Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 77 (2018) 247–250

www.elsevier.com/locate/procedia

8th CIRP Conference on High Performance Cutting (HPC 2018)

A novel approach to roundness generation analysis in centerless through-feed grinding in consider of decisive parameters of grinding gap by use of 3D kinematic simulation

Mohsen Hassanzadeh Otaghvar[a,b]*, Bernhard Hahn[b], Harald Werner[b], Hesam Omiditabrizi[b,c], Dirk Bähre[a]

[a] *Institute of Manufacturing Technology, Saarland University, Saarbrücken, Germany*
[b] *Robert Bosch GmbH, Bühl, Germany*
[c] *Karlsruhe Institute of Technology, Karlsruhe, Germany*

* Corresponding author. Tel.: +49-176-8426-1254. *E-mail address:* MohsenHassanzadeh.Otaghvar@de.bosch.com

Abstract

Grinding gap geometry based on setup conditions and its effect on roundness generation is a complex phenomenon in through-feed centerless grinding process. The objective of this paper is to introduce a suitable solution for the use of simulation in through-feed centerless grinding, to assist in the selection of acceptable set-up conditions for centerless grinding and their effect on roundness quality. A qualitative assessment of geometrical influence parameters is carried out by means of a kinematics simulation based on a non-linear 3-dimensional model of the centerless grinding process. The novel aspect of the model analysis is the determination of the grinding gap with two new decisive parameters in centerless through-feed grinding and their effect on geometrical rounding stability. The ratio of the finishing to roughing length and ratio of the finishing to roughing material removal rate are crucial to minimize roundness errors.

Keywords: Centerless grinding; Geometrical rounding stability; Simulation

1. Introduction

Centerless through-feed grinding combines quickness and accuracy for the production of rotationally symmetrical parts, particularly in modern automotive and bearing manufacturing industry [1]. Because of the increasing energy efficiency, a requirement is needed to improve the roundness accuracy of the component in high productivity [2]. The grinding with higher quality and productivity in centerless grinding depends on the improvement in the workpiece roundness accuracy [3]. Reeka [4] presented an analytical model to describe the geometric roundness error regeneration process in centerless grinding. König et al. [5] and Meis [6] extended this model to through-feed grinding. Some researchers have extensively studied about stability of the geometric rounding mechanism (Furukawa et al. [7], Bueno et al. [8], Zhou et al. [9, 10], Guo et al. [11], and Gallego [12]). Jauregui-Correa et al. [13] developed a nonlinear model for the analysis of a centerless grinding process dynamic stability. The roundness generation depends mostly on the grinding gap geometry in through-feed centerless grinding [14]. Smaller batch sizes and change of tool geometries during grinding lead to the alignment of the process. Thereby the setup of the process, a variety of setting parameters, complex grinding geometry and workpiece without fixed positions are causes for high loss of time and often depend on the empirical experience of an operator [15].

2212-8271
10.1016/j.procir.2018.09.007

Some researchers have studied the modelling and simulation of the centerless through-feed grinding process. Some of the first investigations were done by Kim [16] and [17], who developed a computer 3D simulation method to investigate the mechanism of cylindrical form generation. In addition, Gallego et al. [18] presented geometric stability chart in through-feed grinding to predict geometry lobing. Krajnik et al. [19] developed a grinding gap model to describe macro geometry at any instant along the grinding gap and also workpiece kinematic. Qi Cui et al. [20] used the Lagrange equation to the determination of the workpiece kinematic and the investigation of the material removal process.

The goal of this research is to analyze the influence of geometrical and kinematical parameters on the roundness generation in a through-feed centerless grinding process. A time domain simulation model is developed by consideration of nonlinear effect. The novel aspect of the model analysis is the determination of the grinding gap with two new decisive parameters, the ratio of the finishing to roughing length (R1) and ratio of the finishing to roughing material removal rate (R2), and their effect on geometrical rounding stability.

Nomenclature

β	centre height angle
δ_r	swiveling angle of regulating wheel
α_r	inclination angle of regulating wheel
R_1	ratio of the finishing to roughing length
R_2	ratio of the finishing to roughing material removal rate

2. Grinding Gap

To be able to configure the model based on setting parameters, the model must be parametrically designed. For this purpose three basic components of the grinding machine for the model have to be defined:

- Regulating wheel
- Grinding wheel
- Workrest blade

An important component of the grinding wheel unit is copying template to define the roughing and finishing zone. To modify the grinding gap, the inclination angle αr and swiveling angle δ_r of the regulating wheel are defined in the model, shown in Fig. 1.

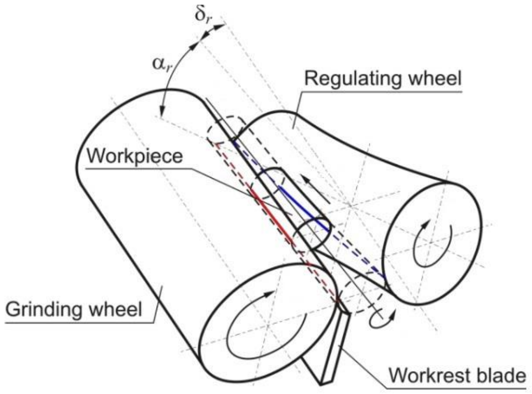

Fig. 1 Geometrical parameters of a grinding gap [19]

The geometry of the grinding gap has to be described to analyse the grinding situation. At the grinding process the workpiece is situated between the regulating wheel and the workrest blade. At the other side the workpiece is machined by the grinding wheel. Thereby a circle with three point contact between regulating wheel, workrest blade and grinding wheel is produced. The swiveling and inclination of the hyperbolic regulating wheel and change of the grinding wheel diameter in through-feed centerless process cause the change of the center height angle and displacement of the workpiece center along the grinding gap. The geometric arrangement of the grinding gap has the most significant influences on the workpiece roundness and forming process.

By ignoring the influence of the machine dynamics on the rounding mechanism and the stable grinding system, the workpiece forming process and rounding mechanism of the centerless grinding process is effected by the geometric arrangement of the grinding gap. In through-feed centerless grinding the material removal situations in different sections are dissimilar. Therefore a kinematic-geometrical simulation of the workpiece forming process in 3D space is required.

3. Kinematics Modell

The kinematic-geometrical simulation is used to calculate the 3D interaction between grinding and workpiece inside the contact zone (penetration calculation), which was developed in MATLAB® Version R2016b from MathWorks. With the simulation it is possible to calculate the variation in depth of cut and workpiece center displacement, while the workpiece has continuous contact with the workrest blade and the regulating wheel. In this simulation the contact deformations are not considered. According to the real process, the actual position and motion of the workpiece can be determined from the workpiece contour and the position of the regulating wheel and support blade. The time domain simulation runs in discrete time steps. In each simulation step the position of the workpiece is first determined, according to the contact between the workpiece, the regulating wheel and the support blade. Then the intersection between the workpiece and the grinding wheel is calculated. The new workpiece contours is generated based on penetration calculation. Finally, a rotary and linear feed based on the regulating wheel diameter and the rotation speed is simulated.

By using the kinematic-geometrical simulation it is possible to separate the geometrical and dynamical effects on the workpiece forming process, to assist in the selection of acceptable geometrical set-up conditions for centerless grinding. The workpiece forming process is studied in 3D geometry with assumptions, as follows:

- The grinding wheel is ideal round and stiff
- The control wheel is ideal round and stiff
- The workrest blade is a perfect plane and stiff
- The grinding system is without any spinning or sliding
- The grinding and regulating wheel and workrest blade are without wear

As a result, the parameters below can be calculated from the workpiece profile in each step along the grinding gap:

- Roundness error in every section of the workpiece
- The amplitudes of lobing order in every section of workpiece

4. Experimental verification for the workpiece forming process

In order to validate the time-domain simulation, an example of a real set-up of the centerless grinding process trial in industrial application is conducted. Grinding experiments were conducted on a CL 660 centerless grinder of UVA Lidköping AB. Process conditions and workpiece requirements are shown in Table 1.

Table 1 Process Condition and workpiece conditions

Process conditions	
Grinding wheel	Vitrified Norton Quantum
Regulating wheel	Rubber bonded
Workrest blade	Cemented carbide (30°)
Grinding wheel speed (rpm)	1730
Regulating wheel speed (rpm)	96
Grinding wheel (mm)	Ø582 × 600
Regulating wheel (mm)	Ø309 × 660
Center height angle β	0°-10°
inclination angle α_r	3°
swiveling angle δ_r	0.16°
Workpiece conditions	
Workpiece (mm)	Ø8.2 × 140
Total removal on diameter (mm)	0.2
Workpiece material	C45 (Hardened 54 HRC)

To verify the simulation model, the simulated and measured workpiece forms are compared together. The measurements were carried out with the MarForm MMQ 100 for measuring the workpiece harmonics and roundness error with a Fourier analysis. The forms of the simulated and measured workpiece are shown in Fig. 2.

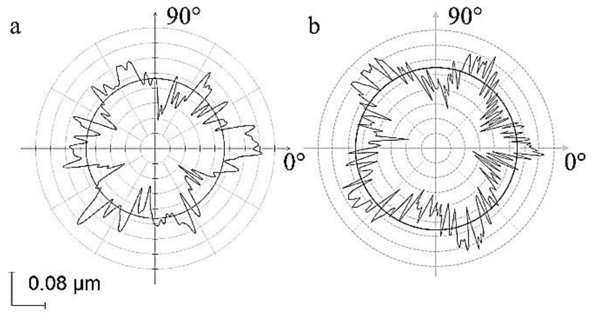

Fig. 2 (a) experiment result, roundness error 0.45µm, amplitudes of lobing order 0.050 µm, (b) simulation result, roundness error 0.58µm, amplitudes of lobing order 0.044 µm

5. Decisive parameter

In through-feed centerless grinding, the length and material removal rate in the finishing and roughing zone are crucial to minimize the roundness errors. In this research, the final roundness errors and the amplitudes of the lobing order under a series of the ratio of the finishing to roughing length (R1) and ratio of the finishing to roughing material removal rate (R2) are investigated. The process conditions for simulations are defined in Table 1 and the grinding gap conditions are listed in Table 2. The final simulated workpiece form with different grinding gap conditions is qualitatively illustrated in Fig. 4.

Table 2 The grinding gap conditions

Trial no.	Roughing length (mm)	Finishing length (mm)	Roughing material removal rate (µm)	Finishing material removal rate (µm)	R_1	R_2
1	300	300	190	10	1	19
2	300	300	175	25	1	7
3	300	300	160	40	1	4
4	350	250	190	10	1.5	19
5	350	250	175	25	1.5	7
6	350	250	160	40	1.5	4
7	400	200	190	10	2	19
8	400	200	175	25	2	7
9	400	200	160	40	2	4

6. Result and Discussion

As shown in Fig. 3, the results of the simulation and grinding trails in the roundness error are very similar. The experimental and simulation results also show that the roundness error with grinding gap conditions R_1=1.5 and R_2=19 is the lowest value (0.58 µm in experimental, 0.61 µm in simulation). The difference between experimental and simulation results is probably caused by the influence of the machine dynamics on the rounding mechanism, that is not considered in the simulation model.

With the increase in the ratio of the finishing to roughing length (R1), the roundness error goes up and so do the amplitudes of lobing order. And with the higher or lower ratio of the finishing to roughing material removal rate (R_2), the roundness error goes up and so do the amplitudes of lobing order. Moreover the roundness error with the grinding gap conditions R_1=2 and R_2=4 is higher than other conditions.

According to Fig. 4 and experimental results, high R_2 value leads to higher amplitudes of lobing order, and on the other hand, low R_2 value leads to form an error at the workpiece.

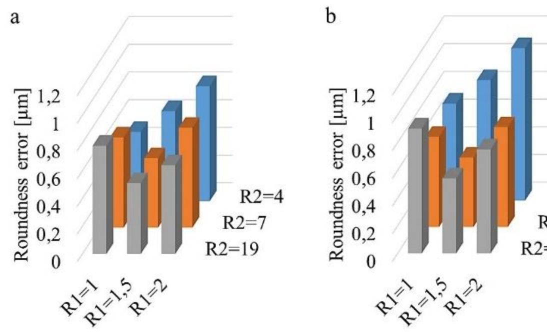

Fig. 3 Workpiece roundness error with different grinding gap conditions (a) experimental (b) simulation

7. Conclusion

In this article, a 3D kinematic simulation of centerless through-feed grinding was developed for the workpiece forming process considering grinding gap geometry. The influence of the ratio of the finishing to roughing length and the ratio of the finishing to roughing material removal rate on the roundness generation are investigated. The research focuses on the workpiece kinematics through simulation on the workpiece forming process and validation using experimentation. The simulation has the capability of predicting the roundness error and the amplitudes of lobing order of the workpiece. The model is adjustable with the real process set-up condition.

Using the new kinematic simulation, the roundness error and the amplitudes of lobing order of the workpiece by considering the different grinding gap conditions were predicted and compared with the experimental results. The accuracy of the 3D kinematic simulation of centerless through-feed grinding was indicated through the good agreement with the experimental results.

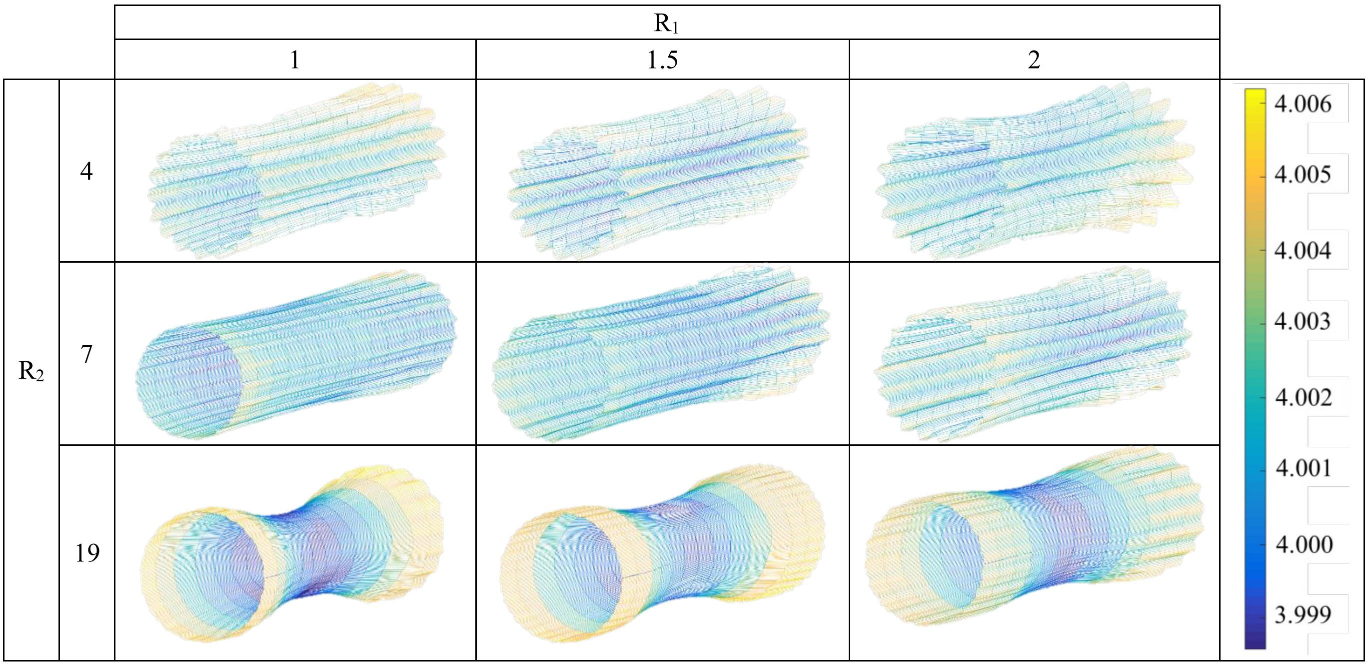

Fig. 4 Workpiece form (radius) with different grinding gap conditions [mm]

References

[1] Krajnik P, Drazumeric R, Vengust I, et al. Simulation of workpiece kinematics in centreless throughfeed grinding. In: Manufacturing systems and technologies for the new frontier: The 41st CIRP conference on manufacturing systems May 26 - 28, 2008, Tokyo, Japan. London: Springer London 2008; 455 - 8.

[2] Cui Q, Ding H, Cheng K. An analytical investigation on the workpiece roundness generation and its perfection strategies in centreless grinding. Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture 2014; 229(3): 409–20

[3] Hashimoto F, Gallego I, Oliveira JF, et al. Advances in centerless grinding technology. CIRP Annals 2012; 61(2): 747–70

[4] Reeka D. On the relationship between the geometry of the grinding gap and the roundness error in centreless grinding: Ph.D. Dissertation RWTH Aachen 1967.

[5] König W, Hönscheid W, Meis FU. Leistungssteigerung beim spitzenlosen Durchlaufschleifen. Wiesbaden: VS Verlag für Sozialwissenschaften 1976.

[6] Meis FU. Geometrische und kinematische Grundlagen für das spitzenlose Durchlaufschleifen: Ph.D. Dissertation RWTH Aachen. Aachen 1980.

[7] Furukawa Y, MIYASHITA M, Shiozaki S. Vibration analysis and work-rounding mechanism in centerless grinding. International Journal of Machine Tool Design and Research 1971; 11(2): 145–75

[8] Bueno R, Zatarain M, Aguinagalde JM, Le Maître F. Geometric and Dynamic Stability in Centerless Grinding. CIRP Annals 1990; 39(1): 395–8

[9] Zhou SS, Gartner JR, Howes TD. On the Relationship between Setup Parameters and Lobing Behavior in Centerless Grinding. CIRP Annals 1996; 45(1): 341–6

[10] Zhou SS, Gartner JR, Howes TD. Lobing Behavior in Centerless Grinding—Part I: Stability Estimation. J. Dyn. Sys., Meas., Control 1997; 119(2): 153

[11] Guo C, Malkin S, Kovach JA, Launch M. Computer simulation of below-center and above-center centerless grinding. Machining Science and Technology 1997; 1(2): 235–49

[12] Gallego I. Intelligent Centerless Grinding: Global Solution for Process Instabilities and Optimal Cycle Design. CIRP Annals 2007; 56(1): 347–52

[13] Robles-Ocampo JB, Jauregui-Correa JC, Krajnik P, Sevilla-Camacho PY, Herrera-Ruiz G. Nonlinear Model for the Instability Detection in Centerless Grinding Process. SV-JME 2012; 58: 693–700

[14] Brecher C, Hannig S. Simulation of plunge centerless grinding processes. Prod. Eng. Res. Devel. 2008; 2(1): 91–5

[15] Klocke F, Friedrich D, Linke B, Nachmani Z. Basics for In-Process Roundness Error Improvement by a Functional Workrest Blade. CIRP Annals 2004; 53(1): 275–80

[16] Kim K. Modeling of the axial movement of parts during centerless through-feed grinding. KSME International Journal 2003; 17(7): 1044–53

[17] Kim K. Modeling of the centerless through-feed grinding process. KSME International Journal 2003; 17(7): 1036–43

[18] Gallego I, Lizarralde R, Barrenetxea D, Arrazola PJ, Bueno R. Precision, Stability and Productivity Increase in Throughfeed Centerless Grinding. CIRP Annals 2006; 55(1): 351–4

[19] Drazumeric R, Krajnik P, Vrabic R, et al. Modelling of grinding gap macro geometry and workpiece kinematics in throughfeed centreless grinding. Journal of Materials Processing Technology 2010; 210(1): 104–9

[20] Qi C, Chen SJ, Ding H, Cheng K. Dynamic Model of Material Removal Process in Through-Feed Centerless Grinding Based on the Lagrange Equation. KEM 2015; 667: 173–80