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Vibration Suppression of Boring Tool Using Two-Cell Particle Damper

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ABSTRACT

Machining is frequently done with a cantilever boring tool, which imposes the vibrations, consequently, results in a poor surface finish and chatter vibrations. In this study, the suppression of vibrations of a boring tool using particle damping technique has been attempted. The boring tool is equipped with particle damper by making an axial hole of 8 mm in diameter and filled with metallic particles. The significant reduction in acceleration amplitude was observed. Further this axial hole was equally divided in two parts by inserting flat strip axially. Testing has been performed for single hole and split hole configurations. A full factorial design with three-level of interactions was used in this analysis. The significant reduction in acceleration was reported for split type damper configuration.

Keywords— **Key Word: boring tool vibration, passive particle vibration damper, vibration suppression**

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I. INTRODUCTION

Boring is an operation commonly used to enlarge holes such as engine cylinder holes. Particularly, in the boring process, the boring bars are, essentially, long and slender. Thus, the boring process is constrained by excessive static deflections and self excited chatter vibrations. Both are influencing, negatively, the surface finish and accuracy of the machined work piece. In addition, it accelerates wearing and chipping of the boring tool. The aim of this research is to suppress the vibration of the boring tool using a novel particle damper in order to preserve the boring process accuracy by avoiding excessive static and dynamic tool vibration.

Many researchers have presented methods to predict the stability of the boring process. C.X. Wong et al [1] carried out an experimental work to investigate how the small (1.5to 3mm) diameter particles interact in particle dampers. They obtained the coefficient of restitution and interface friction. They used these data to estimate the amount of the dissipated energy in a Particle Damper. Zhiyuan Cui et al [2] studied quantitatively the analysis of the energy dissipation mechanism of non-obstructive particle damping based on a theory of statistics. They found that, energy dissipation of non-obstructive particle damping will increase with the granular diameter or with the dense granular flow volume ratio. To control the structure excessive vibration, Sergiu C. Dragomir et al [3] presented a particle-based numerical models which are appropriate to model granular streams for their ability of representing each contact interaction individually. The computational model was able to investigate the flow conduct and the dissipation of the energy in this structure. B. Darabi and J.A. Rongong [4] utilized the Discrete Element Method code in three-dimensions to perform numerical investigations for the dissipation of the power by a granular medium as it experiences sinusoidal vibrations at the same gravity direction. Overall power dissipation levels were found to be relatively insensitive to the friction coefficient. M.R. Brake [5] studied the contact model effect on a system's dynamics prediction. In order to understand the effect of the impact model on the system's dynamics, the author conducted simulations to study a single and two degree of freedom system for five different contact models. Specifically, their piecewise linear contact model predicted more regions of no impact events and lower velocity impacts than any of the elastic–plastic contact models. W.M. Chiua et al [6] developed an overhung boring bar consists of two concentric bars, one of which is used for error detection and the other for error compensation piezoelectric actuator servo system. They performed an on-line and off-line simulation for testing the number of parameters used. M. Xiao et al [7] proposed a cutting model considers a vibration cutting process to evaluate the mechanism of the precision machining. Ismail Lazoglu et al [8] presented an advanced time domain mathematical model of boring process contains the geometry of the work- piece as well as the topography module of the surface. The input parameters for the time domain model include the cutting process parameters as well as the tool and work piece geometries. The output of the model can predicts the cutting forces and vibrations with respect to time. F. Atabey et al [9] They presented a comprehensive model of the cutting mechanics of the boring process by using two approaches, namely, mechanistic, and orthogonal to oblique cutting transformation. They found that, the vibration amplitudes and directions of the cutting forces change with respect to the tool geometry and cutting conditions. C. Mei [10] modeled the boring bar as a cantilevered rod in bending using Euler–Bernoulli's and designed an active controller from wave point of view to retain prattle vibration vitality in an expansive frequency band to enhance performance of the machining process of a non-rotating boring tool bar. Though, they found that the first mode dominates the response, the rest of the modes more or less contribute to the chatter of the system. Giovanni Miragliotta [11] found out how Dimensional Analysis approach can be connected to Operations Management subjects. Phatak and H. B. Dhonde [12] exhibited a dimensional analysis technique for anticipating a maximum torsion stress of strengthened solid bars. They found that, dimensional analysis can be utilized to reasonably obtain the result with sufficient accuracy. Paul Stevenson [13] utilized the dimensional analysis for the procedure of steady drainage of fluid from foam and demonstrated that, if the surface and inertial impacts are ignored, the drainage rate will be non dimensionalzed as a Stokes-sort number may be explained by just the fraction fluid volume of the liquid volume. Also, the author showed that a basic force law relationship between these two quantities and node dominated foam drainage models. Mohammed F. Islam and L. M. Lye [14] proposed a use of a combination of dimensional analysis and recent statistical design of experiment while dealing with a large number of variables. They found the obtained model to in a reasonable accuracy when compared with the obtained results that was not used to develop the model

The paper is organized as follows: In section 2, details about particle damping principles. In section 3, contains the details of the experimental analysis, experimental setup and experimental conditions to study the acceleration response of the boring tool with particle damper. In section 3, the analysis of results obtained by experimental analysis was reviewed. In section 4, the effects of various input parameters on acceleration amplitude of the boring tool were presented. The conclusions of the study are drawn in section 5.

II. PARTICLE IMPACT DAMPING

Particle impact damping PID is a passive vibration control technique in which metallic particles of small size are embedded within the cavities or enclosure attached to a vibrating structure. Inter Particle-to-particle and particle-to-wall collisions arise under the vibrating motion of the hosting structure. As a result particles and structure will exchange momentum and thus dissipate kinetic energy due to frictional inelastic losses [28]. The damping performance depends on several parameters such as geometry of structure, damper parameters, vibration amplitude, material of particle, and packing ratio [28]. It is an attractive alternative in passive damping due to its simplicity, potential effectiveness over broad frequency range, temperature and degradation insensitivity, and very low cost. Since finite element analysis or iteration methods usually result in large amount of computation resources occupation and time consumption for millions of impacts to occur in the particle impact damping system, to obtain an analytical solution of the elastoplastic impact between two spheres has become a hot research in the past years.

2.1 The Contact Models

A number of contact models can be used to quantify the normal and tangential contact forces; however, this is still an active research topic, particularly for the tangential forces. The simulation procedure uses a linear contact model in the normal direction, and Coulomb's law of friction in the tangential direction. Figure 3 presents the linear contact model between the particle and the wall in the normal direction, where k2 is the stiffness of the impact damper 'stops', c2 is the damping constant of the impact damper 'stops', and ω is the natural frequency, which can be used to simulate a rigid barrier to any degree of accuracy, by a proper choice.

Hence, the normal contact force is expressed by

$$F_{ij}^{n}=k_2\,\delta_n+2\zeta\sqrt{m}\;k_2\,\dot{\delta}_n \qquad \text{(particle-wall)} \quad (1)$$

$$F_{ij}^{n}=k_3\,\delta_n+2\zeta^{3}\sqrt{\frac{m_i\;m_j}{m_i+m_j}}\;k_3\,\dot{\delta}_n \qquad \text{(particle-particle)} \quad (2)$$

Where δ_n and $\delta n^{\cdot}$ are the displacement and velocity of particle i relative to particle j, respectively, and ti is the distance from the centre of particle i to the wall.

Considering Coulomb's law of friction, the tangential contact force is expressed by

$$F_{ij}^{t}=-\mu_s F_{ij}^{n}\dot{\delta}_t/\dot{\delta}_t \qquad (3)$$

Where μ_s is the coefficient of friction between two particles or between a particle and the wall of the container, and δ_t is the velocity of particle i relative to particle j or the wall, in the tangential direction.

III. EXPERIMENTAL PROCEDURE AND SETUP

To reduce the boring tool vibration, it is recommended that, the stiffness and damping of the tool is to be increased. To increase the tool damping, in this project, the boring was equipped with a particle damper by means of two particle damper configurations. In the first configuration, a hole with

8mm diameter and 200 mm depth has been drilled axially into a standard boring tool shank. In the second tool configuration, the same axial hole has been divided into two equal parts by inserting a metallic strip into the hole. The first configuration is called single cell damper while later configuration is called two cells damper. Then, each cell has been filled equally with steel granular particles having 2mm diameter and tested.
Three sets of cutting test experiments are carried out on the system of particle damper. In cutting test, experiments were conducted with and without the particle damper to acquire acceleration data in the frequency domain. The data is later used for studying the damping characteristics of the system. A 3-level full factorial design is used to evaluate the effect of five independent variables such as spindle speed, depth of cut, feed rate, tool overhang length, and packing ratio. In order to perform all possible variable combinations, a total of 63 cuts were performed. The schematic of complete experimental setup was shown in Fig 1.

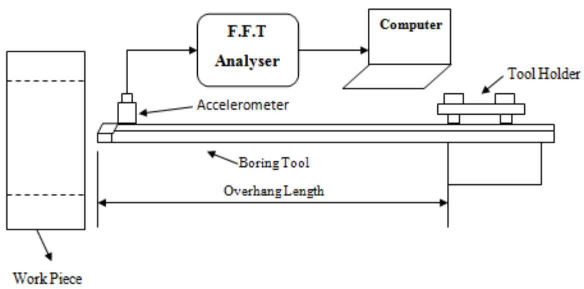

Fig. 1: Schematic of experimental setup

3.1 Hollow Boring Tool

The hollow boring tool used was based on a standard boring tool, S20 SCLCR 09T3 WIDAX (see Table 1).

Table 1: Boring tool specifications

Tool type	**(S20S SCLCR 09T3 WIDAX)**
Bar material	**Steel**
Bar length (mm)	**250**
Bar diameter (mm)	**20**
Insert Relief angle	**7^o**
Insert Lead angle	**95^o**
Insert nose radius (mm)	**0.3**

The hollow tool was used in two different damper configurations. In the first configuration (1-Cell Tool), the standard boring tool shank has been drilled axially to make an axial hole with 8mm diameter and depth of 200mm. Then after, the said hole was filled with 2mm diameter steel granular particles.

In the second configuration (2-Cell Tool), the same axial hole has been divided into two equal parts by inserting a metallic strip into the hole. Then, the both parts have been filled equally with steel granular particles having 2mm diameter.

Properties of the particles used in experimental work are tabulated in Table 4.The specifications of the particles used in the particle damper are listed in Table 2,

Table 2: Particles specification

Particles specification	
Material	**steel**
Density (Kg/m^3)	**7850**
Diameter (mm)	**2**

A full factorial experimental design has been considered to investigate the effect of three levels of each independent variable on the acceleration amplitude. These independent variables are depths of cut, feed rate, spindle speed, tool overhang length and particles packing ratio as listed in Table 3.

Table 3: Levels of independent variables

Variable	**Unit**	**Level 1**	**2**	**3**
Cutting Parameters				
Spindle speed(*S*)	**(r.p.m)**	**280**	**450**	**710**
Feed rate(*f*)	**(mm/rev)**	**0.05**	**0.1**	**0.016**
Depth of cut(DOC)	**(mm)**	**0.1**	**0.2**	**0.3**
Tool Parameters				
Tool Configuration		**Standard**	**1-Cell**	**2-Cell**
Tool Length	**(mm)**	**120**	**140**	**160**
Damper Parameters				
Particles Packing Ratio		**25%**	**50%**	**75%**

The experiments have been conducted and the tool was instrumented with an accelerometer at the tool tip to measure the maximum tool acceleration response and frequency in the vertical direction. The acceleration amplitude was recorded with an F.F.T. analyzer by averaging in the frequency domain. The vibration acceleration response for boring tool without and with particles damping for various damper configurations, i.e., 1-cell and 2-cells, at different cutting parameters (see Table 3) were obtained to determine the maximum amount of damping achieved while using the particle damper. The frequency showing the highest acceleration response amplitude was close to the initial natural frequency. Using a full factorial design 63 runs of experiments are carried out of which 9 are for acceleration response of the boring tool without damper and remaining 27 were for the boring tool with 1-cell damper and 27 were for the boring tool with 2-cell damper. Characteristics of the system with various parameters like effect of cutting forces, tool overhang length, and spindle speed, depth of cut, feed rate and packing ratio were studied.

IV. RESULTS AND DISCUSSION

Cutting tests were carried out to study the behavior of the system by measuring acceleration response amplitude of the tool for various parameters listed in Table 3. The effect of said parameters on tool acceleration response amplitude were examined as follows:

4.1 Effect of Packing Ratio on Acceleration Amplitude

The effects of packing ratio on the acceleration response amplitude of the tool with particle damper for 1-cell and 2-cell damper configurations were studied. The frequency against the acceleration responses have been obtained from F.F.T for standard,

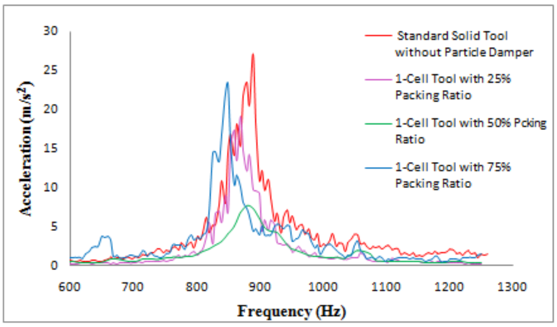

Fig 2: Effect of packing ratio on acceleration response amplitude for 1-cell damper

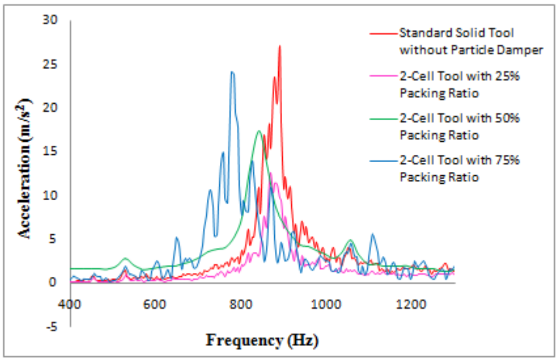

Fig 3: Effect of packing ratio on acceleration response amplitude for 2-cell damper

It can be seen from Fig 2 that the maximum reduction in the vibration amplitude was obtained at 50% packing ratio for 1-cell damper. For 2-cell damper, it can be observed from Fig 3 that maximum damping was achieved at 25% packing ratio. Thus, results emphasised that the particle damper has a positive effect in increasing the tool damping and reducing the vibration acceleration amplitude compared with un-damped solid tool.

4.2 Effect of Tool Overhang Length on Acceleration Amplitude

The effect of tool overhang length on the acceleration amplitude with a particle damper is presented in Fig. 4 for 1-cell damper and Fig 5 for 2-cell damper. Three levels of depth of cuts have been plotted against the reduction in the acceleration amplitude for three levels of tool overhang length and particles packing ratio.

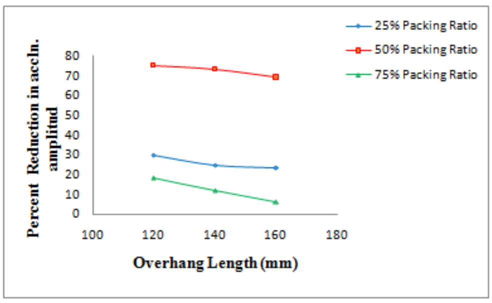

Fig 4: Effect of tool overhangs length on acceleration response amplitude for 1-cell damper

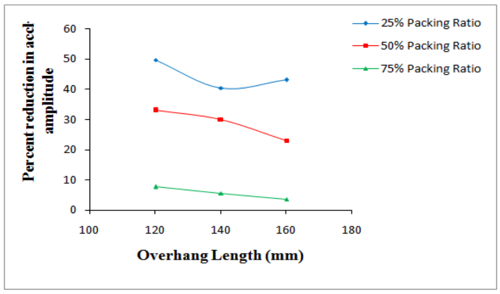

Fig 5: Effect of tool overhangs length on acceleration response amplitude for 2-cell damper

It is observed from Fig.4 and Fig.5 that acceleration amplitude of the boring tool is directly proportional to the tool overhang length and the most effective damping was achieved by particle damping at 50% packing ratio.

4.3 Effect of Depth of Cut on Acceleration Amplitude

The tool vibration increases with the depth of cut due to the increase in the cutting force. In order to study the effect of depth of cut on the tool vibration, the tool has been analyzed for three different depths of cuts and three different packing. Three levels of depth of cuts have been plotted against the reduction in the acceleration amplitude as shown in Fig 6 for 1-cell damper and Fig 7 for 2-cell damper.

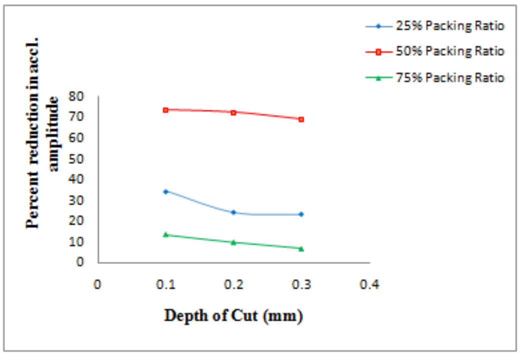

Fig 6: Effect of depth of cut on acceleration response amplitude for 1-cell damper

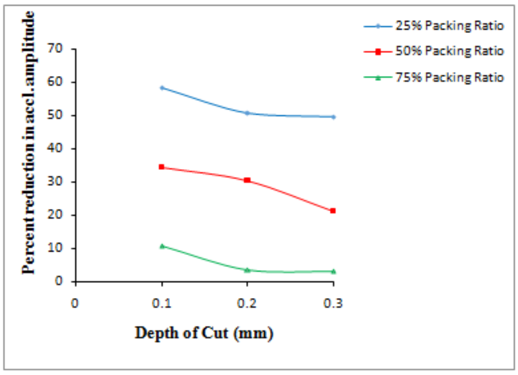

Fig 7: Effect of depth of cut on acceleration response amplitude for 2-cell damper

It is shown that, the vibration response amplitude increases with increase in the depth of cut.

4.4 Effect of Feed Rate on Acceleration Amplitude

In order to study the effect of feed rate on vibration response amplitude, the tool has been analyzed for three different feed rates for two packing ratio. Fig 8 shows the vibration response amplitude for 1-cell damper and Fig 9 for 2-cell damper.

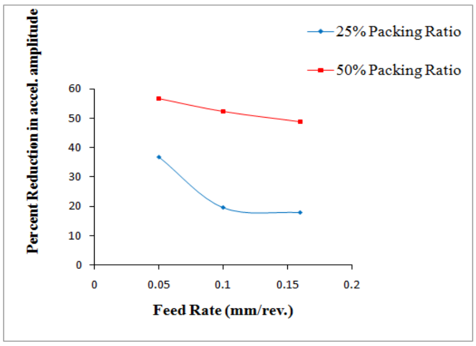

Fig 8: Effect of feed rate on acceleration response amplitude for 1-cell damper

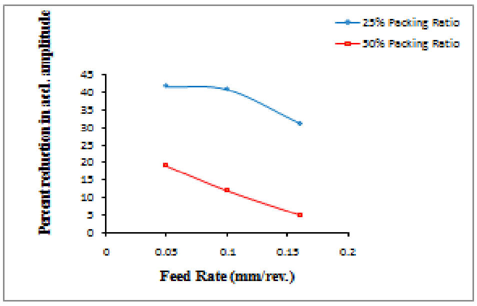

Fig 9: Effect of feed rate on acceleration response amplitude for 2-cell damper

Fig 8 and 9 show that, the vibration acceleration response increases with increase in the feed rate.

4.5 Effect of Spindle Speed on Acceleration Amplitude

Fig. 10 and 11 show the effect of spindle speed on percent reduction in the acceleration amplitude for 1-cell damper and 2-cell damper respectively.

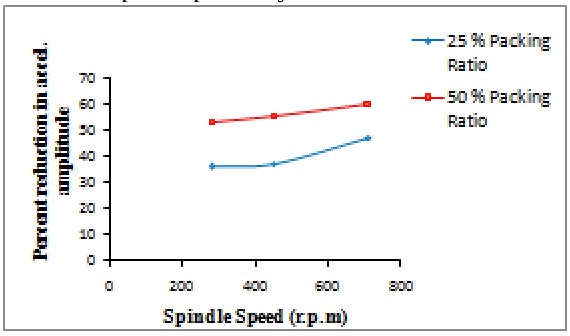

Fig 10: Effect of spindle speed on acceleration response amplitude for 1-cell damper

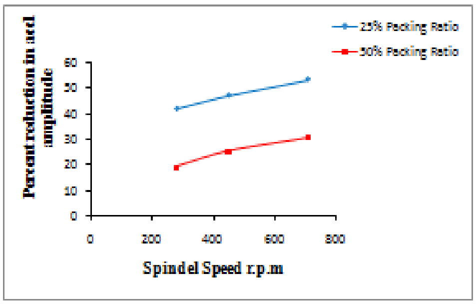

Fig 11: Effect of spindle speed on acceleration response amplitude for 2-cell damper

It is observed from Fig 10 and Fig 11, that acceleration amplitude of the boring tool is inversely proportional to the spindle speed during metal cutting operation.

V. CONCLUSIONS

The damping characteristics of boring tool are analyzed experimentally. The experimental results are used to develop a mathematical model which relates the acceleration amplitude of the boring tool as well as damper parameters. The effect of input parameters, tool overhang length, spindle speed, particle material and packing ratio on acceleration amplitude of the boring tool is studied and verified.

- For 1-cell tool, the maximum damping is observed for 50% packing ratio.
- For 2-cell tool, the maximum damping is observed for 25% packing ratio.
- For 1-cell tool, additional 15-20% extra damping has been obtained at 25% packing ratio while using 2-cell configuration.
- Maximum acceleration amplitude of the boring tool is in vertical direction.
- Acceleration amplitude of the boring tool is directly proportional to tool overhang length, depth of cut and feed rate.
- Spindle speed is inversely proportional to the acceleration amplitude.

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