Effects of Rotating Unbalance on Turning Precision: Analytical and Experimental Investigations and Real-Time Compensation

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Past research has been conducted on the effects of rotating unbalance on precision machining using rotating tools. Real-time balance compensation methods have been applied for decades on precision grinding machines and, more recently, on high-speed milling machines. However, such active balance control has not been extensively applied to metal turning applications. This paper first presents results from traditional analytical machining models to predict the effects of rotating unbalance on various measures of turning precision. Active compensation is described that mitigates the negative effects on precision while not significantly impacting process cycle-time. Experimental results are presented that validate the trends predicted by the analytical models and also suggest other indirect effects of unbalance on process precision. The experimental results also demonstrate the effectiveness of active balance compensation.

The “dynamic” runout caused by rotating unbalance is shown to potentially have a more harmful effect on precision than traditionally measured “static” runout. Dynamic runout is dependent on rotational speed and, thus, can change during a variable-speed turning operation. Furthermore, when spindle and machine stiffness is not symmetric between the X- and Y-directions, the unbalance-induce runout will not be a perfect circle but rather an ellipse. This condition is shown to effect workpiece circularity.

Aside from harming machining precision, the constant excitation of unbalance forces as the spindle rotates exacts a toll on spindle bearing life and transmits vibration throughout the machine. Since bearing fatigue life is proportional to the load cubed, the addition of even small unbalance loads relative to cutting forces can cause premature spindle bearing failure. This leads to the expense and down-time of changing out the spindle or rebuilding the spindle bearings. Machine vibration can also cause other secondary results such as affecting surface finish and tool life.

Balancing is most important for eccentric parts or workpieces that have particularly tight concentricity, roundness, or surface finish tolerances. After setup changes with such parts it is often necessary to rebalance the chuck/workpiece assembly. Workpiece casting weight variation can also lead to significant variation in unbalance from part to part. Unbalance variation is even possible while machining a single part if interrupted cutting is involved.

Off-line manual balancing of each part or setup is usually too time-consuming to be a viable solution. Another method of compensating for lathe setup unbalance is to implement active balance control. Such systems correct for rotating unbalance automatically after a setup or part change and prior to metal cutting. Active balancing is shown to address the problems related to unbalance without the time penalty of off-line balancing. Application case studies of prototype production active lathe balancing systems are presented to provide examples of the economic justification of such systems.

Key words: turning, balancing, vibration, vibration control