

# Burnishing tool actuators and their influence on the burnishing force components

**Yu Chervach, A Kim and D Dorzhiev**

Tomsk Polytechnic University, 30, Lenina ave., Tomsk, 634050, Russia

E-mail: juri@chervach.com

**Abstract.** The article presents the results of studies on measuring components of force of diamond burnishing of surfaces with variable radius of curvature. The impact of structural elements of burnishing tools of different types on components of burnishing force was analyzed. The impact of different actuators of burnishing tools on components of burnishing force was analyzed. The design of the burnishing tool with an air receiver (bellows with compressed air as an actuator) with a parallelogram-type mounting of the indenter on the four flat posts, which ensures burnishing of profiled and other types of surfaces with constant radial force, was proposed.

## 1. Introduction

Cold working processes, which are used to increase fatigue strength, contact endurance, wear resistance and corrosion resistance of mechanical components, to increase equipment durability, are the simplest and most effective methods of finishing-hardening treatment [1, 2].

One of the simple processes of cold working, in terms of manufacturing, is diamond burnishing which uses a diamond crystal, held in a special holder, as a deforming element. The diamond indenter is clamped in a special device which is installed in the tool post of a lathe. The pressure of burnishing with elastic contact is usually created by using a calibrated spring, which provides burnishing force  $P_y$ .

## 2. Experimental procedure

It should be noted that a selection of the burnishing parameters – radius of the spherical diamond indenter  $R_{sp}$ , feed rate  $S$  and burnishing force  $P_y$  – depends on the purpose of the workpiece surface treatment, whether it is in ensuring optimal degree of surface layer work hardening, optimal surface roughness or in achieving a compromise between the above-mentioned parameters. This selection is most frequently carried out experimentally using samples of materials from which manufactured components are made. The radius of the diamond indenter is preliminary chosen with respect to the initial hardness of the workpiece material and the desired rate of work hardening. Experimentally found optimal burnishing force  $P_y$  should remain constant or have very small deviations during the burnishing process. Slight deviations of burnishing force  $P_y$  lead either to a lack of hardening or to over hardening of the surface layer. Also, deviations of burnishing force  $P_y$  lead to increased surface roughness compared to the smallest value  $Ra_{min}$ , obtained by burnishing with optimal force.

The designs of tools used for diamond burnishing [3, 4] – dynamometric (flat spring is used as an actuator), spring-actuated (coil spring is an actuator), hydraulic (energy of the fluid compressed in the hydraulic cylinder is an actuator), etcetera – have a number of drawbacks which lead to significant fluctuations of burnishing force  $P_y$  during the burnishing operation.



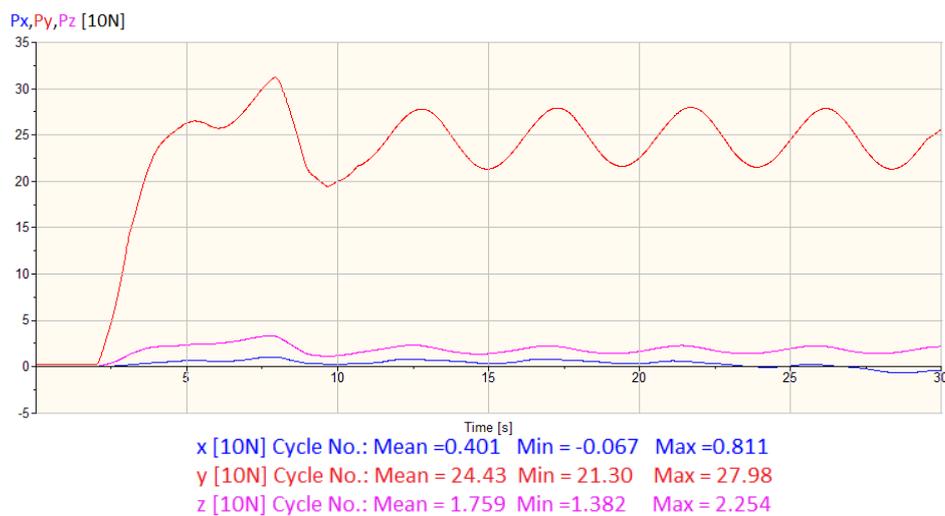
### 3. Results and Discussion

The use of the dynamometric burnishing tool (Figure 1) is possible with the accurate mounting of the workpiece on the machine tool or in case diamond burnishing is performed immediately after finishing machining in a single setup.



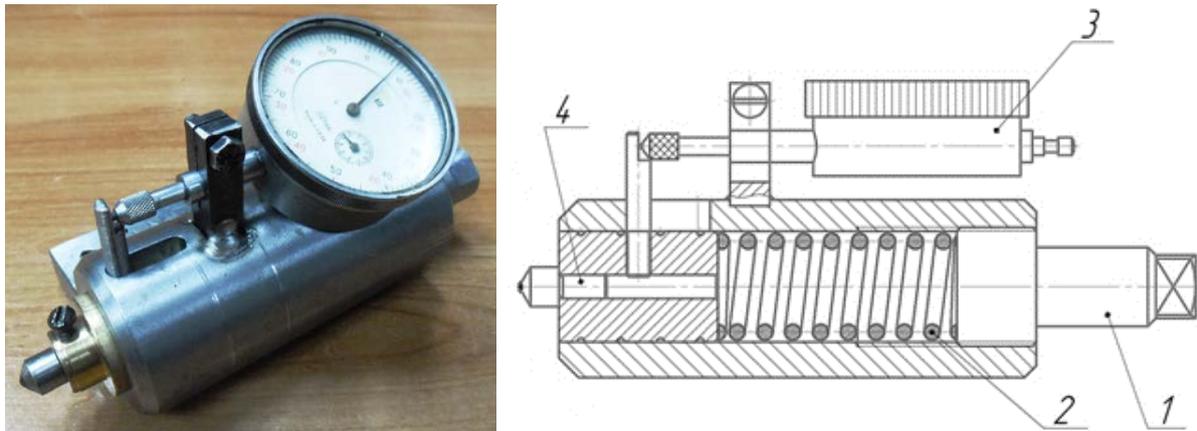
**Figure 1.** Dynamometric burnishing tool (an actuator is a flat spring with a vibration damper).

Sinusoidal change of the radial burnishing force  $P_y$  (Figure 2) shows that the  $\Delta P_y$  depends only on flat spring constant  $k$  (N/m) and radial run-out of the workpiece surface. For comparative experiments, cylindrical samples of 30 mm in diameter made of steel 12H18N10T (0.12% C, 18% Cr, 10% Ni, 1% Ti) GOST 5949-75 were prepared. Radial run during burnishing of the samples was equal to 0.2 mm. Burnishing force components were measured with a KISTLER three-component dynamometer Type 5233A1.

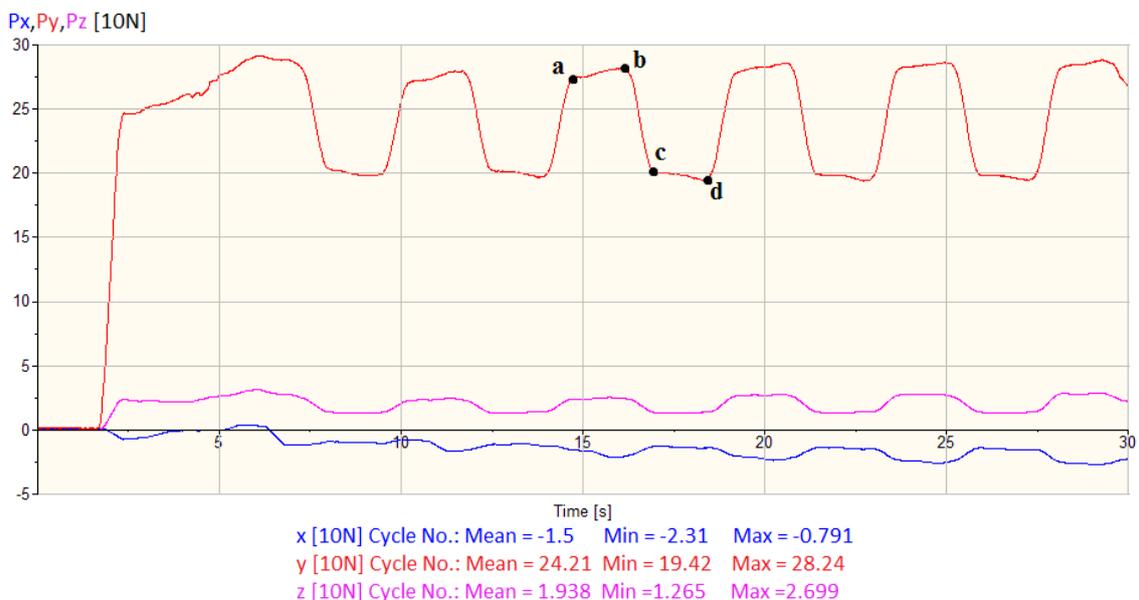


**Figure 2.** Relationship between burnishing force components  $P_y$ ,  $P_x$  and  $P_z$  (kN) and time  $T$  (s) during burnishing with a dynamometric tool with a flat spring. Burnishing parameters: radius of the indenter  $R_{sp}=2$  mm; feed rate  $S=0.05$  mm per rev.; burnishing speed  $v\approx 0.02$  m/s; angular velocity  $\omega=1.3$  s<sup>-1</sup>.  $\Delta P_y\approx 67$  N.

Burnishing with a coil spring tool (Figure 3) of samples mounted with 0.2 mm radial run-out as well as surfaces having substantially smaller radial run-out showed a completely different behavior of the radial force (Figure 4), compared to burnishing with a dynamometric burnishing tool equipped with a flat spring.



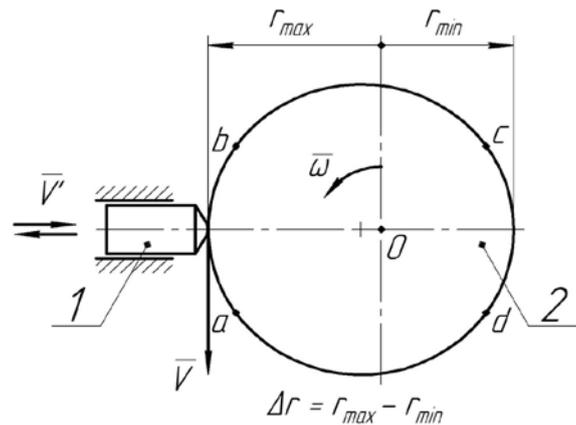
**Figure 3.** Spring-actuated burnishing tool (coil spring is an actuator): 1 – adjusting screw; 2 – coil spring; 3 – dial indicator; 4 – indenter.



**Figure 4.** Relationship between burnishing force components  $P_y$ ,  $P_x$  and  $P_z$  (kN) and time  $T$  (s) during burnishing with a coil spring actuated tool. Burnishing parameters: radius of the indenter  $R_{sp}=2$  mm; feed rate  $S=0.05$  mm per rev.; burnishing speed  $v\approx 0.02$  m/s; angular velocity  $\omega=1.3$  s<sup>-1</sup>.  $\Delta P_y\approx 88$  N.

The evident saw-toothed curve for  $P_y=f(S)$ , as well as  $P_x=f(S)$  and  $P_z=f(S)$  is, most likely, caused by mechanical sticking (seizure) in the precision reciprocating plunger coupling under dry friction conditions. The use of recommendations to reduce the seizure during the reciprocating movement of the plunger, such as pressure lubrication, rotation of the plunger relative to the cylinder of the tool in the process of burnishing, burnishing with external vibrations of different frequency and amplitude, have not changed the nature of dependence  $P_y=f(S)$  and only partially reduced the amplitude of the oscillations of force  $P_y$ . The value of  $\Delta P_y$  depends not only on coil spring constant  $k$  (the change in the length of the spring by the amount of radial run-out  $\Delta r=r_{max}-r_{min}$ ), but also on the conditions of the indenter movement over the workpiece surface (Figure 5) and, consequently, on the micro-displacement of the plunger relative to the cylinder of the burnishing tool (motion of the indenter across the surface with the largest radius – from point  $a$  to point  $b$  and across the surface with the

smallest radius – from point *c* to point *d*). If sticking of the reciprocating plunger coupling is eliminated from the process of burnishing with a coil spring burnishing tool, then the dependence of  $P_y=f(S)$ , shown in Figure 4, takes the form of the curve obtained during burnishing with a flat spring burnishing tool. In these cases, the nature of the force  $P_y$  behavior is virtually the same, and depends only on the elastic bending deformations of the flat spring material (Figure 2) or on the elastic torsion deformations of the coil spring. The difference in form of the dependences shown in Figure 2 and 4 is only caused by the process of plunger sticking during micro-displacements.



**Figure 5.** Movement of an indenter on the surface with radial run-out (eccentric surface). 1 – indenter; 2 – surface being burnished.  $V$  – burnishing speed, m/s;  $V'$  – sliding speed of an indenter with a plunger relative to the body of the burnisher;  $\omega$  – angular velocity of the workpiece,  $s^{-1}$ .

The analysis of results of burnishing surfaces with radial run-out of up to 0.01...0.02 mm with a coil-spring burnishing tool showed that variation of burnishing force  $\Delta P_y$  is caused, to a large extent, by sticking in the reciprocating plunger coupling. It can be concluded that the use of spring-actuated burnishing tools with reciprocating sliding elements for plain and profiled burnishing will lead to variable burnishing force  $P_y$ , and a non-uniform process of surface layer hardening. The increase in burnishing speed may cause self-oscillation of the system 'indenter-part'.

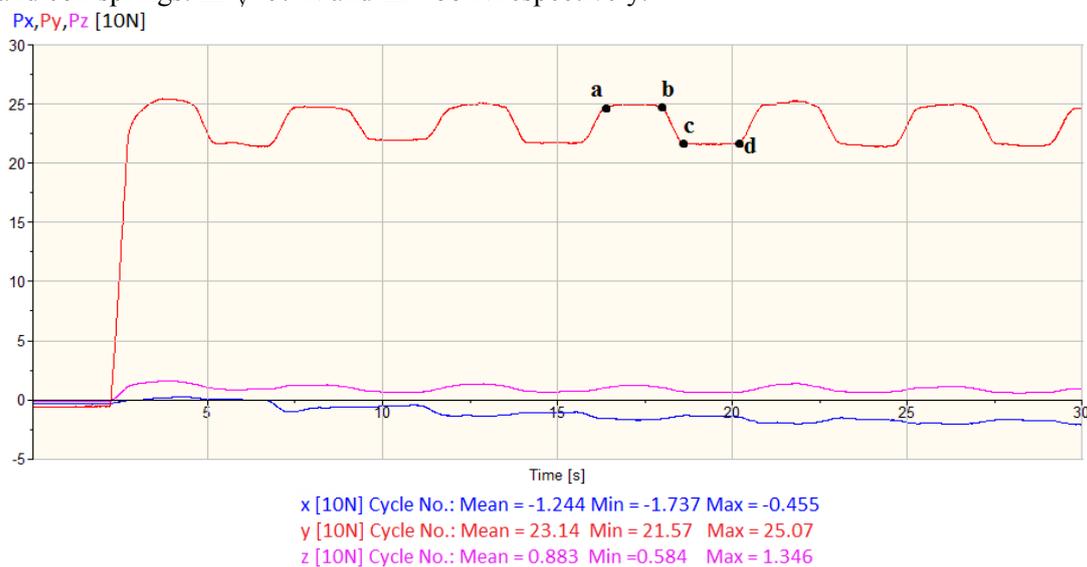
The task of burnishing force  $P_y$  stabilization is particularly acute in burnishing complex profiled surfaces of revolution with variable radius of curvature in both the longitudinal and transverse direction relative to the axis of rotation. The tool for hardening rope thread of drill rods [5, 6] (Figure 6) enables diamond burnishing with speed of about 2 m/s without resonance effects inherent to the tools with flat or coil springs. A pneumatic spring, which is a bellows, is used as an actuator in this burnishing tool. The pressure in the bellows is measured with a pressure gauge. A pneumatic burnishing tool is specially designed for burnishing surface of rope thread R32–R38 with constant burnishing force  $P_y$ .



**Figure 6.** Pneumatic burnishing tool with a receiver (bellows with compressed air is an actuator).

However, the limited volume of the bellows used in the tool leads to the fact that the radial run-out of the surface during burnishing (run-out is approximately 3 mm for thread R38) causes a pressure change in the bellows and, consequently, change in the burnishing force  $P_y$  value. In order to stabilize burnishing force, the system of ‘indenter-bellows’ is equipped with a receiver, which can significantly reduce the pressure fluctuation in the bellows due to the increased volume of compressed air. The volume of a receiver is more than 10 times as big as the volume of the working chamber of the bellows.

The special elements of the pneumatic tool design had to provide constant burnishing force  $P_y$  even with large run-out of the workpiece surface, since the volume change of the bellows is small in relation to the volume of the receiver, a change in pressure in the bellows and thus change in burnishing force is also small. A trapezoidal shape of curves  $P_y=f(S)$ ,  $P_x=f(S)$  and  $P_z=f(S)$ , as shown in Figure 7, leads to the conclusion that the change in  $P_y$  is directly related only to sticking of the plunger reciprocating pair of friction. It should be noted that burnishing force fluctuation  $\Delta P_y \approx 35$  N in burnishing with a pneumatic tool is significantly smaller than the fluctuation during burnishing with flat and coil springs:  $\Delta P_y \approx 67$  N and  $\Delta P \approx 88$  N respectively.



**Figure 7.** Relationship between burnishing force components  $P_y$ ,  $P_x$  and  $P_z$  (kN) and time  $T$  (s) during burnishing with a pneumatic tool equipped with a receiver (bellows with compressed air is an actuator). Burnishing parameters: radius of the indenter  $R_{sp}=2$  mm; feed rate  $S=0.05$  mm per rev.; burnishing speed  $v \approx 0.02$  m/s; angular velocity  $\omega=1.3$  s<sup>-1</sup>.  $\Delta P_y \approx 35$  N.

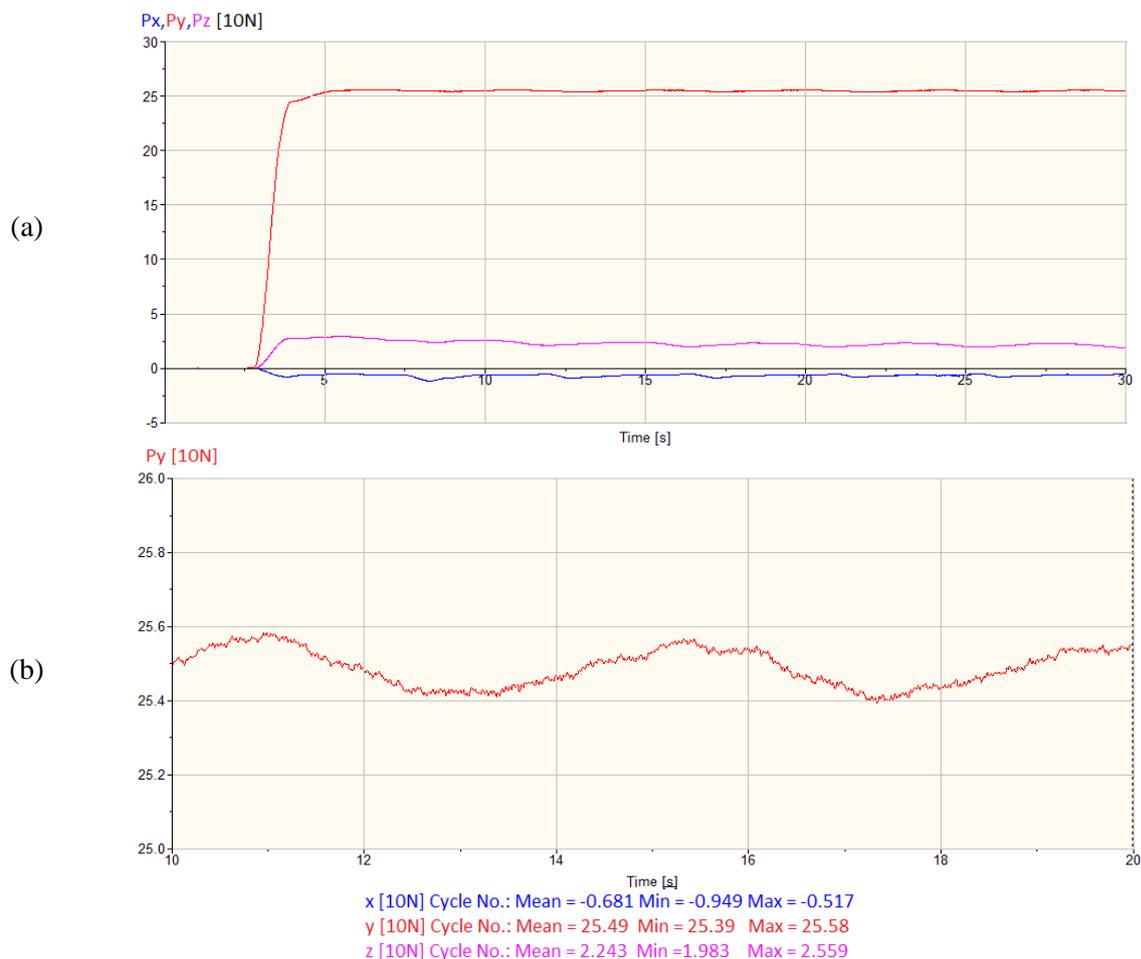
To stabilize force  $P_y$  during burnishing of profiled surfaces and surfaces of the components mounted on the machine with a relatively large radial run-out, it was necessary to completely eliminate the reciprocating and rotational pairs of friction, as well as pairs of rolling friction in the design of the burnishing tool. It was supposed to use a well-proven pressure-regulated ‘bellows-receiver’ system as an actuator. Mounting of the indenter should ensure its free movement in the ‘y’ direction with respect to the frame, and restrict its movement in orthogonal directions ‘x’ and ‘z’ under influence of force components  $P_x$  and  $P_z$ .

According to these requirements, a pneumatic burnishing tool with an air receiver (actuator is a bellows with compressed air) and a parallelogram-type mounting of the indenter on four flat posts was designed (Figure 8).

The measurement of burnishing force components  $P_y$ ,  $P_x$  and  $P_z$  during burnishing of eccentrically mounted parts, showed almost complete absence of variation of force  $\Delta P_y \approx 1.9$  N in comparison with other types of burnishing tools (Figure 9a). The burnishing of profiled surfaces, such as rope thread R32, has shown that the design of the burnishing tool ensures a process with constant burnishing force.



**Figure 8.** Pneumatic burnishing tool with a receiver (actuator is a bellows with compressed air) and a parallelogram-type mounting of the indenter on four flat posts.



**Figure 9.** Relationship between burnishing force components  $P_y$ ,  $P_x$  and  $P_z$  (kN) and time  $T$  (s) during burnishing with a pneumatic tool equipped with a receiver (bellows with compressed air is an actuator) and a parallelogram-type mounting of the indenter on four flat posts. Burnishing parameters: radius of the indenter  $R_{sp}=2$  mm; feed rate  $S=0.05$  mm per rev.; burnishing speed  $v\approx 0.02$  m/s; angular velocity  $\omega=1.3$  s<sup>-1</sup>.  $\Delta P_y \approx 1.9$  N.

Figure 9b shows an enlarged part of dependence  $P_y=f(S)$  at a steady motion: force fluctuation smoothing is about 2 N with  $P_y \approx 250$  N, which is less than 1%. The shape of the curves almost completely corresponds to the shape of the curve shown for the dynamometric burnishing tool: fluctuation of force  $P_y$  is associated with axial elastic deformation of the bellows as a metal spring, and elastic bending deformations of the four flat posts.

#### 4. Conclusion

The investigations of force dependences of diamond burnishing of parts mounted on machine tools with the radial run-out (or burnishing of profiled surfaces) with burnishing tools equipped with different actuators and special elements show that force components fluctuations depend not only on the rigidity and type of the actuator, but also on non-uniform movement in pairs of friction.

The extensive use of diamond burnishing tools with reciprocating pairs of friction requires a very accurate mounting of workpieces prior to burnishing or implementation of a finishing-hardening operation immediately after a preceding operation in the same setup.

Design features of a pneumatic burnishing tool with a receiver (actuator is compressed air in bellows) and a parallelogram-type mounting of the indenter on four flat posts ensure burnishing of surfaces with an intricate profile and surfaces of parts mounted with the relatively large radial run-out with constant burnishing force  $P_y$ . The actuator and special design features of the tool make it possible to perform burnishing at high speeds without causing oscillations in the 'indenter-burnished surface' system.

#### References

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