Experimental Investigation of Particle Impact Damping On Machine Tools

E Muthu\textsuperscript{1}, Shashwat Dashora\textsuperscript{2} and P. Nandakumar\textsuperscript{1}
\textsuperscript{1}Department of Mechanical Engineering, SRM Institute of Science and Technology, Kattankulathur, Chennai, Tamilnadu, India.
\textsuperscript{2}Department of Translational Medicine and Research, SRM Institute of Science and Technology, Chennai, Tamilnadu, India.

E-mail: shaswatdashora_nav@srmuniv.edu.in

Abstract. In machine structure, the boring operations are extensively used for enlarging an existing hole. For large sized workpieces, the overhang length of the boring tool increased, which disturbs the slenderness of the tool (length to diameter ratio) leading to high amplitude vibrations. The tool-workpiece interaction strains the shank and induces vibrations in the workpiece. These vibrations bring along a package of defects such as poor surface finish, dimensional inaccuracy, reduced material removal rate etc. In order to suppress the damping, small metal particles were used. Particle impact damping \cite{6} is a method of achieving high structural damping by using a particle filled enclosure in the region of high displacements. A series of experiments were performed where the closure was attached to the tool at three different locations, the material as well as the size of the particle was changed for obtaining different experimental observations. Further, a particle effectiveness or packing ratio of 25\%, 50\% and 75\% was used for experiments. Using NI signal software and LabVIEW we were able to obtain the natural frequency with and without the damper, in an experiment the frequency of vibration was reduced about 15\% with the damper.

1. Introduction
Boring operations are used to enlarge the existing hole in the mechanical structures. When the overhang length of the tool increases, it leads to high damping response. The most significant factor which affects and strains the workpiece are the cutting forces \cite{1} in this way vibrations are induced in the tool and workpiece. Chatter vibration are the self-excited vibrations which affects the quality of the machining and geometric accuracy, chatter can be reduced by active and passive damping. One of the methods of reducing these induced vibrations is particle impact damping. The use of particles (spherical balls of metal) inside a specific closure which can be attached to the machine structure is termed as particle impact damping. The variations in this can be brought about by changing material, size and shape of the filling used inside the closure. The momentum of the tool vibrations is converted into heat energy; other words the kinetic energy of the machine structure is converted into heat energy. Moreover, the inelastic collision of the particles and frictional contact between the particles also helps in energy dissipation.

Several studies have been conducted by various researchers in this field \cite{1}. R.D Frend studied the nature of particle impact damping using lead, steel and tungsten carbide in a plastic bean bag. He uses a standard Euler -Bernoulli beam and transforms into 4th order differential equation. He assumes in his experiments that the particles move as a lumped mass and hence the relative motion between the particles can be neglected. Since there are large number of particles which will have velocities in...
different directions, he assumes that all the particles have velocity only in one direction i.e., z-axis. He observed that the damping was highly non-linear (amplitude dependent) and has a specific damping coefficient of approximately 50%.

Wangqiang Xiao, Lina Jin and Binqiang Chen [2] studied the collision theory using regression mathematics, they altered the particle density, filling ratio and particle size. The author has defined the collision process into compression and recovery phase. This concludes that the higher the density of the particles, ore is the damping effect. Amongst all the material, tungsten carbide was found to be the best but not economical. For SS 90% packing ratio and 4mm particle size gave the best results.

Yanrong Wang, Bin Liu, Aimei Tian, Dangsheng Wei and Xianghua Jiang [3] used the PID in a wheel rim where they have inserted tubes filled with particles in the several position and provided the rim with forced vibrations. For better mathematical calculation the author has considered that one layer of particles vibrated together with velocity in one direction. The result of the experiment is analysed using logarithmic fitting curve and range-kutta method. In this study, the cast iron particles of 1 mm diameter with different packing ratio is used to suppress the chatter vibration of the cantilever boring bar tool. The particles are put into the closure which is attached with the boring bar tool as a damper unit at different lengths from the free end. Modal analysis and free vibration test were carried out on the boring bar.

Yanchen Du, Shulin Wang [4] have explained the plastic deformation of fine particle impact dampers as reversible energy sink which they have proved to absorb much more vibrations than single mass impact damper. Experiments were conducted on a cantilever beam having FPID and model prediction were portrayed. They have proved that in all the cases possible, the fine particle impact dampers were better than single mass impact damper. They have also proved the fact that damping ratio and clearance are the two most important aspects on which the damping ability depends.

2. Experimental Setup
In this investigation, EN31 (Nomenclature: S20 SCLCR 09) grade boring bar was used. This boring bar when held in the tool post acts as a cantilever beam during the boring operation. The dimensions of the boring bar are 20 mm in diameter with 200 mm in length [5]. The closure contains the spherical particle of 1 mm diameter which is attached at the three different positions (45 mm, 55 mm, 65 mm) from the free end of the boring bar with different packing ratio [6] 25%, 50% and 75% respectively. The closure is made up of Acrylic material because of its light weight properties [7]. The closure is in the shape of a cylinder with diameter of 25.4 mm and thickness of 2.75 mm is shown in Figure 1. The figure 2 shows experimental setup where we attached the closure filled with cast iron i.e. figure 3 particles on to the upper half of the cantilever beam. An accelerometer [8] is attached to the lower half which is then connected to the NI signals software over which the output is obtained.
Figure 1. Closure made of Acrylic material.  
Figure 2. Experimental Setup.  
Figure 3. Cast iron steel particles of size 1 mm.

3. Results and Discussion
For the various packing ratio and position the natural frequency was measured and FRF were plotted. The figure 4 and figure 5 illustrates the natural frequency of the cantilever boring bar with and without damper unit, respectively. The fundamental frequency of the boring bar without damper unit is 118 Hz. The figure 4 illustrates the natural frequency of the boring bar with the damper unit with different packing ratio. It was observed the fundamental frequency is decreasing significantly. From the response of the system we calculated logarithmic decrement and the damping factor and plotted in the figure 6 and figure 7 for with and without damper, respectively. The logarithmic decrement was found to be 0.072 and damping factor is 0.0126. Damping factor was calculated using logarithmic decrement relation given in the Equation (1) [9]

$$\delta = \frac{1}{n} \ln \left( \frac{x_0}{x_n} \right) = \frac{2 \pi \varepsilon}{\sqrt{1 - \varepsilon^2}}$$

Where n is no. of cycles, $x_0$, $x_n$ are the amplitudes of response, $\varepsilon$ is the damping factor [10]. The damping factor calculated for various packing ratio and position of damper unit were listed in the Table 1.

| Packing ratio | Damping Factor | Position of damper | Damping factor |
|---------------|----------------|--------------------|----------------|
| 25%           | 0.0094         | 45 mm              | 0.0045         |
| 50%           | 0.0126         | 55 mm              | 0.00402        |
| 75%           | 0.009          | 65 mm              | 0.0043         |
Figure 4. Natural frequency with damper.

Figure 5. Natural frequency without damper.

Figure 6. Amplitude displacement graph without damper.
By elaborating further, in Table 1, one can clearly observe that the packing ratio should neither be too less not too high. The experiments were so performed that the packing ratio was changed from 25% to 75% while keeping the closure or damper at the same position. The 50% packing ratio has given the best result due to the sufficient clearance available. Using this result, another experiment was performed where the packing ratio was kept constant to 50% and changed the position of the damper. The results of the damping factor with different position of the damper also presented in Table 1.

4. Conclusion
In this experimental study we have found that packing ratio is the major factor which governs the damping in the boring bar tool, hence the packing ratio of 50% was found to be optimum. In this packing ratio, the clearance provided is sufficient and mass ratio is also maintained. The position of damper is not having any significant difference in the damping factor. The Graph 1 below clearly explains the fact that when the damping factor exceeds 0.01 its shows the highest peak shown with red bar. While the three different positions of damper which were placed during the experimentation show a fall in the graph. This shows that best results will be obtained only when we use the damper as near as possible to the cutting edge.

Acknowledgements
We are highly indebted to all the Machine Dynamics Technicians. (Department of Mechanical Engineering, SRM IST) for his timely guidance as well as providing us with the necessary information required to complete the paper.

5. References
[1] Friend R.D, Kinra V.K 2000 *Journal of sound and vibration* 233 93-118
[2] Wangqiang Xiao, Lina Jin and Binqiang Chen 2018 *Journal of sound and vibration* YJSVI 14452
[3] Yanrong Wang, Bin Liu, Aimei Tian, Dangsheng Wei and Xianghua Jiang, 2015 *Shock and vibration*
[4] Yashen Du and Shuling Wang, 2010 *International Journal of Mechanical Sciences* 52 1015-1022
[5] Marhadi S.K, and Kinra K.V 2005 *Journal of sound and vibration* 283 433-488
[6] C. V. Biju & M. S. Shunmugam, 2014 *International journal of Advance Manufacturing Technology*
[7] Eshwar Pawar, 2016, *IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)*
[8] Xian-Ming Bai · Leon M. Keer and Q. Jane Wan 2009 *Granular Matter* 11 417–429
[9] Saiki M 2002 *Journal of Sound and vibration* **251** 153-161
[10] A Textbook of Mechanical Vibrations, Singiresu S Rao