Simulating Vibration Assisted Grinding with Segmented Wheels

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Introduction

Many experiments have demonstrated that vibration assisted grinding can make grinding forces decrease significantly. However, it is difficult to achieve large vibration amplitudes in practice due to the mass of the wheel or workpiece. Therefore, we have to find a way to simulate the large amplitudes. Some researchers have already conducted a series of grinding experiments using segmented wheels. It turns out that the grinding forces also decrease with this special wheel. This paper presents experimental results and theoretical explanations for force reduction with the segmented wheels.

Vibration assisted grinding and segmented wheel grinding are similar in that they both produce intermittent grinding, i.e. sometimes the wheel and workpiece lose contact. Vibration frequency and amplitude can be simulated through the choice of segment spacing and shape. Geometric analysis shows that the finished surface roughness can be made identical for these two grinding methods. Segmented wheels can be made with a relatively deep groove around the perimeter. The segment spacing and shape are infinitely variable, which may prove advantageous when compared to sinusoidal vibration assistance.

Experimental Setup

Three kinds of wheels were used to grind a steel workpiece. Figure 1 depicts the three wheels. The two segmented wheels are cut from regular aluminum oxide wheels. Segmented wheel No. 1 has 20 teeth and segmented wheel No. 2 has 10 teeth.

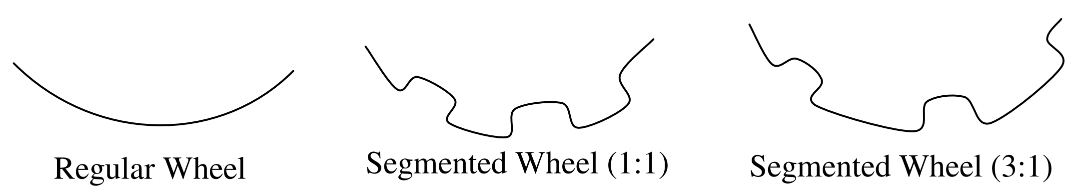


Figure 1: Grinding wheels used in the experiment

Surface grinding was done with a wheel velocity of 29.4m/s. Test were performed with depth of cut ranging from 5 to 25 microns and feedrates from 33 to 47 mm/s. No coolant was used. Both thrust force F_z and tangential force F_x were measured.

Experimental Results

Figure 2 shows the typical thrust force data for the three kinds of wheels. Note that the forces are lower with the segmented wheels.

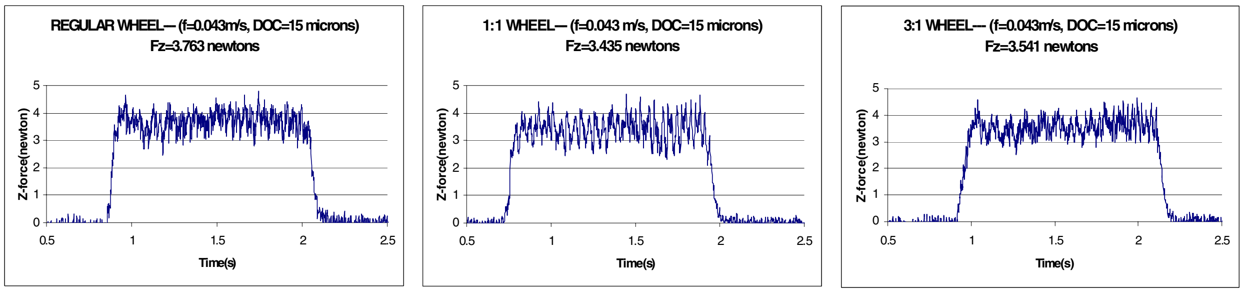
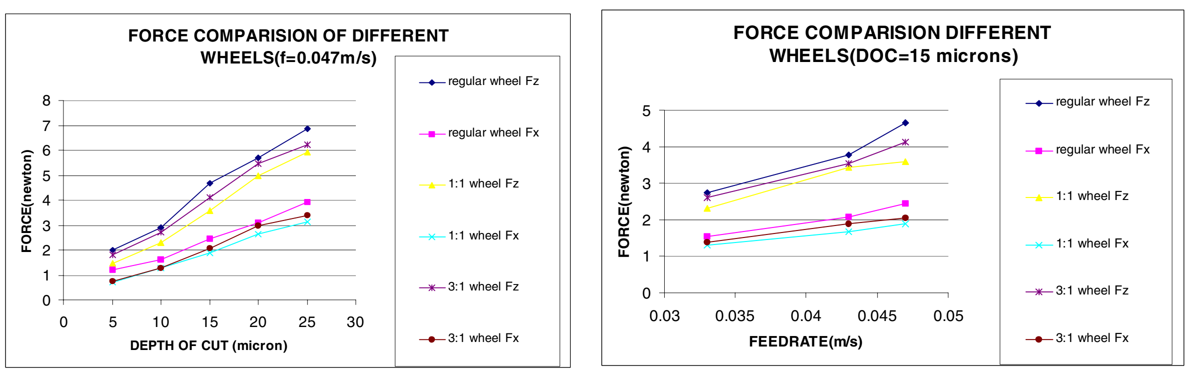


Figure 2: Thrust force results for the three kinds of wheels

Figure 3 shows how the average thrust and tangential forces change with depth of cut and feedrate.



(a) (b)

Figure 3: Effect of (a) depth of cut and (b) feedrate on forces

The data in Figure 3 were combined to look at the dependence of force on material removal rate (MRR) as shown in Figure 4. The best fit lines for the three wheels have similar slopes but different intercepts.

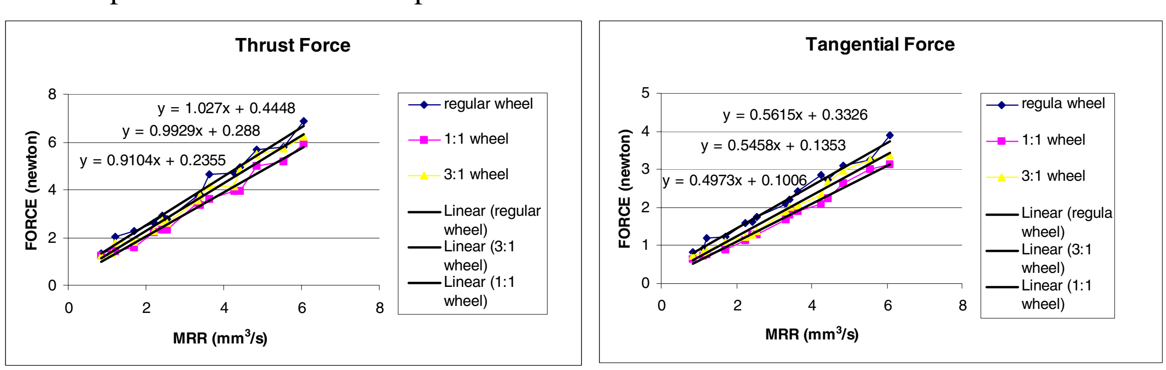


Figure 4: Forces as a function of MRR (Material Removal Rate)

The results suggest that larger segment spacing leads to lower forces. There are several likely reasons. Large segment spacing may facilitate chip evacuation. It may also improve access of the coolant into the cutting zone. In addition, it reduces the amount of time that the rubbing force is active.

Force Model

The grinding force can be modeled as a cutting force, which is proportional to material removal rate (MRR), and a rubbing force, which is independent of MRR:

$$F_z = k_z(MRR) + F_{z0}$$
$$F_x = k_x(MRR) + F_{x0}$$

where k_z and k_x are specific energy constant, and F_{z0} and F_{x0} are the rubbing forces.

Figure 5 compares the material removal rate for the three types of wheels used in our experiment. Using segmented wheels, the workpiece loses contact with the wheel while the wheel groove passes the top of the workpiece. During this period, the grinding force is zero because of loss of contact. During times of contact the forces for the segmented wheels are higher than for the regular wheel.

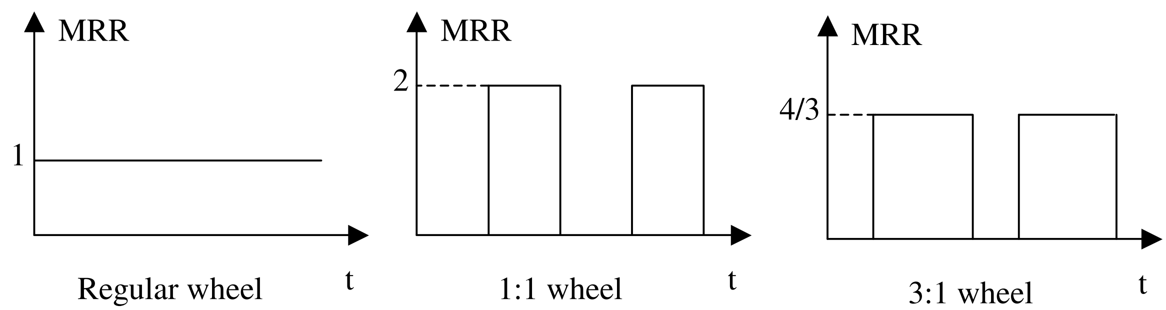


Figure 5: MRR for three kinds of wheels

For the regular wheel, the average grinding forces are:

$$F_{zr} = k_z(MRR) + F_{z0}$$
$$F_{xr} = k_x(MRR) + F_{x0}$$

For the 1:1 wheel, the average grinding forces are:

$$F_{zs1} = [k_z(2MRR) + F_{z0}]/2 = k_z(MRR) + F_{z0}/2$$
$$F_{xs1} = [k_x(2MRR) + F_{x0}]/2 = k_x(MRR) + F_{x0}/2$$

For the 3:1 wheel, the average grinding forces are:

$$F_{zs2} = [k_z(\frac{4}{3}MRR) + F_{z0}] \times \frac{3}{4} = k_z(MRR) + 3F_{z0}/4$$
$$F_{xs2} = [k_x(\frac{4}{3}MRR) + F_{x0}] \times \frac{3}{4} = k_x(MRR) + 3F_{x0}/4$$

According to this model, the slopes of the data in Figure 4 would be constant. This is nearly the case: the thrust force slope ranges from 0.91 to 1.03 and the cutting force slope ranges from 0.50 to 0.56.

The model is not as accurate in its prediction of intercept, i.e. rubbing force. The model predicts intercepts for the segmented wheels that are 0.5 and 0.75 of the regular wheel intercept. Instead the respective ratios are 0.53 and 0.65 for the thrust force and 0.30 and 0.41 for the tangential force.

Suppose k_z and k_x are 0.98 and 0.53, respectively. Based on the model above with F_{z0}=0.43 and F_{x0}=0.24, the amount of force reduction is predicted. Figure 6 shows the % reduction of the segmented wheels over the regular wheel.

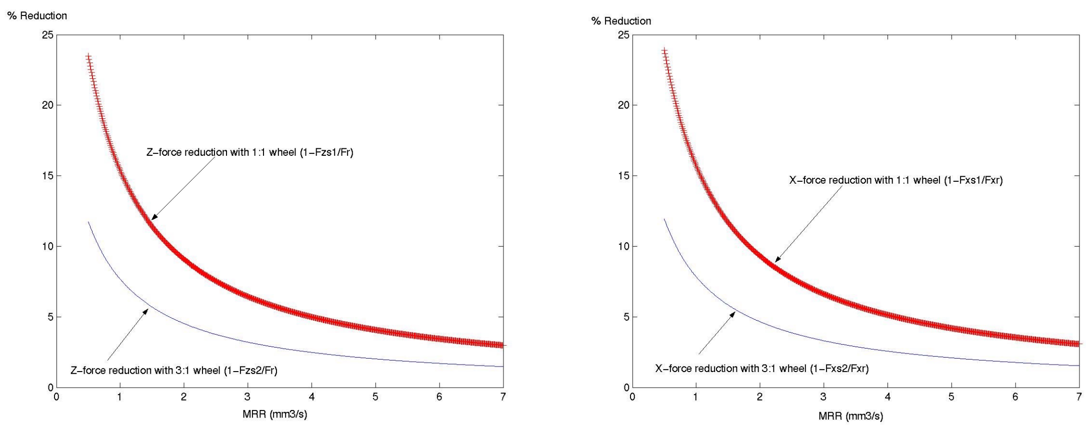


Figure 6: Simulation results of force reduction with 1:1 and 3:1 wheels

Conclusion and Future Work

For all three wheels, the grinding force linearly increases with depth of cut and feedrate. Grinding forces decrease when using segmented wheels due to a net reduction in the rubbing/ploughing component. The model will be refined further to better match the experimental results. In addition, we will investigate wear rates for segmented wheels so that optimal segment geometry can be found.