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Computer simulation of kinematic systems of lapping machines

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Abstract

Lapping of plane surfaces is the technology which allows to achieve high surface quality. Kinematics of lapping has the main effect on the quality of an active plane of lapping tools as well as on the quality of the machined surface of the workpieces. The flatness of working surface of the lapping tool has the essential influence on the shape accuracy of lapped surfaces. Computer simulation models have been developed to evaluate speed and acceleration of lapping and to plot displacement trajectories in lapping tool and separator coordinate systems.

1 Introduction

The high requirements to the machine components and tools cause that the surface treatment becomes more and more important and the interest in precision surface technology is increasing.

Grinding, polishing, honing, lapping and super finishing are the most common methods of producing fine surface finishes. A good surface finish has an important effect on the live of the components. For a small change of surface roughness parameter, a large improvement in the live of the component can result. Lapping of plane surfaces is the technology which allows to achieve high surface quality. However there are many factors which influence on the lapped surface and on its shape accuracy, such as: kinematics of the process, profile wear of a lapping tool, abrasive particles, load [1].

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Because of the complexity of kinematic systems of lapping machines, computer simulation models have been developed in order to calculate velocity and acceleration in the lapping process and to plot displacement trajectories in lapping tool and separator coordinate systems. Results from the computer simulation of kinematic systems of lapping machines are presented in the paper.

2 Description of the process and the equipment

Lapping is usually a free abrasive machining process in which the abrasives are allowed to rotate between the workpiece and the lapping tool- three body abrasion. When an abrasive particles penetrates the tool surface, the abrasive can become embedded in the tool and form an abrasive /workpiece interaction similar to that in the fixed abrasive or two body abrasion process. The deeper the penetration the more likely the abrasive will be fixed in the plate.
The work material is removed with the fixed grains trapped on the lapping plate and loose grains contained in the lapping fluid [3].

2.1 Standard executory system of the single-disk lapping machine

Figure 1 shows a schematic representation of the standard executory system of the single-disk lapping machine. Fixed in the separator workpiece is loaded against a rotating lapping tool and rotates with the separator. Rotational velocity of the separator depends on its arrangement, the lapping tool velocity and friction force between those two elements. There can be also an independent separator drive.

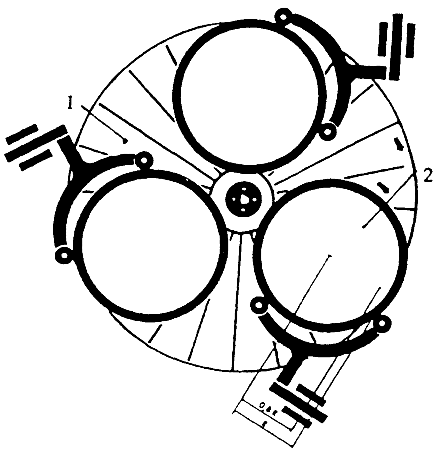

Figure 1: Standard executory system of the single-disk lapping machine: 1- lapping tool, 2- separator.

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2.2 Statement of the problem

The process described above indicates the existence of a correlation between the kinematics of lapping and the shape change of the tool due to its wear. During the process both surfaces: surface of the tool and the workpiece, are wearing. If lapping tool is wearing at a uniform rate along the radius, then surfaces are flat. Otherwise the surface of the workpiece is either concave or convex. Standard kinematic systems do not assure an uniform shape change of the lapping tool, but we can predict the shape change along the radius. The facing operations could be performed to maintain the flatness of the lapping plate and correct the shape change [5]. Workpieces with convex surfaces could be required (because of the exploitation properties). In that case if we can predict the wear of the tool then we can also control the flatness of lapped surfaces.

2.3 Theoretical analysis of the kinematic system

Figure 2 shows a relative x-y and an absolute ς-η lapping tool coordinate systems. The origins of both coordinate systems are at the centre O of a lapping tool which rotates with angular velocity ω_t (relative coordinate system rotates with the same velocity). A separator rotates with angular velocity ω_2. The displacements of point P in x and y directions during time t are

$$x_P(t) = R \cdot \cos(\omega_j \cdot t - \omega_t \cdot t) + r \cdot \cos(\omega_2 \cdot t - \omega_t \cdot t) \tag{1}$$

$$y_P(t) = R \cdot \sin(\omega_j \cdot t - \omega_t \cdot t) + r \cdot \sin(\omega_2 \cdot t - \omega_t \cdot t) \tag{2}$$

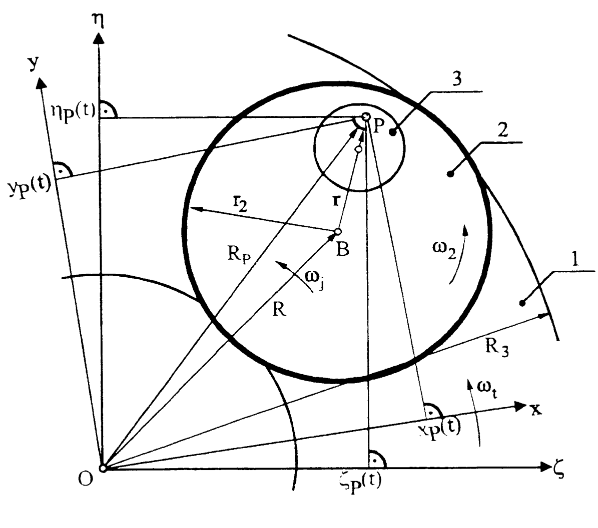

Figure 2: Relative and absolute lapping tool coordinate systems: 1- lapping tool, 2-separator, 3- workpiece.

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The relative velocity is

$$\omega_w = \omega_j - \omega_t \tag{3}$$

The displacement trajectories form depends on a velocity factor

$$k = \frac{\omega_2 - \omega_t}{\omega_j - \omega_t} \tag{4}$$

Trajectories can be in the form of epicycloid (k>0) or hipocycloid (k<0).
The final equations for the displacement trajectory of point P are

$$x_P(t) = R \cdot \cos(\omega_w \cdot t) + r \cdot \cos(k \cdot \omega_w \cdot t) \tag{5}$$

$$y_P(t) = R \cdot \sin(\omega_w \cdot t) + r \cdot \sin(k \cdot \omega_w \cdot t) \tag{6}$$

Velocity and acceleration are given by

$$v_P(t) = \omega_w \sqrt{R^2 + r^2 \cdot k^2 + 2 \cdot R \cdot r \cdot k \cdot \cos(\omega_j \cdot t - \omega_2 \cdot t)} \tag{7}$$

$$a_P(t) = \omega_w^2 \sqrt{R^2 + r^2 \cdot k^4 + 2 \cdot R \cdot r \cdot k^2 \cdot \cos(\omega_j \cdot t - \omega_2 \cdot t)} \tag{8}$$

Figure 3 shows a separator coordinate system. The origin of the relative system is at the centre B of a separator which rotates with angular velocity ω_2. The final displacements of point P_L in the x and y directions during time t are

$$xp = \overline{BP}_L \cos\beta \tag{9}$$

$$yp = \overline{BP}_L \sin\beta \tag{10}$$

Equations given above were used to plot displacement trajectories and to calculate lapping velocity and acceleration.

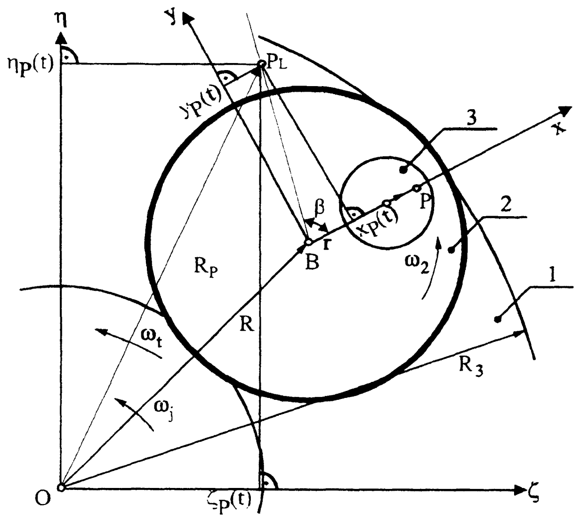

Figure 3: Separator coordinate system: 1- lapping tool, 2-separator, 3- workpiece.

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3 Results from the computer simulation and their discussion

By specifying the time t and geometry of elements of lapping machine (R, R_3, r) it is possible, using eqn. (5,6), to plot displacement trajectories of one point or a number of points in a relative x-y lapping tool coordinate system for various combinations of ω_2 and ω_t . Figure 4c shows the pattern of trajectories of a one point during the time of three cycles for the maximum rotational velocity of the lapping tool ($n_t$max). Figure 4d shows the pattern of trajectories during the same time but for $n_t$min. The velocity and the acceleration of the lapping process for n_t ranging from 20 rpm to 70 rpm during one cycle time are shown in Figures 4a and 4b. Figure 5 shows the pattern of trajectories and kinematic parameters for the same range of the lapping tool rotational velocity but the separator rotates in the opposite direction (ω_2=-Aω_t). It is seen that the velocity and the acceleration achieve higher value in the backward system and the difference between the minimum and the maximum value is bigger as well.

The variations of v_p and a_p in the function of a separator radius r for different lapping tool rotational velocities and different parameters R_3 and r are shown in Figures 6-8. As it was expected, v_p and a_p vary more when the workpiece is located further from the centre of the separator.

The velocity factor k is the characteristic parameter influencing on the kinematic of the lapping process and on the curvilinearity of trajectories. Figures 9, 10 show the variation of v_p and a_p in the function of this parameter .

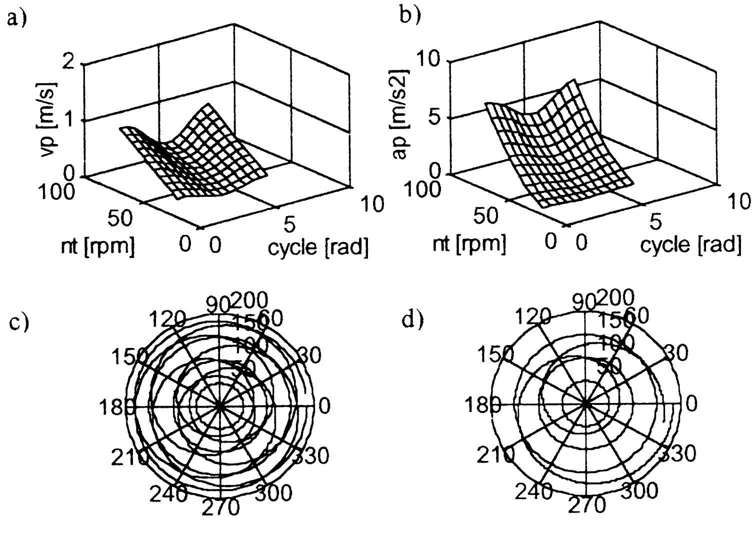

Figure 4: Computational results for the concurrent system: a) velocity vp, b) acceleration ap, c) displacement trajectories for $n_t$max=70rpm, d) displacement trajectories for ntmin=20 rpm, (R_3=190mm, r=65mm).

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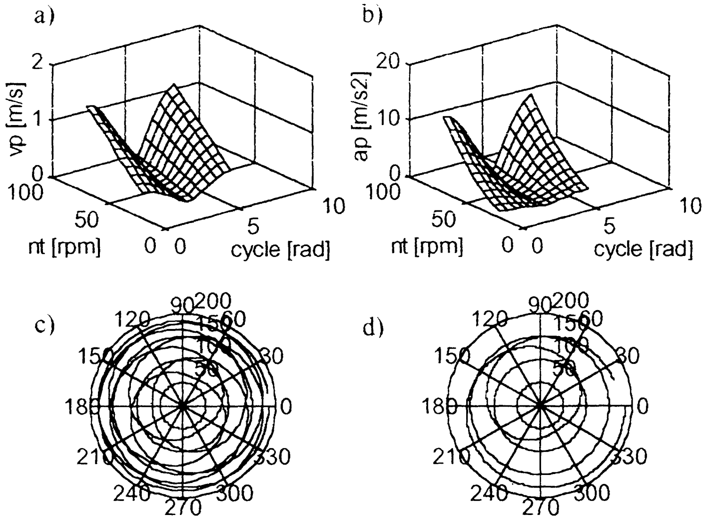

Figure 5: Computational results for the backward system: a) velocity vp, b) acceleration ap, c) displacement trajectories for $n_t max=70rpm$, d) displacement trajectories for ntmin=20 rpm, (R_3=190mm, r=65mm) .

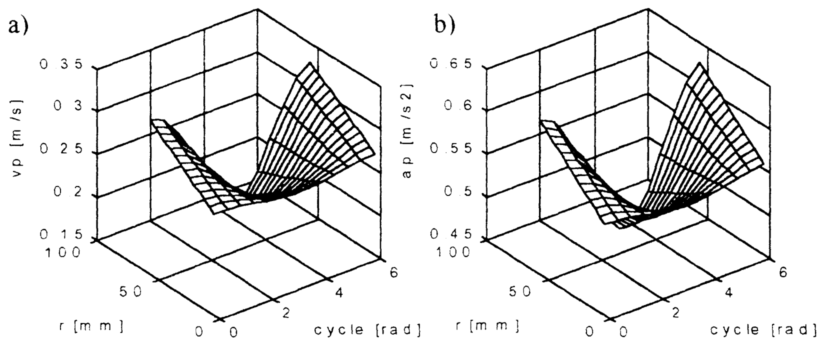

Figure 6: Influence of the workpiece arrangement in the separator on lapping a) velocity, b) acceleration, (R_3=190mm, r=65mm, n_t=20rpm, n_2=9rpm).

Using eqn. (9,10) it is possible to plot displacement trajectories in a relative x-y separator coordinate system. The pattern of displacement trajectories for a number of points located on the contact area (not only on the contact area periphery), shown in Figure 11, was plotted. The curvilinearity of the trajectories depends on the rotational velocities n_2 and n_t. During the specified time t one point P_L of a lapping tool can describe several trajectories within the contact area.

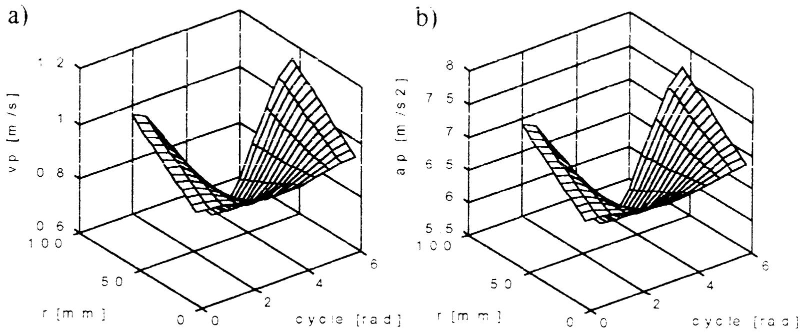

Figure 7: Influence of the workpiece arrangement in the separator on lapping a) velocity, b) acceleration, (R_3=190mm, r=65mm, n_t=70rpm, n_2=32rpm).

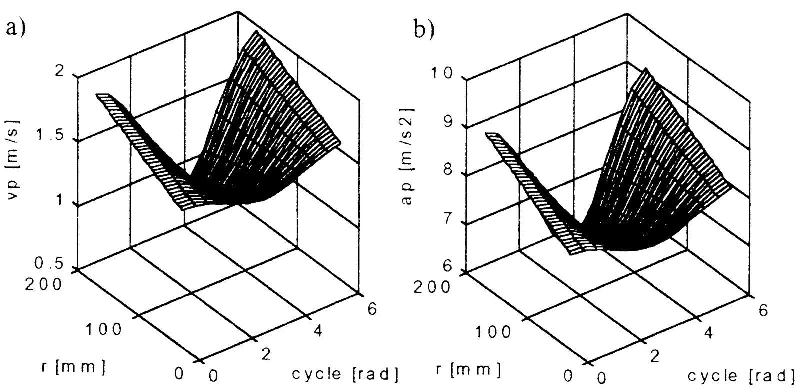

Figure 8: Influence of the workpiece arrangement in the separator on lapping a) velocity, b) acceleration, (R_3=480mm, r=200mm, n_t=50rpm, n_2=22rpm).

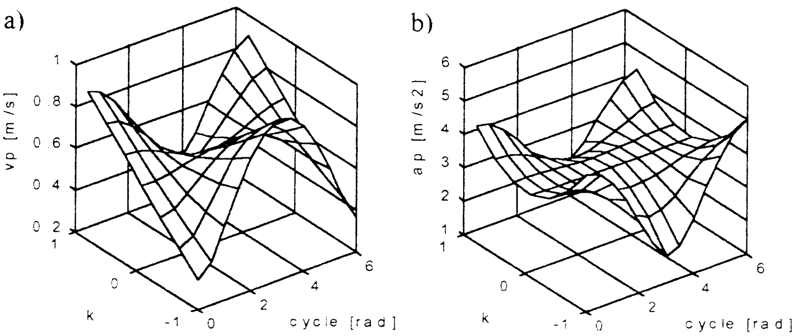

Figure 9: Computational results for the parameter k: a) velocity, b) acceleration, (R_3=190mm, r=65mm, n_t=50rpm, n_2=22rpm).

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a) b)

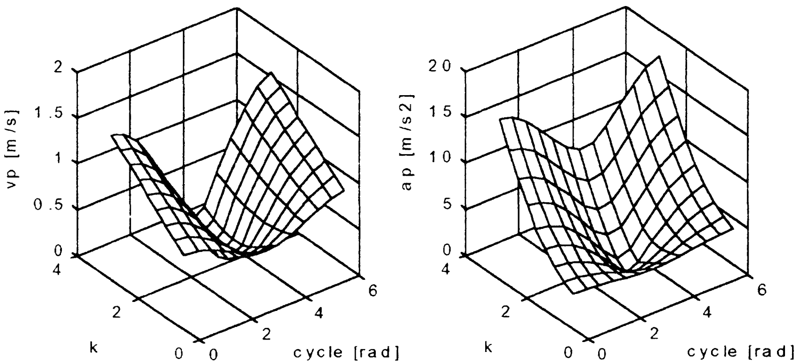

Figure 10: Computational results for the parameter k: a) velocity, b) acceleration, (R_3=190mm, r=65mm, n_t=50rpm, n_2=22rpm).

a) b)

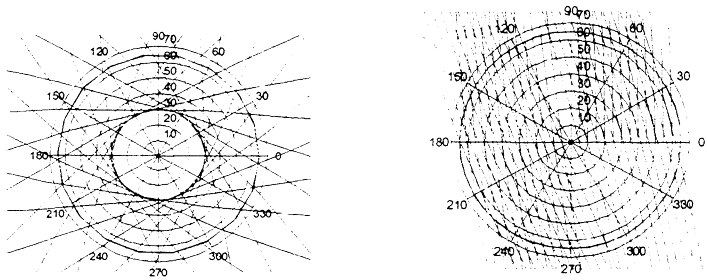

Figure 11: Displacement trajectories in the separator coordinate system a) for one point P_L, t=16s, b) for points located along the radius every 5mm, t=2.5s, (R_3=190mm, r=65mm, n_t=70rpm, n_2=32rpm).

4 Concluding remarks

The results from the computer simulation enable formulation of the following conclusions:

(i) The lapping speed affects the surface finish. Using the computer simulation an optimum value of the lapping rotational velocity can be chosen for different materials.

(ii) Single-disk lapping machines with an independent separator drive allows to control the process more and the required pattern of displacement trajectories can be chosen using various combinations of n_2 and n_t.

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(iii) The lapping speed depends on the arrangement of workpieces in the separator and the arrangement can be changed during the process.
(iv) The curvilinearity of trajectories and the frequency of their repeatability for the specified time t within the contact area can be controlled using the separator coordinate system.

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