International Journal of Machine Tools & Manufacture 82-83 (2014) 1–10

Contents lists available at ScienceDirect

International Journal of Machine Tools & Manufacture

journal homepage: www.elsevier.com/locate/ijmactool

Rounding and stability in centreless grinding

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ARTICLE INFO

Article history:
Received 25 February 2014
Received in revised form
17 March 2014
Accepted 26 March 2014
Available online 1 April 2014

Keywords:
Grinding
Centerless
Roundness
Stability
Lobing
Chatter

ABSTRACT

The paper presents a method for selecting grinding conditions and assists researchers to understand the complex dynamics of centreless grinding. It overcomes the problem of deriving dynamic stability charts for particular geometries and difficulty of interpreting such charts to adjust work speed to overcome lobing problems. Classic dynamic stability charts cannot assess stability levels in proximity to integer lobes, a particular problem for centreless grinding. The paper overcomes these problems employing a simply calculated new dynamic stability parameter A_{dyn}. The new parameter A_{dyn} simplifies the optimisation of grinding variables including set-up geometry and work speed in relation to resonant frequency. It is difficult to interpret relative dynamic stability of centreless grinding by classical methods for different set-ups, work speeds and numbers of lobes. A new method is employed in this paper based on the well-established Nyquist stability criterion. The dynamic stability parameter A_{dyn} is based on the real part of the characteristic equation. It is easily computed and presented on a single chart for particular work speed, resonant frequency and for a wide range of numbers of lobes. The method clearly shows the effect on rounding strength both for stable and unstable conditions. Most authors computing dynamic stability charts have ignored positive down boundaries and negative up boundaries showing a lack of a comprehensive treatment for a situation that conflicts with recommendations for conventional positive up boundaries. The new method simplifies this problem.

Small differences in set-up geometry and work speed selection can be easily assessed. The new method can be used as a diagnostic tool for adjusting grinding conditions to overcome roundness problems. The user is not constrained by a historic set-up range since there are practical situations where other set-ups are preferred such as small tangent angles for large and heavy work-pieces, and even negative tangent angle for some types of centreless machine.

Previous research is reviewed to provide an understanding of the need for a new approach to stability. Practical implications are explained for selection of grinding conditions. The method is supported by reference to experimental results.

1. The centreless process

Centreless grinding is used for fast and accurate production. Centre-holes are not required for location since location is provided from the newly machined surface, thus avoiding shape errors associated with centre-holes. Centreless grinding geometry is illustrated in Fig. 1. The work-piece is pushed against the grinding wheel by a control wheel, alternatively known as a regulating wheel. The workpiece is supported on a work-rest. A control wheel controls work-speed by friction.

Fig. 1 shows the set-up geometry employed in centreless grinding. Rounding depends on the anglesα and β [1] where β is the included angle for the grinding wheel and control wheel contact tangents. The workpiece centre is usually set higher than the grinding wheel and control wheel centres to achieve a rounding action. The contact angles depend on work-height h_w and work-rest angle γ where $\alpha=\pi/2-\gamma-\beta_s$ and $\beta=\beta_s+\beta_c$. Angles $\beta_s$andβ_c are given by $\sin\beta_s=2\cdot h_w/(d_s+d_w)$ and $\sin\beta_c=2\cdot h_w/(d_{cw}+d_w)$. It is convenient to write $\beta_s=\nu\cdot\beta$. Typically, for a workpiece 25 mm dia., GW 300 mm dia., CW 178 mm dia., $\beta=7^\circ$ and $\gamma=30^\circ$, $\alpha=57.3^\circ$ and $\upsilon=0.38$.

At best, roundness errors are less than 1 μm deviation between minimum and maximum radii [21,24]. Experimental results in Fig. 2 were obtained grinding work-pieces having a controlled initial error consisting of a flat ground along the length, 9.2 μm deep. The initial error allowed rounding tendencies to be precisely determined and clearly seen. Odd order lobing, 3, 5, 7… lobes, is not easily removed with tangent angle less than 4° and with larger tangent angles there is a danger of higher order even lobing and higher order odd lobing. Optimum tangent angle lies in the range

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http://dx.doi.org/10.1016/j.ijmachtools.2014.03.004
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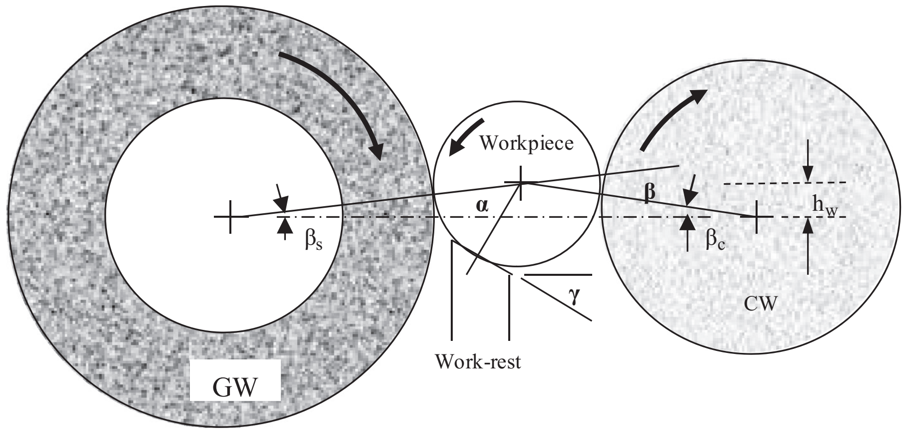

Fig. 1. Centreless grinding geometry.

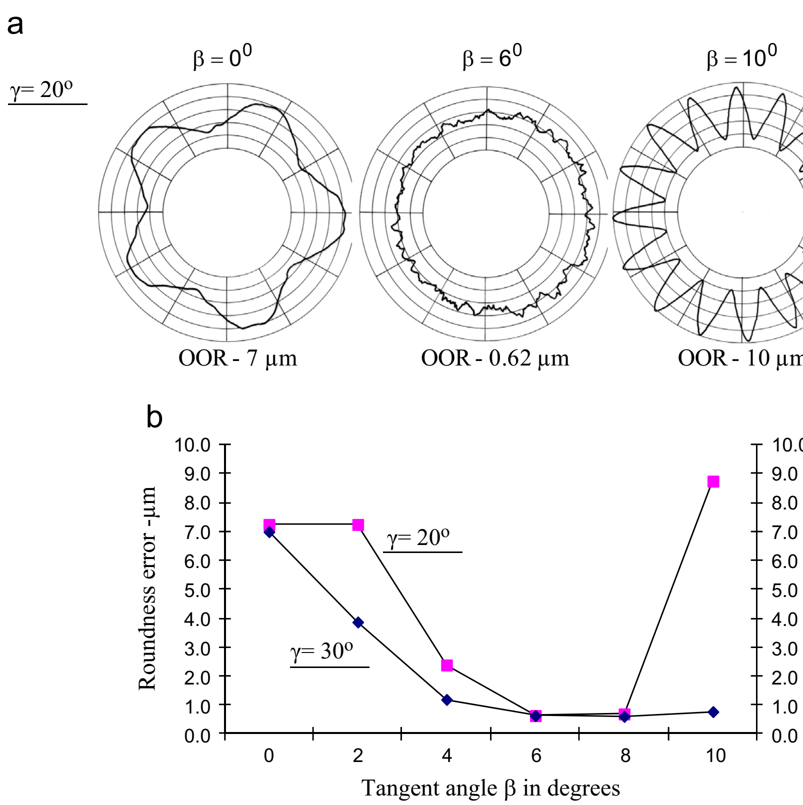

Fig. 2. Experimental roundness errors measured after grinding work-pieces having an initial flat. (a) Roundness shapes for work-rest angle $\gamma=20^\circ$. (b) Results for: $\gamma=20^\circ$ and $\gamma=30^\circ$.

$\beta=6$–8° with work-rest angle $\gamma=30^\circ$. A 30° work-rest angle is more stable than 20° which is geometrically unstable with $\beta=10^\circ$. Often, 16 lobes are produced around the workpiece circumference for this geometry. Geometric instability is not always obvious when grinding because lobing builds up slowly [26]. The condition is often termed convenient waviness.

2. Previous work

2.1. Review of geometric rounding effect

Yonetsu [29,30] described the mechanics of rounding and compared the rounding tendency for odd orders of lobes employing different values of set-up geometry. Experimental results were found by Rowe [21] showing evidence of work-regenerative instability with examples of odd and even higher-order lobing.

Computer simulation developed in 1961 [21,23,24] confirmed the existence of geometric instability defined as instability that exists even with a perfectly rigid machine. However, experiment and simulation showed that lobing build up very slowly unless directly stimulated by machine vibrations or large initial shape errors. With attention to machine design and regulating wheel truing, it was found that roundness errors were very small and approaching the measuring limits [10].

For integer lobes, the geometry is unstable if the geometric stability parameter A becomes negative [21]. Rowe and Richards [20] applied the Nyquist stability criterion using the geometric stability parameter *A*. This parameter allows geometric stability of a wide range of frequencies to be plotted in one figure (Fig. 3). Large positive values of *A* indicate a strong rounding tendency