

BENEFITS OF VARIABLE SPEED GRINDING

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Introduction

In the current state of technology, it is easy to overlook the complications involved in the manufacture of many of the products that are used on a daily basis. In order to convert raw materials into finished products, any number of machining processes can be used including boring, turning, drilling, milling, and grinding. Of these, grinding yields the highest degree of accuracy and surface quality, but is the most costly due to relatively low material removal rates. Despite the large costs involved, grinding still accounts for 20-25% of all machining in the United States [1]. To achieve lower grinding costs it is desired to minimize relative vibrations between the grinding wheel and workpiece in order to increase production rates.

During a grinding operation, forced vibrations from motors, hydraulic systems, bearings, belts, imbalance, and workpiece and wheel non-uniformity can cause an initial disturbance in the cutting process. This disturbance causes relative motion between the wheel and the workpiece that leaves a wave, or undulation, on the surface of the workpiece (and/or wheel). As the workpiece rotates and the wheel comes into contact with the wave from the previous revolution, the wheel is again deflected with respect to the workpiece forming another wave. If the second wave is larger than the first the instability is known as regenerative chatter and its onset is a major limitation of production grinding rates. Depending on the machining parameters, these regenerative waves will exist only on the workpiece, only on the grinding wheel, or on both (doubly regenerative).

Although regenerative chatter is well understood in most metal cutting processes, a model for grinding is complicated by geometric, thermal, and time scale issues. As a result, several different approaches to understanding grinding chatter have been proposed over the last 50 years that model workpiece, wheel, and doubly regenerative chatter [2-6]. The current research deals with the suppression of workpiece regeneration via workspeed variation.

Approach

The objective of this research is to demonstrate experimentally the benefits of variation of workspeed in order to reduce chatter in cylindrical plunge grinding. Several researchers have proposed models that show increased stability with variable wheel speed grinding but few have shown the effect of variable workspeed. Using a short grinding cycle and a compliant (low natural frequency) workpiece, only workpiece regeneration is considered.

Experiments are conducted on an external cylindrical grinder in which the equivalent grinding chip thickness, h_{eq} as defined by CIRP, is held constant over a range of workspeeds [7]. The equivalent grinding thickness is the volume of workpiece removed (Z') at a given grinding wheel speed (v_s). Equation 1 shows that h_{eq} can also be expressed as a function of workpiece diameter (d_w) and the infeed rate (v_f). Grinding data such as normal force and surface roughness have been shown to be logarithmic-linear functions of h_{eq} . [7]

$$h_{eq} = \frac{Z'}{v_s} = \frac{\pi d_w v_f}{v_s} \quad 1)$$

Infeed rates of 340 and 510 nm/s (13 and 20 $\mu\text{in/s}$) are used to plunge grind for 200 seconds. The chatter growth is recorded and compared to chatter growth when grinding with a variable workspeed and the same equivalent chip thickness. The reduced chatter amplitude as compared to constant speed

grinding indicates that variable workspeed grinding may be an effective solution for increasing production rates.

Experimental Setup

The chatter experiments are performed on the Myford MG 12 manual cylindrical grinder shown in Figure 1a. A Professional Instruments 4B BLOCKHEAD[®] air bearing spindle is used in lieu of the original ball bearing workhead to eliminate spindle error. The reed style flexure shown in Figure 1b allows for small motions at a known frequency in the chatter sensitive direction. The workpiece is bolted directly to the BLOCKHEAD[®] air bearing spindle which is held in the flexure.

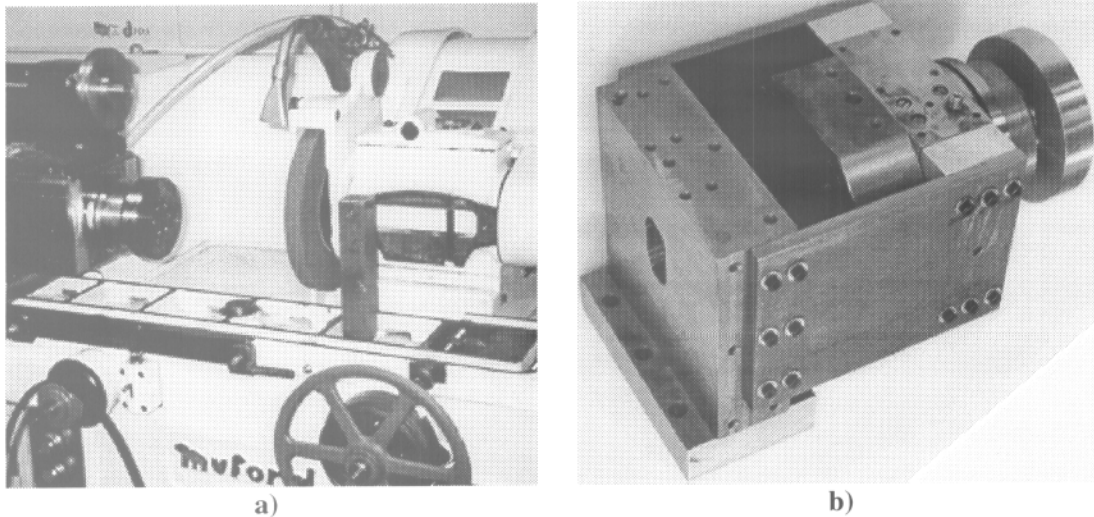


Figure 1 a) Cylindrical grinding testbed, b) single degree of freedom workhead flexure.

Mild steel workpieces 115 mm in diameter by 23 mm wide are ground with a 250 mm (10 in) diameter vitrified aluminum oxide wheel (Norton 32A60-KVBE). The coolant is a 10% chemical emulsion (Master Chemical VHP 320). The wheel is dressed before each test using a single point diamond dressing tool traversing at 130 mm/min. Two passes are taken at dressing depths of cut of 25 μm . The tests are conducted using $h_{eq} = 3.9$ nm and $h_{eq} = 5.8$ nm for workspeeds of 200, 300, and 395 RPM with workspeed step variations of 0%, $\pm 5\%$, $\pm 10\%$, and $\pm 20\%$ every 10 seconds. The vibration amplitude of the flexure and the workpiece roundness is recorded.

Results

The chatter amplitude results of four tests, each using $h_{eq} = 3.8$ nm, are shown in Figure 2. The vibration envelope illustrates that a variation of 20% of the workspeed suppresses the grinding chatter for nominal workspeeds of both 200 RPM and 400 RPM. The roundness polar plots for the same four tests are shown in Figure 3. A summary of the average roundness for all the tests is shown in Table 1. The chatter suppression obtained from workspeed variation results in improved roundness traces.

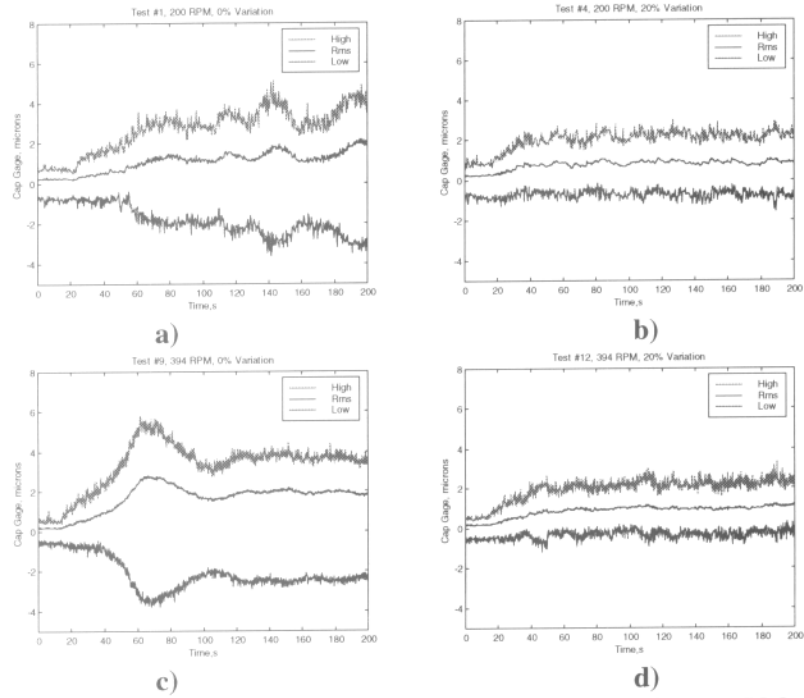


Figure 2 Grinding chatter envelope for **a)** constant 200 RPM grind, **b)** 200 RPM grind with 20% variation, **c)** constant 400 RPM grind, **b)** 400 RPM grind with 20% variation.

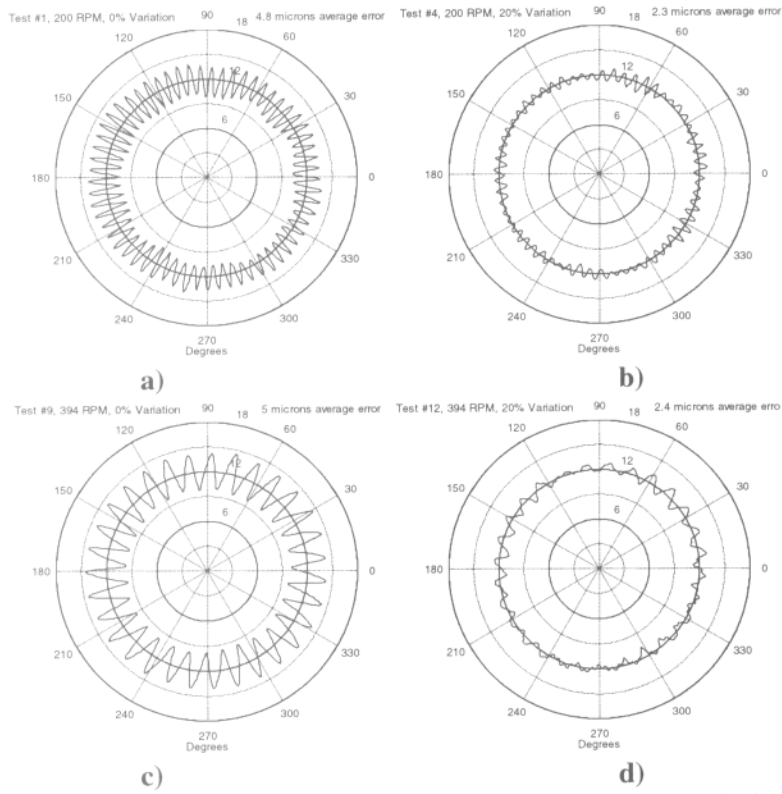


Figure 3 Roundness polar plots for **a)** constant 200 RPM grind, **b)** 200 RPM grind with 20% variation, **c)** constant 400 RPM grind, **b)** 400 RPM grind with 20% variation.

Table 1 Summary of average roundness results.

Roundness, microns		Workhead speed variation			
		RPM	-	5%	10%
h_{eq} 3.9 nm	200	4.8	3.3	1.9	2.3
	300	4.3	4.3	1.9	4.1
	394	5.0	5.2	4.6	2.4
h_{eq} 5.8 nm	200	5.3	4.9	1.7	2.6
	300	7.0	5.7	5.2	4.2
	394	6.8	6.7	5.4	3.5

Conclusions

Grinding chatter experiments are performed in an effort to demonstrate the benefits of variable speed workhead grinding. Cylindrical plunge grinding experiments are conducted and the amplitude of vibration and the workpiece roundness are used to quantify chatter intensity. Increased stability is achieved by decreasing the equivalent grinding thickness and increasing the workhead speed variation.

The amount and period of workhead speed variation are critical parameters in realizing the optimal conditions for each grinding operation. Future work includes determining the optimal variation parameters in order to maximize the MRR. In addition, the tests will be repeated on a production size grinder to validate the testbed results. Finally, this method is beneficial only in operations in which work regenerative chatter exists, for example, operations in which the workpiece has a low natural frequency.

Acknowledgements

The research for this project was made possible through funding provided by the National Science Foundation, Weldon Machine Tool, and Professional Instruments Company. The authors are grateful for the many hours of discussion, consulting, and testing with David Arneson and Mel Liebers at Professional Instruments. Furthermore, the authors are indebted to Jim Flinchbaugh and George Sipe at Weldon Machine Tool for supporting and guiding the direction of the research.

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