CIRP Annals - Manufacturing Technology xxx (2018) xxx–xxx

Contents lists available at ScienceDirect

CIRP Annals - Manufacturing Technology

journal homepage: http://ees.elsevier.com/cirp/default.asp

Truing of diamond wheels – Geometry, kinematics and removal mechanisms

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ARTICLE INFO

Keywords:
Abrasive
Diamond
Truing

ABSTRACT

An investigation is made into traverse truing of diamond grinding wheels using various truing grit types, grit sizes and truing parameters. Geometry and kinematics of the truing contact are modeled. Specific energies are found to depend on truing-grit size but not on truing parameters, indicating little to no size effect. Removal mechanisms are analyzed via SEM examination of diamond- and truing-wheel swarf. A fundamental relationship is established relating the truing compliance number to the truing efficiency, which encompasses truing parameters and truing- and diamond-grit sizes. Recommendations are made for optimum conditions to minimize force-constrained truing time.

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1. Introduction

Diamond grinding wheels are typically used to grind hard materials such as tungsten-carbide/cobalt [1], cermets [2], ceramics [3], PCBN [4] and PCD [5]. Because of diamond's extreme hardness, truing of diamond wheels is challenging. While methods such as wire-EDM [6] and brittle-bond crush dressing [7] are sometimes used, the most common method is traverse truing with a vitrified-bond silicon-carbide (SiC) or aluminum-oxide (Al_2O_3) wheel. This is a long process, which consumes large quantities of truing-wheel abrasive. Unfortunately, very little research has been reported about the fundamentals of truing. Some general guidelines on truing-grit size and abrasive type have been given in handbooks [8] and in catalogues by grinding-wheel manufacturers. However, these reports do not give any information on how these recommendations were arrived upon, nor on the fundamental mechanisms of material removal when the truing-wheel abrasive contacts the diamond. The present study was undertaken to advance the state of knowledge of the truing geometry, kinematics and removal mechanisms. The next step is to explore the effect of truing on grinding performance, particularly truing's effect on cutting-point density [9].

2. Mechanics of diamond wheel truing

Truing involves removing a portion of the diamond grinding wheel using an Al_2O_3 or SiC truing wheel. The consumption of the truing wheel (acting as a "tool") is much larger than the consumption of the diamond wheel (acting as a "workpiece"). While the mechanics of this process is similar to dressing of grinding wheels with a traverse diamond disc, in diamond-wheel truing the roles of the "tool" and the "workpiece" are reversed.

2.1. Truing geometry and kinematics

Truing is performed by traversing a truing wheel at a specified truing depth, a_T, and truing traverse velocity, $v_{fa,T}$, with infeed before both the forward and the reverse stroke. In a typical process configuration, the depth of diamond-wheel successfully removed is only a small fraction of the truing depth (1–20%). Consequently, a large number of truing passes is required and a stepped taper develops on the diamond wheel, as shown in Fig. 1.

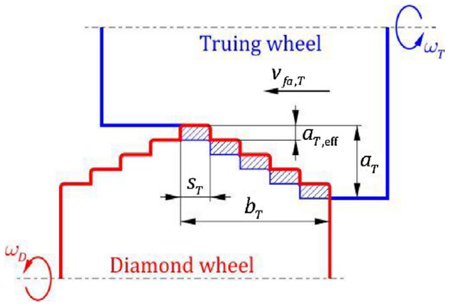

Fig. 1. Traversing of truing wheel with resulting stepped taper.

For a given circumferential truing wheel velocity, $v_T = r_{T0}\omega_T$, where r_{T0} is the truing-wheel radius and ω_T is the truing-wheel angular speed, the truing lead is calculated by:

$$s_T = 2\pi r_{T0} v_{fa,T}/v_T. \tag{1}$$

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https://doi.org/10.1016/j.cirp.2018.04.091
0007-8506/© 2018 Published by Elsevier Ltd on behalf of CIRP.

Please cite this article in press as: Dražumerič R, et al. Truing of diamond wheels – Geometry, kinematics and removal mechanisms. CIRP Annals - Manufacturing Technology (2018), https://doi.org/10.1016/j.cirp.2018.04.091

The truing overlap ratio can then be determined as:

$$U_T = b_T/s_T \; , \tag{2}$$

where b_T is the truing width. For a fixed a_T and stepped taper, the effective truing depth at every point of the truing width, similar to peel-grinding [8], is calculated as:

$$a_{T,\text{eff}} = a_T/U_T \; . \tag{3}$$

The truing geometry and kinematics are illustrated in Fig. 2. Because the truing depth is much smaller than the size of the wheels, the geometrical and kinematical models can be given in linearized form with respect to truing depth.

The derivation of truing kinematics assumes a relative movement of the diamond wheel around a fixed truing wheel. The truing kinematics is determined by the relative velocity vector, $v(s)$, where s is the arc length of the contact. The relative velocity vector comprises the relative truing velocity vector, $v_T(s)$, and the relative diamond velocity vector, $v_D(s)$, calculated as:

$$v_T(s) = v_T(-s/r_{T0}, 1) \; , v_D(s) = -v_D(s/r_{D0}, 1) \; , v(s) = v_T(s) + v_D(s) \; , \tag{4}$$

where $v_D = r_{D0}\omega_D$ is the diamond-wheel circumferential velocity, r_{D0} is diamond-wheel radius, and ω_D is diamond-wheel angular speed. The process can be performed either in uni-directional mode (represented by a positive v_D) or anti-directional mode (represented by a negative v_D), as shown in Fig. 2.

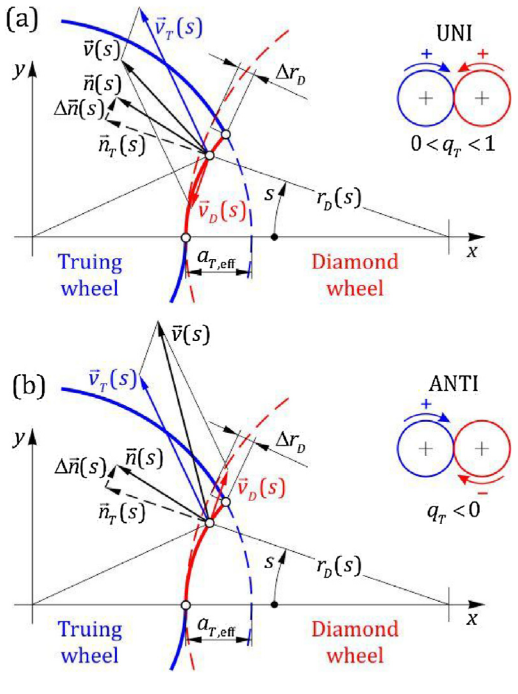

Fig. 2. Truing geometry and kinematics: uni-directional (a) and anti-directional (b).

Considering the truing kinematics, the material removal rate, Q, can be calculated by integrating the normal component of $v(s)$ over the contact surface, as:

$$Q = b_T \int_0^{l_c} v(s) \cdot n(s) \mathrm{d}s = Q_T + Q_D \; , \tag{5}$$

where $l_c = \sqrt{2r_{eq}a_{T,\text{eff}}}$ is the contact length and $r_{eq} = r_{T0}r_{D0}/(r_{T0} + r_{D0})$ is the equivalent radius. The material removal rate consists of the material removal rate of the truing wheel, Q_T, and the material removal rate of the diamond wheel, Q_D. In order to determine both individual rates, the normal vector, n (s), is expressed by: (1) the normal to non-consumed diamond wheel, n_T (s); and (2) the change of this normal due to the diamond wheel consumption, Δn (s); these are calculated as:

$$n_T(s) = (-1, s/r_{D0}) \; , \Delta n(s) = (0, -\mathrm{d}r_D(s)/\mathrm{d}s) \; , n(s) = n_T(s) + \Delta n(s) \; , \tag{6}$$

where $r_D(s)$ is the instantaneous radius of the diamond wheel (Fig. 2). With this approach, the material removal rate of the truing wheel can be calculated by:

$$Q_T = b_T \int_0^{l_c} v(s) \cdot n_T(s) \mathrm{d}s = b_T v_T a_{T,\text{eff}} \; , \tag{7}$$

while the remainder of Q belongs to the material removal rate of the diamond wheel:

$$Q_D = b_T \int_0^{l_c} v(s) \cdot \Delta n(s) \mathrm{d}s = b_T |v_T - v_D| \Delta r_D \; , \tag{8}$$

where Δr_D is the reduction of the diamond wheel radius in the truing contact (Fig. 2).

In the truing experiments, the main output parameter is the truing ratio, G_T, which is defined as the ratio between the consumed volume of the diamond wheel, ΔV_D, and the consumed volume of the truing wheel, ΔV_T:

$$G_T = \Delta V_D/\Delta V_T = Q_D/Q_T = |1 - q_T| \Delta r_D/a_{T,\text{eff}} \; , \tag{9}$$

where $q_T = v_D/v_T$ is the truing speed ratio, which has $0 < q_T < 1$ values in uni-directional truing and $q_T < 0$ in anti-directional truing. However, to capture the mechanics of the process, a new parameter, the truing efficiency, η_T, is introduced, which accounts only for the geometry of the truing interface, calculated by:

$$\eta_T = \Delta r_D/a_{T,\text{eff}} = G_T/|1 - q_T| \; . \tag{10}$$

The truing efficiency is associated with the aggressiveness number of the truing process as:

$$Aggr = \frac{10^6}{l_c} \int_0^{l_c} \frac{v(s) \cdot n(s)}{\sqrt{v(s) \cdot v(s) - \left(v(s) \cdot n(s)\right)^2} \mathrm{d}s} = \frac{10^6}{|1-q_T|} \sqrt{\frac{a_{T,\text{eff}}}{2r_{eq}}} \; . \tag{11}$$

The aggressiveness number, *Aggr*, is a dimensionless parameter that is defined as the average of the ratio between the normal and the tangential components of the relative velocity vector in the truing contact. It is proportional to the radial penetration depth of the diamond grit. *Aggr* is well established in grinding [10,11] and in diamond-wheel stick conditioning [1], but has also been used indirectly in rotary dressing as the interference angle [12].

2.2. *Specific truing energy and truing shear*

The study of truing removal mechanisms is based on truing power analysis. The relation between the truing power, P_T, the tangential truing force, F_T, and the circumferential velocities is:

$$P_T = F_T |v_T - v_D| \; . \tag{12}$$

The characteristic parameter for the analysis, obtained from P_T, is the specific truing energy, e_T, which is the energy expended in removing a unit volume of truing wheel, calculated as:

$$e_T = P_T/Q_T = F_T |1 - q_T| \sqrt{2r_{eq}/a_{T,\text{eff}}}/(b_c l_c) \; . \tag{13}$$

While recognizing that the specific truing energy also accounts for the material removal rate of the diamond wheel, the latter is much smaller than the material removal rate of the truing wheel. Therefore, only Q_T is taken into account in the denominator.

Finally, the mechanics of the truing process can be characterized by the average truing shear:

$$\tau_T = F_T/(b_c l_c) = e_T Aggr/10^6 \; , \tag{14}$$

combining the specific truing energy (Eq. (13)) with the aggressiveness number (Eq. (11)).

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