

L. H. TURNER ET AL

# MACHINE FOR FINISHING GEARS

Filed Nov. 6, 1945

10 Sheets-Sheet 1

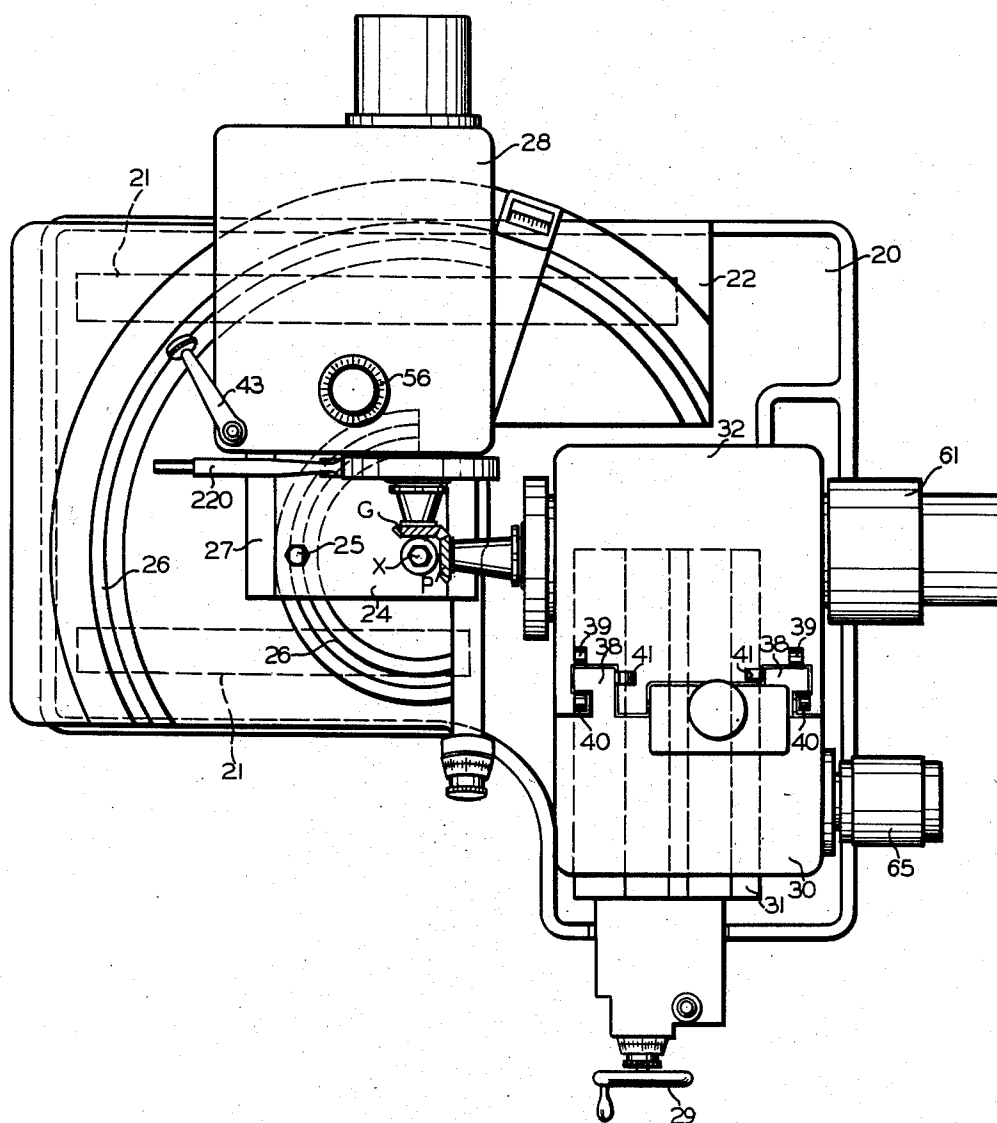


FIG. 1

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July 20, 1948.

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MACHINE FOR FINISHING GEARS

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10 Sheets-Sheet 2

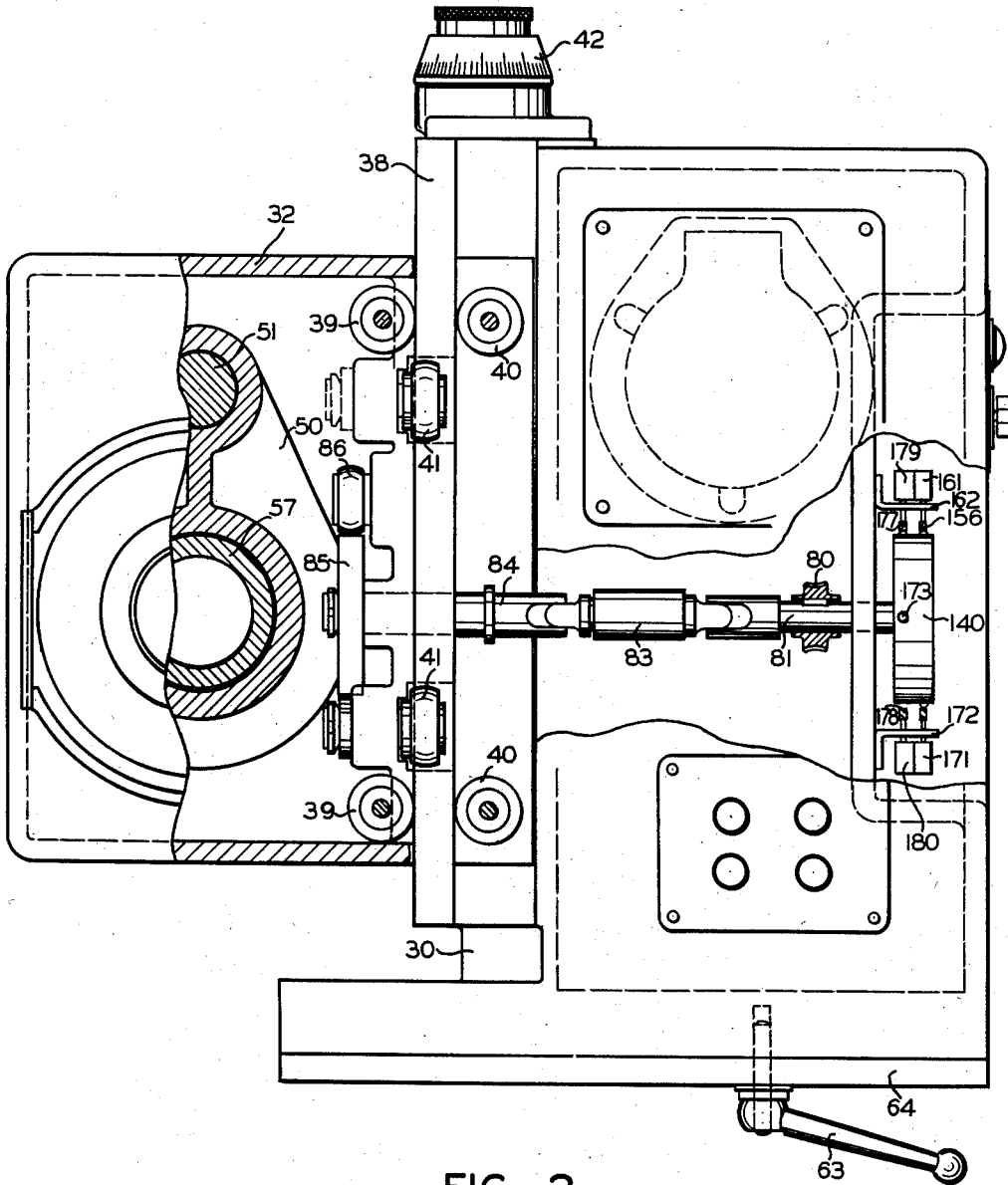


FIG. 2

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10 Sheets-Sheet 3

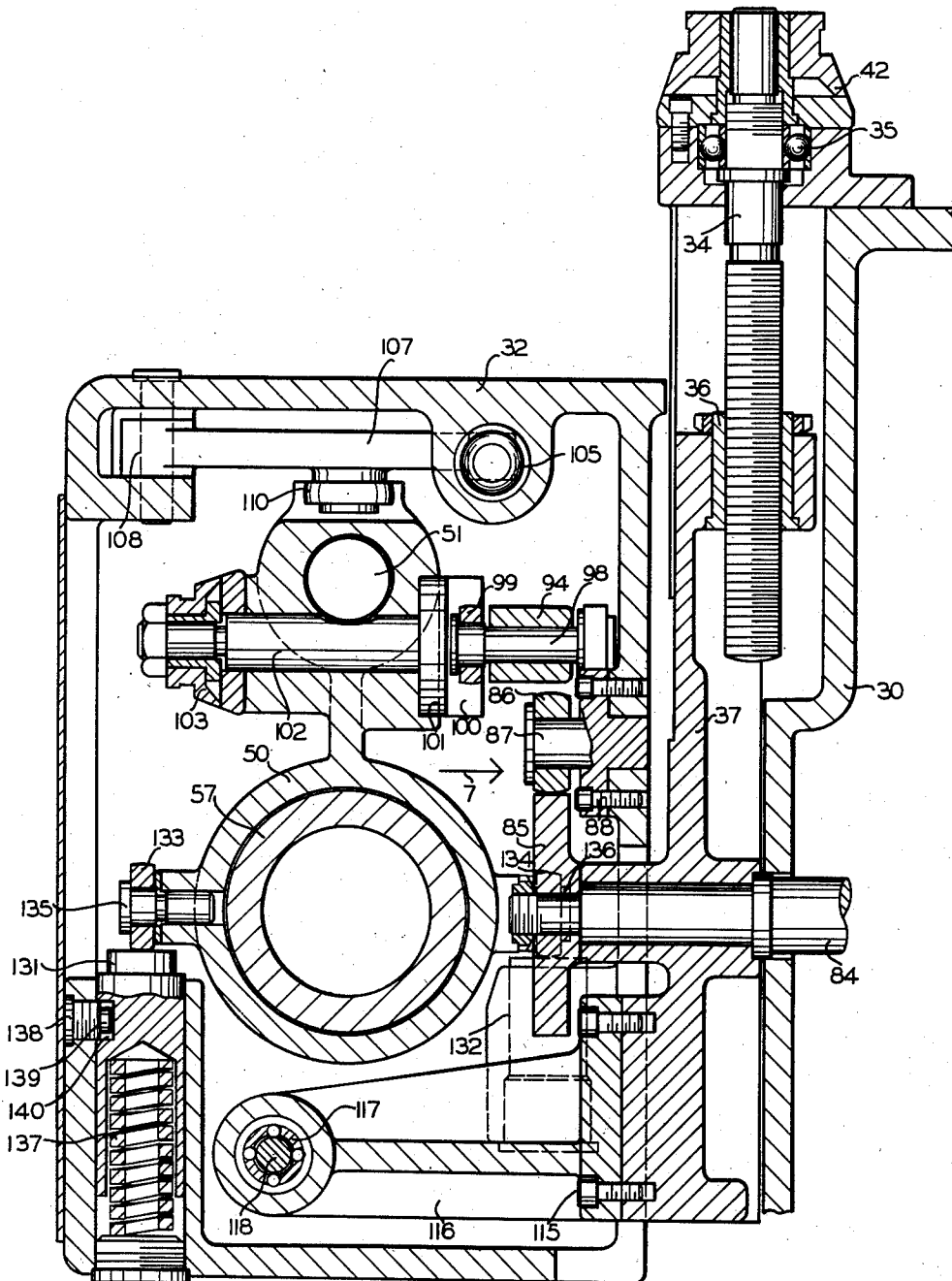


FIG. 3

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10 Sheets-Sheet 4

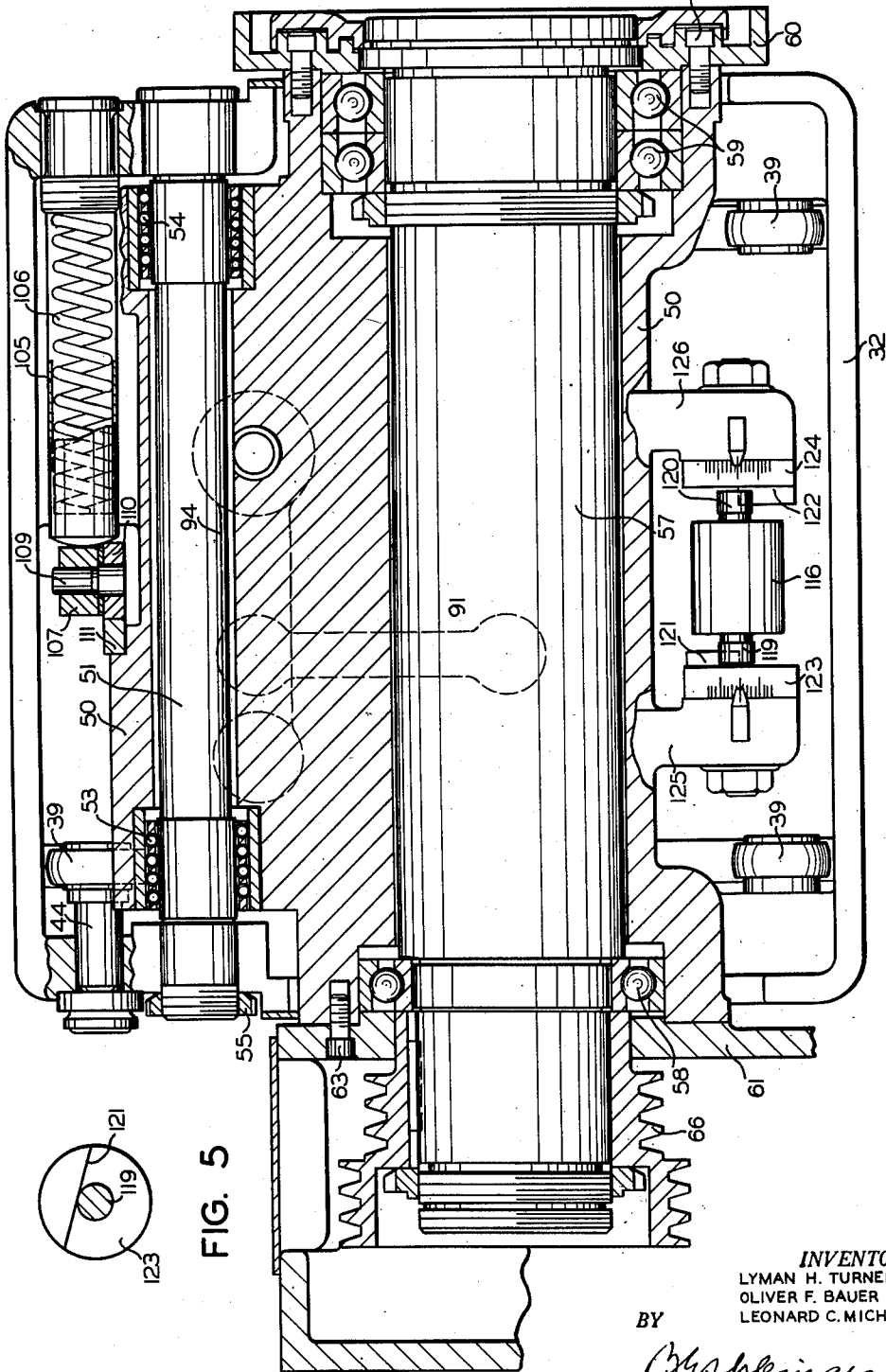


FIG. 4

FIG. 5

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10 Sheets-Sheet 6

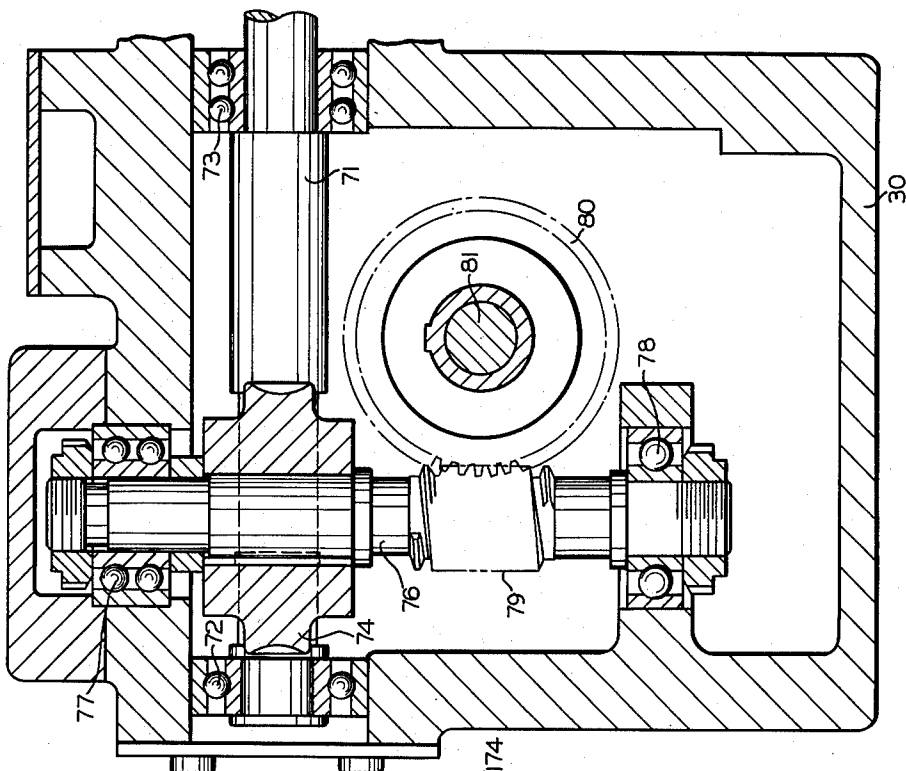


FIG. 9

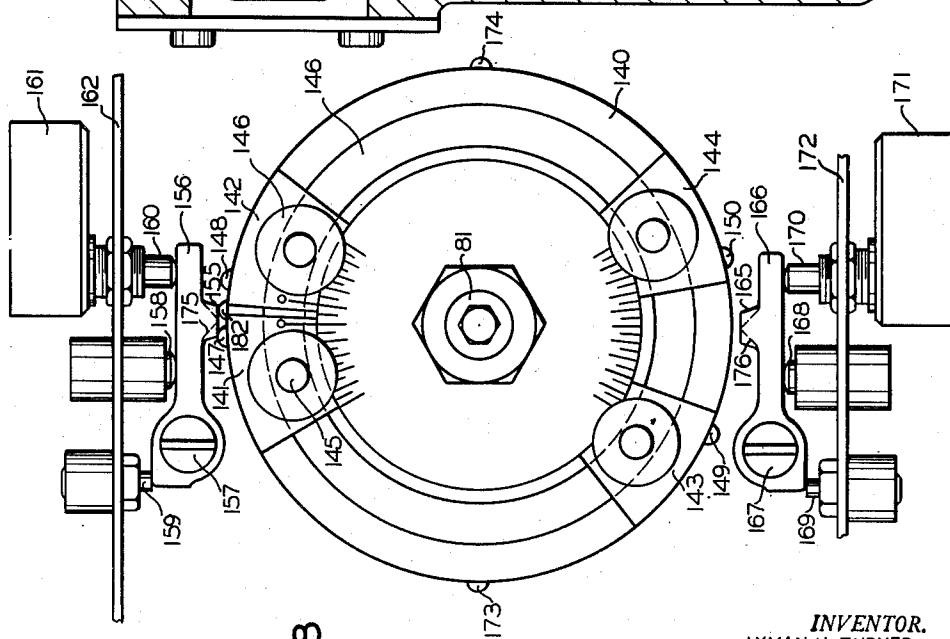


FIG. 8

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# MACHINE FOR FINISHING GEARS

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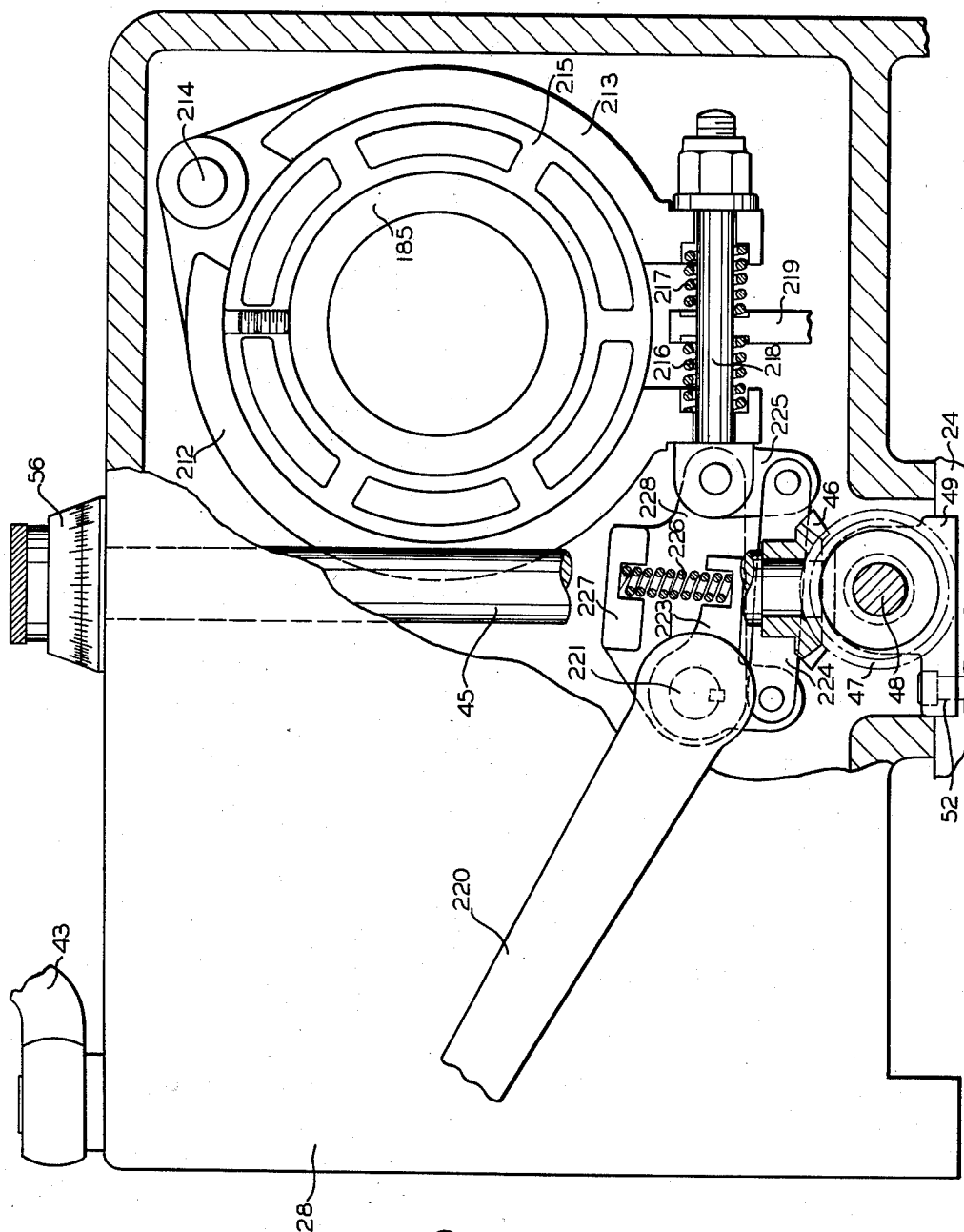


**FIG. 10**

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10 Sheets-Sheet 8

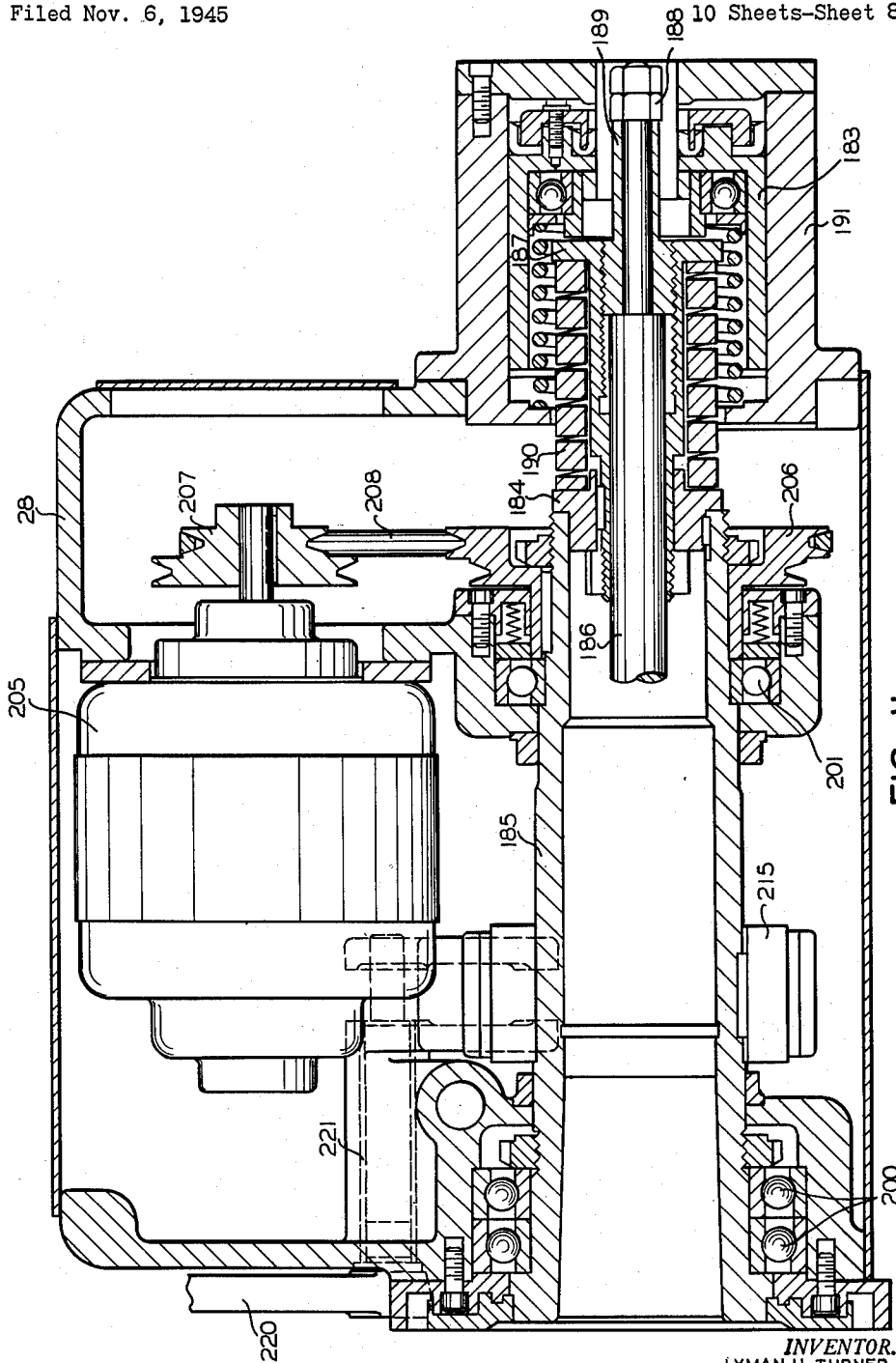


FIG. II

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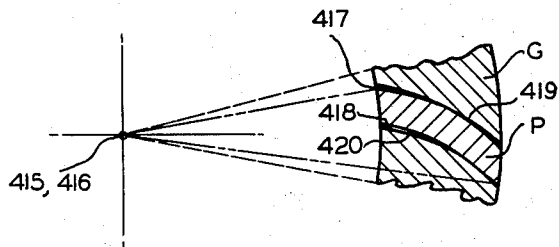


FIG. 12

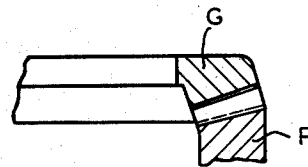


FIG. 13

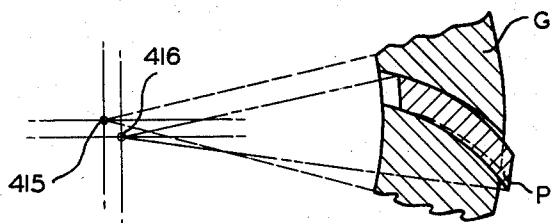


FIG. 14

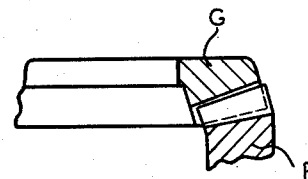


FIG. 15

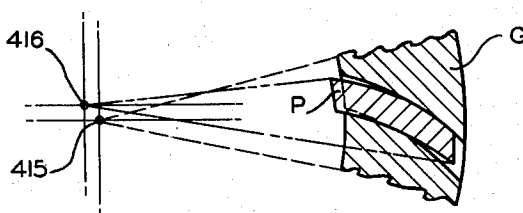


FIG. 16

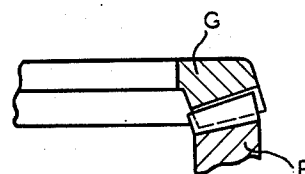


FIG. 17

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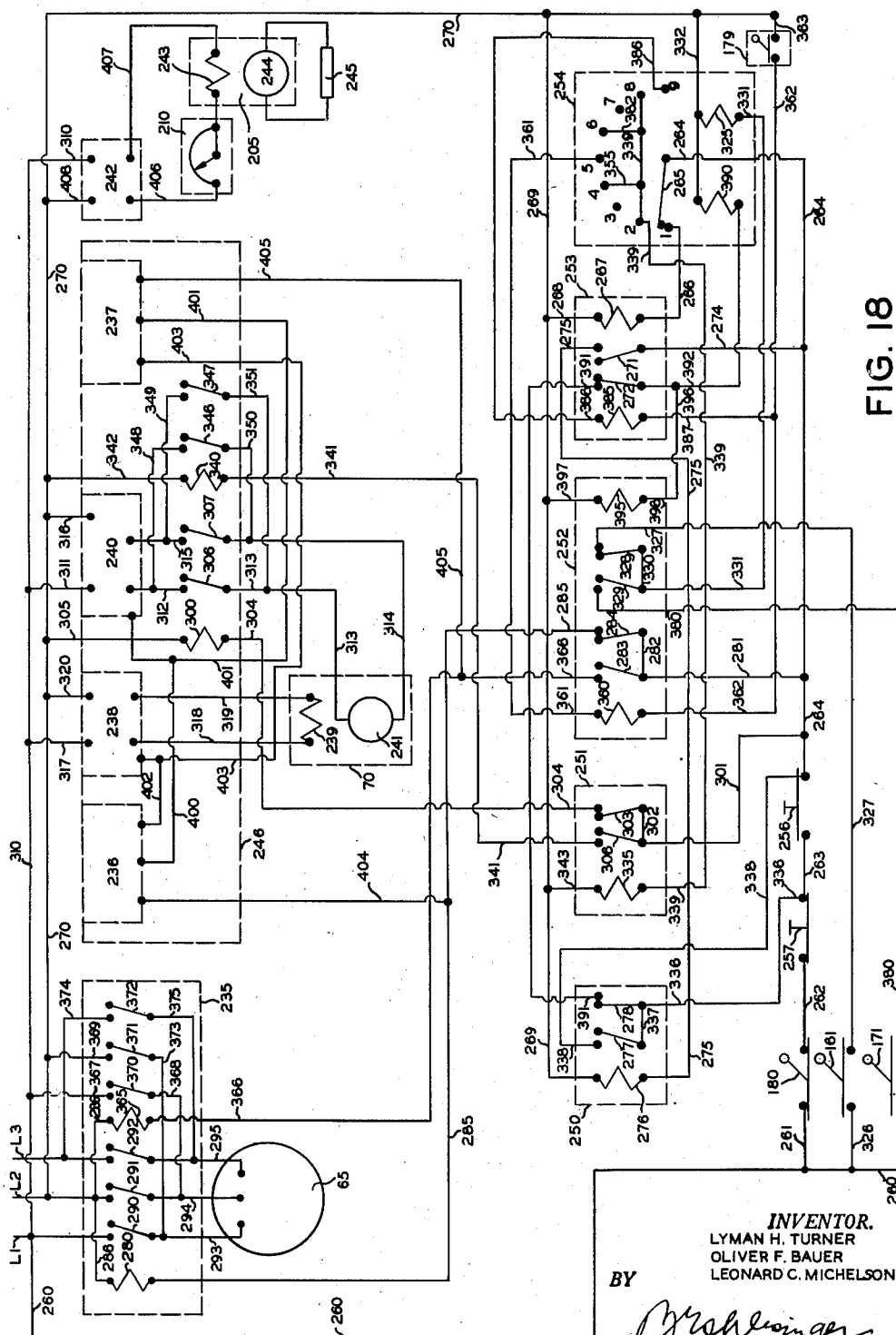


FIG. 18

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## UNITED STATES PATENT OFFICE

2,445,649

## MACHINE FOR FINISHING GEARS

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Application November 6, 1945, Serial No. 627,024

19 Claims. (Cl. 51—26)

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The present invention relates to machines for finishing gears, and particularly to machines for lapping spiral bevel and hypoid gears.

In lapping bevel and hypoid gears, it is the practice to rotate the gears together in mesh under slight load while effecting relative motions between the gears lengthwise and transversely of their teeth and in the direction of tooth depth. In the conventional type of lapping machine, the gear or driven member of the gear pair, which is to be lapped, is mounted on a spindle which is journaled in a quill, that is mounted in an oscillatory carrier for reciprocation in a direction axial of the spindle, and the carrier is mounted for oscillation about an axis parallel to but offset from the axis of the spindle. The lapping operation is effected by reciprocating the quill and oscillating the carrier while the gear and pinion rotate together in mesh. The oscillatory motion of the carrier causes the teeth of the driven gear to slide lengthwise over the teeth of the drive gear and it simultaneously moves the gears relative to one another in a direction transverse to the lengthwise sliding. The reciprocatory motion of the quill produces the relative movement of the gears in the direction of tooth depth and serves to maintain the backlash between the gears constant as the teeth slide lengthwise and transversely over one another. The gears are rotated together in one direction for a predetermined period and then reversed. Then, after a predetermined period of drive in the reverse direction, the machine is stopped.

Since opposite sides of the teeth of spiral bevel and hypoid gears are differently curved, one side being longitudinally convex and the other longitudinally concave, it is usually desirable to employ different rates and amounts of lapping motions during the rotation in opposite directions of the gears being lapped. In the conventional lapping machines, the rates of the oscillatory and reciprocatory movements are controlled by two different sets of change gears, one set controlling the rates of the motions during rotation in one direction of the gears being lapped and the other set controlling the rates of the motions during rotation of the gears in the opposite direction. The two sets of change gears are automatically shifted into and out of operative position at the time of reversal of the gears being lapped.

In the conventional machines, the position of the axis of the driven spindle can be adjusted angularly about the axis of the carrier. This permits of varying the ratio of the lengthwise and transverse motions of the gears. Nevertheless,

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for a given angular position of the spindle, the ratio of lengthwise to transverse movement is fixed. Therefore, it is not possible to adjust the amount of transverse motion independently of the amount of lengthwise movement. Further than this, in the conventional machines, the oscillatory motions of the carrier and the reciprocatory movements of the quill are controlled by cams, and, for lapping or burnishing different pairs of gears, different sets of cams must be used, each cam being shaped to suit the job. Moreover, different parts of the cam, which controls the oscillatory motion, have to be used during the forward and reverse rotations of the gears, respectively, and in order to have different amounts of oscillatory movements during forward and reverse rotations, the two parts of the cam have to have different shapes.

The conventional machines, moreover, because of their structure, are suitable only for lapping gears which mesh with axes at right angles. Heretofore no machine has been available for automatically lapping bevel or hypoid gears which mesh with axes at other than right angles, despite the fact that such gears have been used in great numbers.

The primary objects of the present invention are to provide an automatic machine for lapping spiral bevel and hypoid gears which will be more convenient to operate, cheaper in construction, easier to adjust for different jobs and to change over from one job to another, and generally more flexible in use and in range than any such machine previously built.

Another object of the invention is to provide an automatic machine for lapping spiral bevel and hypoid gears in which the need for special and different cams for different jobs is wholly eliminated, and in which a single cam of simple shape may be employed for lapping any pair of gears within the range of the machine.

Another object of the invention is to provide an automatic machine for lapping spiral bevel and hypoid gears in which the same part of the cam surface is used for producing the oscillatory motions of the carrier during both forward and reverse rotations of the gears, and the necessity for differently shaped cam portions for controlling the movements during rotation of the gears in opposite directions is avoided.

A further object of the invention is to provide an automatic machine in which the times for lapping of the opposite sides of the teeth of a pair of gears can be adjusted at will and in which the character of the lapping action on opposite sides

of the teeth can also be varied at will to suit the particular gears which are to be lapped.

Another object of the invention is to provide an automatic machine for lapping spiral bevel and hypoid gears in which the use of change gears for controlling the character of the finishing operation is eliminated and in which quite simple controls are employed instead for governing the amounts of the several motions which together effect the lapping operation.

Still another object of the invention is to provide a lapping machine in which the several motions for lapping are derived from a single cam and in which, therefore, the structure of the machine may be very much simplified.

A still further object of the invention is to provide a machine of the character described in which simple, very efficient means is provided for applying a brake-load of any desired amount to the gears during the lapping operation.

Still another object of the invention is to provide a machine on which all types of spiral bevel and hypoid gears may be lapped regardless of whether they mesh with axes at acute, right, or obtuse angles.

Other objects of the invention will be apparent hereinafter from the specification and from the recital of the appended claims.

In the machine of the present invention, the lapping motions are preferably applied to the pinion or drive member of the gear pair, which is to be lapped, instead of as in the conventional design to the gear or driven member. In the embodiment of the invention illustrated in the drawings, the drive spindle is journaled in a carrier that is mounted in a head for oscillation and reciprocation about and in the direction of an axis offset from and parallel to the axis of the spindle, and the head is mounted in a column or upright for reciprocation in a direction perpendicular to the axis of oscillation of the carrier. The axial reciprocation of the carrier effects lengthwise sliding of the teeth of one gear on the other; the oscillatory movement of the carrier varies the depth of engagement of the gears as they move lengthwise; and the reciprocatory movement of the head effects transverse movement of the gears relative to one another.

All of the motions are derived from a single cam. This cam reciprocates the head; and the carrier is so connected to the relatively stationary upright, on which the head slides, that as the head reciprocates it can both oscillate and reciprocate the carrier. There are two rollers secured to the upright. One of these engages the straight guide surface of a block that is adjustable angularly about an axis extending at right angles to the axis of the carrier. The other of these engages the straight guide surface of a block that is adjustable angularly about an axis extending in the direction of the axis of the carrier. When the guide surface of the first block is inclined to the direction of reciprocation of the head, axial movement is imparted to the carrier as the roller rolls along the straight guide surface of the block through reciprocation of the head. When the guide surface of the second block is inclined to the direction of reciprocation of the head, swinging movement is imparted to the carrier as the roller rolls along the straight guide surface of the second block in the reciprocation of the head. By adjusting the blocks, the angles of inclination of their guide surfaces to the direction of reciprocation of the head may be varied. Thereby the distance through which

the carrier reciprocates and the angle through which it oscillates for any amount of reciprocation of the head may be varied. Thus, the lengthwise, transverse, and depthwise movements of the gears can be varied relative to one another and the ratio of these movements can readily be changed to suit the requirements of any particular job to be lapped.

The cam is oscillated to effect the reciprocation of the head. It may be provided with an operative surface of progressively increasing radius so that the greater the angle through which the cam is swung, the greater the distance through which the head is reciprocated. Adjustable stops carried by a control member, that is mounted on the same shaft with the cam, determine the angle through which the cam swings. There is one set of stops provided for controlling the angle of oscillation of the cam during forward rotation of the gears, that are to be lapped, and there is a second set of stops provided for controlling the angle of oscillation of the cam during reverse rotation of the gears. Since the angle of oscillation of the cam determines the extent of the reciprocation of the head, and since the angles of adjustment of the guide-blocks determine the extent of the oscillatory and reciprocatory movements of the carrier for a given amount of movement of the head, it will be obvious that a single cam can be used for controlling the extent of the motions of the machine for lapping any pair of gears within the range of the machine.

The rates of the motions are controlled electrically. Through suitable electrical controls, also, the operation of the machine is rendered fully automatic. These controls allow the gears to be moved relative to one another back and forth a plurality of times during rotation of the gears in one direction, then reverse the gears, then allow them to be moved back and forth a plurality of times during rotation of the gears in the reverse direction, and then stop the machine.

The mounting of the drive member on the head to which the lapping motions are imparted, enables the gear or driven spindle to be mounted in a head which may be adjusted angularly to incline its axis at any desired angle to the axis of the drive spindle, thereby permitting tapered gears that mesh with axes at right angles or at other than right angles to be lapped without inordinately increasing the amount of floor space required for the machine.

In the drawings:

Fig. 1 is a plan view of a machine built according to one embodiment of this invention;

Fig. 2 is an end view, partly in section, of the drive head of the machine and its supporting column;

Fig. 3 is a transverse vertical sectional view through the drive head taken in a plane parallel to the view of Fig. 2 and on a somewhat enlarged scale, showing, also, a fragmentary section of the supporting column;

Fig. 4 is a longitudinal vertical sectional view through the drive head taken at right angles to the view of Fig. 3;

Fig. 5 is a detail view showing one of the angularly adjustable blocks and rollers for controlling the oscillatory movement of the drive head;

Fig. 6 is a fragmentary view looking in the direction of the arrow 7 of Fig. 3, showing the cam, which effects the lapping motions, and its follower, one of the adjustable control blocks, the

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roller which engages this block, the other roller, and the supports for both rollers;

Fig. 7 is a fragmentary sectional view taken at right angles to the view of Fig. 6;

Fig. 8 is an enlarged view looking at the right hand end of the cam drive shaft shown in Fig. 2 and showing the control member, adjustable stops, and limit switches which govern the amount of oscillation of the cam shaft;

Fig. 9 is a fragmentary sectional view showing the drive to the cam shaft;

Fig. 10 is an elevational view, with parts broken away, of the driven head of the machine;

Fig. 11 is a vertical sectional view through the driven head and driven spindle;

Figs. 12 to 17 inclusive are diagrammatic views illustrating the relative movements of the gear and pinion during lapping of a pair of gears on a machine constructed according to this invention; and

Fig. 18 is an electrical wiring diagram of the machine.

Referring to the drawings by numerals of reference, 20 indicates the bed or frame of the machine. Mounted on the bed or frame for sliding adjustment on ways 21, which are formed on the upper face of the bed, is a plate 22. Mounted on the plate 22 for angular adjustment thereon about an axis  $x$  is a swinging base 24. The swinging base is secured in any adjusted position on the plate 22 by T-bolts 25 which engage in arcuate T-slots 26 formed on the upper face of the plate 22 concentric of the axis  $X$ . Mounted on the swinging base 24 for rectilinear adjustment thereon along the ways 21, which are formed on the upper face of the swinging base, is the gear or driven head 28 of the machine. Adjustment of the head 28 on the base 24 may be effected by rotation of the shaft 45 (Fig. 10) which is journaled in the head. This shaft has a bevel gear 46 secured to its lower end that meshes with a bevel gear 47. This bevel gear is secured to a screw-shaft 48 that is journaled in the head and that threads into a nut 49 that is fastened by bolts 52 to the sliding base 24. A graduated dial 56 with a knurled knob that is secured to upper end of shaft 45 permits the adjustment to be made precisely. The head 28 can be secured in any adjusted position on the sliding base by manipulation of the lever 43 which operates a suitable clamping device (not shown).

Mounted on the bed 20 for rectilinear adjustment thereon in a direction at right angles to the direction of adjustment of the plate 22 on the base is a column or upright 30 which is adapted to slide in its adjustment on the ways 31 (Fig. 1) that are formed on the upper face of the bed. The adjustment is effected by rotation of the handwheel 29 which is secured to a screw-shaft (not shown) that is journaled in the bed and that threads into a nut (not shown) which is secured to the column 30. The column can be secured in any adjusted position on the ways 31 by manipulation of lever 63 (Fig. 2) which serves to clamp the gib 64 against the underside of one of the ways 31.

Mounted on the column 30 for vertical adjustment thereon is the drive head 32 of the machine. The adjustment of the drive head is effected by rotation of the screw shaft 34 (Fig. 3). This shaft is rotatably mounted in the column 30 on anti-friction bearings 35 and threads into a nut 36 that is secured in a plate 37. The plate 37 has a guide portion of dove-tailed shape, as shown in Fig. 7, which is adapted to fit into and

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slide in a correspondingly shaped guide slot formed in the column 30. A tapered gib 68 and screw 69 serve to take up wear between the dove-tailed guide portion and its way.

The drive head 32 is guided in its adjustment on the column 30 by the L-shaped ways 38 (Fig. 1). For the purpose of reducing friction to a minimum and of making this adjustment as smooth as possible, there are two sets of rollers mounted in the drive head 32 to engage and roll on the two ways 38 as the head is adjusted on the column. In each set of rollers, there is an upper and a lower roller 39 (Fig. 2) which engage the front face of a guide way 38, an upper and lower roller 40 which engage the rear face of the guide way, and an upper and lower roller 41 which engage one side face of the guideway, see Fig. 1. The adjustment of the head 32 on the column 30 may be made precisely through use of the knurled knob and graduated dial 42 which is secured to the screw shaft 34. The several rollers 39, 40, and 41 are rotatably mounted on studs, such as the stud 44 shown in Fig. 4, which are secured in the head 32.

The mountings and adjustments of the heads 28 and 32 on the bed 20 of the machine are similar to those of the heads in the gear testing machine of the United States patent of Oliver F. Bauer, No. 1,909,088, issued May 16, 1933.

Mounted in the head 32 for oscillatory and reciprocatory movement therein is a carrier 50 (Figs. 2, 3, and 4). This carrier is mounted on a rod or bar 51 which is secured at its opposite ends in the drive head 32. The carrier is mounted on this bar by means of the sleeve bearings 53 and 54 so that it may not only swing about the bar but also have limited sliding movement to and fro along the bar. The bar has an enlarged head at one end which holds it against movement in the drive head 32 in one direction, and the nut 55, which is threaded to the bar, serves to hold the bar against movement relative to the drive head in the opposite direction.

Journaled in the carrier 50 with its axis offset from but parallel to the bar 51 is the drive spindle 57 of the machine. This spindle is mounted in the carrier on anti-friction bearings 58 and 59. A labyrinth seal 60 is secured to the carrier at one end of the spindle 57 to prevent entry of dirt or grit into the bearings 59, while the bearing 58 is protected by the front wall of a cylinder 61, which is shown only fragmentarily in Fig. 4, and which is secured to the opposite end of the carrier by screws 63.

The pinion or drive member P (Fig. 1) of the gear pair, which is to be lapped, is adapted to be secured to the drive spindle 57 by any suitable means as, for instance, by a clamp and draw bar (not shown). The cylinder 61 may form part of a conventional hydraulic chucking mechanism for securing the pinion to the spindle 57.

During operation of the machine, the drive spindle 57 is adapted to be driven first in one direction and then in the other from the motor 65. This motor is secured to the column 30 and drives the spindle 57 through a belt (not shown) and the pulley 66, the latter being keyed to the spindle 57.

During operation of the machine, also, the head 32 is moved up and down on the column 30. The reciprocatory movement of the head 32 is effected through operation of a motor 70 which is indicated diagrammatically in Fig. 18. This motor drives a shaft 71 (Fig. 9) which is journaled on anti-friction bearings 72 and 73 in the column 30.

This shaft has a worm (not shown) secured to or integral with it that meshes with a worm wheel 74 which is keyed to a shaft 76. The shaft 76 is journaled in the column 30 on anti-friction bearings 77 and 78 and has a worm 79 integral with it that meshes with a worm wheel 80 (Figs. 9 and 2) that is keyed to a shaft 81. The shaft 81 is journaled in any suitable manner in the column 30 and is connected through universal joints and a stub shaft 83 with a shaft 84 (Figs. 2 and 3) that is suitably journaled in the plate 37.

Secured to the inner end of the shaft 84 is the cam 85 (Figs. 2, 3, and 6). A roller 86 rides on the periphery of this cam. This roller is rotatably mounted upon a stud 87 that is secured to the head 32 by screws 88. The cam 85 may be formed as shown in Fig. 6, so that its peripheral surface is at a progressively varying distance from the axis of the shaft 84. Hence, as the shaft swings, the head 32 rises or falls depending upon the direction of movement of the shaft.

Pivotally mounted upon a pin 90 that projects forwardly from the plate 37 through a slot 92 in the head 32 (Figs. 6 and 7) is a link 91. This link is pivotally connected by means of a pin 92 to a lever 94. The lever 94 is pivotally mounted at one end upon a pin 95 that is secured in a bracket 96. This bracket is fastened by means of screws 97 to the work head 32. The lever 94 carries a pin 98 at its free end. Upon this pin is rotatably mounted a roller 99 (Figs. 3, 6, and 7). The roller 99 is adapted to engage a straight slabbed-off guide surface 100 formed on a block 101. This block is integral with a shaft 102 which is mounted in the carrier 50 for rotatable adjustment therein. The axis of this shaft extends at right angles to the axis of the spindle 57.

The angle of adjustment of the block 101 determines the amount of axial movement imparted to the drive spindle 57, that is, the amount of relative lengthwise movement between the teeth of the pinion P and the teeth of the mating gear G (Fig. 1), for as the drive head 32 rises and falls under actuation of the cam 85, the roller 99 will ride up and down on the guide surface 100 of the block 101. If this guide surface is vertical, that is, is parallel to the direction of movement of the head 32, no axial movement will be imparted to the spindle 57 and the carrier 50. If the guide surface 100 is inclined to the vertical, however, the carrier 50 and, with it, the spindle 57 will move back and forth as the work head rises and falls.

The amount of the back and forth movement will depend upon the angle of adjustment of the block 101. Moreover, the direction of adjustment of the block angularly one side or other of the vertical will determine the direction of movement of the carrier and spindle for rise and fall of the head 32. Thus, for one angular position of the block 101, the carrier and work spindle will move inwardly as the head rises, while when the block is adjusted to the opposite angle, the carrier and work spindle will move outwardly as the drive head rises. This permits of lapping gears whether the pinion is chucked in the usual fashion on the drive spindle with its apex extending forward of the spindle or is chucked backward with its apex extending toward the rear of the spindle. The angular position of the block 101 may be adjusted precisely through use of the micrometer dial 103 which is secured to the shaft 102 (Fig. 3).

A spring-pressed plunger 105 (Figs. 3 and 4), which is housed in the head 32, serves to con-

stantly urge the carrier 50 and spindle 57 toward rearward position. This plunger which is actuated by the spring 106 engages one end of a lever 107 that is pivotally mounted at its opposite end by means of the pin 108 in the head 32. The lever carries a pin 109 between its ends on which is mounted a roller 110 that is adapted to engage a hardened block 111 which is secured in the carrier 50.

Fastened to the plate 37 by means of screws 115 is a bracket 116 (Figs. 3, 4, and 6). Journaled on anti-friction bearings 117 in this bracket is a cylinder 118 which is formed at opposite ends with roller portions 119 and 120. These rollers are adapted to engage, respectively, the straight-sided projecting portions 121 and 122 of blocks 123 and 124, respectively. These blocks are mounted on arms 125 and 126, respectively, which are integral with and project from the carrier 50. The blocks are adjustable angularly about aligned axes which extend parallel to the axis of the drive spindle 57, and they may be adjusted angularly to incline the straight surfaces 121 and 122 at any desired angle to the vertical. Thereby the amount of swing of the carrier 50 about the axis of shaft 51 may be adjusted to adjust the amount of depthwise in-and-out movement of the pinion P as the head 32 rises and falls under actuation of the cam 85. It will be obvious that if the blocks 123 and 124 are adjusted so that the surfaces 121 and 122 are vertical, then no swinging movement will be imparted to the carrier 50 about the bar 51 as the head 32 rises and falls, but if the surfaces 121 and 122 are inclined to the vertical, then as the head 32 rises and falls, the carrier will be oscillated about the axis of bar 51 and in-and-out depthwise movement will be imparted to the pinion. The direction of this movement for the rise of the head can be determined by the setting the guide surfaces 121 and 122 one side or other of the vertical. For precisely adjusting these guide surfaces, the blocks 123 and 124 are graduated as shown in Fig. 4 to read against zero index pointers carried by the arms 125 and 126, respectively.

For holding the guide surfaces 121 and 122 against the rollers 119 and 120, respectively, two spring-pressed plungers 131 and 132 (Fig. 3) are provided. These are housed in the head 32. The plunger 131 operates against a roller 133 which is rotatably mounted on a stud 135 that is secured in one side of the carrier 50. The plunger 132 operates against the roller 134 that is rotatably mounted on a stud 136 that is secured in the opposite side of the carrier 50. The spring 137, which actuates the plunger 131, is more powerful than the spring, which actuates the plunger 132, and will ordinarily overcome the action of the latter spring.

When the blocks 123 and 124 are in the positions shown in Fig. 4, the spring 137 overcomes the spring of the smaller plunger 132 and tends to hold the guide surfaces 121 and 122 of the blocks against the rollers 119 and 120. When the blocks are reversed, however, the plunger 131 is locked down by rotating the lock-screw 138 which has a lock-pin 139 formed eccentrically on its inner end that engages in a recess 140 in one side of the plunger. Then the smaller plunger 132 is operable to urge the carrier 50 in the opposite direction to hold the guide surfaces 121 and 122 against the rollers 119 and 120.

The amount of the up-and-down movement of the drive head 32 is governed from a control member 140 (Figs. 2 and 8) which is secured

to the shaft 81. There are two pairs of stop plates secured to the rear face of the control member 140. The two members of one pair are denoted at 141 and 142, respectively, while the two members of the other pair are designated at 143 and 144, respectively. Each of these members is adjustable angularly about the axis of the shaft 81 and may be fastened in any adjusted position on the rear face of the control member 140 by a T-bolt 145 whose head engages in a circular T-slot 146 that is formed in the rear face of the member 140. The stop plates are locked in position by tightening the knurled nuts 146 which thread onto the T-bolts.

The stop plates have stop buttons 147, 148, 149, and 150, respectively, formed on their peripheral surfaces. The rear face of the control member is suitably graduated, as clearly shown in Fig. 8, to read against zero marks on the stop plates so that each pair of stop plates can be adjusted to space the stop buttons of that pair the desired distance apart.

The stop buttons 147 and 148 are adapted, during oscillation of the shaft 81, to rock a lever 156 that is pivotally mounted by means of the stud 157 on the column 30. The stop buttons engage the nose 155 of this lever. The lever is constantly urged in one direction about its pivot by the spring-pressed plunger 158 which is carried by a bracket 162 that is secured to the column. Pivotal movement of the lever in this direction is limited by an adjustable stop 159 which is also carried by bracket 162. As the lever rocks about its pivot 157, it pushes in the plunger 160 to close the limit switch 161. This limit switch is also carried by the bracket 162.

The buttons 149 and 150 are adapted to engage the nose 165 of a lever 166 which is pivoted by the stud 167 in the column 30. The lever 166 is constantly urged inwardly about its pivot pin 167 by a spring-pressed plunger 168 that is carried by a bracket 172 which is secured to the column 30. An adjustable stop-pin 169, which is also carried by the bracket 172, serves to limit the inward movement of the lever 166. As the lever is rocked about its pivot against the resistance of the spring-pressed plunger 168 by engagement of one of the stop buttons 149 or 150 with the lug 165, the lever presses the plunger 170 of the limit switch 171 inwardly to trip the limit switch. This limit switch is also carried by bracket 172.

The machine shown is wired, as will be described more particularly hereinafter, so that the shaft 81 and control member 140 are oscillated back and forth, being driven first in one direction and then in the other, the direction of rotation being reversed by tripping the limit switches 161 and 171. When the machine is started up, the limit switch 161 controls the direction of rotation of the control member 140 and shaft 81, and each time that one or other of the buttons 147 or 148 strikes the nose 155 of the lever 156, the control member and shaft are reversed. Thus, at this stage of the operation, the amount of oscillation of shaft 81, that is, the amount of movement of drive head 32, is controlled by the distance that stop-buttons 147 and 148 are set apart.

The machine illustrated is further so wired that after two complete oscillations of the shaft, the limit switch 161 is rendered inoperative and the limit switch 171 becomes operative. Then the oscillations of the shaft and control member are controlled by the stop buttons 149 and 150. Each time that one of these stop-buttons contacts the nose 165 of lever 166, the direction of rotation of

the shaft 81 is reversed, and the amount of swing of shaft 81 and of movement of drive head 32 is controlled at this stage of the operation by the distance that buttons 149 and 150 are set apart. The machine illustrated is so wired further that after two complete oscillations of the shaft under control of buttons 149 and 150, the limit switch 171 is rendered inoperative and the machine is stopped.

Safety stops are provided to stop the machine in case the stop-buttons 147 and 148 or 149 and 150 fail to function and fail to reverse the direction of rotation of the shaft. These safety devices are in the form of additional stop-buttons 173 and 174 which are provided on the periphery of the control member 140. These stop-buttons 173 and 174 are placed diametrically opposite from one another, one between the stop plates 141 and 143, and the other between the stop plates 142 and 144. These buttons 173 and 174 are adapted to engage with the V-shaped nose of a lever 178 (Fig. 2) which is pivotally mounted alongside the lever 166 on the stud 167. The lever 178 is constantly urged toward the periphery of the control member 140 by a spring-pressed plunger similar to the plunger 168 and its movement may be limited in one direction through an adjustable stop pin similar to the stop pin 169. The lever 178 is adapted to actuate, when rocked, the limit switch 180, which is carried by the bracket 172. This limit switch is wired to stop the machine, when tripped, as will be described more particularly hereinafter.

Mounted on the periphery of the control member 140 at an angular position between the buttons 147 and 148 (see Fig. 8) but in a position displaced axially from buttons 147 and 148 so as to clear the nose 155 of lever 156 is a button 182. This button is adapted to engage the tapered nose 175 of a lever 177 (Fig. 2) which is mounted alongside lever 156 to pivot about stud 157. The lever 177, when rocked, is adapted to trip a limit switch 179. On each swing of control member 140, whether under control of stop-buttons 147 and 148 or of stop-buttons 149 and 150, then, limit switch 179 will be tripped. The purpose of this limit switch will appear hereinafter.

The gear G, or driven member of the pair, which is to be lapped, is mounted on the spindle 185 (Figs. 10 and 11). This spindle is rotatably mounted in the driven head 28 of the machine on suitable anti-friction bearings 200 and 201. The gear G may be secured to this spindle by any suitable means, for instance, by a draw bar 186 and a clamping disc (not shown). The draw bar is secured to a sleeve 187 through the nuts 188 and a nipple 189, the latter threading into the sleeve. The draw bar is constantly urged toward work-clamping position by a coil spring 190 which surrounds the sleeve 187 and which is interposed between the head of the sleeve and a nipple 184 that is keyed to spindle 185. The draw-bar is adapted to be moved to work-releasing position through application of fluid pressure to the rear end of a piston 193, which is housed within a cylinder 191 that is secured to head 28. Fluid under pressure may be admitted to cylinder 191 through a suitable duct in the cylinder (not shown).

The gear G and spindle 185, on which it is mounted, are driven during operation of the machine in opposite directions alternately through intermeshing engagement of the teeth of gear G and drive pinion P. To obtain a smooth, uniform motion during lapping and to prevent backlash between the gears accentuating the errors,

which it is desired to lap away, very simple means have been provided for taking up the backlash and exerting a moderate pressure between the gears throughout the whole lapping operation. For these purposes, a generator 205 is mounted in the driven head 28 to be driven from the driven spindle 185 through the pulleys 206 and 207 and the connecting belt 208. A rheostat 210 (Fig. 18) of any suitable construction is provided for varying the resistance of the generator to adjust the brake-load on the gears.

The machine of this invention, like the machine of the Bauer patent above mentioned, may be used for testing gears. When used for testing gears, the various oscillating and reciprocating motions of head 32 and carrier 50 are not employed, but the gears are simply run together under load. For applying a load to the gears during testing, a standard hand brake may be employed which may, as illustrated in Fig. 10, be in the form of a pair of brake-shoes 212 and 213 that are pivoted on the shaft 214 to engage the periphery of a brake-drum 215 that is secured to the spindle 185. The brake-shoes are constantly urged toward released position by coil-springs 216 and 217. These springs surround the pin 218 and are interposed between the free ends of the brake-shoes and opposite faces of a lug 219 which is integral with or secured to the head 28. The hand-brake is adapted to be actuated by a hand lever 220 which is keyed to a shaft 221 that is journaled in the head 28. Keyed to the shaft 221, also, is a bell-crank 223. One arm of this bell crank is connected through a link 224 with an actuating member 225 that engages one of the brake shoes 212. The other arm of the bell-crank is engaged by a coil spring 226. This spring is interposed between this arm of the bell-crank and a lug 227 formed on a bracket 228 that is integral with or secured to the head 28. Spring 226 serves to counterbalance lever 220. By pressing down on the lever more or less load can be applied to pinion P and gear G as they run together in mesh. This means of applying brake load to the gears may be used advantageously not only in testing but also in lapping if a considerable amount of stock is required to be removed in lapping.

One way in which the machine may be wired to accomplish the purposes of the present invention is illustrated diagrammatically in Fig. 18. Here 235 denotes the controller for the main motor 65; 236 and 237 designate combination armature-field rheostats for controlling the speed of rotation of the oscillating motor 70 during rotation in opposite directions of the gears that are to be lapped; 238 denotes an A. C.-D. C. rectifier for the field 239 of the oscillating motor 70; 240 denotes an A. C.-D. C. rectifier for the armature 241 of the oscillating motor 70; 242 designates an A. C.-D. C. rectifier for the generator 205; 243 the shunt field of the generator 205; 244 the armature of the generator; and 245 the load resistor for the generator. The motors 65 and 70, and the generator 205 may be of standard construction. The parts 235, 236, 238, 240, 237, 242, 210 and 245 may also be standard parts of any suitable structure. The machine is provided with a plurality of relays 250, 251, 252, 253, and 254. The relay 254 is a ratchet relay. All of these relays may be of any standard or suitable structure. The machine is also provided with standard start and stop-buttons 256 and 257, respectively. The parts are shown in Fig.

18 in the positions which they occupy when the machine is stopped.

To put the machine in operation, the operator pushes in the normally-open start-button 256. This closes a circuit to the coil 280 of the controller 235, this circuit being from the main line L<sub>1</sub> through the lines 260 and 261, the normally-closed limit switch 180, the line 262, the stop-button 257, the line 263, the start-button 256, the line 264, the lines 281 and 282, the switch-arm 284 of the relay 252, the line 285, the coil 280, and the line 286 to the main line L<sub>2</sub>. When the coil 280 of controller 235 is energized, the switch-arms 290, 291, and 292 of the controller 235 are closed, thus closing the circuit to the main motor 65 from the main lines L<sub>1</sub>, L<sub>2</sub>, and L<sub>3</sub> through the lines 293, 294, and 295 and starting this motor.

When the starting button is closed, the oscillating motor is also started. This is affected by energizing the coil 300 of the controller 246. The circuit to the coil 300 is made from the main line L<sub>1</sub> through the lines 260 and 261, the limit switch 180, the line 262, the stop-button 257, the line 263, the start button 256, the lines 264, 301, and 302, the switch arm 303 of the relay 251, the line 304, the coil 300 and the lines 305 and 270 to the main line L<sub>2</sub>. The energizing of the coil 300 closes the switch arms 306 and 307 of the controller 246 making a circuit to the armature 241 of the oscillating motor from the main line L<sub>1</sub> through the lines 310 and 311, the rectifier 240, the line 312, switch arm 306, line 313, the armature 241, the line 314, the switch arm 307, the line 315, the rectifier 240 and the lines 316 and 270 to the main line L<sub>2</sub>. The circuit to the shunt field 239 of the oscillating motor 70 is always closed, when the machine is in operation, from the main line L<sub>1</sub> through the lines 310 and 317, the rectifier 238, the line 318, the shunt winding 239, the line 319, the rectifier 238, and the lines 320 and 270 to the main line L<sub>2</sub>. Thus, the motor 70 is started.

When the start button 256 is closed, a circuit is also closed from the main line L<sub>1</sub> through the lines 260 and 261, the normally-closed limit switch 180 (Figs. 8 and 2) the line 262, the normally-closed stop button 257, the line 263, the start button 256, the line 264, the movable switch arm 265 of the ratchet relay 254 and the number one station of this relay, the line 266, the coil 267 of relay 253, and the lines 268, 269, and 270 to the main line L<sub>2</sub>. This energizes the coil 267 of the relay 253 closing the switch-arm 271 of this relay and causing the switch-arm 272 of the relay to be opened. The closure of the switch-arm 271 makes a circuit from the main line L<sub>1</sub> through the lines 260 and 261, the limit switch 180, line 262, stop-button 257, line 263, start-button 256, lines 264 and 274, switch-arm 271 of relay 253, line 275, coil 276 of relay 250, and lines 269 and 270 to main line L<sub>2</sub>, thus energizing the coil 276 of the relay 250, closing the switch-arm 277 and opening the switch-arm 278 of this relay.

With the main motor 65 running, the gears P and G, which are to be lapped, rotate in engagement, and with the oscillating motor 70 running, the shaft 81 and cam 85 are oscillated to move the head 32, to swing and reciprocate the carrier 50. As the shaft 81 swings in one direction from starting position, the button 182 (Fig. 8) may strike the nose 175 of the lever 177 (Fig. 2), closing the limit switch 179 (Figs. 2 and 18). At this stage, however, the closing of

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limit switch 179 does not effect any action. As the shaft 81 swings on, though, the button 147 strikes the nose 158 of the lever 156, closing the limit switch 161. This energizes the coil 325 of the ratchet relay 254, the circuit to this coil being made from the main line L<sub>1</sub> through the lines 260 and 326, the now-closed limit switch 161, the line 327, the switch-arm 328 of relay 252, the lines 330 and 331, the coil 325, and the lines 332 and 270 to the main line L<sub>2</sub>. When the coil 325 is energized, the switch-arm 265 is advanced from station 1 to station 2 of the ratchet relay 254.

The shift of the switch-arm 265 causes the coil 335 of the relay 251 to be energized, the circuit to this coil being made from the main line L<sub>1</sub> through the lines 260 and 261, the limit switch 180, line 262, the stop button 257, the lines 336 and 337, the now-closed switch-arm 277 of the relay 250, the lines 338 and 264, the switch-arm 265 of ratchet relay 254, No. 2 station of that relay, the line 339, the coil 335, and the lines 343, 269 and 270 to the main line L<sub>2</sub>.

The energizing of the coil 335 causes the switch-arm 306 to be closed and the switch-arm 303 to be opened. The opening of the switch-arm 303 breaks the circuit to the coil 300 of the controller 246 and stops the forward rotation of the oscillating motor 70. The closing of the switch-arm 306 makes a circuit to the coil 340 of this controller, causing the motor 70 to be driven in reverse. The circuit to the coil 340 is from the main line L<sub>1</sub> through the lines 260 and 261, the limit switch 180, the line 262, the stop-button 257, the lines 336 and 337, the switch-arm 277 of relay 250, the lines 338, 264, and 301, the switch-arm 306 of relay 251, the line 341, the coil 340, and the lines 342 and 270 to the main line L<sub>2</sub>. The energizing of the coil 340 causes switch-arms 346 and 347 of controller 246 to be closed, closing the reversing circuit to the armature 241 of motor 70, this circuit being made from the rectifier 240 through the lines 348 and 349, the switch arms 346 and 347, the lines 350 and 351 and the lines 314 and 313.

The shaft 81 is now driven in the reverse direction, causing the direction of movements of the head 32 and carrier 50 to be reversed. The shaft 81 and controller 140 now rotate in a counter-clockwise direction as viewed from the rear (Fig. 8).

When the button 182 passes under the nose 175 of the lever 177, the limit-switch 179 is closed but nothing happens. When the button 148 contacts the nose 158 of the lever 156, however, the limit-switch 161 is closed. This again causes a circuit to be made to the coil 325 of the ratchet relay 254 in the manner already described and this coil is again energized. The switch-arm 265 is, therefore, moved from station No. 2 to station No. 3 of the relay. This causes the circuit to the coil 335 of the relay 251 to be broken, causing the switch-arm 306 to drop out of engagement, disconnecting the lines 301 and 341, and causing the switch-arm 303 to move into engagement, connecting the lines 302 and 304.

The dropping of the switch-arm 306 out of engagement breaks the circuit to the coil 340 of the controller 246 while the closing of the switch-arm 303 makes the circuit to the coil 300 of this controller. Thus the oscillating motor 70 is again reversed to cause it again to drive in the forward direction. Again the shaft 81 swings clockwise between the limit set by the stop-buttons 147 and

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148 and during this counter-clockwise movement, the button 182 again trips the lever 177 and the limit-switch 179 without effecting any operation. At the end of the clockwise movement, the button 148 again strikes the nose 158 of the lever 156, again closing the limit-switch 161 and again energizing the coil 325 of the ratchet relay 254 to again shift the switch-arm 265.

This time the switch-arm moves from station No. 3 to station No. 4 of relay 254. This again causes the coil 335 of relay 251 to be energized, the circuit to this coil being made from the main line L<sub>1</sub> through the lines 260 and 261, the limit-switch 180, the line 262, the stop-button 257, the line 336, the line 337, the switch-arm 277, the line 338, the line 264, the switch-arm 265, station No. 4 of relay 254, the line 355, the line 339, the coil 335, and the lines 343, 269, and 270 to the line L<sub>2</sub>.

The energizing of the coil 335 again closes the switch-arm 306 and opens the switch-arm 303, causing the oscillating motor 70 to be again reversed as already described. Then the shaft 81 and control member 140 move in a counter-clockwise direction and again the button 182 rides idly over the nose 175 of the lever 177 and again when the button 148 strikes the nose of the lever 156, the limit-switch 161 is closed. This again causes the coil 325 to be energized, advancing the switch-arm 265 to station No. 5. This breaks the circuit to the coil 335, allowing the switch-arm 306 of the relay 251 to open and the switch-arm 303 of this relay to close.

This again reverses the oscillating motor 70 and shaft 81. On this swing of the control member 140, however, when the button 182 rides over the nose 175 of the lever 177, closing the limit-switch 179, a circuit is made to the coil 360 of relay 252. This circuit is from the main line L<sub>1</sub> through the lines 260 and 261, the limit-switch 180, the line 262, the stop-button 257, the lines 336 and 337, the switch-arm 277 of relay 250, the lines 338 and 264, the switch-arm 265 of relay 254, the line 361, the coil 360 of relay 252, the line 362, the now-closed limit-switch 179, and the lines 363 and the line 270 to the main line L<sub>2</sub>.

The energizing of the coil 360 of relay 252 causes the switch-arm 283 to be closed and the switch-arm 284 to be opened. When the switch-arm 284 is opened, the circuit to the coil 280 of the controller 235 is broken, stopping the forward rotation of the main motor 65. When the switch arm 283 is closed, a circuit is made to the coil 365 of the controller 235, starting the main motor 65 in reverse. The circuit to the coil 365 is from the main line L<sub>1</sub> through the lines 260 and 261, the limit-switch 180, the line 262, the stop-button 257, the lines 336 and 337, the switch-arm 277 of relay 250, the line 338, the line 264, the line 281, the switch-arm 283 of relay 252, the line 366, the coil 365, and the line 286 to the main line L<sub>2</sub>. The energizing of the coil 365 closes the switch-arms 370, 371, and 372, closing the reverse circuit to the motor 65 from the main line L<sub>1</sub> through the lines 310, 367, switch-arm 370 and lines 368 and 294; from the main line L<sub>2</sub> through the lines 270 and 369, switch-arm 371, and lines 373 and 293; and from the line L<sub>3</sub> through the line 374, the switch-arm 372, and lines 375 and 295. The main motor 65 now drives the gears P and G in reverse.

At the same time that the energized coil 360 closes the switch-arm 283 and opens the switch-arm 284 of relay 252, it closes the switch-arm 329 and opens the switch-arm 328 of this relay. This

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puts the limit-switch 171 in the control circuit and cuts out the limit-switch 181. This means that the buttons 149 and 150 (Fig. 8) now control the limit of movement of the controller 140 and of shaft 81. The shaft 81 now oscillates for the distance determined by the settings of the buttons 149 and 150. During each swing, the button 182 closes the limit-switch 179 as before, and, as before, at the end of each swing, one or other of the buttons 149 and 150 closes the limit-switch 171.

When the limit switch 171 is closed, a circuit is made to the coil 325 of the ratchet relay 254. This circuit is from the main line L<sub>1</sub> through the line 260, the limit-switch 171, the line 330, the now-closed switch-arm 329 of relay 252, the line 331, the coil 325, and the lines 332 and 270 to the main line L<sub>2</sub>.

This energizes the coil 325 and advances the switch-arm 265 of the ratchet relay 254 from station No. 5 of the relay to station No. 6. This causes the coil 335 of relay 251 to be energized, the circuit to this coil being made from the main line L<sub>1</sub> through the lines 260 and 261, limit-switch 180, the line 262, the stop-button 257, the lines 336 and 337, the switch-arm 277 of the relay 250, the lines 338 and 264, the switch-arm 265, the lines 332 and 339, the coil 335, and the lines 343, 269, and 270 to the main line L<sub>2</sub>. This closes the switch-arm 306 and opens the switch-arm 303 of the relay 251, reversing the oscillating motor 70 in the manner already described.

When the limit-switch 171 is closed again at the end of the new reverse swing of control member 140 and shaft 81, the coil 325 is again energized to shift the switch-arm 265 of ratchet relay 254 to station No. 7. This breaks the circuit to the coil 335 and again reverses the oscillating motor 70 and with it the direction of swing of control member 140 and shaft 81.

When the limit-switch 171 is closed once more at the end of the new swing of control member 140 and shaft 81, the coil 335 is again energized through the connection of station No. 8 of ratchet relay 254 with line 339. This again reverses the oscillating motor 70, shaft 81, and control member 140. When the limit-switch 171 is again closed at the end of this new swing of shaft 81 and control member 140, the coil 325 is again energized to advance the switch-arm 265 to station No. 9 of the ratchet relay 254. This again reverses the oscillating motor 70, again causing reversal of swing of shaft 81 and control member 140.

When the button 182 closes the limit-switch 179, on this swing of shaft 81 and control member 140, the coil 385 of the relay 253 is energized. The circuit to this coil is made from the line L<sub>1</sub> through the lines 260 and 261, the limit-switch 180, the line 262, the stop-button 257, the lines 336 and 337, the switch-arm 277 of relay 250, the lines 338 and 264, switch-arm 265 of ratchet relay 254, station No. 9 of relay 254, the line 386, coil 385 of relay 253, the lines 337 and 362, limit-switch 179, and lines 363 and 270 to the main line L<sub>2</sub>.

This causes the switch-arm 272 of relay 253 to be closed and switch arm 271 of this relay to be opened. The opening of the switch-arm 271 breaks the circuit to the coil 276 of the relay 250. This allows the switch-arm 277 of relay 250 to open and the switch-arm 278 of this relay to close.

When the switch arm 278 is closed, the coil 395 of relay 252 is energized to reset the switch-arms 283, 284, 329, and 328 of this relay to the

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positions shown in Fig. 18. The circuit to the coil 395 is made from the main line L<sub>1</sub> through the lines 260 and 261, the limit-switch 180, the line 262, the stop-button 257, the line 336, the switch arm 278 of relay 250, the line 391, the switch-arm 272 of relay 253, the line 396, the coil 395, and the lines 397, 269 and 270 to the main line L<sub>2</sub>.

The closing of the switch arms 272 and 278 also makes a circuit to the coil 390 of ratchet relay 254. This circuit is from the main line L<sub>1</sub> through the lines 260 and 261, the limit-switch 180, the line 262, the stop-button 257, the line 336, the switch-arm 278, the line 391, the switch-arm 272, the line 392, the coil 390, and the lines 332 and 270 to the main line L<sub>2</sub>. When the coil 390 is thus energized, the switch-arm 265 is reset from station No. 9 back to station No. 1.

When the switch-arm 277 of the relay 250 is opened, the hold-in circuit to the coil 280 of controller 235 is broken, and the circuits to the coils 300 and 340 of controller 248 are also opened. Hence, the main drive motor 65 and the oscillating motor 70 are stopped, stopping the machine. The operation of lapping the pair of gears is complete, and the gears may be removed from the machine and a new pair chucked thereon. To restart the machine, it is again necessary to press in the start-button 256.

It is to be noted regarding the above-described circuit that, if the power should fail and the machine stop before the lapping operation is completed, the switch-arm 265 of ratchet relay 254 will not be reset. When the machine is started again, therefore, the operations already performed will not be repeated, but the switch-arm 265 will simply remain at whatever station it has reached when the power is cut off, and when the power is restored again, the machine will resume its operations from the point where it was stopped. The switch-arm 256 can only be reset when it has reached No. 9 station of the ratchet relay 254, that is, when it has reached the position where the lapping operations on the pair of gears have been completed.

As already stated, if one of the stop-buttons 147, 148, 149, or 150 should fail for any reason to trip the limit switch 161 or 171 to reverse the direction of swing of shaft 81, then the button 173 or 174 will open the normally-closed limit-switch 180. This will break the circuits to the motors 65 and 70 and stop the machine.

In order to obtain the desired tooth bearing or contact on opposite sides of the teeth of a pair of spiral bevel or hypoid gears, it has been demonstrated that it is desirable to run the meshing gears together first in one direction and then in the other and that during rotation in opposite directions, the gears should be moved through different angles and at different rates. The adjustable stops 141, 142, 143, and 144 allow moving the gears through different angles. The different rates are obtained by adjustment of the rheostats 236 and 237 which control the shunt field and armature voltages of the motor 70 and hence its speed of rotation during forward and reverse drives, respectively. The two rheostats are connected together through the lines 400 and 401. The lines 400 and 401 serve, also, to connect the two rheostats to the rectifier 240. The two rheostats are connected to the rectifier 238 through the lines 402 and 403. The rheostat 236 is connected to the line 285 by the line 404, while the rheostat 237 is connected to the line 366 by the line 405. Thus, the rheostat 236 is wired to control the speed of the motor 70 during forward ro-

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tation of the gears being lapped under actuation of motor 65, while the rheostat 237 is wired to control the speed of the motor 70 during the reverse rotation of the gears.

As already stated, the load on the gears during lapping may be varied by adjustment of the rheostat 210 which controls the field 243 of the generator 205. The lines 406 and 407 serve to connect the rheostat 210 and shunt-field 243 with the rectifier 242, while the line 310 serves to connect the rectifier with the main line L<sub>1</sub> and the lines 408 and 270 serve to connect the rectifier with the main line L<sub>2</sub>.

The operation of the machine will be understood from the preceding description but may be summed up briefly here. It will be understood, of course, that during operation of the machine, a suitable lapping compound is applied to the gears by means known in the art. After the various adjustments have been made to bring the gears to be lapped into meshing engagement; the several rheostats have been set to control the speed of the oscillating motor during forward and reverse rotation of the gears and to control the load on the gears; the stops 141, 142, 143, and 144 have been adjusted to control the angle through which the control member 140, shaft 81, and cam 85 are oscillated during forward and reverse rotation of the gears; and the blocks 101 (Fig. 3), 123 and 124 (Fig. 4) have been adjusted to determine the amounts of axial and oscillatory movements of carrier 50 and spindle 57 for the up and down movement of head 32; the operator starts the machine by pressing in start button 256. Then the gears are driven in mesh by motor 65 and the head 32 is moved up and down, and the carrier 50 is moved back and forth and swung from side to side through operation of the motor 70. The cam shaft 81 is rotated by motor 70 in one direction until one of the buttons 147 or 148 strikes the lever 156 to close the limit-switch 161. Then the motor 70 is reversed, and head 32 and carrier 50 are moved in the opposite direction. Two complete forward and reverse swings of the cam shaft 81, that is, two complete up and down movements of the head 32, oscillations of carrier 50, and reciprocations of carrier 50 are effected. Then, when the switch-arm 265 of relay 254 reaches station No. 5 of that relay, the limit-switch 161 is rendered ineffective and the limit-switch 171 is made effective. Then the motor 65 is reversed, reversing the direction of rotation of the gears being lapped. Then the shaft 81 is swung back and forth through the distance determined by stops 149 and 150. Two full up-and-down movements of the head 32, two full oscillations and two full reciprocations of the carrier 57 are made. Then the switch-arm 265 reaches station No. 9 of the ratchet relay 254, and the lapping is completed.

Figs. 12 to 17 inclusive illustrate diagrammatically the motions of the machine in the lapping of a pair of spiral bevel or hypoid gears P and G. The gears shown are of left-hand spiral curvature, and they are constructed to have the usual amount of tooth surface mismatch or localization of tooth bearing, the side surfaces 417 and 418 of a tooth space of the gear contacting at a central area along the sides with the mating side surfaces 419 and 420, respectively, of a tooth of the pinion.

Figs. 12 and 13 show the gear G and pinion P in mesh in correct running position with their apices 415 and 416 coinciding. As the carrier 50

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moves rectilinearly in one direction, moving the pinion toward the large end or heel of the gear teeth, the head 32 is simultaneously moved down, and the carrier 50 is swung outwardly. Thus, as shown in Figs. 14 and 15, the apex 416 of the pinion is displaced downwardly and outwardly from the apex 415 of the gear, and simultaneously the pinion is withdrawn axially to prevent interference between the gear and pinion teeth and to maintain the backlash constant. When the carrier 50 moves rectilinearly in the opposite direction, the head 32 is simultaneously moved up, and the carrier 50 swung first inwardly and then outwardly again. Thus, the pinion moves through the position shown in Figs. 12 and 13 to the position shown in Figs. 16 and 17. In this last position, the apex 416 of the pinion is displaced upwardly and inwardly with reference to the apex 415 of the gear. Thus, the tooth surfaces of gear and pinion slide over one another and effect the lapping operation.

While the invention has been described particularly with reference to a machine for lapping gears, it will be understood that essentially the same structure may be used in a machine for burnishing gears, as will be obvious from the art. It will further be understood that, while the invention has been described in connection with a machine for finishing gears, certain features are capable of general application. This application is intended to cover any variations, uses, or adaptations of the invention following, in general, the principles of the invention and including such departures from the present disclosure as come within known or customary practice in the art to which the invention pertains and as may be applied to the essential features hereinbefore set forth and as fall within the scope of the invention or the limits of the appended claims.

Having thus described our invention, what we claim is:

1. In a machine for finishing tapered gears, a pair of rotatable spindles whose axes are angularly disposed to one another, means for detachably securing a gear to each of said spindles, means for adjusting the gears into mesh, means for driving one of the spindles to drive the other spindle by the meshing engagement of the gears, means for reciprocating the drive spindle axially to move the gear carried thereby lengthwise of the teeth of the other gear, and means for reciprocating one of said spindles in time with the first named reciprocating movement in a direction at right angles to the axis of the drive spindle to effect relative movement between the gears in a direction transverse of their teeth.

2. In a machine for finishing tapered gears, a pair of rotatable spindles whose axes are angularly disposed to one another, means for detachably securing a gear to each of said spindles, means for adjusting the gears into mesh, means for driving one of the spindles to drive the other spindle by the meshing engagement of the gears, means for reciprocating the drive spindle axially to effect relative lengthwise motion between the teeth of said gears, means for reciprocating one of said spindles in a direction at right angles to the axis of the drive spindle to effect relative movement between the gears in a direction transverse of their teeth, and means for moving one of said spindles in a direction transverse to the axis of the drive spindle and at right angles to the direction of the last named movement and in time with the last named movement to effect relative depthwise movement between the teeth of

said gears as their teeth move longitudinally and transversely of one another.

3. In a machine for finishing tapered gears, means for supporting a pair of gears to run together in mesh with angularly disposed axes, means for rotating one of the gears to effect rotation of the pair through their intermeshing engagement, means for effecting relative movement between the gears in a direction lengthwise of their teeth during their rotation, means for simultaneously effecting relative movement between the gears transversely of their teeth, and means for adjusting one of said two last named means to adjust the amount of one of said movements independently of the other.

4. In a machine for finishing tapered gears, means for supporting a pair of gears to run together in mesh with angularly disposed axes, means for rotating the gears together, means for effecting relative movement between the gears lengthwise of their teeth during their rotation, means for simultaneously effecting relative movement between the gears transversely of their teeth, means for simultaneously effecting relative movement between the gears in the direction of tooth depth, and means for adjusting at least two of the last three named means to adjust the amounts of said relative movements with respect to one another.

5. In a machine for finishing tapered gears, means for supporting a pair of gears to run together in mesh with angularly disposed axes, means for rotating one of the gears to effect rotation of the pair through their intermeshing engagement, said gears being mounted for relative movements lengthwise, transversely, and depthwise of their teeth, means for effecting one of said movements, and means operable on said movement to effect simultaneously and in time therewith the other two movements, said last named means being adjustable to vary the ratio of the three movements relative to one another.

6. In a machine for finishing tapered gears, means for supporting a pair of gears to run together in mesh, means for rotating the gears first in one direction and then in the other, means for effecting a plurality of reciprocatory movements between the gears lengthwise of their teeth and a plurality of reciprocatory movements transversely of their teeth during rotation of the gears in each direction, and means for adjusting the amount and speed of the reciprocatory movements during rotation of the gears in one direction independently of the amount and speed of the reciprocatory movement during rotation of the gears in the opposite direction.

7. In a machine for finishing gears, a pair of spindles for supporting a pair of gears to run together in mesh, means for rotating the spindles first in one direction and then in the other, a support in which one of the spindles is journaled, a cam, a follower engaging said cam and secured to said support, means for oscillating the cam to effect reciprocation of the support during rotation of the spindles, adjustable means for limiting the amount of oscillation of the cam during rotation of the spindles in the forward direction, and separately adjustable means for limiting the angle of oscillation of the cam during rotation of the spindles in the reverse direction.

8. In a machine for finishing gears, a pair of spindles for supporting a pair of gears to run together in mesh, means for rotating the spindles first in one direction and then in the other, a support in which one of the spindles is journaled,

an oscillatory cam for reciprocating said support, means for oscillating said cam, means for reversing the direction of rotation of the spindles after a predetermined number of oscillations of the cam, and separate means for determining the rates of oscillation and angles through which the cam is oscillated during rotation of the spindles in both the forward and reverse directions.

9. In a machine for finishing gears, a support, a head reciprocally mounted on the support, a carrier movably mounted in the head, a spindle journaled in the carrier, a second spindle journaled in the support, said spindles being adapted to carry a pair of gears, an oscillatory cam for reciprocating the head, means for oscillating the cam, and a block and follower, one of which is secured to the carrier and the other to the support, said block having a guide surface on which the follower rides during movement of the head to impart movement to the carrier on movement of the head, said block being adjustable angularly to incline its guide surface to the direction of reciprocation of the head.

10. In a machine for finishing gears, a pair of spindles, means for securing a gear to each of the spindles, a support, a head reciprocally mounted on the support, a carrier in which one of the spindles is journaled, said carrier being mounted on the head for oscillation about an axis parallel to the axis of said spindle and for reciprocation in the direction of said axis, means for reciprocating the head, two control devices each of which comprises a block and follower, one of which is secured to the carrier and the other of which is secured to the support, each of the blocks having a straight guide surface on which the follower rides during reciprocation of the head, one of the blocks being adjustable about an axis extending in the direction of the axis of oscillation of the carrier and the other of the blocks being adjustable about an axis extending at right angles to the axis of oscillation of the carrier, and means for rotating the spindles first in one direction and then in the other.

11. In a machine for finishing tapered gears, a pair of spindles that are angularly disposed to one another, means for detachably securing a gear to each of said spindles, means for adjusting the spindles relative to one another to bring the gears into mesh, means for rotating the spindles first in one direction and then in the other to rotate the gears in mesh, an oscillatory cam for effecting relative reciprocatory movements between the gears while they are rotating, separately adjustable means for controlling the angle through which the cam is oscillated and the speed at which it is oscillated during rotation of the spindles in the opposite directions, and means actuated by said reciprocatory movements for effecting further relative reciprocatory movements between the gears in a direction inclined to the first named reciprocatory movements.

12. In a machine tool, a rotary spindle, an electric motor for driving said spindle in both directions, separately adjustable means for controlling the speed of rotation of the motor during forward and reverse rotations of the spindle, respectively, an oscillatory control member, and means adapted to be advanced step-by-step by oscillation of said control member for automatically reversing the motor after a predetermined number of oscillations of the control member.

13. In a machine tool, a rotary spindle, an electric motor for driving said spindle in both directions, separately adjustable means for controlling

the speed of rotation of the motor during forward and reverse rotations of the spindle, respectively, an oscillatory control member, a second motor for driving the control member, adjustable stops carried by the control member for reversing the second motor after swing of the control member through a predetermined distance first in one direction and then in the other, and means adapted to be advanced step-by-step with each swing of the control member for automatically reversing the first motor after a predetermined number of oscillations of the control member.

14. In a machine tool, a rotary spindle, an electric motor for driving said spindle in both directions, an oscillatory control member, a second motor for driving the control member, a part operatively connected to the control member to be reciprocated on oscillation of the control member, adjustable stops operatively connected to the control member for reversing the second motor after swing of the control member through a predetermined distance first in one direction and then in the other, means adapted to be advanced step-by-step with each swing of the control member for automatically reversing the first motor after a predetermined number of oscillations of the control member and for automatically stopping both motors after a predetermined number of oscillations of the control member during the reverse operation of the first motor, said adjustable stops being arranged in two pairs, one pair of which controls the amount of swing of the control member during forward drive of the first motor and the other pair of which controls the amount of swing of the control member during reverse operation of the first motor.

15. In a machine tool, a rotary spindle, an electric motor for driving said spindle in both directions, separately adjustable means for controlling the speed of rotation of the motor during forward and reverse rotations of the spindle, an oscillatory control member, a second motor for driving the control member, a part operatively connected to the control member to be reciprocated on oscillation of the control member, a pair of limit switches, which are so connected in the electrical circuit of the machine that only one is operative at a time and each of which is arranged, when tripped while operative, to reverse the second motor, two sets of adjustable stops operatively connected to the control member for tripping the limit switches, each set comprising two stops adjustable relative to one another, one set of stops being adapted to cooperate with one of said limit switches and the other set of stops being adapted to cooperate with the other of said limit switches, a third limit switch, means adapted to be advanced step-by-step with each swing of the control member to trip the third limit switch after a predetermined number of oscillations of the control member, said third limit switch being so connected in the electrical circuit of the machine that when it is tripped it renders one of the first two limit switches inoperative and the other operative and so that it simultaneously reverses the first motor, and means operative after a predetermined further number of oscillations of the control member to stop both motors.

16. In a machine for finishing gears, a pair of spindles for supporting a pair of gears to run together in mesh, means for rotating the spindles first in one direction and then in the other, a support in which one of the spindles is journaled, a cam, a follower engaging said cam and secured to said support, means for oscillating the

cam to effect reciprocation of the support during rotation of the spindles, adjustable means for limiting the amount of oscillation of the cam during rotation of the spindles in one direction, and separately adjustable means for limiting the angle of oscillation of the cam during rotation of the spindles in the opposite direction, said cam having an operative surface conforming to a spiral of continuously increasing radius.

17. In a machine for finishing gears, a pair of spindles for supporting a pair of gears to run together in mesh, means for rotating the spindles first in one direction and then in the other, means for imparting reciprocating movement to one spindle in a direction at right angles to its axis, adjustable means for limiting the amount of said reciprocating movement during rotation of the spindles in one direction, separately adjustable means for limiting the amount of said reciprocating movement during rotation of the spindles in the opposite direction, and means operable on operation of said reciprocating means for imparting a reciprocating movement to one of the spindles in a direction at right angles to the first reciprocating movement, said last named means being adjustable to vary the ratio of the two reciprocating movements.

18. In a machine for finishing gears, a pair of spindles for supporting a pair of gears to run together in mesh, means for rotating the spindles first in one direction and then in the other, means for imparting a reciprocating movement to one spindle in a direction at right angles to its axis, adjustable means for limiting the amount of said reciprocating movement during rotation of the spindles in one direction, separately adjustable means for limiting the amount of said reciprocating movement during rotation of the spindles in the opposite direction, and means operable on operation of said reciprocating means for imparting a reciprocating movement to one of the spindles in the direction of its axis, said last named means being adjustable to vary the ratio of the two reciprocating movements.

19. In a machine for finishing gears, a support, a head reciprocally mounted on the support, a carrier oscillatably mounted in the head, a spindle journaled in the carrier, a second spindle journaled in the support, means for securing a pair of gears to said spindles, an oscillatory cam for reciprocating the head, means for oscillating the cam, means operatively connecting the carrier with the support to effect oscillation of the carrier about an axis parallel to the axis of the spindle, which is mounted in the carrier, on reciprocation of the head, separate means operatively connecting the carrier with the support to effect reciprocation of the carrier in the direction of the axis of the spindle, which is mounted therein, on reciprocation of the head, each of the two last named means being adjustable to vary, respectively, the angle of oscillation of the carrier and the amount of reciprocation of the spindle on reciprocation of the head, means for rotating the spindles first in one direction and then in the other, adjustable means for controlling the amount of oscillation of the cam during rotation of the spindles in one direction, and separately adjustable means for controlling the amount of oscillation of the cam during rotation of the spindles in the opposite direction.

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