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(54) METHOD OF FINISHING WORKPIECES ON SURFACE-LAPPING MACHINES AND MACHINE FOR REALIZATION THEREOF

(71) We, MOSKOVSKOE VYSSHEE TEKHNICHESKOE UCHILISCHER IMENI N.E. BAUMANA, a Russian Corporate Body of 2 Baumanskaya ulitsa 5, Moscow U.S.S.R., do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to the surface-machining of workpieces made of hard-to-work materials such as ceramics, hard alloys, quartz, ruby, silicon, saphire, glass, etc.

More particularly, the invention relates to surface-lapping machine and to a method of operating a surface-lapping machine.

Known method of finishing workpieces the lapping tools are dressed kinematically directly in the process of lapping by the same workpieces being machined which is effected due to a special cyclic change in the value and direction of the rotation speeds of the operating elements of the finishing machine.

A disadvantage of this known method consists in that during prolonged operation the lapping tools become mutually "worn-in" which increases the amount of required labour considerably and impairs the effectiveness of kinematic dressing. The "wearing-in" phenomenon with regard to the lapping tools is characterized by two features.

Firstly, the profile of the lapping tool acquires a definite shape of the worn working surface differing from the initial shape. In this case, when the workpiece is finished from two sides, the profiles of the upper and lower lapping tools become mutually matching, i.e. one of them becomes a mirror image of the other.

This disadvantage is caused by the error of the method in which the velocities are selected with no regard to the redistribution of pressure over the surfaces of the gradually wearing lapping tools.

Secondly, the surface layer of the lapping tools acquires a maximum wear resistance due to the redistribution of internal stresses and the formation of a dynamic equilibrium (for the given wearing conditions at the given working duty) between the developing microscopic grooves produced by the products of abrasion and responsible for the intensity of shaping the surfaces of the workpiece and lapping tools.

This results in that changes in the kinematic conditions in the prior art method make difficult the finishing of workpieces with simultaneous kinematic dressing of the lapping tools, the finishing time sharply increases so that the accuracy of finishing depends on the duration of the transitional dressing period.

One of the methods of eliminating the "wearing-in" phenomenon is the cyclic change in the external pressure in order to bring the system out of equilibrium.

In practice it is possible to stabilize the accuracy of the geometric shape of the machined surfaces of parts. Throughout the process of machining after achieving the required quality of the surface layer of the machined workpieces by two radically different methods, viz., by retaining the initial geometrical shape of the working surface of the lapping tool or by finding a combination of factors of the finishing process which at any given moment of time and a given condition of the working surface of the lapping tool would ensure minimum deviations from the required shape of the surface of the workpiece and the accuracy of obtained dimensions.

Also known in the prior art are machines for finishing the workpieces located between the lapping tools in the sockets of a holder mounted on an eccentric shaft which mounts a planet pinion meshing with the sun wheel of a planetary mechanism.

This layout of the machine does not permit changing the eccentricity of holder rotation and thus changing the trajectory of the workpiece moving over the lapping tools in the process of machining, i.e. it fails to ensure finishing with simultaneous kinematic dressing of the lapping tools.

The invention disclosed in the U.S.S.R. Author's Certificate No. 483229, describes a surface lapping machine designed for grinding and polishing flat surfaces which comprises a fixed lower lapping tool, a rotating upper lapping tool, a holder fixed on a gear linked kinematically with the sun wheel of a planetary mechanism, with a pinion cage and a carrier fixed on the pinion cage axle, said axle carrying a free-mounted idler gear located between the holder gear and the sun wheel while the holder gear is installed on an additional axle passing through the carrier which rests on the pinion cage.

The disadvantages of this machine are as follows:

Impossibility of changing the ratio of rotation speeds of the pinion cage and holder gear on changes in eccentricity.

Impossibility of changing the eccentricity in the process of machining. The eccentricity can be changed only periodically, after stopping the machine.

The present invention aims to eliminate the above disadvantages and provides a method of operating a surface-lapping machine for finishing workpieces received in sockets of a holder of the machine, wherein the holder is rotated about an axis of the holder and the holder axis is simultaneously rotated about a second axis parallel to the holder axis, and during said rotations about the holder and second axes, the holder axis is rotated about a third axis parallel to and spaced from said holder and second axes thereby to vary the eccentricity of the holder axis with respect to the second axis for obtaining uniform abrasion over the entire surfaces of the workpiece and lapping tool of the machine.

With this method the process of finishing the workpieces can be stabilized with regard to the quality of machining in two respects, viz., to retain with time the geometrical shape of the working surface of the lapping tool or to carry out programmed machining of workpieces by changing the abrasion of the surfaces of the lapping tool and the workpiece with time.

The holder axis may be rotated in stepwise manner about the third axis for varying the said eccentricity of the holder axis between differing values, and the time period of operation for each value of the eccentricity so selected that there is uniform abrasion of the workpiece and lapping tool surfaces during said time period.

In a preferred method, during the finishing process the following parameters are changed in successive steps: the velocity of the relative motion of the workpieces and lapping tool, the tangential acceleration of this motion, and the pressure between the workpiece and the lapping tool.

This allows the machining process to be optimized with regard to quality, output and prime cost by changing the intensity of abrasion of the material of the workpiece and lapping tool at cyclic changes of the finishing conditions due to intensification of the effect of the mechanism forming microscopic failure cracks of the material of the workpiece and lapping tool.

In one embodiment, during a first rough-machining stage said parameters are increased in steps from initial values to certain maximum values and then returned to said initial values, and during a second stage the velocity is increased in steps while the tangential acceleration is reduced in proportion thereto.

As a result the output and the quality of the machined surface can be improved by combining the first, rough and second, finishing stages of machining within a single operation without replacing the lapping tool and changing the abrasive material by selecting the sequence of changes in the pressure in the zone of contact between the workpiece and the lapping tool, in the velocity and tangential acceleration of the relative motions of the workpiece and lapping tool.

The present invention also provides a surface lapping machine for finishing workpieces, comprising a holder with sockets for receiving the workpieces, the holder being mounted for rotation about an axis thereof, a drive shaft having its axis parallel to the holder axis, means coupling the drive shaft to the holder for the holder to be rotated about said drive shaft axis in response to rotation of the drive shaft, and means connected to the coupling means and operable during rotation of said drive shaft to rotate the holder axis about a further axis parallel to and spaced from said holder and drive shaft axes thereby to vary the eccentricity of the holder axis with respect to the drive shaft axis.

In one embodiment of the machine the drive shaft has an eccentric axle, and the coupling means comprises a planetary mechanism including a planet pinion rotatably mounted on said eccentric axle of the drive shaft and having an axle eccentric with respect to the axis of said pinion and on which said holder is mounted.

In an alternative machine the coupling means comprises a planetary drive and a pinion cage fast with the drive shaft, the holder being mounted on a gear which is linked kinematically with a sun wheel of said planetary drive, with said pinion cage and with a carrier, the carrier being rotatable about an axle fixed on said pinion cage and carrying a freely rotatable idler gear located between the holder gear and sun wheel, the holder gear being mounted on an axle which passes through the carrier and rests on the pinion cage, and the means connected to the coupling means comprises a disc coaxial with the pinion cage and having an axle engaged with the carrier for rotating said carrier about the pinion cage axle in response to rotation of said disc relative to the pinion cage, the disc being mounted for rotation with a shaft coupled to the drive shaft through a differential mechanism which is adjustable to rotate the disc relative to the pinion cage.

A better understanding of the invention will be had from the following detailed description given by way of example and with reference to the accompanying drawings in which:

Figures 1 and 2 are the schematic views of a machine according to the present invention, Figure 1 also showing one of the possible trajectories of the holder axle movement relative to the lapping tool axis;

Figures 3*a* and *b* illustrate possible trajectories of the holder axle with relation to the lapping tool axis in the machine shown in Figures 1 and 2;

Figure 4 is a longitudinal section of a machine according to the present invention;

Figure 5 shows another machine according to the present invention also in axial cross-section;

Figure 6 shows the double-slider coupling used in the machine according to Fig. 5;

Figure 7 shows in axial section a further machine according to the present invention;

Figure 8 is a top view of the operating mechanism of the machine shown in Fig. 7.

During the finishing process the workpieces move relative to the working surfaces of the lapping tools along complicated trajectories due to the eccentric-planetary motion of the axle 1 (Figs. 1, 2) of the holder 2 with simultaneous changes in the value of eccentricity "e" and rotation around the axle 1 of the holder 2 with the pieces 3 at a variable or constant speed of rotation.

Shown in Fig. 1 is possible trajectories ABCD of the movement of the axle 1 of the holder 2 with the workpieces 3 relative to the working surfaces of the lapping tools 4.

In this case the machining zone 5 is located on the periphery of the working surface of the lapping tool 4.

Fig. 3*a* and 3*b* show trajectories $a_0 \ldots a_n$ of the axle 1 of the holder 2 relative to the axle of the lapping tools 4 around which the holder 2 rotates.

The vibration amplitude of the workpieces 3 over the working surfaces of the lapping tools 4 and the machining time within the limits of each zone 5 of the working surface of the lapping tools 4 are determined from the sought-for condition of equality of wear of each elementary section of the lapping tool 4 or tools. The abrasion of each elementary section of the lapping tool is determined at each kinematic machining mode within the time $\Delta t = t_2 - t_1$, and is calculated by the formula:

$$V = \int_{t_1}^{t_2} K(v, a^{\tau}, p, h, T^{\circ}) v \, dt \qquad \text{(I)}$$

wherein: $K(\nu, a^\tau, p, h, T^\circ)$=intensity of abrasion of the material of the lapping tools and is a function of velocity (ν) of the relative motion of the workpiece over the surface of the lapping tool, tangential acceleration (a^τ), specific pressure (p) between the workpieces and the lapping tool, abrasive clearance between the workpiece and the lapping tool, i.e. the thickness (h) of the abrasive layer between the workpiece and lapping tool, and temperature (T°) in the lapping zone, and the intensity of abrasion is measured in microns/mm or in m²/mm. Letters t_1 and t_2 designate the time limits of integration.

The intensity of abrasion $Kt(V_t, a_t^\tau, p_t, h_t, T_t^\circ)$ at $t_2(K)$ is calculated by the Taylor's formula of the first-order approximation.

$$K_t(V_t, a_t^\tau, p_t, h_t, T_t^0) \approx K_0(V_0, a_0^\tau, p_0, h_0, T_0^0) + \left(\frac{dK}{dV}\right)_0 (V_t - V_0) + \left(\frac{dK}{da^\tau}\right)_0 (a_t^\tau - a_0^\tau) + \left(\frac{dK}{dp}\right)_0 (p_t - p_0) + \left(\frac{dK}{dh}\right)_0 (h_t - h_0) + \left(\frac{dK}{dT^0}\right)_0 (T_t^0 - T_0^0), \quad \text{(II)}$$

wherein:

$\nu_0, a_0^\tau, p_0, h_0 T_0^\circ$ correspond to values of
$\nu, a^\tau, p, h, T^\circ$ at moment of time t_1,
$\nu_t, a_t^\tau, p_t, h_t, T_t^\circ$ corresponding values
$\nu, a^\tau, p, h, T^\circ$ at a moment of time t_2, and

$$\left(\frac{dK}{dV}\right)_0, \quad \left(\frac{dK}{da^\tau}\right)_0, \quad \left(\frac{dK}{dp}\right)_0 \quad \text{and} \quad \left(\frac{dK}{dT^0}\right)_0$$

are the partial derivatives of $K(\nu, a^\tau, p, h, T^\circ)$ at t_1.

Then, in order to improve the efficiency of kinematic dressing, the zonal lapping is carried out on the assumption that the abrasion of the working surface of the lapping tools 4 in individual zones 5 is equal, i.e.

$$V_1 = V_2 = V_3 = \ldots = V_i = \ldots = V_n \quad \text{(III)}$$

where: $i=1, 2, 3, \ldots n$ is the number of the zone within which the surfaces are lapped, either in successive or different combinations.

Uniform abrasion of the surfaces participating in the process is obtained on the assumption of equality of the removed material from individual circular zones of the workpiece surface during one-sided or two-sided finishing by successive or continuous changes in the relative positions of the lapping tool and workpiece axes in the process of machining.

In this case the lapping tool and the workpiece come in contact on the individual zones of the workpiece which makes it possible to control the process of shaping the surface of the tool and workpiece.

The intensity of abrasion of the working surface of the tool (workpiece) is as mentioned above influenced by such factors of the process as:

ν—velocity of the relative motion of the workpiece over the surface of the lapping tool (or of the tool over the workpiece);

a^τ—tangential acceleration during relative motion of the workpiece over the surface of the tool (or of the tool over the workpiece);

p—specific pressure in the machining zone between the tool and the workpiece;

h—abrasive clearance, i.e. thickness of an abrasive layer between the workpiece and the tool; and

T°—temperature in the machining zone.

Variations in the individual factors during machining or simultaneous changes of several factors change the intensity of abrasion of the material of the workpiece (lapping tool). The dependence of changes in the intensity of abrasion of the workpiece (K_o) and the lapping tool (K_d) on the speed of the relative motion of the workpiece over the lapping tool (v), tangential acceleration (a^τ) and contact pressure (p) has been proved experimentally by the values of K_o and K_d for silicon and ceramics.

It has also been found that the temperature exerts a certain effect on the properties of the nonabrasive component of the lapping compound and governs the temperature conditions of machining (see "Diamond-abrasive lapping of workpieces" by Orlov P. N. published by NIIMACH, Moscow 1972) which influence the intensity of abrasion (K) of the material.

The physical basis of the finishing method is as follows:

An equilibrium strained state in the material of the workpiece and lapping tool during zonal lapping which is achieved by uniform distribution of the contact pressure in the zone of contact between the workpiece and the tool with simultaneous presence of all the parts in a certain zone within a single kinematic mode of a cycle.

Combination of zonal finishing at a single constant kinematic mode when the workpieces are being lapped with the entire working surface of the lapping tools with changes in the kinematic conditions within the limits of a cycle. This means that in finishing the workpieces with the entire surface of the lapping tools, one kinematic mode is changed to another within one machining cycle.

In this case there will be periodical changes in the equilibrium strained state of the material assessed by the magnitude of stresses and the density of microscopic cracks on changes in the kinematic modes.

One finishing cycle may comprise two or more kinematic modes characterized by the speed ratio i, b.

The transition from the zonal finishing of parts to the lapping by the entire surface of the lapping tools can be carried out automatically with the aid of an eccentric mechanism (Fig. 4) which comprises a sectional eccentric shaft consisting of an eccentric drive shaft 6 where eccentric axle 7 carries an intermediate planet pinion 8 meshing with the shaft 9 of the planetary mechanism and having an addition eccentric axle which serves as the axle 1 of the holder 2 with the workpiece finished by the lapping tools 4.

This design of the sectional eccentric shaft will permit the eccentricity "e" of the centre of rotation of the holder with workpiece relative to the centre of rotation of the lapping tools to be changed from zero to a maximum value "e_{max}" in the course of machining.

In the process of machining the workpieces may perform concentric motions relative to the centre of the working surfaces of the lapping tools combined periodically with the motions along the trajectories of epicycloids, hypocycloids and pericycloids in case of an eccentric setting of the machine (see "Diamond-abrasive lapping of workpieces" by P. N. Orlov, publ. by NIIMACH, 1972, Moscow).

The quality of the surface layer at variable speeds is impaired so that finishing should be carried out at a constant speed (V_{const}) of the workpiece motion over the surface of the lapping tool, which means that the movement should follow a circular trajectory while rough-machining should be performed at variable speeds (V_{var}) and variable tangential accelerations (a^τ).

This method of finishing with periodical or constant changes in the amplitude of workpiece vibrations over the surface of the lapping tool will permit stabilization of the finishing process with regard to the accuracy of workpiece machining by keeping the shape of the lapping tool profile within the required range of out-of-planeness (for a flat lapping tool), out-of-sphericity (for a spherical lapping tool) and etc.

Besides, this method can be relied upon for machining workpieces by the zonal method, i.e. machining individual zones, with the use of the same expressions and relationships of abrasion for successive removal of the material from the individual zones of the workpiece surface.

Thus, the method may include cyclic and periodical changes of the angular and linear velocities of the elements of the machine operating mechanism in accordance with the law of abrasion of the working surfaces of the lapping tools and with the formula of distribution of mechanical work:

$$A=K_g S_{t_1}^{t_2}\sqrt{R^2\cdot\omega_{4c}^2+r_b\cdot\omega_{bc}^2-2\cdot R\cdot r_b\cdot\omega_{4c}\cdot\omega_{bc}\cdot\cos(\omega_{4c}-\omega_{bc})t}\cdot dt \qquad \text{(IV)}$$

where:

K_g—correction factor for the effect of dynamics of the finishing process;

R and rb—components of the vectorial calculation diagram determining the trajectory of the relative motion of the point of the lapping tool surface over the workpiece;

ω_{Bc}— angular velocity of the lapping tool centre relative to the holder;

ω_{4c}—angular velocity of the lapping tool relative to the holder;

t_1 and t_2—time of the beginning and end of contact of the lapping tool point with the workpiece.

Besides, the use is made of additional stage-by-stage changes of the velocity, tangential acceleration of the relative motion of the workpiece over the lapping tool, and pressure in the zone of contact between the workpiece and the lapping tool and alternating the sequence of these changes, the workpieces being first rough-machined with the velocity, tangential acceleration and pressure increased cyclically relative to their nominal values then the workpieces are finished with a cyclic increase in the velocity and a proportional reduction in the tangential acceleration.

The analysis of changes in these factors of the finishing process and their interaction with time makes it possible to create a controllable process for finishing both for one-sided and two-sided machining. If the efficiency of the process is regarded as a criterion of its optimization, then the interaction of the factors, v, a^τ and p will have to ensure a maximum possible amount of removed material of the workpiece (intensity of abrasion). If the criterion of optimization of the process of finishing is the quality of the surface layer of the workpiece, then the interaction of the factors v, a^τ, and P must ensure the required depth of the disturbed layer and the degree of disturbance therein.

The physical basis of the effect produced by the dynamism of loading of the system "workpiece-abrasive interlayer-lapping tool" on the factors of the finishing process is the change in the physical and mechanical properties of the surface layers of the workpiece and lapping tool at various relationships between pressure P, velocity V and acceleration a^τ.

Fig. 1 shows an arbitrary trajectory of the relative motion of the workpiece 3 over the lapping tool 4, the type of said trajectory depending on the speed ratio $i_2b=n_2/nB$ (relation of the holder speed n_2 to the speed of a notional pinion cage n_b).

A proportional change in the speeds n_2 and n_b brings about a change in the average speed and acceleration of the relative motion of the workpiece 3 over the lapping tool 4, without changing the type of trajectory.

One and the same type of trajectory a_b, a_1, $a_2 \ldots a_n$ of the relative motion of the workpiece 3 over the lapping tool 4 in the form of an epicycloid may exist for two absolute values of V and a^τ at any moment of time (Fig. 3*a* and *b*), which means that the workpiece moves along one and the same trajectory at various absolute values of V and a^τ.

The absolute values of the velocity V and tangential acceleration a^τ of the relative motion of the workpiece 3 over the lapping tool 4 depend on the angular velocities of the elements of the operating mechanism of the finishing machine and can be found from the known formulas of theoretical mechanics.

Different susceptibility of the material of the workpiece and lapping tool to the effect and interaction of the factors V, a^τ and P, displayed first of all in the change of the structure of the layer disturbed by machining and the depth (thickness) of the zone covered with microscopic cracks and of the zone with elastic and plastic deformation depends on the properties of the system "workpiece-abrasive layer-lapping tool" and, in particular, on the degree of hardening or embrittlement of the surface layer of the workpiece and lapping tool.

By changing the velocity v, acceleration a^τ and pressure P cyclically according to a periodic or aperiodic law, it is possible to create a nonequilibrium strained state in the surface layer and thus to change the law of distribution of dislocations and other defects both in the depth of individual zones and throughout the entire depth of the surface layer.

The spreading of microscopic failure cracks of individual defects through the depth will depend on the amplitude and frequency characteristics of the acting variable stress in the surface layer which changes the nature and spreading speed of the failure cracks. The changes in V, a^τ and P bring about changes in the amount of mechanical work spent for abrading the materials of the lapping tool and workpiece. As a result, the efficiency and quality of finishing the workpieces made of brittle materials can be attained by combining their rough and finish machining in a single operation without replacing the lapping tool and changing the grain size of the abrasive material as has been practised heretofore, but by following a certain sequence of changes in the velocity V, acceleration a^τ and pressure P and by alternating them in various combinations. For this purpose it is proposed during rough machining with a cyclic change of velocity V as practised in the prior art method, to change simultaneously the acceleration a^τ and pressure P so that each increase in the velocity would correspond to a proportional increase in acceleration. a^τ and a reduction of 1.5—2 times in pressure and conversely, during finish machining when the velocity V is increased, this is accompanied by a proportional reduction in acceleration a^τ while pressure P is kept at one and the same level. In some cases one of the factors may be left unchanged.

The sequence of changes in velocity V, acceleration a^τ and pressure P, i.e. $V \to p \to a^\tau$ or $V \to a^\tau \to p$ or $V \to p \to V \to a^\tau$, etc., or $a^\tau \to p \to v$, or $p \to v \to a^\tau$, or $p \to a^\tau \to p$, or $a^\tau - p - v$, also the changes in their level ($V_1 \to V_2 \to p_2 \to p_1 \to p_2 \to a^\tau$ or $p_1 \to p_2 \to v_1 \to v_2 \to v_3$ etc.) make it possible to control the plasticity and brittleness, the value and law of changes of stresses in the surface layer of the workpiece and lapping tool in accordance with the properties of the system "workpiece-abrasive inter-layer-lapping tool".

From the viewpoint of mechanics of failure of brittle materials in the process of finishing, each elementary act of making and separating chips of the material of the workpiece and lapping tool by an individual abrasive grain retains all the basic peculiarities of the process of failure, viz., an intensification of the mechanism of brittle failure of solid bodies with an increase in the dynamism of loading. In the course of finishing the dynamism of loading of the surface layer of the material being finished grows with the increase of the tangential acceleration a^τ of the relative motion of the workpiece over the lapping tool.

Thus, in order to increase the amount of removed material, it is required to create the conditions of nonmonotonic loading. Therefore, for stepping up the efficiency during rough machining, it is suggested to increase both the velocity and acceleration of the relative motion.

The pressure should be changed in the direction of its reduction at an increase in V and a^τ. Elimination of all kinds of irregularities in the process of microscopic cutting is conducive to a reduction in the extent of destruction of the surface layer and in the depth of the defective layer with a large degree of heterogeneity of the strained state and the microscopic cracks of failure. Therefore, in the course of finish-machining of brittle materials calling for the provision of a high-quality surface layer, each cyclic change of velocity V in the known finishing process is suggested to be accompanied by an inverse change of acceleration a^τ with the pressure P remaining constant. Thus, by controlling constantly the velocity, acceleration and pressure in the course of machining with the use of kinematic dressing of the lapping tools of the machined surface of the workpiece, it appears possible to carry out both rough and finish machining of workpieces in a single operation which raises the efficiency of the process at the same time ensuring a high quality of the finished surfaces.

The use of the claimed method in the finishing of ceramic workpieces has made it possible to increase the accuracy of shape of the spherical surfaces and to improve 1.5—2 times the wear resistance of the lot of ceramic workpieces.

Fig. 4 shows diagrammatically the machine for surface-lapping workpieces with free abrasive in accordance with the above-described method.

This machine which has already been described briefly above comprises an eccentric drive shaft 6 which carries an axle eccentric 7 arranged with an eccentricity of "$e_{max/2}$" with relation to the central axis 0—0. Mounted movably on said axle 7 with the aid of bearings 10 is an intermediate planet pinion 8 whose outer rim 12 is in mesh with the inner toothed rim 13 of a hollow shaft 9.

The intermediate planet pinion 8 carries an additional eccentric axle 1 installed with an eccentricity $e_{max/2}$ relative to its axle, said eccentric axle serving as the axle of the holder 2.

The holder 2 accommodates workpieces 3 which are located between the lapping tools 4.

The rotation drives of the eccentric shaft 6, shaft 9 and lapping tools 4 are not shown in the drawing.

The workpieces 3 are placed into the holder 2 and are machined between the lapping tools 4, moving along a complicated trajectory due to their eccentric motion and rotation around the additional eccentric axle 1.

In service the summary eccentricity "e" between the centre of the holder 2 and the centre of rotation of the lapping tools 4 can change from zero (0) to a maximum value (e_{max}) due to the use in the machine of a sectional eccentric shaft consisting of the eccentric drive shaft 6, the intermediate planet pinion 8 and the additionul eccentric axle 1.

The machine functions as follows.

When the rotation speed of the eccentric drive shaft 6 is equal to that of the shaft 9 of the planetary mechanism, the intermediate planet pinion 8 does not rotate with relation to the eccentric axle 7 so that the axis 0'—0' rotates at a constant summary eccentricity "e" relative to the axis 0—0, said eccentricity being capable of ranging from zero to its maximum value depending on the initial position of the additional eccentric axle1.

In case of mismatching of the rotation speeds of the shafts 6 and 9, the intermediate planet pinion 8 is rotated relative to the axle 7 which changes the summary eccentricity of the additional eccentric axle 1 relative to the central axis 0—0 with time.

At the moment when the position of the additional eccentric axle 1 coincides with the position of the central axis 0—0 (rotation radiuses of the axle 7 relative to the central axis 0—0 and of the additional eccentric axle 1 relative to the axle 7 being equal to each other and to "$e_{max/2}$"), the angular rotation speeds of the shafts 6 and 9 will be the same and the workpieces will move in the holder along circular trajectories over the surfaces of the lapping tools.

By varying the velocities of the eccentric drive shaft 6 and shaft 9 and the rotation speeds of the lapping tools 4 it is possible to obtain various trajectories of movement of the workpieces over the lapping tools, i.e. zonal machining of workpieces (machining of the workpieces within a certain zone of the lapping tools with a provision for extending the machining zone and shifting over to machining over the entire surface of the lapping tools), which ensures intensity of kinematic dressing of the lapping tools by the workpieces proper.

Fig. 5 shows another embodiment of the machine for surface-lapping of workpieces and Fig. 6 shows the elements of a double-slider coupling incorporated in this machine.

The machine consists of an eccentric drive shaft 14 which carries an eccentric axle 15 arranged with an eccentricity of $e_{max/2}$ relative to the central axis 0—0. Mounted movably on said axle 15 with the aid of bearings 16 is a planet pinion 17 with a hub whose outer rim 18 meshes with the sun wheel 19 of a hollow shaft 20.

Installed with the aid of ball bearings 21 on the hub of the planet pinion 17, coaxially with it, is an additional planet pinion 22 whose upper end 23 constitutes a coupling member of a double-slider coupling.

The outer toothed rim 24 of the additional planet pinion 22 is in mesh with the inner toothed rim 25 of the spindle 26 which is set coaxially with the eccentric drive shaft 14 and the hollow shaft 20.

Mounted on the planet pinion 17 with an eccentricity $e_{max/2}$ relative to its axis is an additional eccentric axle 27 which serves as the axle of the holder 28.

The upper disc (coupling member) 30 of the double-slider coupling is installed with the aid of ball bearings 29 on the additional eccentric axle 27, said disc being connected rigidly with the holder 28. The lower face of the disc 30 is provided with a slot 31 receiving the projection of the coupling intermediate disc 32. At the opposite side the intermediate disc 32 has another projection which enters the slot in the lower disc of the double-slider coupling.

The holder 28 accommodates the workpieces 33 which are located between the lapping tools 34 and 35.

The rotation drives of the eccentric shaft 14, shaft 20, spindle 26 and lapping tools 34 and 35 are not shown in the drawing.

The machine operates as follows. The workpieces are inserted into the holder 28 and machined between the lapping tools 34 and 35, moving along a complicated trajectory owing to the eccentric motion and rotation around the eccentric 14.

In service the summary eccentricity can change from zero to a maximum.

When the speed of rotation of the eccentric drive shaft 14 is equal to that of the shaft 20, the planet pinion 17 does not rotate around the eccentric axle 15 so that the additional eccentric axle 27 rotates with a constant summary eccentricity relative to the central axis 0—0, said eccentricity varying from zero to its maximum value depending on the initial position of the additional eccentric axle 27.

When the rotation speeds of the drive eccentric shaft 14 and shaft 20 are mismatched, the planet pinion 17 starts rotating around the axle 15 which changes the summary eccentricity of the additional eccentric axle 27 relative to the central axis 0—0 with time.

At the instant when the position of the additional eccentric axle 27 coincides with that of the central axis 0—0, the angular rotation speeds of the shafts 14 and 20 are equalized and the workpieces in the holder 28 will move along circular trajectories over the surfaces of the lapping tools 34 and 35.

Rotation is transmitted from the spindle 26 via the planetary drive to the lower disc of the double-slider coupling which comprises an intermediate disc 32 and an upper disc 30 rigidly connected with the holder 28 which is free-mounted on the additional eccentric axle 27.

When the rotation speed of the hollow shaft 20 is equal to that of the spindle 26, the additional planet pinion 12 does not receive additional rotation relative to the planet pinion 17, nor does the holder 28 around the additional eccentric axle 27.

When the rotation speeds of the shaft 20 and spindle 26 are mismatched, the holder 28 receives additional rotation around the additional eccentric axle 27.

By varying the rotation speeds of the eccentric drive shaft 14, hollow shaft 20, spindle 26 and of the lapping tools 34, 35 it is possible to obtain various trajectories of the workpieces 33 over the lapping tools, i.e. to carry out zonal machining of workpieces (machining them within a certain zone of the lapping tool) with a possibility of widening the machining zone and shifting over to machining over the entire surface of the lapping tools thereby ensuring intensity of kinematic dressing of the lapping tool surface by the workpieces proper.

A diagram of the next design of the machine appears in Fig. 7 and the holder drive, in Fig. 8.

The machine comprises a holder 36 with workpieces 37 in sockets, said holder being located between two lapping tools 38 and 39 and secured on a gear 40 of the holder 36 meshing with an idler gear 41. The axle A—A of the holder gear 40 is connected with a carrier 42 which is free-mounted on the axle C—C of the idler gear 41.

The idler gear 41 meshes with the sun wheel 43 and is free-mounted on the axle C—C which is fixed on a pinion cage 44. The axle A—A rests on the pinion cage 44 and can turn together with the carrier 42 relative to the axle C—C.

The additional shaft 45 is provided with a disc 46 carrying an additional axle B—B which passes through an arc-shaped slot of the pinion cage 44 and enters into the slot of the carrier 42, thus forming a link motion between the additional shaft 45 and the carrier 42. The pinion cage 44 and the additional shaft 45 are moved by the drive 47 via the gear transmissions 48, 49 and a bevel gear differential 50. The differential housing can be turned about a vertical axis by a handle 51. The eccentricity "e" of the rotation axes of the holder gear and sun wheel is determined by the turning angle α of the additional shaft 45 relative to the pinion cage 44.

The machine functions as follows: the parts of the drive 47, 48, 49, 50 rotate the shaft 45 with the disc 46 and the pinion cage 44; the axle of the pinion cage 44 forces the idler gear 41 to roll around the sun wheel 43 and to rotate the holder gear 40 of the holder 36. The workpieces 37 located in the ports of the holder 36 are machined between the upper and lower lapping tools 39 and 38. The directions of the angular speeds ω_1 and ω_2 of the pinion cage 44 and the gear 40 of the holder 36 coincide. The angle α between the additional shaft 45 with the disc 46 and the pinion cage 44 is determined by the speed ratio of the idler gears 48 and 49 and by the turning angle β of the housing of the differential 50. When the speed ratios of the elements 48 and 49 are 1:1, angle α is equal to angle β. Thus, on changes in angle β the differential housing 50 turns the carrier 42 so that angle α and eccentricity "e" change in the course of machining of the workpieces 37.

This makes it possible to automate the process of finishing the workpieces and improve their quality since the use of this machine allows the finishing parameters to be controlled directly in the course of machining.

WHAT WE CLAIM IS:—

1. A method of operating a surface lapping machine for finishing workpieces received in sockets of a holder of the machine, wherein the holder is rotated about an axis of the holder and the holder axis is simultaneously rotated about a second

axis parallel to the holder axis, and during said rotations about the holder and second axes, the holder axis is rotated about a third axis parallel to and spaced from said holder and second axes thereby to vary the eccentricity of the holder axis with respect to the second axis for obtaining uniform abrasion over the entire surfaces of the workpiece and lapping tool of the machine.

2. A method according to Claim 1, wherein the holder axis is rotated in a stepwise manner about the third axis for varying the said eccentricity of the holder axis between differing values, and the time period of operation of each value of the eccentricity is so selected that there is uniform abrasion of the workpiece and lapping tool surfaces during said time period.

3. A method according to Claim 1 or 2, wherein during the finishing process the following parameters are changed in successive steps: the velocity of the relative motion of the workpieces and lapping tool, the tangential acceleration of this motion, and the pressure between the workpiece and the lapping tool.

4. A method according to Claim 3, wherein during a first rough-machining stage said parameters are increased in steps from initial values to certain maximum values and then returned to said initial values, and during a second stage the velocity is increased in steps while the tangential acceleration is reduced in proportion thereto.

5. A surface lapping machine for finishing workpieces, comprising a holder with sockets for receiving the workpieces, the holder being mounted for rotation about an axis thereof, a drive shaft having its axis parallel to the holder axis, means coupling the drive shaft to the holder for the holder to be rotated about said drive shaft axis in response to rotation of the drive shaft, and means connected to the coupling means and operable during rotation of said drive shaft to rotate the holder axis about a further axis parallel to and spaced from said holder and drive shaft axes thereby to vary the eccentricity of the holder axis with respect to the drive shaft axis.

6. A surface lapping machine according to Claim 5, wherein the drive shaft has an eccentric axle, and the coupling means comprises a planetary mechanism including a planet pinion rotatably mounted on said eccentric axle of the drive shaft and having an axle eccentric with respect to the axis of said pinion and on which said holder is mounted.

7. A surface lapping machine according to Claim 6, wherein the planetary mechanism comprises a second planet pinion mounted coaxially with the first planet pinion and forming one part of a double slider coupling, another part of the slider coupling being journalled on the eccentric axle of the first plane pinion and fixedly connected to the holder.

8. A surface lapping machine according to Claim 5, wherein the coupling means comprises a planetary drive and a pinion cage fast with the drive shaft, the holder being mounted on a gear which is linked kinematically with a sun wheel of said planetary drive, with said pinion cage and with a carrier, the carrier being rotatable about an axle fixed on said pinion cage and carrying a freely rotatable idler gear located between the holder gear and sun wheel, the holder gear being mounted on an axle which passes through the carrier and rests on the pinion cage, and the means connected to the coupling means comprises a disc coaxial with the pinion cage and having an axle engaged with the carrier for rotating said carrier about the pinion cage axle in response to rotation of said disc relative to the pinion cage, the disc being mounted for rotation with a shaft coupled to the driveshaft through a differential mechanism which is adjustable to rotate the disc relative to the pinion cage.

9. A method according to Claim 1 and substantially as herein disclosed.

10. A surface lapping machine substantially as herein described with reference to Figure 4, Figures 5 and 6 or Figures 7 and 8 of the accompanying drawings.

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1592498 COMPLETE SPECIFICATION
4 SHEETS *This drawing is a reproduction of the Original on a reduced scale*
Sheet 1

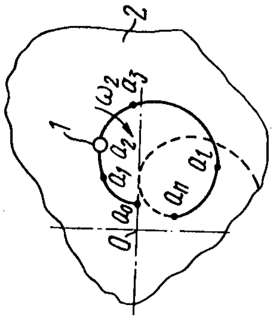

FIG.3a

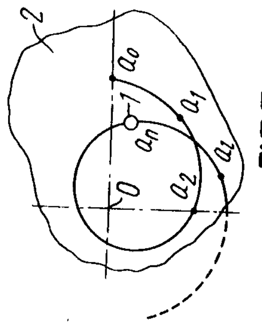

FIG.3b

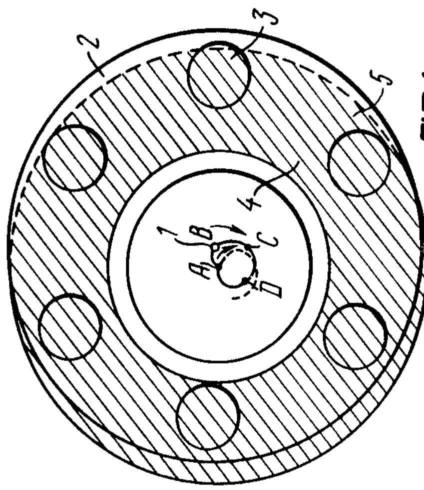

FIG.1

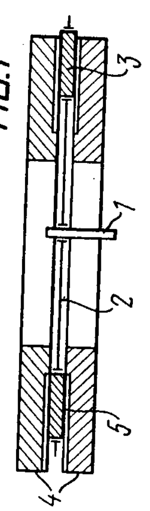

FIG.2

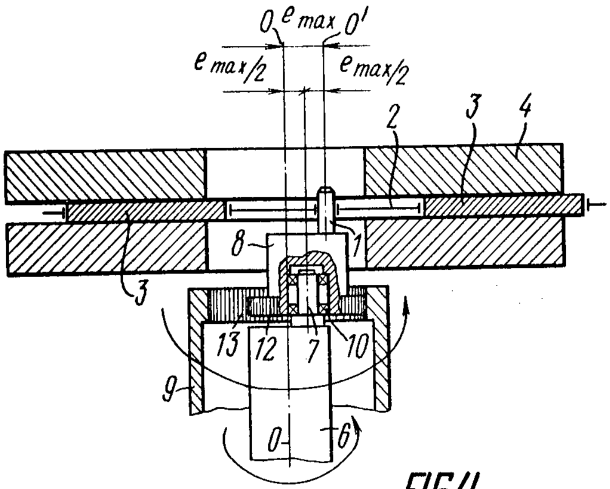
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FIG.4

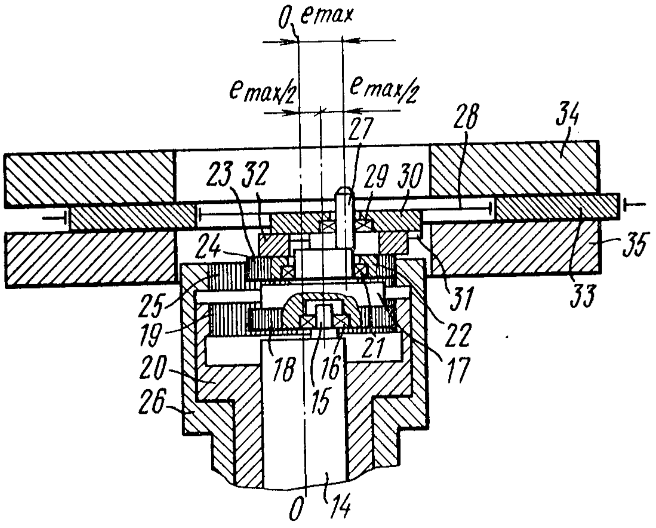
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FIG.5

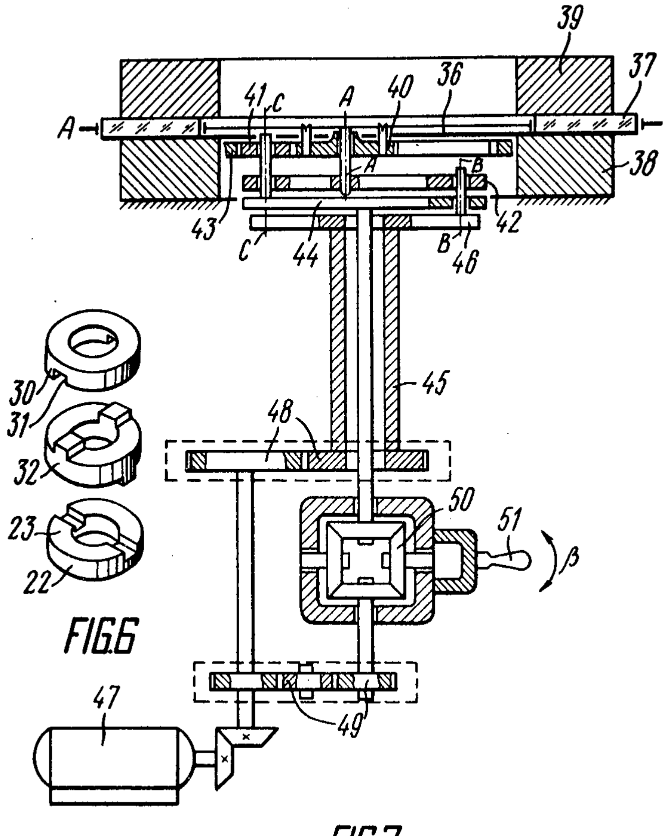
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FIG.6

FIG.7

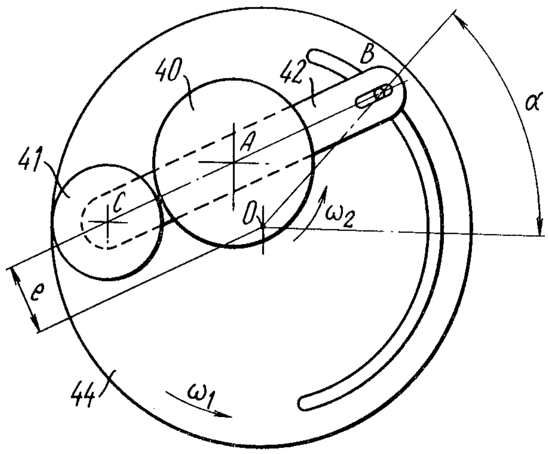

FIG.8