

[54] **APPARATUS FOR THE LAPPING OF TWO GEAR WHEELS**

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[58] Field of Search.....29/90.90

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[57] **ABSTRACT**

Apparatus for the lapping of two gear wheels which are given a lapping movement which comprises at least two oscillatory components. Apparatus comprises separate control units for the control of each component of movement. Each control unit has means for changing the velocity of the components of movement during a cycle so that the lapping movement is performed along a line of adjustable shape. The control units produce periodic voltages of the same frequency.

5 Claims, 12 Drawing Figures

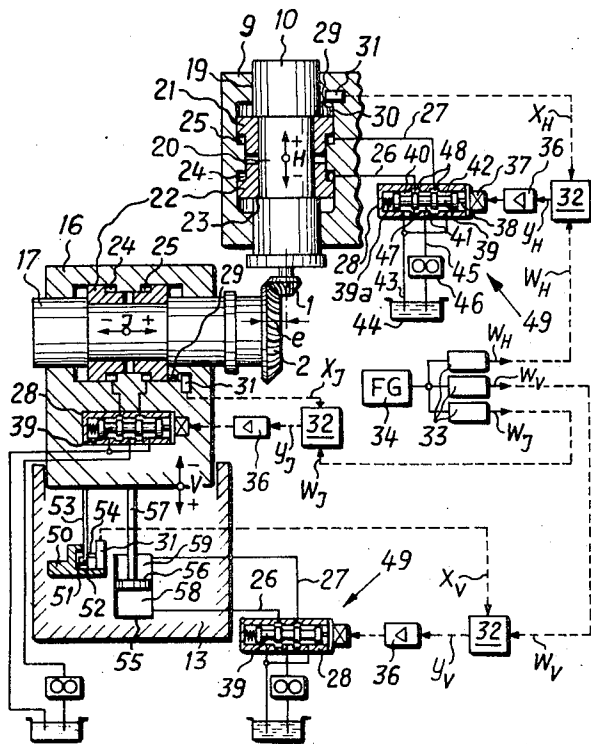


Fig. 1

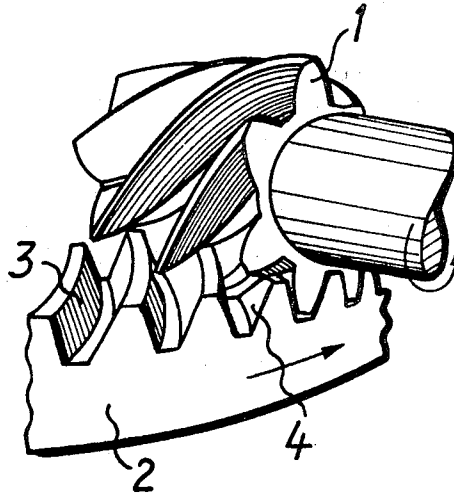


Fig. 2a

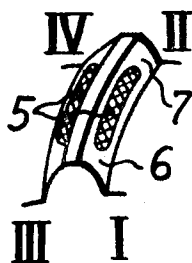
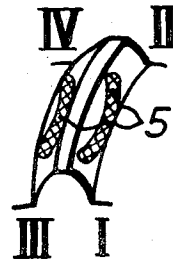


Fig. 2b



Fig. 2c



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Fig. 5

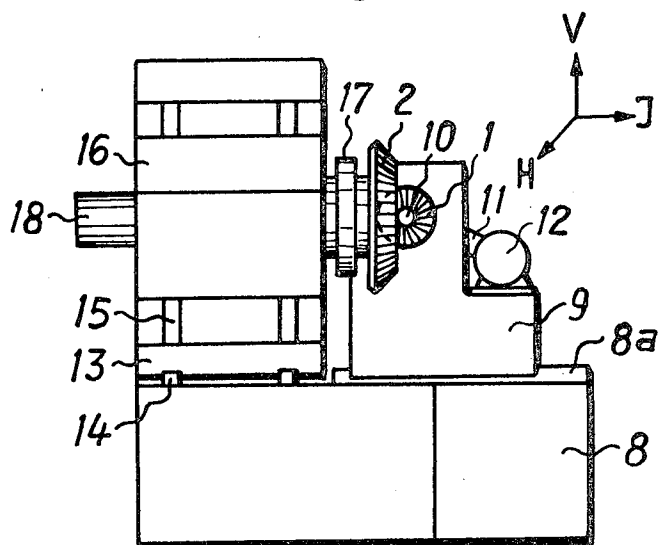
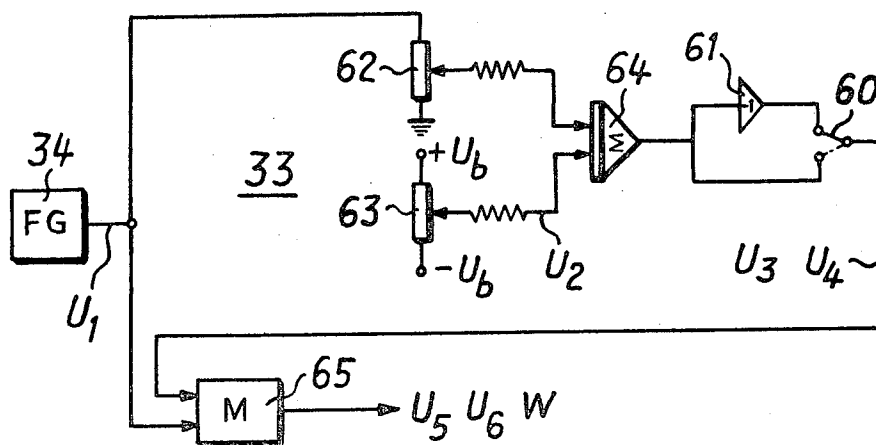


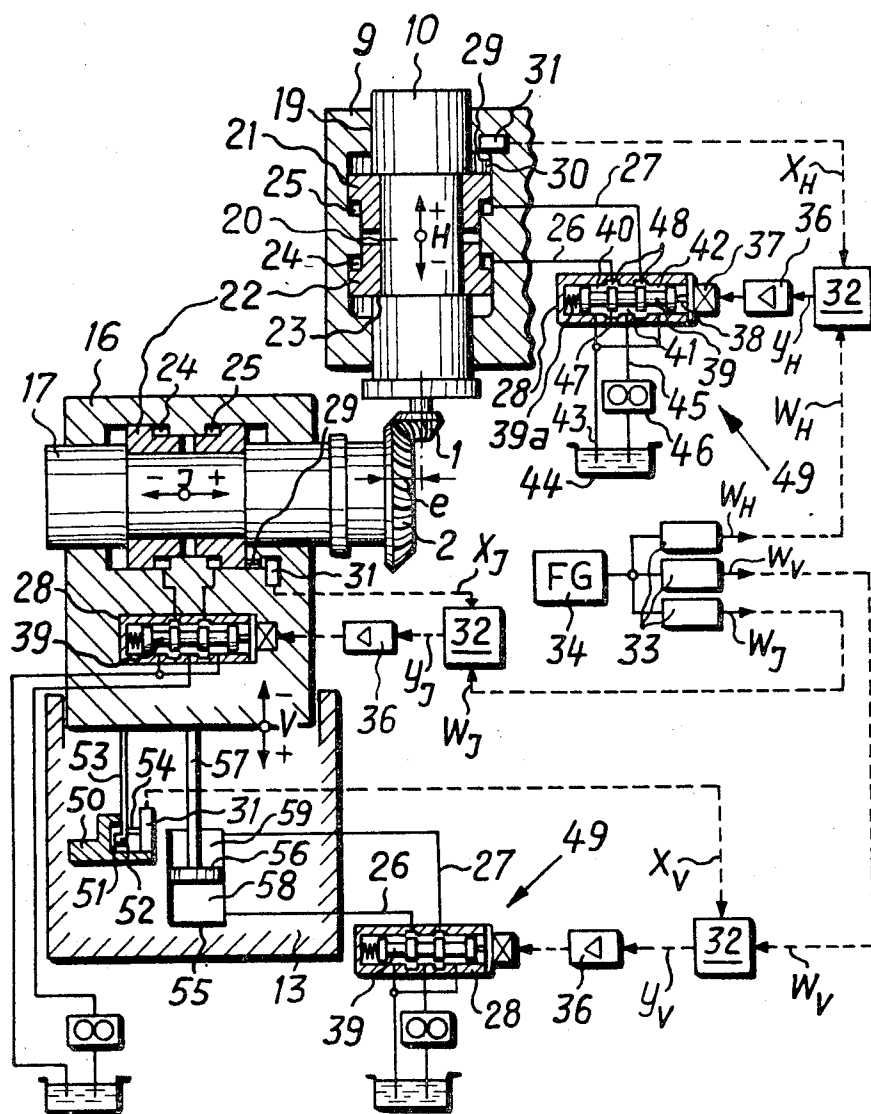
Fig. 7



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Fig. 6



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Fig. 8

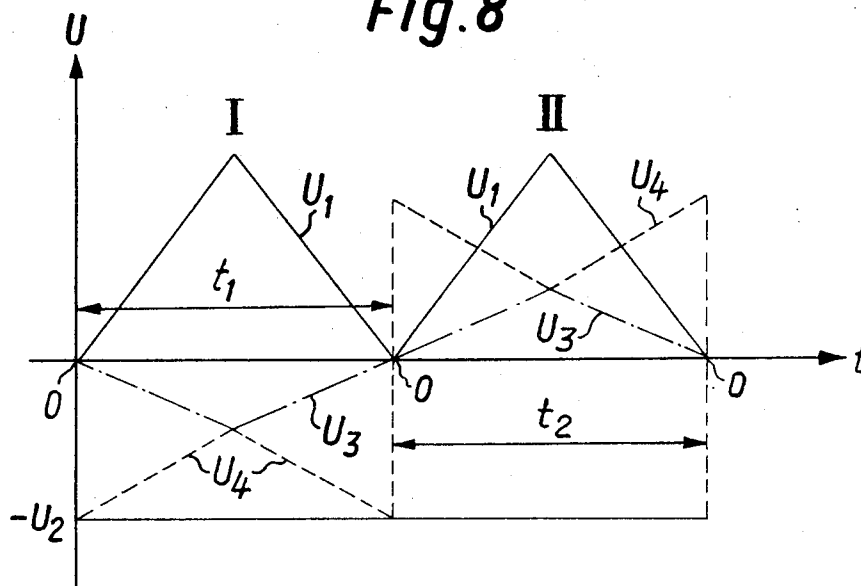
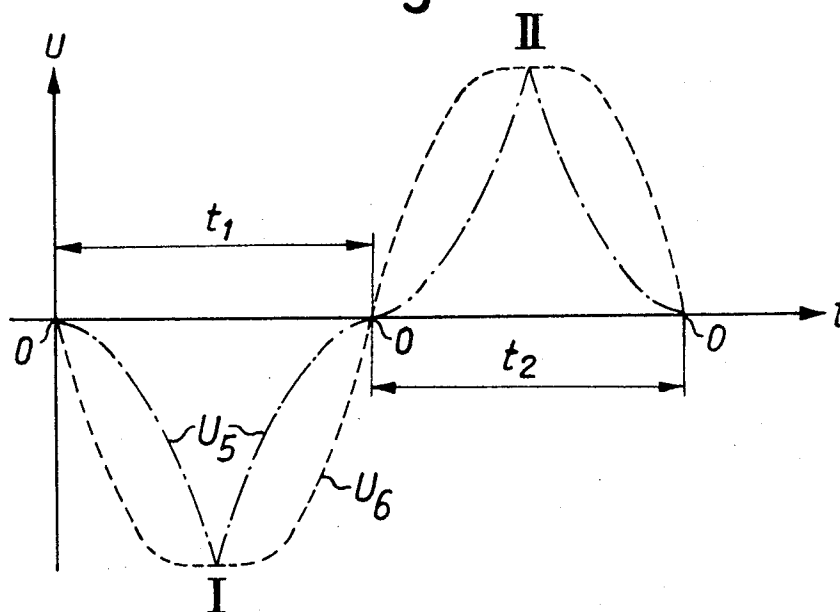


Fig. 9



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APPARATUS FOR THE LAPPING OF TWO GEAR WHEELS

The present invention concerns apparatus for the lapping of two gear wheels, in particular helical bevel gear wheels, which are given a lapping motion compounded from at least two oscillatory components, the apparatus further comprising a control arrangement for the control of each component of the motion.

Two meshed gear wheels have on the flanks of their teeth an area over which they bear upon one another, called the bearing area configuration. The object of lapping is generally to correct a bearing area configuration which, through distortion due to hardening, for example, fails to meet the requirements, or, when necessary, to improve the surface finish of the teeth. For this purpose the gears must be given a lapping motion in addition to the rotary movement around their axes, the relative movement between the gears generally following a curved line which will be called the theoretically required lapping curve p . The lapping effect of this procedure is a function of the speed at which the lapping motion is performed. In the case of a known apparatus the gears are given an oscillatory movement in two directions aligned across and parallel to the axes of the gears. The oscillatory movements mentioned are each controlled by a control device operated by a hydraulic control valve and a hydraulic positioning cylinder. In this the theoretical lapping curve p is approximated by two straight lines s_1 and s_2 which meet in a zero point 0 (see FIG. 3). Each control device has two templates provided with flat control surfaces which meet at a point of inflexion associated with the zero point. By inclining the control surfaces in respect of a plane through the point of inflexion the lengths of the straight lines s_1 and s_2 can be adjusted. The speed of the resulting movement is determined by the number of revolutions and the shape of a cam plate which drives the templates mentioned. The disadvantage of this arrangement is that the shaping of the configuration of the bearing area cannot be arbitrarily influenced because the lapping curve p is only approximated by the two straight lines s_1 and s_2 , while the speed along each of the lines s_1 and s_2 is constant.

There is a known lapping machine which has a template for the control of the movement of a toothed wheel across the axis of rotation, the template being driven by a motor with adjustable speed. From this single movement a further movement is derived by means of a roller drive with a flat guide surface. This guide surface establishes proportionality between the two movements. The resulting lapping movement is indeed effected at varying speeds, but always along a straight line, which is a considerable disadvantage.

The object of the present invention is to overcome these disadvantages and to provide apparatus with which the configuration of the bearing area can be arbitrarily corrected or with which, while preserving a given bearing area configuration, the surface finish of the teeth can be improved.

In accordance with the invention there is provided apparatus for the lapping of two gear wheels, in particular of helical bevel gears, which are given in operation a lapping movement composed of at least two oscillatory components, the apparatus comprising separate control units for the control of each component of movement, wherein each control unit has

means for changing the velocity of the components of movement during a cycle, so that the lapping movement is performed along a line of adjustable shape, and wherein the control units produce periodic voltages of the same frequency.

This provides the great advantage that lapping takes place exactly at the required spot, so that a given bearing area configuration can be established or maintained.

In a particularly advantageous embodiment the control units comprise hydraulic control valves and hydraulic control pistons for moving the gear wheels wherein the periodic voltages can be independently adjusted by means of two potentiometers for amplitude and timing, and wherein each hydraulic control valve is provided with an electro-magnetic system. A further advantage of the apparatus is its ease of operation, and the arrangement of the potentiometers for variation of the speeds can be made readily accessible to the operator.

The invention will now be described by way of example with reference to the accompanying drawings in which:

FIG. 1 is a perspective view of two helically toothed bevel gears in normal meshing position;

FIGS. 2a, 2b, 2c are both flank surfaces of a profile of a tooth with various bearing area configurations;

FIG. 3 is the lapping curves for the forward and reverse bearing areas drawn in a three dimensional system of coordinates H-J-V, compared with the approximations to these lapping curves so far achieved;

FIG. 3a is a lapping curve of a forward bearing flank of a tooth with a change in the distance of assembly of two helical gears, compared with the corresponding lapping curve of two gears in the normal position;

FIG. 4 is the components of the lapping motion of the forward bearing flank of a tooth as in FIG. 3 shown in a distance-time diagram;

FIG. 5 is a front view of a bevel gear lapping machine;

FIG. 6 is a schematic diagram of the device in accordance with the invention with a block diagram of a control circuit;

FIG. 7 is a schematic diagram of a control device;

FIG. 8 is the voltage conditions in a control device for two different adjustment values;

FIG. 9 is the output voltages of the control device for the adjusted values of FIG. 8.

Referring to the drawing, FIG. 1 shows two intermeshed gears 1 and 2. Flanks 4 of the toothed wheel 2 will be load bearing when gear 1 is driven forward in the direction of the arrow, flanks 3 when it is running in reverse. FIGS. 2a, b, c show the bearing area configurations 5 of various positions and shapes on the tooth flanks 3 and 5. The bearing area configuration 5 of FIG. 2a is generally aimed at, as for reasons of strength the inner (6) and outer (7) tooth ends should not carry any load. The bearing area configurations of FIGS. 2b and c must be corrected by lapping because they are too near the tip and/or shoulder of the tooth.

FIG. 3 shows, much enlarged, the spatial curve I-O-II of a lapping curve p for a forward bearing flank 4 of a tooth, and a second lapping curve III-O-IV for a reversed bearing tooth flank 2 in a system of coordinates H-J-V. In the normal meshing position the

flanks of the teeth touch in the zero point O of the lapping curve. The position of the end points of the curves I and II associated with an inner (6) or outer (7) tooth end of the forward bearing tooth flank 4 is given by the straight lines s_1 and s_2 with the coordinates in space h_1, i_1, v_1 or h_2, i_2, v_2 drawn from the zero point. The straight lines s_1 and s_2 characterize the resultant lapping movement obtained with a known device as compared to the theoretically required lapping curve p which is achieved with the device according to the invention.

FIG. 3a shows a further possibility for lapping flank 4 of a tooth along a prescribed lapping curve p . The lapping curve already shown in FIG. 3 for flank 4 of a tooth is indicated in FIG. 3a by a dotted line. With this lapping curve p a given bearing area configuration 5 is obtained for two gear wheels 1 and 2 in the normal meshing position. When a bearing area configuration of the same shape is required for a different fitting distance, e , a shift of the lapping curve p corresponding to the change in fitting distance e is necessary. With an adjustment of gear wheels 1 and 2 this shift must be made axially in the negative or positive H direction and it is achieved by a displacement ΔH of the origin O to O'. The required curve I'-O'-II' has thus been shifted parallel to the lapping curve I-O-II.

FIG. 4 shows the three components of the movement of the gear wheels in the H-J-V direction in the form of a distance-time diagram in which the momentary values are indicated by h, i and v . The components of movement run with the same phase during a period t_1 from the origin O via the end point I of the curve back to the origin, so that the lapping movement is effected along leg p_1 of the lapping curve p (see FIG. 3). Similarly leg p_2 of the curve results from the two components of the movement over a period t_2 . Times t_1 and t_2 of a period t can be arbitrarily adjusted, and the variation with time of the components of the movement can also be adjusted independently of one another. During a period of time Δt the momentary values are subject to a change in position $\Delta h, \Delta i, \Delta v$, the sum of which results in a displacement Δp on the lapping curve. It may be stated in general that the velocity of the lapping movement is determined in accordance with the value of the displacements at a given time. It will thus be seen from FIG. 4 that the velocity is greater near the origin than near the end point of curve I. The shape of the lapping curve is determined by the geometrical coordination of the momentary values h, i and v of the three movement components. If for example in subsequent periods of time the displacements, and therefore the velocities, are proportional, the lapping movement follows a straight line.

A bevel gear lapping machine in accordance with the above description will now be described with reference to FIGS. 5 and 6. For the sake of clarity the following explanation is somewhat simplified.

FIG. 5 shows the arrangement of a headstock 9 movable on two guide rails 8a of the bedplate 8. The headstock 9 contains a spindle 10 with its axis parallel to the H axis; it is supported in bearings to permit axial adjustment. One end of the spindle 10 is driven by a motor 12 via a V-belt drive 11. Motor 12 drives spindle 10 during the lapping process. One of the gear wheels (1) to be worked is clamped to the other end of spindle

10. One the bedplate 8 there is further a post 13 which is slidable along two parallel guide rails 14. Post 13 has two parallel guide rails vertically arranged on which a second headstock 16 can also slide. Headstock 16 carries a spindle 17 with its axis parallel to the J axis and enclosing an angle 90° with the axis of spindle 10 running parallel to the H axis, supported in bearings for axial adjustment. Spindle 17 carries the other of the two gear wheels (2) to be processed. To provide the pressure on the flanks required for the lapping process an infinitely variable hydraulic brake 18 works on spindle 17.

FIG. 6 shows the spindle 10 supported in a stepped cylinder 19 of the headstock 9. Spindle 10 has a part 20 of smaller diameter on which are two ring-shaped control pistons 22 with a collar 21. Each control piston 22 rests with the edge surface of its collar 21 against the shoulder 23 of the spindle 10. The control pistons 22 are so placed in the stepped cylinder 19 as to form two annular chambers 24, 25 each of which is connected to a control pipe 26, 27, of a control valve 28. The two control pistons 22 form a rigid integral part with the spindle 10.

The headstock 9 is further provided with a feeler 30 which rests against the face 29 of control piston 22 and of which the deflection — derived from the axial oscillations of spindle 10 — works on an inductive displacement transmitter 31 of which the changes in voltage are fed as the position voltage x_H to the comparator 32.

A function generator 34 is connected, via a control device 33 referred to hereafter as the actual value transmitter and shown in detail in FIG. 7, to the comparator 32 in which the position voltage x_H is continuously compared with the control voltage w_H received from the actual value transmitter 33. When a difference y_H is experienced between the two values w_H and x_H this is amplified by the amplifier 36, the output of which activates the electro-magnetic system 37 of control valve 28.

The electrical system 37 has a coil with a constant magnetic field into which an axially free-moving servo piston 38 protrudes. The servo piston 38 exerts a controlling force on a control piston 39, which is always returned to its central position under the influence of a spring 39a. Control piston 39 is provided with 3 grooves which form the annular chambers 40, 41 and 42. The left hand 40 and right hand 42 annular grooves are connected via pipe 43 to an oil tank, while the central annular chamber 41 is connected to a hydraulic pump 46 via pipe 45. The control valve 28 also has on its inner surface near the collars 47 of the piston two control openings connected via pipes 26 and 27 to the annular chambers 24 and 25 of spindle 10. In the balanced condition, indicating either the rest position or the normal meshing position of the two gear wheels 1 and 2, the control piston 39 and the servo piston 38 are in the central position as shown in FIG. 6. The pressures in the lefthand 40 and righthand 42 chambers are equal. The feed pipes 26 and 27 to the hydraulic control piston 22 (10) are closed. The system described is called the follow-up system 49 and provides the axial movement of spindle 10 in the H-axis.

As can be seen from FIG. 6, spindle 17 supported in headstock 16 is linked with a similar follow-up system for the axial movement of gear wheel 1 in the J-axis,

this follow-up system 49 being controlled by a second actual value transmitter 33.

A third follow-up system 49 controlled by a third actual value transmitter 33 is fitted in post 13; its task is to transfer a vertical movement in the V-axis to headstock 16 and thus also to spindle 17. The headstock 16 slides on the guide rails 15 of post 13 (FIG. 5). FIG. 6 also shows a slide 50 sliding vertically over post 13. A slot 51 in slide 50 houses a stop 52 of a limit switch 53 for limiting the stroke, the other end of which is rigidly connected to headstock 16. Because the arm of limit switch 53 is in constant contact with a feeler 54 of displacement transmitter 31 which is fitted to slide 50, the momentary vertical position of headstock 16 can be transmitted as the position voltage x_V to the comparator 32 which, after comparison with the control voltage w_V derived from the actual value transmitter 33, actuates a control valve 28 via an amplifier 36 in the manner described above, which in turn actuates a cylinder 55. An axially movable piston 56 housed in cylinder 55 is rigidly connected to the headstock 16 by a piston rod 57. The space 58 in front of piston 56 is connected to control valve 28 via pipe 26, the annular space 59 behind piston 56 via pipe 27.

A schematic circuit diagram of the electronic actual value transmitter 33 is given in FIG. 7. The function generator 34 controlling the three actual value transmitters 33 for movements in the H-J-V axes generates a positive variable voltage U_1 , indicated in FIG. 8 as a triangular voltage curve; this might be a saw-tooth generator of known construction. The three control voltages w_H , w_J , w_V are therefore always in phase. Facilities are provided for adjusting the steepness and inflexion points, i.e. amplitude and frequency, of the saw-tooth voltage at the function generator 34. It is also possible to adjust the part of the saw-tooth voltage U_1 corresponding with leg p_1 of the curve with end point I independently from the part of voltage U_1 corresponding with leg p_2 and end point II. For the sake of clarity, however, these parts of the voltage U_1 are shown in FIG. 8 as having the same shape.

After the function generator 34 follows the actual value transmitter 33, the construction of which is described below. A potentiometer 62, connected as a voltage divider, feeds the output of the function generator 34 to one input of the summing amplifier 64. A second input of the summing amplifier 64 is connected to the wiper of a potentiometer 63 connected between the two poles $+U_b$ and $-U_b$ of a constant voltage source. Depending on the position of the wiper of potentiometer 63, either a positive or a negative voltage U_2 is fed to the second input of the summing amplifier 64. An output of the summing amplifier is connected to one input of a multiplier 65 via an inverter 61 and a switch 60, by which the inverter can be switched off. The multiplier 65, provided at its second input with a voltage U_1 , gives an output voltage of the actual value w , an example of which is given by the voltages U_5 or U_6 in FIG. 9. The output of the multiplier, which is also the output of the actual value transmitter 33, is connected with the comparator 32. Two further potentiometers, not shown, can be switched in circuit in place of potentiometers 62 and 63, so that the movement on leg p_1 can be adjusted with potentiometers 62 and 63 and the movement on leg p_2 with the potentiometers not shown.

The device in accordance with the invention is operated as follows: two gear wheels 1 and 2 which are to be lapped with one another are first chucked in the two spindles 10 and 17 and adjusted to the normal meshing position; they are then turned round their axes by the motor driving spindle 10. The required pressure on the flanks of the teeth is adjusted with brake 18 operating on spindle 17.

A triangular wave voltage U_1 , adjustable in amplitude and frequency, is generated in the conventional manner by function generator 34. Depending on the adjustment of potentiometer 62 a given voltage, smaller than but proportional to the voltage U_1 , is fed to the input of the summing amplifier. To this voltage another, for example negative voltage U_2 , adjusted with potentiometer 63, is added in the summing amplifier 64 so that over the period t_1 the curve U_4 shown by the dotted line in FIG. 8 is produced. Voltage U_4 is multiplied by the voltage U_1 in the multiplier 65, resulting in the voltage curve U_6 shown by the dotted line in FIG. 9. When the voltage U_1 has again reached zero value at the end of period t_1 , the inverter 61 is switched into circuit with switch 60. The inversion of the output voltage of the summing amplifier 64 results in the voltage U_4 for the period t_2 and as shown in FIG. 9 provides the positive part of U_6 . When the voltage U_1 once more passes through zero the inverter 61 is again switched out of circuit by switch 60 so that the voltages already described for period t_1 are again found. The lapping movement can thus be repeated as often as required.

For other settings of the potentiometers 62 and 63 with the voltage U_2 as zero the dotted line of the voltage curve U_3 results (see FIG. 8). Multiplication by voltage U_1 in the multiplier 65 gives an actual value w as indicated in FIG. 9 by the dash-dot line U_5 . In this manner any required shape of the actual value w can be adjusted with the potentiometers 62 and 63 of the actual value transmitter 33.

Each of the actual values w_H , w_J , w_V , are fed to one of the comparators 32. The working process described in the following applies to the movement components in the direction of the H axis: after comparison has been made in comparator 32 between the received actual value w_H and the measured value x_H transmitted by the sensor 30 via the inductive position transmitter 31 the difference between the values of w_H and x_H is fed to the amplifier 36 as an electric control current y_H . The output of amplifier 36 supplies the coil of the electro-magnetic system 37 of the control valve 28.

The servo piston 38 is given a direction-controlled deviation proportional to the value of the control current y_H . When the control current y_H decreases the servo piston moves in the negative direction, i.e. as seen in FIG. 6 to the left, through which the hydraulic balance of the control piston 39 is disturbed at the control edges 48. The pressure in the lefthand chamber 40 of control piston 39 increases while that in the righthand chamber 42 decreases. This differential pressure causes a displacement of the control piston 39. Chamber 41, supplied by the hydraulic pump 46 from oil tank 44, feeds the oil via pipe 26 into the ring chamber 24 of control piston 22 while the oil in ring chamber 25 is simultaneously drained off via pipe 27 and the righthand chamber 42 of control valve 28 into the oil tank 44. The spindle 10 has thus been given an axial movement in the negative H direction which is followed by gear wheel 1.

Every position of spindle 10 is read off by a corresponding deviation of the sensor 30 and is transmitted by the inductive displacement transmitter 31 as the position value x_H to the comparator 32 where comparison between the actual value w_H and the position value x_H takes place. The position control piston 22 is therefore subject to a displacement Δh in negative direction for as long as a difference y_H exists between the values w_H and x_H . When the maximum adjusted actual value w_H coincides with the position value x_H of spindle 10 the latter has reached the end point I of the curve.

After this the control piston 32 is returned to its central position by the force of spring 39a in accordance with the change in actual value w_H . This brings spindle 10 into its central position through the resultant pressure equalization in the two ring chambers 24 and 25.

The movement in the positive H direction then takes place in the same manner. Initiated by a corresponding actual value w_H an increase in control current y_H occurs and through this a proportional displacement of the control piston 39 in the positive direction; this in turn causes a displacement in the positive direction of spindle 10 also until end point II of the curve is reached. The spindle is then returned until balance of pressure is once more obtained after spring 39a has moved back the control piston 39 of control valve 28. This completes the total movement of spindle 10 in the H direction.

As the course of the two remaining movements on a tooth flank 4 along the J and V axes is identical to that described exhaustively above, a repeated detailed description is superfluous. A tooth flank 4 can, however, only be given the required bearing area configuration 5 along the pre-determined lapping curve p (FIG. 3) by the sum total of the simultaneous mutually independent movements (FIG. 4) of spindle 17 in the J and V directions and spindle 10 in the H direction. As the lapping curves can be altered at will, the bearing area configurations best adapted to practical requirements can be obtained. Once adjusted, the lapping curve p can be repeated any number of times during a lapping

process.

We claim:

1. Apparatus for the lapping of two gear wheels, in particular of helical bevel gears, which are given in operation a lapping movement composed of at least two oscillatory components, the apparatus comprising separate control units for the control of each component of movement, wherein each control unit has means for changing the velocity of the components of movement during a cycle, so that the lapping movement is performed along a line of adjustable shape, and wherein the control units produce periodic voltages of the same frequency.

2. Apparatus as defined in claim 1 in which the control units control hydraulic control valves and hydraulic control pistons for moving the gear wheels, wherein the periodic voltages can be adjusted independently of one another in timing and amplitude by means of two potentiometers and wherein each hydraulic control valve is provided with an electromagnetic system.

3. Apparatus as defined in claim 2, wherein each control unit is fed by a function generator which produces a periodic triangular wave voltage, wherein each control unit has a multiplier and a summing amplifier one input of the said summing amplifier being derived from a potentiometer connected as a voltage divider and a second input from a potentiometer connected to a constant voltage source.

4. Apparatus as defined in claim 3, wherein an output of the summing amplifier is connected to one input of the multiplier via an inverter which can be switched in and out of circuit by means of a switch, the other input of the multiplier being connected to the function generator.

5. Apparatus as defined in claim 2, wherein that for each component of movement a closed control loop is arranged by which means the voltage supplied by the control unit representing an actual value is compared with a position value produced by an inductive distance transmitter in a comparator, the comparator feeding the electro-magnetic system via an amplifier.

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