# Planar Motions in Grinding Chatter[1]

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*Summary*. This paper discusses planar motions in a plunge grinding process, where regenerative, Stribeck frictional forces and workpiece imbalance are successively considered as the cause of grinding vibration. With a model of the grinding, eigenvalue and bifurcation analyses are performed to reveal the stable and unstable grinding processes. It is observed that the regenerative instability introduces bistability but the frictional one does not. In addition, external excitation due to the workpiece imbalance is involved, which perturbs the stable grinding and periodic chatter into forced periodic and quasi-periodic vibrations, respectively.

## Grinding stability

A deep understanding of the sources of the chatter is required for the development of modern machining technology, and thus the obstacle in achieving automation can be removed [1]. For a machining process, the sources of vibration are classified into internal and external types. An internal source lies in the cutting forces generated during the processing, while an external one is from mass imbalance of rotating tools or workpieces. To reveal various grinding dynamics, a mechanical model is proposed and illustrated in Fig. 1, which shows a plunge grinding processes. As seen, the normal and tangential wheel-workpiece forces promote the horizontal, vertical and torsional motions of the workpiece, as well as the horizontal wheel displacement. The tangential force is induced by the wheel-workpiece friction, which involves the so-called Stribeck effect, and thus introduces frictional instability.

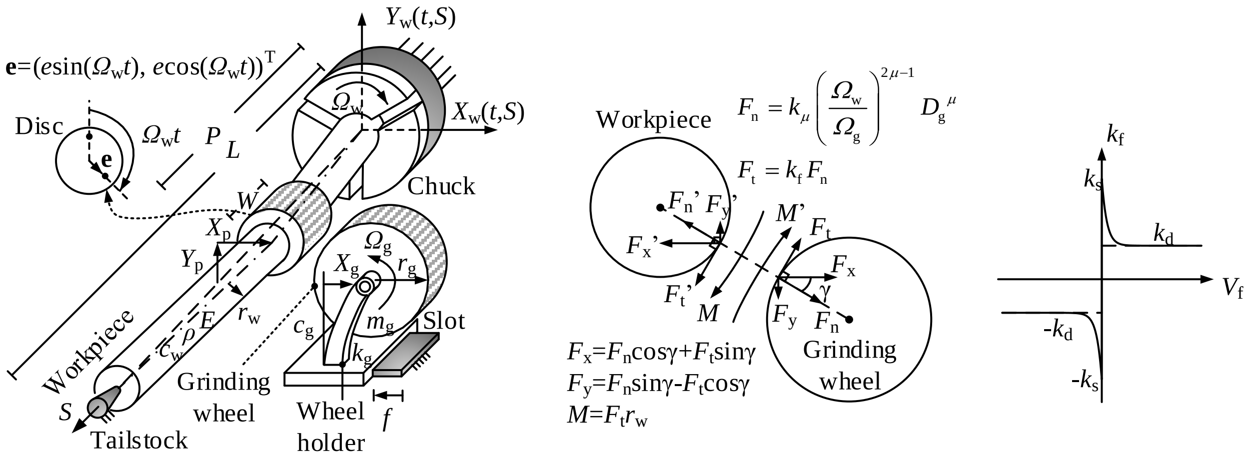


Figure 1: (a) schematic of the plunge grinding process, (b) normal cutting and tangential frictional forces between the wheel and the workpiece, (c) frictional coefficient with Stribeck effect.

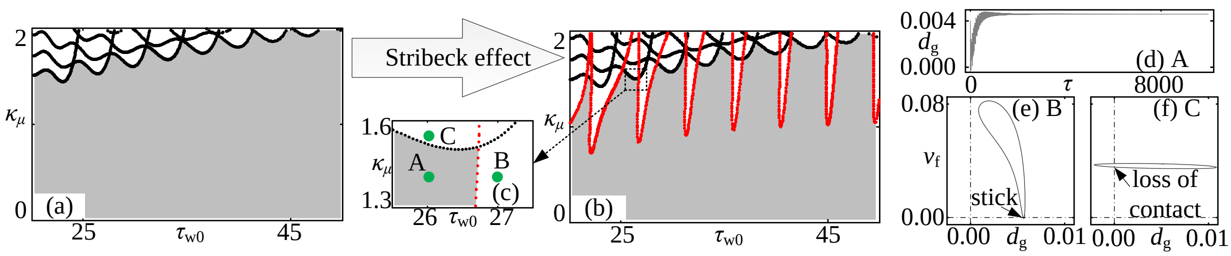


Figure 2: Stability diagrams for a plunge grinding process (a) with and (b) without Stribeck effect. A region is blown up in (c) to illustrate (d) the stable grinding, (e) the frictional chatter and (f) the regenerative chatter.

In this model, the regenerative effect are represented by time-delayed terms, while the Stribeck is given by a non-smooth function in Fig 1(c). Due to the vertical and torsional motions of the workpiece, the delays for the regeneration are changed into state-dependent, governed by implicit equations [2]. For the linear stability, these equations are

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linearized by perturbation methods before numerical eigenvalue calculations with the help of a continuation algorithm. Firstly, the Stribeck has been ignored, and thus only the regenerative instability can be found, which yield the stability diagram in Fig. 2(a), a very typical lobes stability diagram for metal cutting. Then, The Stribeck effect in the friction is involved, which yields the stability diagram in Fig 2(b). It can be seen that the red boundaries are newly introduced. For a closer observation, one region is blow up in Fig 2(c), which contains Points A, B and C for the stable grinding, the frictional vibration and the regenerative chatter in Figs 2 (d), (e) and (f), respectively.

## Planar chatter motions

With an understanding of the linearly regenerative and frictional stability of the grinding process, several bifurcation analyses by numerical simulations are performed. Figs 3(a) and (b) display maximum grinding depth and minimum frictional velocity as functions of grinding stiffness, where the mass imbalance does not play a role. The regenerative chatter illustrated in Fig 3(d) coexists with a stable grinding process in Fig 3(g), but the frictional chatter in Fig 3(f) does not, which only shows up in the unstable region. Moreover, Figs 3(e) and (h) show a coexistence of quasi-periodic and periodic chatters. The grinding depth is in the normal direction at the wheel-workpiece contact, while the frictional velocity in the tangential direction. Thus the phase portrait demonstrates the planar motions during the grinding chatter. In addition, another source of planar chatter motions is the external excitation. This case is displayed in Fig 4, which involves a mass imbalance in the workpiece. Basically, the bifurcation patterns for the regenerative and frictional instabilities are unchanged, but the sinusoid excitation introduce another frequency into the vibration, and thus perturb the stable grinding and the periodic chatter into forced periodic and quasi-periodic vibrations, respectively.

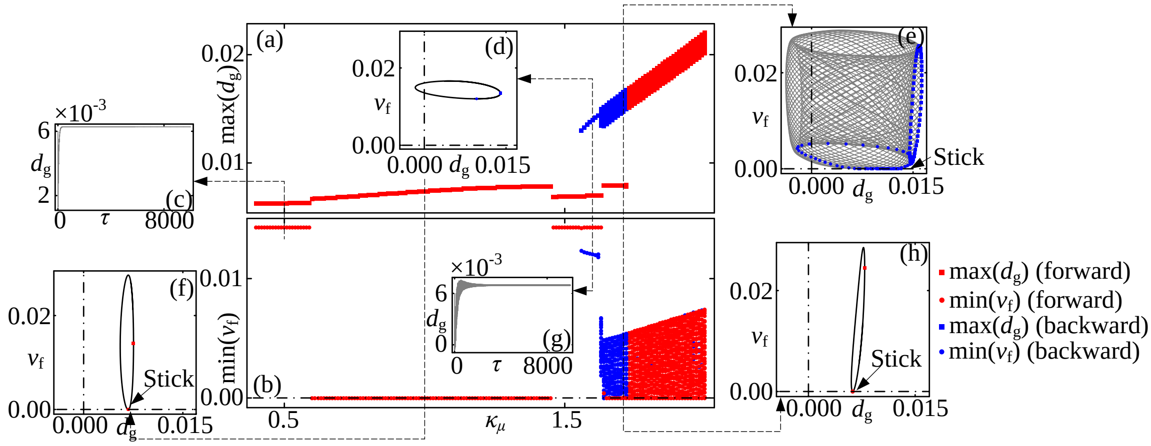


Figure 3: Maximum grinding depth and frictional velocity are displayed in (a) and (b) as functions of grinding stiffness $\kappa_\mu$, with time histories or phase portraits for $\kappa_\mu$=0.5, 1.1, 1.6 and 1.7 are displayed, respectively.

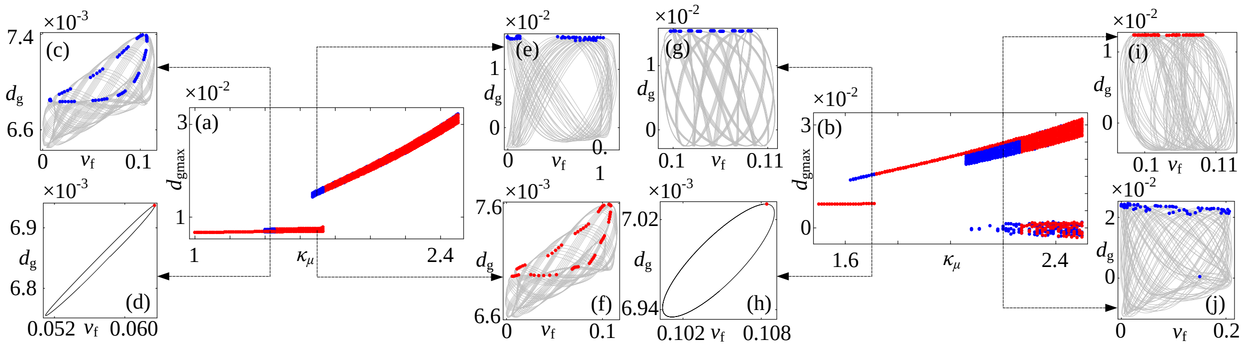


Figure 4: With mass imbalance in the workpiece, maximum grinding depth is displayed in (a) and (b) as functions of grinding stiffness $\kappa_\mu$, with several phase portraits plotted: $\kappa_\mu$=1.43 for (c) and (d), $\kappa_\mu$=1.7 for (e), (f), (g) and (h), and $\kappa_\mu$=2.2 for (i) and (j).

## Conclusions

Grinding dyanmics with considering internal and external sources of vibration are investigated, which involves regeneration, Stribeck effect and workpiece imbalance, promoting various periodic and quasi-periodic chatters. It has been found that the regenrative chatter coexists with the stable grinding while the frictional one does not.

## References


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[2] Yan Y., Xu J., Wiercigroch M. (2016) Regenerative and Frictional Chatter in Plunge Grinding. Nonlinear Dyn **86**:283-307