CIRP Annals - Manufacturing Technology xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

CIRP Annals - Manufacturing Technology

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

Grinding process for profiled texturing

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ARTICLE INFO

Keywords:
Dressing
Grinding wheel
Part texturing

ABSTRACT

Hydrodynamic textures require the production of cavities with a profile composed by two ramps with different angles. This demands the development of a grinding process able to firstly dress such patterns on the wheel surface and later copying them to the workpiece by grinding. Dressing patterns on wheels is a speed critical process, since very fast interpolations have to be performed. Grinding kinematics also influence the obtained geometry. This paper shows the development of a grinding process able to produce profiled workpiece patterns. Simulations and results show good process control and feasibility for industrial application.

1. Introduction

Considering the great amount of energy losses due to friction of internal moving parts in combustion engines, product engineers currently demand alternatives in terms of redesign or downsizing (e.g. camless, three-cylinder engines), as well as wear resistant – low friction – coatings [1–3].

Since about 30% of the viscous losses in a combustion engine are related to the crankshaft, there is a great interest in its bearing optimization. Also, the start-stop technology requires special surface profile/texture able to retain oil in the bearings aiming wear reduction. The enhancement of crankshaft lubrication can be achieved by introducing textures on its bearings. Better pressure distribution, higher oil retention, higher lift forces and optimized oil film thickness are reached by adding micro tailored features at a particular arrangement to the main and pin external diameters [4]. Previous CIRP keynote paper on the manufacturing of freeform optics provides a comprehensive view on process configurations and innovative methods to synchronize tool and workpiece for the production of patterns using a piezo actuator [5]. This extensive work was adapted here for the application in a fast production grinding scheme.

The concept of producing textures by grinding using patterned wheels was first introduced in CIRP in 2010 [6]. In this development a dressing tool with one extra degree of freedom radial to the grinding wheel was used to produce patterns on the wheel surface. These patterns were later copied to the workpiece by performing a synchronized grinding operation. Different types of features could be consistently applied as textures on ground parts.

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http://dx.doi.org/10.1016/j.cirp.2016.04.116
0007-8506/© 2016 CIRP.

The study of process feasibly and its application as a core technology for forged crankshafts of advanced engines has started in 2012, in a partnership with a major global crankshaft manufacturer for high performance engines. One of the first requirements was to control surface roughness inside and outside the texture cavities (or pockets) independently. This was accomplished by developing new grinding strategies and presented as a CIRP contribution in 2013 [7].

Among the surface finishing characteristics and shape (and distribution) of the texture cavities, it is now required that each texture has a specific profile in the circumferential direction. This paper is the third step in the development of a grinding process fully able to control the characteristics of textured surfaces including shape/distribution, roughness and now circumferential profile.

2. Grinding of profiled workpiece textures

Simulations and tests showed that the improvements in the operational parameters of the hydrodynamic radial bearings were extremely higher when featured with micro-ramp structures [4] of generic shape, as shown in Fig. 1.

A desired circumferential pocket profile has to be precisely reproduced in the part during the texturing process by grinding. In particular, the transition between the bottom and the top of each feature in the circumferential direction, which is responsible for the increment in the localized lift force, should be composed by two ramps with different angles α_1 and α_2.

Fig. 2 shows the developed active dressing unit to apply similar pattern production strategy as presented in [6]. Here a diamond-dressing tool is attached to a linear bearing and, now, to a piezo-actuator. The unit is instrumented with a capacitive displacement transducer and an AE sensor connected to a fast RMS amplifier with time constant of about 10 μs. This design is quite rigid and

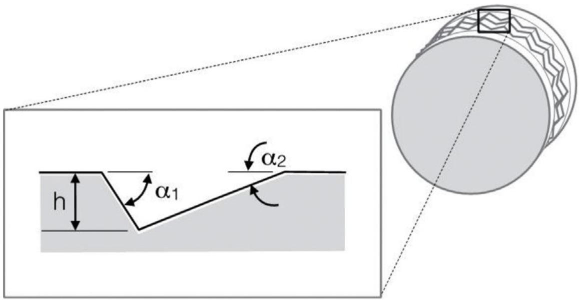

Fig. 1. Generic micro-ramps profile for hydrodynamic radial bearings.

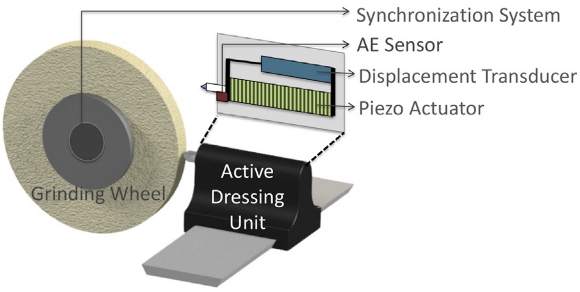

Fig. 2. Active piezo-dressing unit for the production of profiled patterns on the grinding wheel surface.

provides a precise and fast dressing tool movement radial to the grinding wheel.

The dressing system control is performed using an open loop control in an external computer integrated to the machine CNC, where software runs the dressing programme and the acoustic mapping monitoring [8]. The last is used for monitoring the correct pattern features distribution on the wheel surface.

Considering that each pocket shape is firstly generated during the dressing process and later transferred to the part by a synchronized grinding operation, the obtained design details will depend on three main aspects:

- Response of the dressing unit: The interpolation movement between wheel rotation and diamond radial feed is quite fast. Thus, it is important to determine the limits of interpolation speed that can be obtained by the dressing unit.
- Machine/wheel/dressing system response during dressing.
- Deformation in the profile caused by the intrinsic elements of the grinding contact geometry.

For a robust process design, it is important to model, test and simulate these three aspects, allowing the determination of feasible features for a given set of dressing and grinding conditions.

3. Modelling of the texturing process

3.1. Influence of the contact kinematics

Fig. 3 brings a schematic grinding representation of a texture ramp in surface grinding, where a is the depth of cut and h_k is the depth of the texture (Eq. (1)). The wheel is considered as a milling cutter, as proposed by Malkin [9], with cutting points corresponding to the cutter teeth equally spaced at a distance L. Dressing produces the texture angle on the wheel with a linear reduction in its radius. This should result in an increase in the workpiece size of h_k along the segment AA′.

$$h_k = \frac{d_{s1} - d_{s2}}{2} \tag{1}$$

In up-grinding configuration, the last cutting point of the outermost diameter of the grinding wheel (d_{s1}) begins its contact with the workpiece at point A, following the blue curve path to point B, centred in O, with a depth of cut a. Displaced at distance

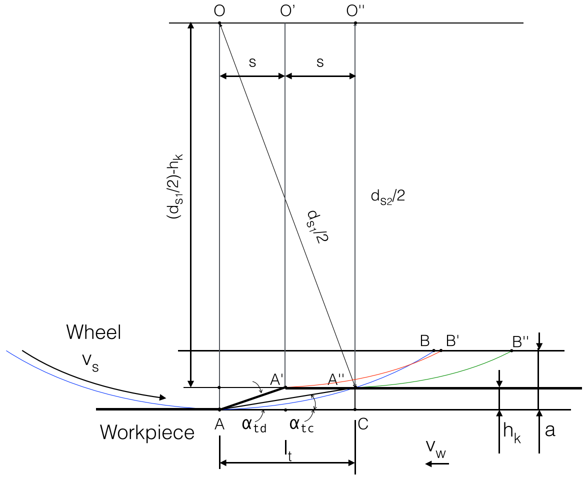

Fig. 3. Schematic representation of the cutting path for an idealized textured wheel.

O–O′, the next cutting point represents the first of the innermost diameter of the grinding wheel ramp (d_{s2}). It describes the red curve path (A′ to B′), but its depth of cut will be between zero and a–h_k. Therefore, in Fig. 3, this grain will not touch the final surface of the workpiece and the desired ramp angle will not be produced. As a result, the cutting edges at the wheel ramp should not touch the workpiece.

The ramp angle α_{td} is a design parameter set in the dressing control software. The obtained ramp angle will be defined after the first grain in the innermost surface able to cut from the point A″. The curve path A″–B″ represents a consecutive cutting point of the innermost diameter, in which a depth of cut equal to a–h_k is removed.

The length of the texture ramp (l_t) and the texture cavity step angle α_t are primary parameters for the cavity design. They are the geometrical constrains for a given wheel and workpiece sizes and kinematic configuration.

Considering the order of magnitude of the wheel diameter and texture depth, the curve path A–A″ can be approximate as a straight line. Thus, the obtained cavity step angle for Fig. 3 is defined by:

$$\alpha_{tc} = \tan^{-1}\left(\frac{h_k}{l_t}\right) \tag{2}$$

Eq. (3) presents the value of l_t similarly to the contact length expression [9]:

$$l_t = (h_k d_{s1})^{1/2} \tag{3}$$

By considering the equivalent diameter (d_e) instead of d_{s1} Eq. (3) can be applied to cylindrical grinding configurations.

So, for design proposes, it will be impossible to produce ramps with ramp angle higher than the critical value α_{tc}. For α_{td} values lower than, or equal to α_{tc}, the resulting angle will be α_{td}.

3.2. System response constrains

The implementation of the texturing process starts with the wheel patterning during dressing. Fast penetration and/or retraction speeds are required. The free dynamic response of the developed active piezo-dressing unit is presented in Fig. 4. The dressing was programmed for a sinusoidal movement of constant amplitude equal to 12 μm. The frequency was linearly varied from a minimum value corresponding to the wheel speed (21 Hz) up to 56 times higher (1200 Hz). It can be seen that the resulting dressing tool displacement (measured with the displacement transducer described in Fig. 2) was highly influenced by the excitation frequency, being nearly constant only for a short frequency interval (up to 107 Hz). The displacement value decreased and reached its minimum at 2.35 μm. System speed