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Grinding forces in regular surface texture generation

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Abstract

Certain grinding operations need a specially shaped wheel for regular surface texture (RST) generation. In such cases, wheel nominal active surface is reproduced on the ground surface in a special way. The simple version of the method consists in grinding with the wheel having helical grooves which are deeper than the grinding depth. Pattern regularity depends in longer time on wheel wear. The grinding force is thus one of the most important process indicators. A simulation model of grinding process, assuming random arrangement of abrasive grains was developed and is presented in this paper. The model was verified by grinding force measurements. These measurements showed specific features that were different from those characteristic of conventional grinding. Explanations of the untypical effects observed at force–time series signals for the three basic types of surface patterns are provided.

Keywords: Grinding; Simulation model; Force measurement; Regular surface texture

1. Introduction

Surfaces having local, regular groove cavities arranged in a regular way show many advantageous features, regarding mainly tribological effects. The main features of regular surface texture (RST) are: reduction of fluid and boundary friction coefficients, absorption of small hard particles from the lubricant, reduction of residual stress and shape deviation, better leak-tightness of static and dynamic couplings and better adherence of coating and adhesive bonds. RST may be generated by several methods: precise diamond turning [1], rolling [2], embossing [3,4], etching [5,6], vibrorolling [7], abrasive jet machining [8] and EDM [9]. Many recent papers [10–15] have demonstrated impressive results using laser surface texturing. ‘‘Pattern grinding’’ with the wheel shaped in a special way was first presented in 1989 [16] as a simple, cheep and productive alternative to better known methods of RST generation. The practical application of ‘‘pattern grinding’’ for shaping ceramic discs of gas lubricated, self-acting thrust bearings was demonstrated [17] in 1994.

The effect of coarse dressing on ground surface topography has generally been described [18–22] as a grinding fault. However, it is possible to generate RST by a controlled grinding process with the wheel shaped in a particular way [23,24]. The wheel circumference may have, for example, deep helical grooves of h depth which are deeper than the grinding depth d. The v_w:v_s ratio should be great enough to prevent any changes to the nominal dimensions of the resultant surface. Such a process generates regularly arranged grooves separated from each other. A schematic view of the wheel surface reproduction is given in Fig. 1 for two variants of the method. The third variant involves grinding with the wheel having a single helical groove in two reverse passes of the work material. Examples of the three basic types of RST are given in Fig. 2.

The grooves on the work material are generated without sparking out in a single pass of the wheel by many individual grains. The roughness of the groove bottoms reaches high values (up to $R_a = 5\,\mu m$) while the roughness of the nominal surface of the work material does not change. The rough bottoms of the grooves increase lubricant and coating adherence. All types of RST, presented in Fig. 2, show better wear resistance as small, hard debris and contaminants coming form the lubricant

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Nomenclature

A	cross-section area of an undeformed chip
a	undeformed chip thickness
c	length of rectilinear segment of wheel cross section
C_A	mean number of cutting edges per wheel surface unit
C_n, C_t	coefficients of normal and tangential force components for a single grain
d	grinding (groove) depth
f_d	dresser feed rate (pitch of helical groove)
F_n, F_t	normal and tangential grinding force components
f_n, f_t	specific normal and tangential grinding force components per 1 mm of the wheel height
F_{ng}, F_{tg}	normal and tangential grinding force components for a single grain
F_{nm}, F_{tm}	normal and tangential grinding force components for wheel module
F_{ns}, F_{ts}	normal and tangential grinding force components for wheel elementary slice
h	height of a helical groove (dressing depth)
H	wheel height
H_a	wheel active height
l	length of a groove
L	longitudinal pitch of grooves shaped on work-material
l_c	nominal length of the wheel-work material contact zone
l_g	mean directional distance between adjacent cutting edges
m, u	shape and scale parameters of the Weibull distribution
n	number of cutting edges generated at a single elementary slice
n_A	number of active grains generated for a single elementary slice
n_n, n_t	exponents of normal and tangential force components for a single grain
n_{PA}	number of potentially active grains for a single elementary slice
n_s	wheel rotational speed
r	radius of imaginable wheel, rolling without slip along rolling line $r = R\,(v_w/v_s)$
R	wheel radius
r_D	radius of diamond dresser tip
s	number of elementary slices for one wheel module
T	time of one wheel rotation
T_F	time period of force periodicity
T_{ns}	nominal (maximal) contact time for wheel elementary slice
v^*	ratio between work material and grinding speed
v_s	grinding speed
v_w	work material speed
$y = f(z)$	general equation of the helical groove profile in axial wheel cross section
α	angular coordinate of cutting edges in polar system
δH	height of elementary wheel slice
Δx, Δy	coordinates of cutting edges
λ	parameter of exponential distribution ($\lambda = 1/l_g$)
$\rho_N(\alpha)$	radius of nominal profile of grinding wheel
φ	angle of wheel rotation
ω	angular speed of grinding wheel

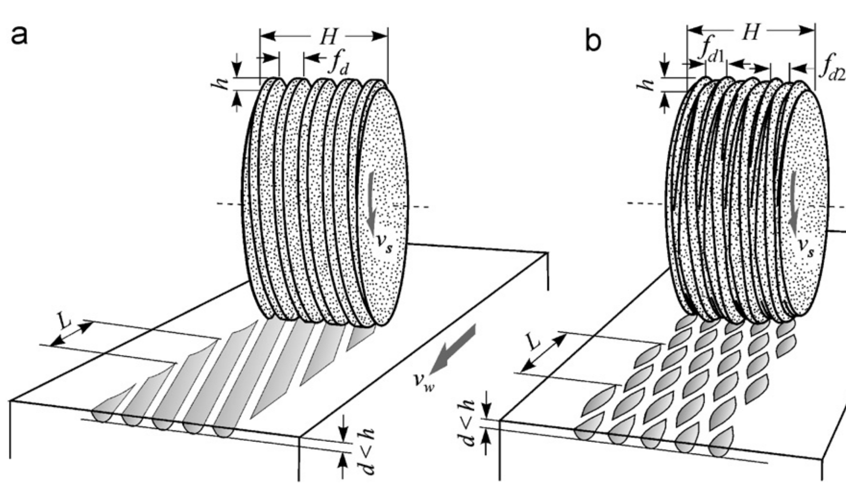

Fig. 1. Schematic views of a grinding with the wheel having single (a) and double (b) helical grooves for shaping regular patterns on a flat surface [17, 24].

can be absorbed in the groove spaces. Hence, the lubricant filtering system can be simplified to capture large pieces of debris only and is thus more productive. Types I and II of RTS are preferred for cases where the lubricant is more contaminated and open-surface structure facilitates the circulation of the lubricant. Type III shows superior results