form of gears conjugate to the gear to be ground and spaced circumferentially with respect to the gear throughout more than one-half the circumference thereof, constraining the laps to rotation about fixed parallel axes, yieldably supporting the gear to permit slight lateral movements with respect to the laps, driving the gear and simultaneously imparting thereto an axial reciprocating movement with respect to the laps, and driving the laps by means other than the gear at the speeds at which the laps would be driven by the gear.

24. The herein described method of grinding gears which consists in meshing the gear to be ground with a series of laps having the form of gears conjugate to the gear to be ground and spaced circumferentially with respect to the gear throughout more than one-half the circumference thereof, constraining the laps to rotation about fixed parallel axes, yieldably supporting the gear to permit slight lateral movements with respect to the laps, driving the gear and simultaneously imparting thereto an axial reciprocating movement with respect to the laps, driving the laps by means other than the gear at the speeds at which the laps would be driven by the gear, and maintaining a torsional thrust on the gear.

25. The herein described method of grinding gears which consists in meshing the gear to be ground with a series of laps having the form of gears conjugate to the gear to be ground and spaced circumferentially with respect to the gear throughout more

than one-half the circumference thereof, constraining the laps to rotation about fixed parallel axes, yieldably supporting the gear to permit slight lateral movements with respect to the laps, positively driving the gear and simultaneously imparting thereto an axial reciprocating movement with respect to the laps, positively driving the laps by means other than the gear at the speeds at which the laps would be driven by the gear, and supplying abrasive material between the interengaging tooth faces of the gear and lap.

26. The herein described method of grinding gears which consists in meshing the gear to be ground with a series of laps having the form of gears conjugate to the gear to be ground and spaced circumferentially with respect to the gear throughout more than one-half the circumference thereof, each lap having a number of teeth differing from that of the gear and from that of each of the other laps, constraining the laps to rotation about fixed parallel axes, yieldably supporting the gear to permit slight lateral movements with respect to the laps, driving the gear and simultaneously imparting thereto an axial reciprocating movement with respect to the laps, driving the laps by means other than the gear at the speeds at which the laps would be driven by the gear, and supplying abrasive material between the interengaging tooth faces of the gear and lap.

27. The herein described method of grinding gears which consists in meshing the gear to be ground with a series of laps having the form of gears conjugate to the gear to be ground and spaced circumferentially with respect to the gear throughout more than one-half the circumference thereof, each lap having a number of teeth differing from that of the gear and from that of each of the other laps, constraining the laps to rotation about fixed parallel axes, yieldably supporting the gear to permit slight lateral movements with respect to the laps, driving the gear and simultaneously imparting thereto an axial reciprocating movement with respect to the laps, driving the laps by means other than the gear at the speeds at which the laps would be driven by the gear, supplying abrasive material between the interengaging tooth faces of the gear and lap, and applying a torsional thrust to the gear.

28. The herein described method of grinding helical gears which consists in meshing the gear to be ground with a series of laps having the form of helical gears conjugate to the gear to be ground and spaced circumferentially with respect to the gear throughout more than one-half the circumference thereof, constraining the laps to rotation about fixed parallel axes, yieldably supporting the gear for lateral movements with respect to the laps to permit the gear

to assume a position in which it is centered with respect to the lap teeth engaged by it, driving the gear and simultaneously imparting thereto an axial reciprocating movement with respect to the laps, and driving the laps by means other than the gear at the speeds at which the laps would be driven by the gear in its rotary and relative axial movements.

29. The herein described method of grinding helical gears which consists in meshing the gear to be ground with a series of laps having the form of helical gears conjugate to the gear to be ground and spaced circumferentially with respect to the gear throughout more than one-half the circumference thereof, constraining the laps to rotation about fixed parallel axes, yieldably supporting the gear for lateral movements with respect to the laps to permit the gear to assume a position in which it is centered with respect to the lap teeth engaged by it, driving the gear and simultaneously imparting thereto an axial reciprocating movement with respect to the laps, driving the laps by means other than the gear at the speeds at which the laps would be driven by the gear in its rotary and relative axial movements and applying a torsional thrust to the gear.

30. The herein described method of grinding helical gears which consists in meshing the gear to be ground with a series of laps having the form of helical gears conjugate to the gear to be ground and spaced circumferentially with respect to the gear throughout more than one half the circumference thereof, each lap having a number of teeth differing from that of the gear and from that of each of the other laps, constraining the laps to rotation about fixed parallel axes, yieldably supporting the gear for lateral movements with respect to the laps to permit the gear to assume a position in which it is centered with respect to the lap teeth engaged by it, driving the laps, imparting to the gear an axial reciprocating movement with respect to the laps, and driving the gear by means other than the laps at the speeds at which it would be driven by the laps.

31. The herein described method of grinding helical gears which consists in meshing the gear to be ground with a series of laps having the form of helical gears conjugate to the gear to be ground and spaced circumferentially with respect to the gear throughout more than one-half the circumference thereof, each lap having a number of teeth differing from that of the gear and from that of each of the other laps, constraining the laps to rotation about fixed parallel axes, yieldably supporting the gear for lateral movements with respect to the laps to permit the gear to assume a position in which it is centered with respect to the lap

teeth engaged by it, driving the laps, imparting to the gear an axial reciprocating movement with respect to the laps, positively driving the reciprocating gear by means other than the laps at the speeds at which the gear would be driven by the laps, applying a torsional thrust to the gear, and supplying abrasive material between the interengaging tooth faces of the gear and laps.

32. The herein described method of grinding gears which consists in meshing the gear to be ground with a series of laps having the form of gears conjugate to the gear to be ground and angularly spaced circumferentially of the gear, constraining said laps to rotary movements about fixed parallel axes, driving said gear and simultaneously imparting thereto an axial reciprocating movement with respect to said laps, and applying to said gear a yielding torsional thrust to maintain a driving pressure between the teeth of the gear and the teeth of the laps.

33. The herein described method of grinding gears which consists in meshing the gear to be ground with a series of laps having the form of gears conjugate to the gear to be ground and angularly spaced circumferentially of the gear, constraining said laps to rotary movements about fixed parallel axes, driving said laps, imparting to the gear an axial reciprocating movement with respect to said laps, driving the gear by means other than the laps and simultaneously applying to said gear a yielding torsional thrust, and supplying abrasive material between the interengaging tooth faces of the gear and laps.

34. The herein described method of grinding gears which consists in meshing the gear to be ground with a series of laps having the form of gears conjugate to the gear to be ground and angularly spaced circumferentially of the gear, each lap having a number of teeth differing from that of the gear and from that of each of the other laps, constraining said laps to rotary movements about fixed parallel axes, yieldably supporting the gear for lateral movements with respect to the laps to permit the gear to assume a position in which it is centered with respect to the lap teeth engaged by it, driving said gear and simultaneously imparting thereto an axial reciprocating movement with respect to said laps, and applying to said gear a yielding torsional thrust.

35. The herein described method of grinding gears which consists in meshing the gear to be ground with a series of laps having the form of gears conjugate to the gear to be ground and angularly spaced circumferentially of the gear, constraining said laps to rotary movements about fixed parallel axes, imparting to the gear an axial reciprocating movement with respect to said

laps, driving the laps at equal peripheral speeds at their pitch circles, and applying to the gear a substantially uniform torsional thrust tending to rotate it at a speed differing from peripheral speed of the laps and pressing the teeth of the gear against the teeth of the laps.

36. The herein described method of grinding helical gears which consists in meshing the gear to be ground with a series of laps having the form of helical gears conjugate to the gear to be ground and angularly spaced circumferentially of the gear, constraining said laps to rotary movements about fixed parallel axes, driving the same at equal peripheral speeds at their pitch circles, yieldably supporting the gear for lateral movements with respect to the laps, imparting to the gear an axial reciprocating movement with respect to the laps and driving the same by means other than the laps, and applying to the gear a substantially uniform torsional thrust to maintain pressure between the interengaging tooth faces of the gear and laps.

37. The herein described method of grinding helical gears which consists in meshing the gear to be ground with a series of laps having the form of helical gears conjugate to the gear to be ground and angularly spaced circumferentially of the gear, constraining said laps to rotary movements about fixed parallel axes, driving the same at equal peripheral speeds at their pitch circles, yieldably supporting the gear for lateral movements with respect to the laps, imparting to the gear an axial reciprocating movement with respect to the laps and driving the same by means other than the laps, applying to the gear a substantially uniform torsional thrust to maintain pressure between the interengaging tooth faces of the gear and laps, and supplying abrasive material between the interengaging tooth faces of the gear and laps.

38. The herein described method of grinding helical gears which consists in meshing the gear to be ground with a series of laps having the form of helical gears conjugate to the gear to be ground and angularly spaced circumferentially of the gear, each lap having a number of teeth differing from that of the gear and from that of each of the other laps, constraining said laps to rotary movements about fixed parallel axes, driving the same at equal peripheral speeds at their pitch circles, yieldably supporting the gear for lateral movements with respect to the laps, imparting to the gear an axial reciprocating movement with respect to the laps and driving the same by means other than the laps, and applying to the gear a substantially uniform torsional thrust to maintain pressure between the interengaging tooth faces of the gear and laps.

39. The herein described method of grinding helical gears which consists in meshing the gear to be ground with a series of laps having the form of helical gears conjugate to the gear to be ground and angularly spaced circumferentially of the gear, each lap having a number of teeth differing from that of the gear and from that of each of the other laps, constraining said laps to rotary movements about fixed parallel axes, driving the same at equal peripheral speeds at their pitch circles, yieldably supporting the gear for lateral movements with respect to the laps, imparting to the gear an axial reciprocating movement with respect to the laps and driving the same by means other than the laps, applying to the gear a substantially uniform torsional thrust to maintain pressure between the interengaging tooth faces of the gear and laps, and supplying abrasive material between the interengaging tooth face of the gear and laps.

40. The herein described method of grinding gears which consists in meshing the gear to be ground with pairs of diametrically opposed laps having the form of gears conjugate to the gear to be ground, constraining said laps to rotary movements about fixed parallel axes and driving the same at equal peripheral speeds at their pitch circles yieldably supporting the gear for lateral movements between the laps, imparting to the gear an axial reciprocating movement with respect to the laps, rotating said gear by means other than the laps at the peripheral speeds at which it would be driven by the laps during its reciprocating movements, and maintaining a substantially uniform torsional thrust on the gear.

41. The herein described method of grinding gears which consists in meshing the gear to be ground with pairs of diametrically opposed laps having the form of gears conjugate to the gear to be ground, constraining said laps to rotary movements about fixed parallel axes and driving the same at equal peripheral speeds at their pitch circles yieldably supporting the gear for lateral movements between the laps, imparting to the gear an axial reciprocating movement with respect to the laps, rotating said gear by means other than the laps at the peripheral speeds at which it would be driven by the laps during its reciprocating movements, maintaining a substantially uniform torsional thrust on the gear, and supplying abrasive material between the interengaging tooth faces of the gear and laps.

42. The herein described method of grinding gears which consists in intermeshing the gear to be ground simultaneously with a series of laps having the form of gears of different sizes conjugate to the gear to be ground and constrained to rotate about axes spaced circumferentially with respect to the

gear, the number of teeth of each lap differing from the number of teeth of the gear, simultaneously rotating the gear and imparting thereto a relatively rapid axial reciprocating movement with respect to the laps meshing therewith, and maintaining a torsional pressure between interengaging tooth faces of the gear and laps during the said rotating and reciprocating movements whereby a continuous and progressive abrading action on the gear tooth faces is obtained.

43. Apparatus for grinding gears comprising a series of parallel spindles, a lap mounted on each of said spindles, each lap being in the form of a gear, a work spindle parallel with the lap spindles and centrally disposed with respect thereto, said work spindle having means for detachably holding a gear to be ground in mesh with the laps, means for rotating the gear and for imparting thereto an axial reciprocating movement relative to the laps, means other than the gear for positively driving the laps, and means for imparting an angular feed movement to the gear.

44. Apparatus for grinding gears comprising a series of parallel spindles, a lap mounted on each of said spindles, each lap being in the form of a gear, a work spindle parallel with the lap spindles and centrally disposed with respect thereto, said work spindle having means for detachably holding a gear and for imparting thereto an axial reciprocating movement relative to the laps, means other than the gear for positively driving the laps, means for imparting an angular feed movement to the gear, and means for supplying abrasive material between the interengaging tooth faces of the gear and laps.

45. Apparatus for grinding gears comprising a series of parallel spindles, a lap mounted on each of said spindles, said laps being in the form of gears of different pitch diameters, a work spindle parallel with the lap spindles and centrally disposed with respect thereto, said work spindle having means for detachably holding the gear to be ground in mesh with the laps, means for rotating the gear and for imparting thereto an axial reciprocating movement relative to the laps, means other than the gear for positively driving the laps, and means for causing a relative angular feed movement between the gear and laps.

46. Apparatus for grinding gears comprising a series of parallel spindles, a lap mounted on each of said spindles, the number of teeth of each lap differing from that of each of the other laps and all of the laps being conjugate to the same rack, a work spindle parallel with the lap spindles and centrally disposed with respect thereto, said work spindle having means for detachably

holding a gear to be ground in mesh with the laps, means for rotating the gear and for imparting thereto an axial reciprocating movement relative to the laps, means other than the gear for positively driving the laps, and means for causing a relative angular feed movement between the gear and laps.

47. Apparatus for grinding gears comprising a series of parallel spindles, a lap mounted on each of said spindles, each lap being in the form of a gear, a work spindle parallel with the lap spindles and centrally disposed with respect thereto, said work spindle having means for detachably holding a gear to be ground in mesh with the laps, a drive shaft, gearing connecting the drive shaft with each spindle for driving said spindles at angular speeds inversely proportional to the pitch diameters of the gear and gear shaped laps carried thereby, means for reciprocating the gear axially with respect to the laps, and means for causing a relative angular feed movement between the gear and laps.

48. Apparatus for grinding gears comprising a series of parallel spindles, a lap mounted on each of said spindles, said laps being in the form of gears of different pitch diameters, a work spindle parallel with the lap spindles and centrally disposed with respect thereto, said work spindle having means for detachably holding a gear to be ground in mesh with the laps, a drive shaft, gearing connecting the drive shaft with each spindle for driving said spindles at angular speeds inversely proportional to the pitch diameters of the gear and gear shaped laps carried thereby, means for reciprocating the gear axially with respect to the laps, and means for causing a relative angular feed movement between the gear and laps.

49. Apparatus for grinding gears comprising a series of parallel spindles, a lap mounted on each of said spindles, each lap being in the form of a gear, a work spindle parallel with the lap spindles and centrally disposed with respect thereto, said work spindle having means for detachably holding a gear to be ground in mesh with the laps, a drive shaft axially aligned with the work spindle, a gear fixed to said shaft of the same pitch as the gear on the work spindle, gears fixed to the lap spindles of the same pitch as the laps on said spindles and meshing with said gear on the shaft, gearing connecting said shaft with the work spindle, means for reciprocating the gear axially with respect to the laps, and means for supplying abrasive material between the interengaging tooth faces of the gear and laps.

50. In a machine of the character described, a supporting frame, two parallel spindles journaled in the frame, one mounted for endwise reciprocating move-

ment, one of said spindles having thereon a tool in the form of a gear and the other of said spindles having thereon a gear meshing with said tool, and means for driving said spindles including a sleeve rotatably mounted in the frame and held against longitudinal movement therein, a shaft slidably mounted in said sleeve, a helical spline forming a driving connection between said sleeve and shaft, means for applying an endwise pressure on said shaft tending to slide and turn the same in the sleeve and a driving connection between said sleeve and one of the spindles.

51. In a machine of the character described, a supporting frame, a sleeve rotatably mounted in the frame and held against endwise movement therein, two parallel spindles, one slidably mounted in the sleeve and the other journaled in the frame independently thereof, one spindle having thereon a tool in the form of a helical gear and the other a helical gear meshing with the tool, means for driving the spindles including a gear on said sleeve, means for reciprocating the slidable spindle, and a helical spline forming a driving connection between said sleeve and slidable spindle and causing the spindle to turn within the sleeve upon endwise movement therein.

52. In a machine of the character described, a supporting frame, two parallel spindles journaled in the frame, one mounted for endwise reciprocating movement, one of said spindles having thereon a tool in the form of a gear and the other of said spindles having thereon a gear meshing with said tool, a sleeve rotatably mounted in the frame and held against longitudinal movement therein, a shaft slidably mounted in said sleeve, a helical spline forming a driving connection between said sleeve and shaft, means for applying an endwise pressure on said shaft tending to slide and turn the same in the sleeve, means for driving said shaft, a driving connection between said sleeve and one of the spindles, and a driving connection between said shaft and the other of said spindles.

53. In a machine of the character described, a supporting frame, a sleeve rotatably mounted in the frame and held against longitudinal movement therein, a spindle slidably mounted in the sleeve, a helical spline forming a driving connection between the sleeve and spindle and serving to turn the spindle in the sleeve when the spindle is moved endwise in the sleeve, means for driving said sleeve, and means for reciprocating the spindle in the sleeve.

54. In a machine of the character described, a supporting frame, a work spindle mounted for endwise movement in the frame and having means for holding a gear to be ground, a series of spindles parallel with

the work spindle and grouped around the same, a lap on each of the latter spindles in the form of a gear conjugate to the gear to be ground and meshing therewith, a drive shaft coaxial with the work spindle, a gear of the same pitch diameter as the gear to be ground fixed to the drive shaft, a gear on each lap spindle of the same pitch diameter as the lap carried by the spindle and meshing with the gear on the drive shaft, gearing connecting the drive shaft with the work spindle for driving the work spindle in the same direction and at the same speed as the shaft, means for reciprocating said work spindle, and means for driving said shaft at different speeds.

55. In a machine of the character described, a supporting frame, a work spindle mounted for endwise movement in the frame and having means for holding a gear to be ground, a series of spindles parallel with the work spindle and grouped around the same, a lap on each of the latter spindles in the form of a gear conjugate to the gear to be ground and meshing therewith, a drive shaft coaxial with the work spindle, a gear of the same pitch diameter as the gear to be ground fixed to the drive shaft, a gear on each lap spindle of the same pitch diameter as the lap carried by the spindle and meshing with the gear on the drive shaft, gearing connecting the drive shaft with the work spindle for driving the work spindle in the same direction and at the same speed as the shaft, means for reciprocating said work spindle, and means for applying a torque to the work spindle to create pressure between the teeth of the gear and the teeth of the laps.

56. In a machine of the character described, a supporting frame, a work spindle mounted for endwise movement in the frame and having means for holding a gear to be ground, a series of spindles parallel with the work spindle and grouped around the same, a lap on each of the latter spindles in the form of a gear conjugate to the gear to be ground and meshing therewith, a drive shaft coaxial with the work spindle, a gear of the same pitch diameter as the gear to be ground fixed to the drive shaft, a gear on each lap spindle of the same pitch diameter as the lap carried by the spindle and meshing with the gear on the drive shaft, a countershaft parallel to said spindles, gearing connecting said countershaft with the work spindle and with the drive shaft, means for reciprocating said work spindle, and means for supplying abrasive material between the interengaging tooth faces of the gear and lap.

57. In a machine of the character described, a supporting frame, a work spindle mounted for endwise movement in the frame and having means for holding a gear to be ground, a series of spindles parallel with the

work spindle and grouped around the same, a lap on each of the latter spindles in the form of a gear conjugate to the gear to be ground and meshing therewith, a drive shaft
 5 coaxial with the work spindle, a gear of the same pitch diameter as the gear to be ground fixed to the drive shaft, a gear on each lap spindle of the same pitch diameter as the lap carried by the spindle and meshing with
 10 the gear on the drive shaft, gearing connecting the drive shaft with the work spindle for driving the work spindle in the same direction and at the same speed as the shaft, means for reciprocating said work spindle, and means for simultaneously varying the
 15 speed of rotation and reciprocation of the work spindle.

58. In a machine of the character described, a supporting frame, a work spindle
 20 mounted for endwise movement in the frame and having means for holding a gear to be ground, a series of spindles parallel with the work spindle and grouped around the same, a lap on each of the latter spindles in
 25 the form of a gear conjugate to the gear to be ground and meshing therewith, a drive shaft coaxial with the work spindle, a gear of the same pitch diameter as the gear to be ground fixed to the drive shaft, a gear
 30 on each lap spindle of the same pitch diameter as the lap carried by the spindle and meshing with the gear on the drive shaft, gearing connecting the drive shaft with the work spindle for driving the work spindle
 35 in the same direction and at the same speed as the shaft, means for reciprocating said work spindle, means for varying the speed of rotation of the drive shaft and for simultaneously varying the speed of reciprocation
 40 of the work spindle.

59. In a machine of the character described, a supporting frame, a work spindle mounted for endwise movement in the frame and having means for holding a gear to be
 45 ground, a series of spindles parallel with the work spindle and grouped around the same, a lap on each of the latter spindles in the form of a gear conjugate to the gear to be ground and meshing therewith, a drive shaft coaxial with the work spindle, a gear
 50 of the same pitch diameter as the gear to be ground fixed to the drive shaft, a gear on each lap spindle of the same pitch diameter as the lap carried by the spindle and meshing with the gear on the drive shaft, gearing
 55 connecting the drive shaft with the work spindle for driving the work spindle in the same direction and at the same speed as the shaft, means for driving said shaft, means operated by said driving means for reciprocating said work spindle, and means for simultaneously and inversely varying the speeds of the drive shaft and spindle reciprocating means.

60. In a machine of the character de-

scribed, a supporting frame, a sleeve rotatably mounted in the frame and held against longitudinal movement, a reciprocable spindle splined in said sleeve, a second spindle
 70 parallel with the first, a tool in the form of a gear and a gear in mesh with the tool, the tool and gear being mounted, one on the first spindle and the other on the second spindle, means for reciprocating the first spindle, a
 75 second sleeve rotatably mounted in the frame, a shaft slidably mounted in the second sleeve, a helical spline forming a driving connection between the shaft and its sleeve and serving to turn the sleeve on the shaft upon endwise movement of the shaft in the
 80 sleeve, a driving connection between said rotatable sleeves, means for driving said shaft and said second spindle, and means for applying an endwise pressure on said shaft.

61. In a machine of the character described, a supporting frame, a sleeve rotatably mounted in the frame and held against longitudinal movement, a reciprocable spindle splined in said sleeve, a second
 90 spindle parallel with the first, a tool in the form of a gear and a gear in mesh with the tool, the tool and gear being mounted, one on the first spindle and the other on the second spindle, means for reciprocating the
 95 first spindle, a second sleeve rotatably mounted in the frame, a shaft slidably mounted in the second sleeve, a helical spline forming a driving connection between the shaft and its sleeve and serving to turn the sleeve on the shaft upon endwise movement of the shaft in the sleeve, a driving
 100 connection between said rotatable sleeves, means for reciprocating the first spindle, means for driving said shaft and said second spindle, and a spring operatively connected to said shaft for maintaining a substantially uniform endwise pressure thereon.

62. In a machine of the character described, a supporting frame, a sleeve rotatably mounted in the frame and held against longitudinal movement, a reciprocable spindle splined in said sleeve, a second spindle
 110 parallel with the first, a tool in the form of a gear and a gear in mesh with the tool, the tool and gear being mounted, one on the first spindle and the other on the second spindle, means for reciprocating the first spindle, a second sleeve rotatably
 115 mounted in the frame, a shaft slidably mounted in the second sleeve, a helical spline forming a driving connection between the shaft and its sleeve and serving to turn the sleeve on the shaft upon endwise movement of the shaft in the sleeve, a driving connection between said rotatable sleeves, means for reciprocating the first spindle, means for driving said shaft and said second spindle, means for applying an
 120 endwise pressure on said shaft, and manual-

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ly operable means for relieving the pressure on said shaft.

63. In a machine of the character described, a supporting frame a sleeve rotatably mounted in the frame and held against longitudinal movement, a reciprocal spindle splined in said sleeve, a second spindle parallel with the first, a tool in the form of a gear and a gear in mesh with the tool, the tool and gear being mounted, one on the first spindle and the other on the second spindle, means for reciprocating the first spindle, a second sleeve rotatably mounted in the frame, a shaft slidably mounted in the second sleeve, a helical spline forming a driving connection between the shaft and its sleeve and serving to turn the sleeve on the shaft upon endwise movement of the shaft in the sleeve, a driving connection between said rotatable sleeves, means for driving said shaft and said second spindle, a spring operatively connected to said shaft for maintaining a substantially uniform endwise pressure thereon, and means for adjusting the tension of said spring.

64. In a machine of the character described, a supporting frame, a sleeve rotatably mounted in the frame and held against longitudinal movement, a reciprocal spindle splined in said sleeve, a second spindle parallel with the first, a tool in the form of a gear and a gear in mesh with the tool, the tool and gear being mounted, one on the first spindle and the other on the second spindle, means for reciprocating the first spindle, a second sleeve rotatably mounted in the frame, a shaft slidably mounted in the second sleeve, a helical spline forming a driving connection between the shaft and its sleeve and serving to turn the sleeve on the shaft upon endwise movement of the shaft in the sleeve, a driving connection between said rotatable sleeves, means for driving said shaft and said second spindle, means for simultaneously varying the speed of said driving and reciprocating means, and means for maintaining a substantially uniform endwise pressure on said shaft.

65. In a machine of the character described, a supporting frame, a sleeve rotatably mounted in the frame and held against longitudinal movement, a reciprocal work spindle splined in said sleeve, a second sleeve rotatably mounted in the frame and held against longitudinal movement, a shaft slidably mounted in the second sleeve, a helical spline forming a driving connection between the shaft and its sleeve and serving to turn the sleeve on the shaft upon endwise movement of the shaft in the sleeve, a driving connection between the two sleeves, means for driving said shaft, and means for applying endwise pressure to said shaft.

66. In a machine of the character de-

scribed, a supporting frame, a sleeve rotatably mounted in the frame and held against longitudinal movement, a reciprocal work spindle splined in said sleeve, a second sleeve rotatably mounted in the frame and held against longitudinal movement, a shaft slidably mounted in the second sleeve, a helical spline forming a driving connection between the shaft and its sleeve and serving to turn the sleeve on the shaft upon endwise movement of the shaft in the sleeve, a driving connection between the two sleeves, means for driving said shaft, and a spring operatively connected to said shaft for exerting an endwise pressure thereon.

67. In a machine of the character described, a supporting frame, a work spindle mounted for endwise reciprocation in the frame and having means at one end thereof for holding a gear, a series of spindles parallel with the work spindle and grouped about the same, a lap on each of said spindles having the form of a gear conjugate to the gear on the work spindle and meshing therewith, a drive shaft having separate driving connections to the work spindle and to the lap spindles, means for reciprocating the work spindle, bearings for the lap spindles closely adjacent the laps for rigidly holding the laps against lateral movements, and a bearing for the work spindle relatively remote from the end thereof to which the gear is attached whereby a slight flexing of the work spindle is permitted.

68. In a machine of the character described, a work spindle having means for securing a gear thereon, a second spindle parallel with the work spindle, a tool in the form of a gear secured to the second spindle and meshing with the gear on the work spindle, separate means for driving the work and tool spindles at speeds inversely proportional to the pitch diameters of the gear and gear shaped tool, means for applying a torsional thrust to one of said spindles to create pressure between the teeth of the gear and tool, and means for disengaging the gear and tool and for simultaneously releasing said thrust applying means.

69. In a machine of the character described, a work spindle having means for securing a gear thereon, a second spindle parallel with the work spindle, a tool in the form of a gear secured to the second spindle and meshing with the gear on the work spindle, separate means for driving the work and tool spindles at speeds inversely proportional to the pitch diameters of the gear and gear shaped tool, means for applying a torsional thrust to one of said spindles to create pressure between the teeth of the gear and tool, and means for shifting one of said spindles axially to disengage the gear and tool and for simultaneously releasing said thrust applying means.

70. In a machine of the character described, a work spindle having means for securing a gear thereon, a work spindle parallel with the work spindle, a tool in the form of a gear secured to the latter spindle and meshing with the gear on the work spindle, spindle driving means, spring actuated means operatively connected to one of said spindles for applying a torsional thrust thereto to create pressure between the teeth of the gear and tool, and means for shifting one of the spindles to disengage the gear and tool and for simultaneously releasing said thrust applying means.

71. Apparatus for grinding gears comprising a series of parallel spindles, a lap mounted on each of said spindles, each lap being in the form of a gear, a work spindle parallel with the lap spindles and centrally disposed with respect thereto, said work spindle having means for detachably holding a gear to be ground in mesh with the laps, means for rotating the gear and for imparting thereto an axial reciprocating movement relative to the laps, means other than the gear for positively driving the laps, means for applying torsional thrust to the gear, and means for reversing the torsional thrust on the gear.

72. In a machine of the character described, a supporting frame, a sleeve rotatably mounted in the frame and held against longitudinal movement, a reciprocable work spindle splined in said sleeve, a second sleeve rotatably mounted in the frame and held against longitudinal movement, a shaft slidably mounted in the second sleeve, a helical spline forming a driving connection between the shaft and its sleeve and serving to turn the sleeve on the shaft upon endwise movement of the shaft in the sleeve, a driving connection between the two sleeves, means for driving said shaft, a spring operatively connected to said shaft for exerting an endwise pressure thereon, and means for reversing the direction of thrust of the spring on said shaft.

73. Apparatus for grinding gears comprising a work spindle having means for holding a gear, a series of parallel fixed spindles spaced circumferentially about the work spindle, a lap on each of the latter spindles in the form of a gear conjugate to the gear to be ground and positioned to mesh with said gear, each lap having a number of teeth different from the number of teeth of the gear, means for driving the gear and imparting a reciprocating movement thereto, means separate from the gear driving means for driving the laps at the speeds at which they would be driven by the gear, and means for causing a relative angular feed movement between the gear and laps to create pressure between intermeshing gear and lap teeth.

74. Apparatus for grinding gears comprising a work spindle having means for holding a gear, a series of parallel fixed spindles spaced circumferentially about the work spindle, a lap on each of the latter spindles in the form of a gear conjugate to the gear to be ground and positioned to mesh with said gear, each lap having a number of teeth different from the number of teeth of the gear and from that of each of the other laps, means for driving the gear and imparting a reciprocating movement thereto, means separate from the gear driving means for driving the laps at the speeds at which they would be driven by the gear, and means for applying a torsional thrust to the gear to create pressure between intermeshing gear and lap teeth.

In testimony whereof I affix my signature.

ALFRED CHARLES PAGE.