Determining a contact spot in the orbital burnishing deformation

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Abstract. The influence of the orbital burnishing main parameters on the configuration, size and area of the plastic contact spot during cylindrical parts processing is studied using SolidWorks software. The computer modeling results show that indent size and contact area are mainly affected by the working tool inclination angle, orbital rotation radius and the penetration depth, while the working tool radius and the workpiece diameter are of less significance.

1. Introduction
Practically there are various methods of machine parts and structural elements hardening finishing treatment. They mainly differ by the deforming element impact on the treated surface. The efficiency of surface plastic deformation depends on the processing modes, the deformation behavior, the workpiece material temper and properties, the shape and size of the deforming tool [1-4].

Alternatively, to the traditional treatment schemes [3], SPD processes have been developed based on more complex deforming tool kinematics [4]. The technical idea of intensifying the stress state in the deformation zone consists in the working tool kinematics development, which increases grain distortion. Studies [4, 5] propose to change the cylindrical roll rotation axis, which passes through the diametral plane center. The modified kinematics of the working tool movement allows to change the stress state within the deformation zone and increase hardening. Authors of several works [6, 7] on the study of the deforming tool kinematics influence on the hardened part surface quality propose to change the working tool rotation direction.

New SPD method has been developed at the Irkutsk National Research Technical University, based on the orbital revolution of the working tool [8]. The efficiency of the new process was demonstrated during loading a flat surface with an orbiting tool [9].

The aim of the present work is to study the configuration, size and area of the workpiece and deforming tool contact during orbital burnishing of cylindrical parts.

2. Orbital burnishing scheme
Figure 1 schematically shows a surface plastic deformation process with the orbital movement of the deforming tool, which is carried out by rotating the loaded indenter about an axis perpendicular to the workpiece axis. In this case, the rotation path of the indenter axial line forms a conical surface with an apex angle $2\alpha$ [9].
Without longitudinal feed, the deforming force is decomposed into normal (P2) and tangential forces (P1). The main force that creates the required pressure in the tool – workpiece contact spot is the normal component of the force P. It remains constant during the tool orbiting, while the tangential component changes both in magnitude and direction.

In case of the orbital burnishing, a rod-like deforming tool with a spherical tip, is set at an angle to the workpiece axis, and the indent shape depends on the interference, the workpiece surface curvature, value of angle α, the working tool radius and the orbital rotation radius. There may be several positions of the working tool relative to the workpiece axis.

At its simplest, an elliptical indent is formed when the working tool is positioned without tilt to the workpiece axis (Figure 2.a). When the working tool is set at an angle α to the treated surface, the shape and center of the working tool imprint change depending on the direction of the tangential force (Figure 2.b, c, d).

As is known from [10, 11], based on a system analysis of machining methods, the main function of static characteristics is to ensure a certain relative position of the tool and workpiece during machining. Their choice is determined by the direction and magnitude of the acting forces, as well as the shape and relative position of the tool and the workpiece.

Computer modeling is successfully used to determine the workpiece – tool contact area during hardening by various SPD methods. One of the widely used general-purpose programs is SolidWorks, which was used for present study. A geometric model that is a cylinder and a rod with a spherical tip was developed for calculation.

### 3. Orbital burnishing scheme

When SolidWorks is started, the model creating in the 3D solid modelling environment should be chosen. First, a cylindrical workpiece sketch of the specific diameter is created, then a model is developed through the operation New - Part.
Next, a plane is constructed in which the deforming tool sketch will be defined. Any plane can be chosen for this purpose, except that containing the workpiece sketch. In the selected plane a sketch is drawn in the form of a straight line - this will be the tool model rotation axis. Then, the orbital rotation radius, the deforming tool radius, the depth of penetration (interference) and the tool inclination angle are specified. All these values can be easily changed in edit mode.

The Revolved cut operation is performed and the volume that the tool model occupies at a given value of the interference will be removed from the surface of the workpiece model. As a result, we get the area of tool – workpiece plastic contact. Choosing the Evaluate - Section Properties, the plastic contact size and area are calculated.

The plastic contact spot configuration and area evaluated using this method are in good agreement with the experimental data obtained after a solid indentor penetration into metal samples with subsequent measurement of the contact spot using a microscope [12-13].

Figure 4 shows the shape and geometric characteristics of the workpiece – tool contact spot when changing the inclination angle of the working tool.

| Figure 3. The deforming tool sketch. |
|-------------------------------------|

| Figure 4. Shape and geometric characteristics of the workpiece – tool contact spot when changing the inclination angle of the working tool: 1 – plastic zone; 2 - elastic zone. |

Table 1 shows the calculation results for the influence of the inclination angle on the geometric characteristics of the tool – workpiece contact spot.
Table 1. Geometric characteristics of the tool – workpiece contact spot when changing the working tool inclination angle.

| Contact spot size | Tool inclination angle |
|-------------------|------------------------|
|                   | 0°         | 15°       | 30°       | 45°       | 60°       |
| a, mm             | 0.89      | 1.41      | 1.89      | 2.30      | 2.61      |
| b, mm             | 0.82      | 1.24      | 1.61      | 1.88      | 2.06      |
| r, mm             | 0.12      | 0.12      | 0.55      | 0.83      |

Table 1 demonstrates that the inclination angle significantly affects the tool – workpiece contact spot size. With inclination angle $\alpha$ increase from 0° to 60°, the spot width $2b$ increases by 2.5 times, and the spot length $2a$ increases by 3 times. With angle $\alpha$ increase from 30° to 60°, the elastic contour radius increases by 7 times.

Table 2 shows the results of the tool – workpiece contact spot modeling in the absence of longitudinal feed. During the orbital burnishing, the contact area changes.

Table 2. Change in the tool – workpiece contact area during orbital burnishing.

| Tool inclination angle, deg | 0    | 15   | 30   | 45   | 60   |
|-----------------------------|------|------|------|------|------|
| Contact area, $F_k$ (mm$^2$) | 2.26 | 5.44 | 9.40 | 12.64| 14.59|
| Penetration depth $t$, mm    | 0.05 | 0.075| 0.1  | 0.125| 0.15 |
| Contact area, $F_k$ (mm$^2$) | 3.56 | 4.54 | 5.44 | 6.30 | 7.13 |
| Tool radius $R_t$, MM        | 3    | 3.5  | 4    | 4.5  | 5    |
| Contact area, $F_k$ (mm$^2$) | 6.59 | 6.02 | 5.44 | 4.88 | 4.33 |
| Orbital rotation radius, $R_L$, MM | 4 | 4.5 | 5 | 5.5 | 6 |
| Contact area, $F_k$ (mm$^2$) | 2.26 | 2.94 | 3.70 | 4.53 | 5.44 |
| Workpiece diameter, $d$, MM  | 40   | 45   | 50   | 55   | 60   |
| Contact area, $F_k$ (mm$^2$) | 5.30 | 5.38 | 5.44 | 5.50 | 5.68 |

As a result of orbital burnishing modeling, it was found that the plastic indent has an elliptical shape, which changes the main axes direction with the working tool rotation. The tool inclination shifts the material in the external load direction. This results not only in the material compression, as in a conventional SPD, but also in structural refinement.

With the working tool inclination angle increase, the surface contact area increases, which leads to a decrease in the contact pressure. With a decrease in the inclination angle the contact pressure increases, but the shear process is reduced.

4. Conclusion

Calculations proved that the working tool inclination angle, orbital rotation radius and penetration depth have the most significant effect on the contact spot size and area during orbital burnishing. The working tool radius and the workpiece diameter are of less significance. With an angle increase from 0° to 60°, the spot width $2b$ increases by 2.5 times, the spot length $2a$ increases by 3 times and the contact area increases by 6.5 times. With the workpiece diameter increase from 40 to 60 mm, the contact area increases by 1.1 times.

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