Sept. 25, 1945. A. RICKENMANN 2,385,650

PROCESS AND MACHINE FOR GRINDING TOOTHED GEARS

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Fig. 1

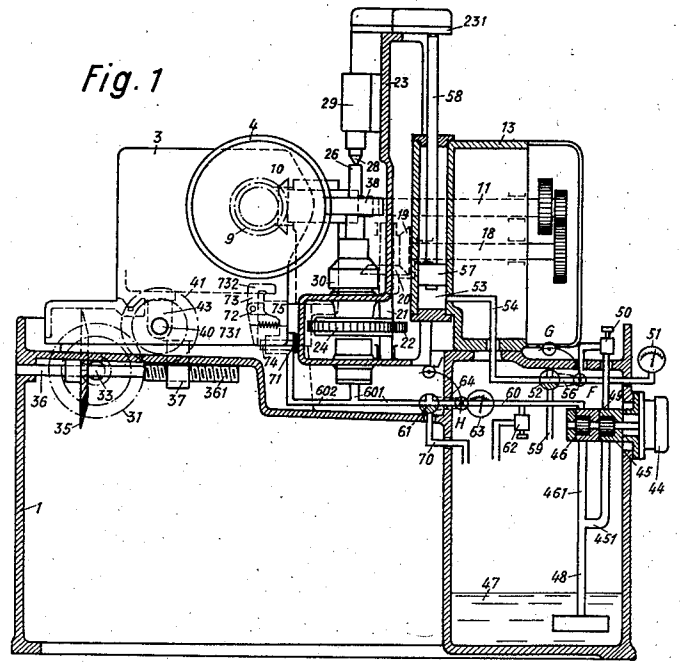


Fig. 6

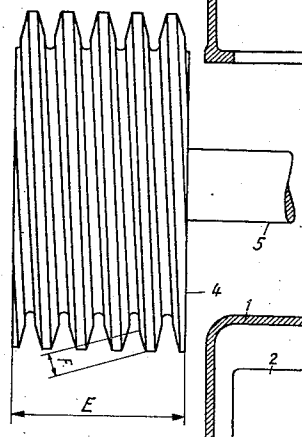
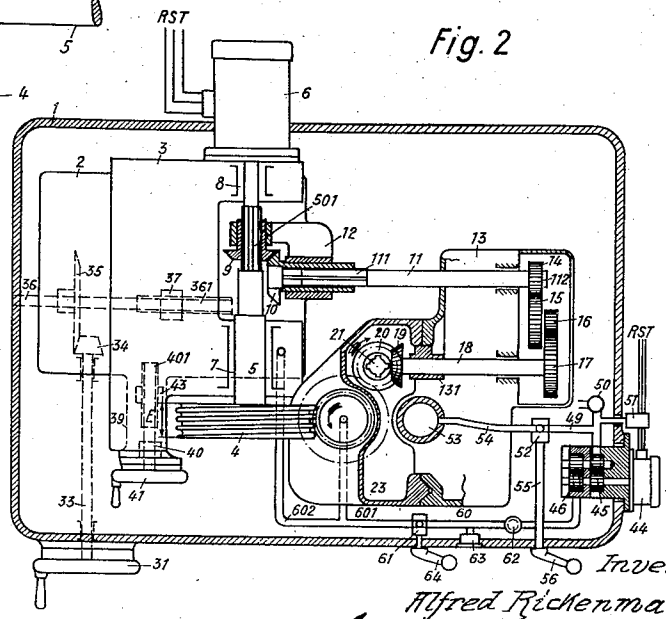


Fig. 2



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PROCESS AND MACHINE FOR GRINDING TOOTHED GEARS

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Fig. 3

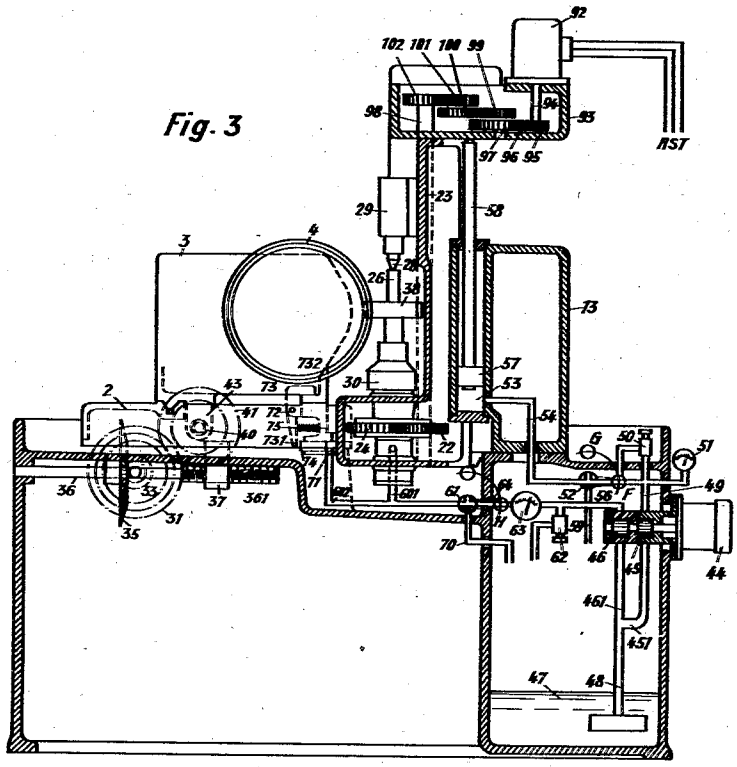


Fig. 7

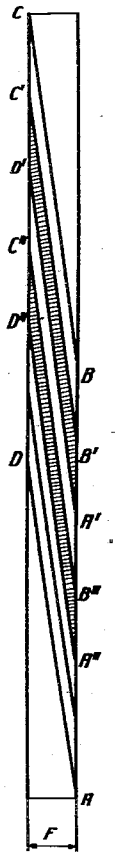
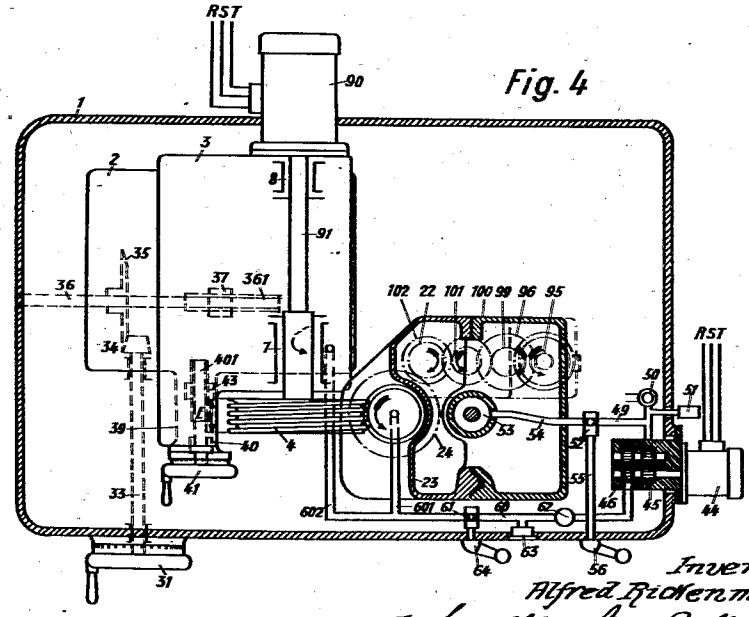


Fig. 4



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Fig. 5

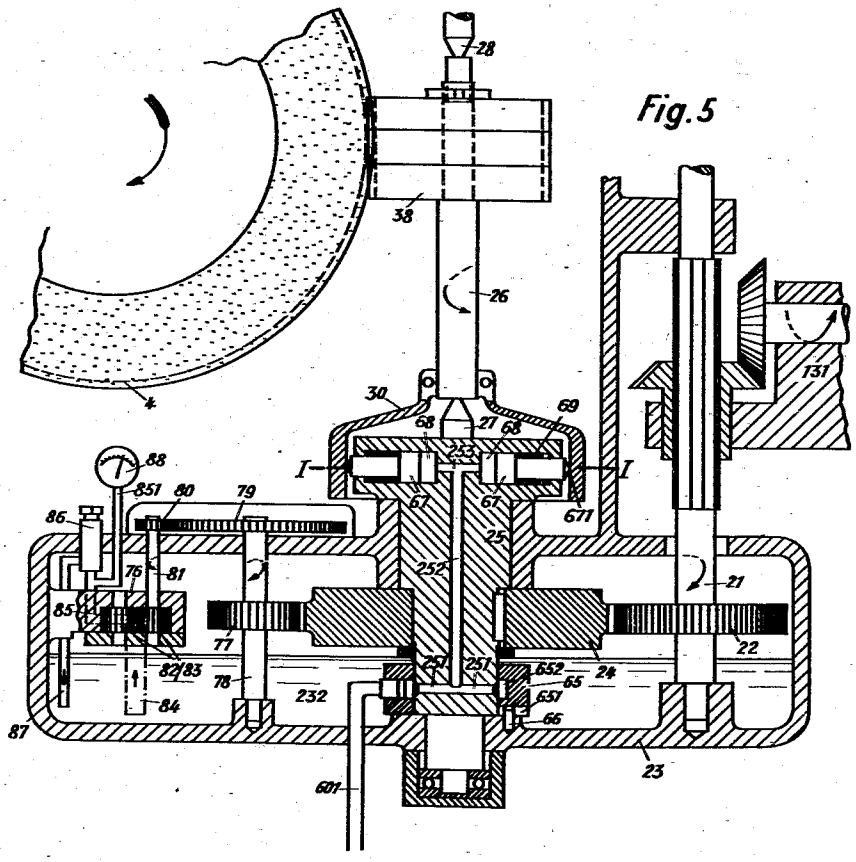


Fig. 10

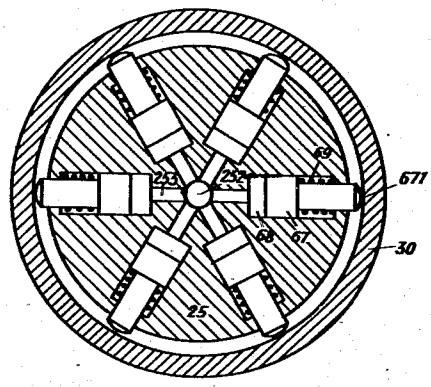


Fig. 8

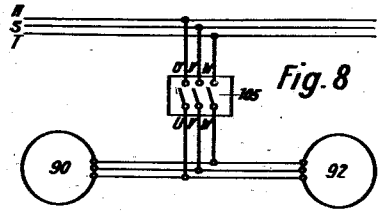
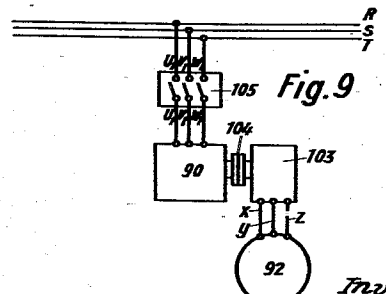


Fig. 9



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Patented Sept. 25, 1945

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UNITED STATES PATENT OFFICE

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PROCESS AND MACHINE FOR GRINDING TOOTHED GEARS

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Application May 22, 1944, Serial No. 536,700
In Switzerland January 28, 1944

8 Claims. (Cl. 51—71)

The present invention relates to a new and improved process for grinding toothed gears.

The main object of the invention resides in the provision of a process to attain perfect accuracy by very simple means.

It has been proposed to grind the teeth of a gear by means of a helical-profile rotary grinding tool of the hob type. By grinding toothed gears by the said worm-like grinders it has been further proposed not to drive the blank positively but to advance the workpiece i. e. the toothed gear blank by the helical grinding faces of the hob, the latter acting in the manner of a positively driving worm. When hobbing the preshaped teeth of gear wheels the blank is driven at irregular speed even if the speed of the grinding hob is maintained with extreme accuracy as the irregularities of the pitch of the gear and of the shape of its teeth produce retardations and accelerations in the rotary motion of the blank. No inaccuracy of the toothed blank is mitigated by driving same with a positively driving grinding hob.

It has been further proposed to drive the toothed blank positively during the whole of the grinding operation while the toothed blank is in intermeshing engagement with the grinding hob. The accuracy of the finished ground teeth and of the toothed gear generally depends on the accurate maintenance of a predetermined ratio of the rotary movement of the blank and of the grinding hob. The rotational speeds of the toothed blank and of the hob are dependent on the number of teeth of the blank and of the number of threads of the hob.

If n_1=number of revolutions of the hob,
n_2=number of revolutions of the blank,
f=number of threads of the hob,
z=number of teeth of the blank,

$$\frac{n_1}{n_2}=\frac{z}{f}$$

Machine tools adapted to perform the grinding of toothed gears by means of a grinding hob have to include the following auxiliary means:

(a) means for radial adjustment of the hob to and from the blank,

(b) means for tangential adjustment of the hob with reference to the blank,

(c) means for axial feed of the blank if spiral teeth have to be ground,

(d) means for the oblique positioning of a blank having spiral teeth to be ground,

(f) means to produce a varying number of teeth.

It has already been proposed to drive the blank spindle positively from the grinding tool spindle. It is apparent, that such machine tools need a complicated driving train of gears and numerous transmission members to perform all the named functions. Any member of the driving train is apt to have inaccuracies, the inaccuracies of all the members are additive. The inaccuracies have a very unfavorable influence on the accuracy of the ground toothed gear.

To minimize the inaccuracies in the pitch and in the shape of the finished teeth it has been proposed to make use of two electric synchronous motors, one to drive the blank spindle and one to drive the hob spindle. A train of change speed gears is interposed between the blank spindle and the shaft of the electric motor driving same to produce gears of different number of teeth. Moreover to produce gears with spiral teeth a special differential gear arranged in said train of gears had to be resorted to.

All the processes of the type named and proposed up to now have not been satisfactory, the accuracy desired having not been attained therewith.

The object of the present invention resides in the provision of improved means and processes to attain the theoretic accuracy in grinding toothed gears by the new hobbing process, an accuracy is to say + or —0.002 millimeter.

To attain this object the following facts have to be considered:

A positive drive of the blank spindle is only possible by making use of a plurality of mechanical devices being in engagement with each other, for instance of a train of toothed gears, shafts, etc. By making use of electric synchronous motors the train of gears is shorter than with the exclusive use of mechanical transmission members.

It is well known that no driving train of toothed gears and shafts is a perfect inflexible and rigid motion transmission device. Each transmission by toothed gears is affected by elastic deformation of the teeth, of torsional deformation of spindles and so on. In starting the working process a certain play or backlash of the gears has to be taken up and the train of all the gears and the whole set of the driving members have first to be brought under a certain directed strain precluding any further faults while the process is proceeding.

By making use of electric synchronous motors for driving the blank and the hub, it is of first importance that perfect synchronization is at-

tained from the very beginning of the hobbing process. Shocks are produced thereby having a bad effect on the drive of the blank.

To obviate these and other drawbacks of the known hobbing processes the present invention contemplates a process to grind toothed gear blanks by means of a grinding hob in which at the start of the processing and at least during the time to get the blank and the hob into full driving engagement, the blank and the hob are not in a positive driving connection. During this interval of time the hob drives the blank the latter running freely. After the play, backlash or distortions of any and all the members of the train of driving elements have been taken up and when the rotational movements of the blank and of the hob have attained the correct predetermined magnitude the drive of the blank and of the hob is made to be strictly positive to attain all the advantages of the positive driving connection. To change over from the free drive to the positive drive suitable means are arranged between the spindle of the blank and the spindle of the hob for reasons set out hereinafter.

The new manner for hobbing the blank does away with all the inaccuracies due to play in the train of gears.

The principles and particulars in which the invention consists may best be stated in connection with concrete machines embodying such particulars by having reference to the drawings.

In the accompanying drawings, machines for grinding straight spur gears are shown in a diagrammatical manner.

Fig. 1 shows in a diagrammatical manner a part of a straight spur gear grinding machine in sectional elevation in which the grinding worm and the work piece are driven by the same motor.

Fig. 2 shows the plan view of the machine shown in Fig. 1.

Fig. 3 shows in an elevation a grinding machine similar to that shown in Fig. 1 in which however the grinding worm and the work piece are driven by two separate synchronous motors.

Fig. 4 shows the plan view of the machine shown in Fig. 3.

Fig. 5 shows details of the work drive—the drive of the work piece spindle, of a clutch between carrier and work piece spindle and the pump acting as brake—all in section.

Fig. 6 shows the grinding hob.

Fig. 7 shows the development of one working flank of the grinding hob.

Figs. 8 and 9 show two different circuits for the driving motors of the machine shown in Figs. 3 and 4.

Fig. 10 shows the clutch in a cross section on line I—I of Fig. 5.

On the frame 1 a carriage 2 is slidably mounted and adapted to be displaced radially with reference to the work piece. On the carriage 2 a slide 3 is mounted carrying the grinding hob 4 and adapted to move the same tangentially with reference to the work piece.

The hob 4 is driven by an electric motor 6 by means of a spindle 5. Journalled in bearings 7 and 8 the spindle 5 is direct coupled to the shaft of the driving motor 6 which is flanged to the slide 3. An arrangement may be made by which the spindle 5 may be driven by a separately installed motor with the help of a belt drive or by similar means. A bevel wheel 9 carried on a horizontal splined shaft 501 meshing with a bevel wheel 10 drives a horizontal shaft 11. The two bevel wheels 9 and 10 are rotatably mounted in a bearing 12 which is mounted on the carriage 2. The splined end 111 of shaft 11 is guided in the long boss of the bevel wheel 10 while the other end 112 supported in the bracket 13 carries a spur wheel 14. The spur wheel 14 drives by a train of change speed gears 15, 16, 17 and of a shaft 18 which is journalled in a bearing 13, a bevel gear 19 meshing with a bevel wheel 20 on a vertical shaft 21 and so to the keyed-on spur wheel 22. The two bevel wheels 19, 20 are rotatably mounted in an arm 131 of the bracket 13. The vertical shaft 21 is carried in a slide 23 sliding vertically on the bracket 13, it passes loosely through the bore of the bevel wheel 20. The spur wheel 22 drives a gear wheel 24 and therewith the work piece spindle 25 to which it is firmly fixed.

Between the centres 27, 28 (Fig. 5) of the work piece spindle 25 and the tailstock 29 fixed on slide 23 an arbor 26 is arranged on which the work piece 38 is fastened. A hydraulically operated clutch 30 carried on the work piece spindle 25 serves to interconnect the same with the arbor 26. It is a special feature of the invention to have the clutch 30 arranged at the end of the train of driving gears and in close proximity to the blank 38.

The displacement of the hob 4 for the radial feed towards the work piece 38 is effected by handwheel 31 and the carriage 2. The handwheel 31 (Fig. 2) drives by a shaft 33 and bevel wheels 34, 35 the feed spindle 36 journalled in the bed 1. The feed nut 37, which is fixed to the carriage 2 runs on the threaded portion 361 of the feed spindle 36.

The flanks of the grinding hob 4 are shown in the development Fig. 7 as two bands of a breadth=F. During the grinding the line of contact is marked on the hob 4 as a narrow strip wandering over the flank F. This is shown in the development as the narrow strip A'B'C'D'. So that not only the single small strip, but the whole of the available flank surface ABCD can be brought to work, a device is provided which enables the grinding worm 4 to be moved tangential with reference to the work piece 38.

The carriage 2 (Figs. 2, 3, 4) is provided with an extension 39 in which a screwthreaded spindle 40 is journalled. By means of handwheel 41 and of a nut 43 on the screw threaded part 401 of the spindle 40 the grinding hob slide 3 can be moved tangentially with reference to the work piece 38.

By a motor 44 (Fig. 1) two gear pumps 45, 46 are driven feeding liquid under pressure from a reservoir 47 into pipes. Pump 45 (Figs. 1, 2) is connected to the suction branch 48 by a pipe 451 and provides the pressure liquid for operating the work piece slide 23. A pressure regulating valve 50 (Figs. 3, 4) is placed in the pressure pipe 49 as well as a pressure gauge 51 (Fig. 3). By means of a pressure regulating valve 52 the flow of the pressure liquid to the cylinder 53 is controlled, the valve may be a throttling valve operated by a hand lever 56 (Figs. 2, 4) through a shaft 55. In the position F (Fig. 1) of the valve 52 the pressure liquid passes by pipe 54 below the piston 57 and lifts thus the work piece slide 23. When the slide 23 has reached its uppermost position the valve 52 is turned by hand lever 56 into the vertical position G (Fig. 1). Cylinder 53 is now emptied through the pipes 54, 59. The work piece slide 23 consequently moves downwardly by its own weight and with it the piston 57.

In this hydraulically operated device pressure variations occur due to the control operations.

All hydraulically controlled elements e. g. holding or clamping fixtures for which a constant pressure is necessary have to be connected to a separate pressure system which insure a constant and non-variable pressure. To attain this object a second pump 46 is provided. The pump 46 is connected to the suction branch 48 of a pipe 461 (Fig. 1). The pressure liquid delivered by the pump 46 passes through a pipe 60 to a control valve 61. A pressure regulating valve 62 and a pressure gauge 63 are provided to facilitate the maintenance of the correct pressure. The valve 61 may be set into the positions H and J (Fig. 1) by a handlever 64 (Fig. 2). By placing the lever 64 in the position H, horizontally to the right (Fig. 1), the pressure liquid flows through the valve 61 via pipe 601 to a channel 652 in a distributor ring 65 (Fig. 5) in the work piece spindle 25. A pin 66 fixed to the slide 23 engages a groove 651 of the distributor ring 65 and prevents the latter from rotating. The pressure liquid enters the channel 652 of the ring 65 and passes by radial bores 251 to the central bore 252 and by a plurality of radial bores 253 into cylinders 68 with pistons 67 arranged therein.

The cylinders 68 are radially disposed round the axis of the work piece spindle 25 at regular distances apart. When the pressure liquid enters the cylinders 68 the pistons 67 move outwardly against the action of springs 69 until the ends of the piston rods 671 come to bear on the inner wall of a cup shaped member of clutch 30, the member being fast on the spindle 25.

When placing the lever 64 into the position J (Fig. 1) vertically upwards, the valve 61 cuts-off the flow of pressure liquid to the distributor 65. The pressure liquid passes through pipe 601 and the passages 251, 252, 263, the cylinders 68, valve 61 and the discharge branch 70 into the reservoir 47.

By changing over the valve 61 to the discharge position J the pressure in all the cylinders 68 falls immediately. The springs 69 press the pistons 67 inwardly and open the clutch 30 instantaneously.

To the carriage 2 a cylinder 71 (Fig. 1) is attached which is connected by pipes 601, 602 to the pipe 60. Above the cylinder 71 there is a double armed lever 73 pivoted in a bracket 72 of the carriage 2. When there is pressure in the pipes 601, 602 and with the clutch 30 closed and the arbor 26 thereby coupled with the work piece spindle 25 then the piston 74 in cylinder 71 presses on the arm 731 of lever 73. The nose 732 of the lever 73 interconnects positively the slide 3 with the carriage 2.

In the discharge position of valve 61 with the lever 64 in the position J the spring 75 presses the piston 74 back and releases the slide 3. The pressure liquid passes the pipes 602, 601, the openings in valve 61 and the discharge pipe 70 into the reservoir 47.

In the base of the work piece slide 23 a pump 76 (Fig. 5) is arranged, this pump serving as a brake. The pump is driven by the spur wheel 24 keyed to the work piece spindle 25, through the spur wheel 77 on a shaft 78, the change speed gears 79, 80, shaft 81 and the two pump pinions 82, 83 which latter are in mesh with each other.

The speed of the work piece spindle 25 is made dependent on the number of teeth of the blank 38 to be ground. The change speed gears 79, 80 are used to bring the number of rotations of the work piece spindle 25 in such a relation to the speed of pump 76 so that the latter can be run continuously under the most favourable working conditions.

The liquid to be pumped is taken from the base of the work piece slide 23 which serves as reservoir 232 and passes through the suction pipe 84 to the pump 76. The liquid under pressure flows through pipe 85 to the valve 86 and from there through the return pipe 87 back to the reservoir 232. The pressure gauge 88 connected to pipe 85 by the pipe 851 facilitates the maintenance of the correct pressure.

Before and during the grinding process the following measures are taken:

On the arbor 26, carried between the centres 27, 28 of the work piece spindle 25 and tailstock 29 a number of blanks are fastened. The lever 64 is placed into the position J. The clutch 30 is not fully closed. Between the piston rods 671 and the inner wall of the cup there remains a gap. The motor 44 is now started and both pumps 45, 46 start in delivering liquid under pressure. By turning the handwheel 31 the carriage 2 and the slide 3 are simultaneously brought up so that the pre-machined teeth of the blank 38 and the grinding hob 44 are brought into intermeshing engagement while the hob 44 is still at rest.

After these preliminary operations the grinding wheel motor 6 is switched in.

The blank 38, the arbor 26 and the clutch 30 are now solely driven by the grinding hob 4.

Positively and instantaneously the work piece spindle 25 and the braking pump 76 are rotated via the described gear train 9, 10, 11, 14 to 22, 24. The machine is kept running a certain time in this manner until in the driving train the existing tooth play and "backlash" of the gears have been taken up. During this phase of operation the blank 38 is not to be driven positively or even influenced in its rotation except by the hob as the ratio of the speeds

$$\frac{n_1}{n_2}$$

is not the same as that pre-determined by the various gear ratios.

As soon as the driving train has taken up the play and as soon as the drive of the work spindle 25 rotates with the speed n_2 so that there is practically no difference between the angular velocities of the clutch 30 and of work piece spindle 25, then the lever 64 may be placed into the position H.

By setting the valve 61 by said lever 64 the pistons 67 have moved against the action of springs 69, the clutch 30 is closed and the work piece spindle 25 and the arbor 26 with the blank 38, are instantaneously coupled. By this coupling the speed of the blank 38 will not be changed in any way.

During the "free drive" starting phase of the process that is during the "free drive grinding" the blank 38 follows the grinding hob 4 the latter acting as a helical screw. The inaccuracies of the blank 38 are neither corrected nor increased. After closing the clutch 30 the blank 38 is no longer "freely driven" by the grinding hob 4 but positively rotated by the spindle 25. The blank 38 rotates now unaffected by the inaccuracies of the teeth of the blank 38, exactly at the predetermined speed n_2.

By arranging the clutch 30 at the work piece spindle 25 i. e. between the blank 38 and the last member of the driving train for the blank 38

the latter can be rotated "freely" by the hob 4 offering practically no resistance.

If the clutch 30 were placed in any other position in the driving train, the hob 4 would have to drive, beside the blank 38 a number of driving elements including the braking pump 76. The work to be done by the hob 4 would be considerable and would influence unfavorably the quality and the life of the grinding hob 4. Simultaneously with the closing of the clutch 30, the lever 73 presses the slide 3 on to the carriage 2 and any accidental displacement of the slide handwheel 41 is now impossible.

If it is desired to finish the grinding of the blank 38 by making use of an unworn strip A''B''C''D'' (Fig. 7) of the hob 4 the lever 64 is to be brought into the position J before the grinding process is started. With the lever 64 in said position the clutch 30 is open and the work piece spindle 25 is running idle. The slide 3 is freed by the lever 73. The slide 3 may now be moved by turning the handwheel 41. After the hob 4 has been moved axially the lever 64 is returned to the position H. The blank 38 will now be positively driven until the blank 38 is finally ground.

In the Figs. 3 and 4 the arrangement of two synchronous motors for driving hob and work piece is illustrated. The said motors are made with a damped starting torque and an asynchronous driving characteristic.

The synchronous motor 90 is flanged to the slide 3, it drives the hob 4 by means of a shaft 91 journalled in bearings 7, 8 (Fig. 4).

A gear box 93 (Fig. 3) is fixed to the work piece slide 23. To this gear box the second synchronous motor 92 for driving the work piece 38 is attached. This motor 92 drives via a shaft 94, two gear wheels 95 and 96, a shaft 97 and the change speed gears 99, 100, 101, 102 and shaft 98. The latter is carried in bearings in the gear box 93 and in the work piece slide 23 and transmits the revolutions via the gear wheel 22, to the gear wheel 24 and the spindle 25 to which it is fastened. The arrangement of the feed and control devices is otherwise exactly the same as described above with reference to Figs. 1 and 2.

During the starting period the work piece 38 and the clutch 30 and therewith hob 4 are in the "free drive" meshing engagement. The lever 64 is left in the position J long enough to have the tooth space play and backlash in the gears of the driving train taken up and to get the two motors to run synchronously.

The movement of the hob 4 tangentially to the blank 38 while the grinding is going on is carried out by the same method as described when describing the device shown in Figs. 1 and 2.

Great advantages are obtained by utilising toothed transmission elements of which the number of teeth were prime numbers.

In the description of the device shown in Figs. 1 and 2 showing a drive with but one motor, the bevel wheels 9 and 10 and a spur wheel 22 or 24 are provided with a nondivisible number of teeth.

In the drive with two motors shown in Figs. 3 and 4 one gear of each of the spur wheel pairs 95, 96 and 22, 24 must have a number of teeth which is a prime number.

In the example shown in Fig. 9 only one motor is connected to the mains R, S, T via the main switch 105 and the leads U, V, W. The motor 90 in this case does not only drive the hob 4 but also the generator 103 coupled through the clutch 104. This generator feeds the work drive motor 92 via the leads x, y, z. This arrangement has the advantage that by choosing a much higher frequency than that of the mains a greater "inflexibility" in the drive is obtained.

To produce gears with spiral teeth by a process as described above a differential gearing device would have to be used as a part of the driving trains of blank and hob.

As stated above it has been proposed to make use of two synchronous motors to drive the blank and the worm. But by using synchronous motors both the said motors must from the very start run absolutely synchronously which means that extremely hard starting up is obtained which has a bad effect especially on the blank. This drawback is done away with.

A feature of my invention consists in that synchronous motors with damped starting torque are employed i. e. motors which have asynchronous characteristics at starting and only after attaining full speed do they run synchronously. It is clear that according to the loads, the one or the other of the two motors attains its full speed first. The use of synchronous motors is therefore not feasible at all unless the method of operation described above is employed.

It is a known fact that two synchronous motors with unequal and varying loads never run exactly in synchronism. The differences are dependent on the value of the starting torque and the maximum load variation. One feature of this invention consists in that comparatively greatly over dimensioned motors are employed which have a large starting torque and in which the load variation is only a small percentage of the normal torque.

Both of the synchronous motors may be connected direct to the mains. Then however there are large and specially rapid frequency variations in the mains, errors can become noticeable due to unequal reactions of the motor speeds caused through unequal centrifugal effects. These sources of error can be overcome by arranging auxiliary flywheels at suitable places in the train of gears. Moreover these sources of error can be overcome by other means. As is well known the grinding motor has to be considerably more powerful than the motor for driving the work piece. It is therefore quite feasible to connect only the grinding motor to the mains, to couple it direct to a generator and feed the second motor from this generator. With such an arrangement it is of advantage to have the generator and the second motor constructed for a much higher frequency to improve the evenness in running of the two driving motors still further.

The new grinding method starting the drive of the blank while the latter runs free and proceeding with the grinding while the blank is positively driven has a further advantage.

It is known that grinding wheels working on the hob grinding method theoretically machine each tooth flank along a line which corresponds to the line of contact. In practice these lines represent small strips which naturally are subjected to a certain amount of wear. It has proved necessary, especially on work pieces with long teeth not to finish the grinding with the same part of the working face of the grinding worm with which the rough grinding has been done. To obviate this the grinding worm must be moved tangentially relative to the work piece so that another axially displaced line of contact i. e. a new, not worn strip of the working face of the grinding worm, comes into action. To economize the grinding

worm and to improve the accuracy, it is very important that this displacement can take place without having to stop the gearing. With an absolutely positive drive this is only possible by making use of a differential gear and this is undesirable. With the process described it is possible to carry out this displacement of worm and blank without stopping the drive and without employing an extra differential gear. In the particular manner described above according to which the connection between the work piece and work spindle is freed during the time that the tangential displacement of the worm takes place.

Whether the work spindle drive is transmitted from the grinding spindle drive mechanically or whether a second motor is employed for the work spindle drive, in either case a bigger or smaller gear wheel train is necessary. These gear wheels and the bearings of the transmission shaft incorporate certain errors which can be made very small through careful workmanship. These errors, small as they may be singly, can however for certain gear ratios add up to such an extent that their influence on the accuracy of the work piece becomes unpermissible. Particularly unfavourable conditions occur when the last transmitting members of a train of toothed gears have ratios up or down of 1:2, 1:3 or thereabouts. Rhythmically recurring errors are then produced which exactly correspond to these ratios.

A further feature of the invention described above is found in the means by which these errors are overcome. Grinding machines of this type work with high grinding worm speeds. As a consequence of this the speed of the grinding spindle and the work spindle become comparatively high even when large diameter grinding wheels are employed. It is therefore possible to work with very small feeds, and in spite of this obtain a high production. These small feeds and the large grinding wheel diameter are the means by which the errors caused by the gear drives are overcome.

The contacting surface of the grinding wheel with the blank is, due the latter's diameter much larger than the normally employed infeed. The result of this is that the large surface of contact wanders relatively slowly so that, apart from the small difference caused by the feed, the worm always work with the same part of its surface. If the gears ratio of the last driving elements are chosen 1:2, 1:3 or thereabout, then the same errors always occur on the same teeth. If however the gear ratios are chosen such that the errors can never repeat on the same teeth then these errors are continuously and automatically equalized. The assumption is apparent that pitch errors that are balanced out by this method simply occur in another form i. e. as tooth shape errors. Due to the frequent successive overlapping of pitch errors a balance is nevertheless obtained which can no longer influence the accuracy of the shape of the tooth. The tooth-shape errors thus caused are so slight that they can be ignored. The most favorable results are attained when in the first and last transmission elements of a train of gears there is in each a wheel with the highest possible prime number.

During the actual grinding process rapidly fluctuating loads work in an axial direction on the grinding wheel or the grinding spindle. The fluctuating loads are caused by the errors in the work piece to be ground. They are of no influence on the grinding spindle as in grinding machines as the ones in question the spindle is in any case carried in bearings in such a manner that no axial displacement can take place. The faulty teeth of the work piece therefore influence the work side of the drive and primarily the last pair of meshing gear wheels.

Errors which tend to cause retardation i. e. a force opposite to the direction of the drive, simply cause a bigger load and elastic deformation of the meshing teeth of the driving system. The inaccuracies caused by this means on the work piece to be finish ground can be ignored. Should there however be an error working in the opposite direction to the one above, then there is a tendency for the grinding wheel to accelerate the movement of the work piece. This means that the tight coupling of the meshing teeth is interrupted.

The effect of the retardation and acceleration forces caused by the work piece errors is so great that without further auxiliary devices no accurate gear wheels can be ground.

A further feature of the invention consists that the work spindle drive is incorporated in a closed power circuit of which the torque is considerably greater than the torque needed for the grinding work. Thus the above mentioned load fluctuations in the work drive are made ineffective. This closed power circuit is suitably obtained by driving a brake off the work spindle which must absorb as constant a load as possible. In itself it is immaterial whether the brake load is brought about by mechanical, hydraulic or electric brakes, hydraulic or electric brakes ensure greater load stability than mechanical brakes.

I claim:

1. A method of grinding toothed gears by means of a helical-profile rotary grinding tool of the hob type comprising a first phase in which the work piece to be ground derives its rotational drive from the said grinding tool and a second phase in which the work piece is positively driven in a predetermined ratio to the rotations of said grinding tool.

2. In a method as claimed in claim 1 the changing over from the first phase to the second phase as soon as the work piece has attained its full speed and the backlash of the driving gear has been taken up.

3. In a grinding machine of the type described, the combination of, a helical-profile rotary worm-like grinding tool, means to positively drive said grinding tool while in intermeshing engagement with the teeth of a workpiece to be ground, an arbor on which said workpiece is adapted to be fixedly secured, means for supporting said arbor freely rotatably so that the workpiece is adapted to be rotated by the rotating grinding tool, a positively driven gearing adapted to drive said arbor and the workpiece thereon with the same speed the latter is driven by said grinding tool, and a selectively operable clutch for positively driving said arbor by said gearing, said clutch having a driven member which is attached to said arbor and a driving member connected to said gearing.

4. In a machine as defined in claim 3 the provision of means to axially displace said worm-like grinding tool while the same is in intermeshing engagement with said work piece.

5. In a grinding machine of the type described, the combination of, a helical-profile rotary worm-like grinding tool, means to positively drive said grinding tool while in intermeshing engagement with the teeth of a workpiece to be ground, an arbor on which said workpiece is adapted to be fixedly secured, means for supporting said arbor freely rotatably so that the workpiece is

adapted to be rotated by the rotating grinding tool, a positively driven gearing adapted to drive said arbor and the workpiece thereon with the same speed the latter is driven by said grinding tool, a selectively operable clutch for positively driving said arbor by said gearing, said clutch having a driven member which is attached to said arbor and a driving member connected to said gearing, and means for operating said clutch while said gearing and said arbor are in motion.

6. In a grinding machine of the type described, the combination of, a helical-profile rotary worm-like grinding tool, means to positively drive said grinding tool while in intermeshing engagement with the teeth of a workpiece to be ground, an arbor on which said workpiece is adapted to be fixedly secured, a dead center and a live center for supporting said arbor freely rotatable so that the workpiece is adapted to be rotated by the rotating grinding tool during the grinding operation, a positively driven gearing for driving said live center with the same speed the arbor and the workpiece thereon are driven by said grinding tool, a clutch having a driven member and a driving member for operatively connecting said live center with said arbor, said driven member being attached to said arbor and said driving member to said live center, and means for engaging and disengaging said clutch while said gearing and said arbor are in motion.

7. In a grinding machine of the type described, the combination of, a helical-profile rotary worm-like grinding tool, means to positively drive said grinding tool while in intermeshing engagement with the teeth of a workpiece to be ground, an arbor on which said workpiece is adapted to be fixedly secured, a dead center and a live center for supporting said arbor freely rotatable so that the workpiece is adapted to be rotated by the rotating grinding tool during the grinding operation, a positively driven gearing for driving said live center with the same speed the arbor and the workpiece thereon are driven by said grinding tool, a hydraulic clutch including a driven member and a driving member, said driven member being attached to said arbor and having a circumferential flange surrounding said driving member which is attached to said live center, said driving member being provided with hydraulically operable radially displaceable clutch elements adapted to engage frictionally the circumferential flange of said driven member, spring means to normally maintain said clutch elements in an inoperative position, and means to conduct pressure fluid into said driving member for displacing said clutch elements and causing engagement of said clutch while said gearing and said arbor are in motion.

8. In a grinding machine of the type described, the combination of, a helical-profile rotary worm-like grinding tool, means to positively drive said grinding tool while in intermeshing engagement with the teeth of a workpiece to be ground, said means including a motor, a shaft driven by said motor and on which said grinding tool is attached, an arbor on which said workpiece is adapted to be fixedly secured, means for supporting said arbor freely rotatably so that the workpiece is adapted to be rotated by the rotating grinding tool, a positively driven gearing adapted to drive said arbor and the workpiece thereon with the same speed the latter is driven by said grinding tool, a selectively operable clutch for positively driving said arbor by said gearing, said clutch having a driven member which is attached to said arbor and a driving member connected to said gearing, and a gear connection between said motor driven shaft and said gearing for driving the latter and the driving member of said clutch.

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