Analysis of the Reduction of Vibration and Chatter Effect in Boring Process Due to the Addition of *Spring Radial Vibration Damper* (SRVD) on the Workpiece

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Abstract. Modern machining processes have been rapidly evolving into much more sophisticated forms. However, even with such sophistication in hand, the effect of chatter remains to be a significant problem. To date, engineers keep referring to the traditional chatter stability lobe to address the problem of limiting themselves in creativity to achieve high efficiency. The research aims to observe the vibration reduction along the boring process achieved by adding one type of DVA called Spring Radial Vibration Damper (SRVD) onto the workpiece. The workpiece is a cylindrical rod with the ratio of overhang length to a diameter at 6:1. The experiment conducted in different depths of cut (DoC) varies at 0.25 mm, 0.2 mm, and 0.15 mm. The experiment results show a comparison between the main system and without the SRVD in a graphical representation of the dynamic response, percentage of RMS reduction in each parameter, and surface finish of each parameter. This paper concludes that SRVD can be beneficial for the cutting process within the unstable area of the chatter stability lobe. It will worsen the cutting process if the parameters still lie within the stable area.

Keywords: Boring · Chatter · Reduction of vibration · Spring radial vibration damper · Dynamic vibration absorber

1 Introduction

Modern machining processes have been rapidly evolving into their sophisticated forms as we know them today. However, even with such sophistication in hand, the effect of chatter remains significant to this day. The excessive vibration from the chattering effect reduces the effectiveness of the machining process and the durability of the machine [1, 2].

Engineers keep on referring to the traditional chatter stability lobe to address the problem. A combination of particular spindle speed and specific cutting depth is needed to avoid the chatter generation. Several attempts had been made in the past, such as

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using Dynamic Vibration Absorber (DVA) in the boring bar [3–5]. By taking the DVA concept further, one way to reduce the excessive vibration in lathe machines would be using Spring Radial Vibration Damper (SRVD). This study aims to examine the reduction of chatter given by the SRVD through experimental methods. The experiment was conducted in different depths of cuts (DoCs) with variation of 0.25 mm, 0.2 mm, and 0.15 mm. The purpose of observing the experiment result would be to compare the surface finish with the naked eye.

The scope of this study includes: the workpiece used is cylindrical rod ST-41 steel; the workpiece's overhang length to diameter ratio is 6:1; SRVD's weight bending effect can be neglected; the workpiece is assumed to be homogenous; no deflection at the boring bar; lathe machine and the tool insert are assumed to be in good condition; friction between the mass and its pin is neglected; chuck of the lathe machine is assumed to be the system's boundary. The boring bar must be sufficiently stiff to minimize tool deflection and thus maintain dimensional accuracy and avoid vibration and chatter. For this reason, a material with a high elastic modulus (such as tungsten carbide) is desirable [6, 7].

Uncontrolled vibration and chatter of the cutting tools and the machining components have adverse effects on product quality, such as poor surface finish, loss of dimensional accuracy of the workpiece, premature wear, chipping, and failure of the cutting tool [8, 9].

In 2017, Ufuk Yigit, Ender Cigeroglu, and Erhan Budak researched the effect of piezoelectric shunt damping (PSD) on chatter vibrations in a boring process. This study stated that regenerative chatter is considered the criteria for determining cutting stability as it is less stable than mode coupling. The phase difference between previously machined and the new cutting surfaces creates variation in chip thickness [10–12]. A sample stability lobe diagram is given in Fig. 1, which illustrates the unstable (chatter) and stable (chatter-free) regions.

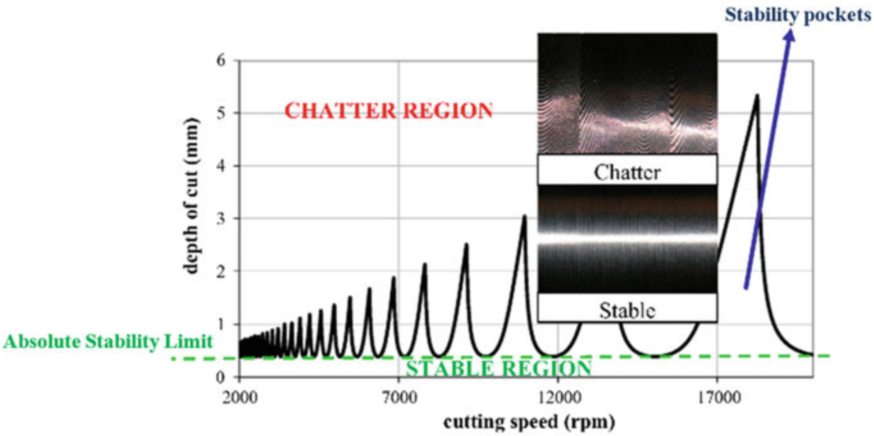


Fig. 1. Stability lobe diagram for chatter problem [10]

2 Methods

2.1 Developing the SRVD Design

The vibration dampers will be designed to overcome the vibrations that arise in the boring process. The input of this research is the design of SRVD and variations in the working frequency, mass of the SRVD, and stiffness constant from the spring of SRVD attached to the workpiece. The output of the experiment is the main system vibration response before and after SRVD installation.

The modelling of the dynamic system in this research consists of two steps: first the modelling of the main system without the SRVD and the other is the modelling of the main system with the SRVD. The physical model embodies the experiment model with cutting force as the input to the main system, as demonstrated in Fig. 2. As for the dynamic models of the system without and with SRVD are shown in Fig. 3.

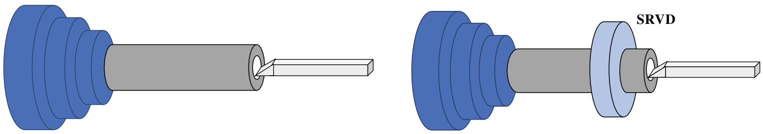


Fig. 2. Physical model of the workpiece with and without the SRVD

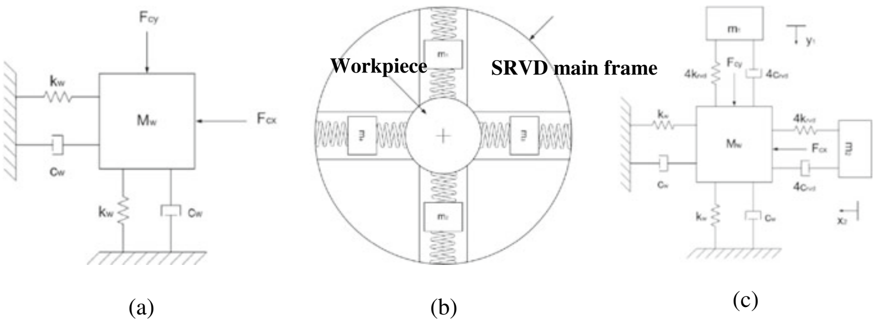


Fig. 3. **a** Dynamical model of the workpiece without the SRVD. **b** The proposed SRVD. **c** Dynamical model of the workpiece with SRVD

The equation of motion can be derived from the forces that work on the system.

$$M_w\ddot{x}_w + c_w\dot{x}_w + k_w x_w = F_{cx} \tag{1}$$

$$M_w\ddot{y}_w + c_w\dot{y}_w + k_w y_w = F_{cy} \tag{2}$$

The vertical and horizontal axis of motion can be determined by the forces that work on the system. Equation 3 and 4 are the equation of motion for the SRVD mass on both vertical and horizontal axis. Meanwhile, the value of all parameters is shown in Table 1.

Table 1. Parameters

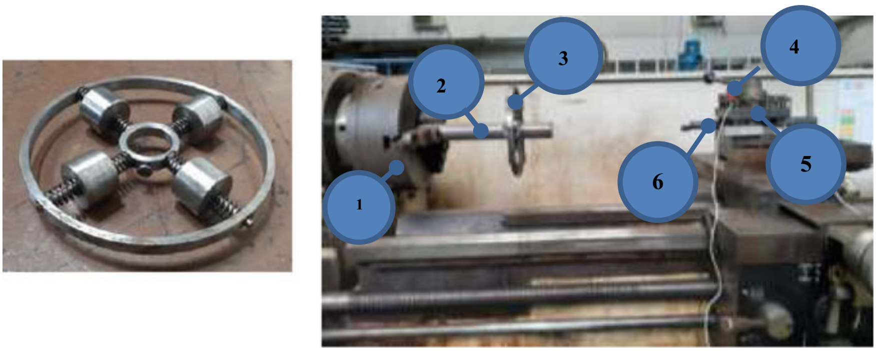
Parameter	Value	Units	Notes
M_w	1.7	kg	Mass of workpiece
m_1	0.231	kg	Vertical axis SRVD mass
m_2	0.231	kg	Horizontal axis SRVD mass
k_w	4.55×10^6	N/m	Workpiece stiffness coefficient
k_{rvd}	650.25	N/m	SRVD stiffness coefficient
c_w	0	Ns/m	Workpiece damping coefficient
c_{rvd}	0	Ns/m	SRVD damping coefficient

$$m_1\ddot{y}_1 + 4k_{rvd}(y_1 - y_w) + 4c_{rvd}(\dot{y}_1 - \dot{y}_w) = 0 \quad (3)$$

$$m_2\ddot{x}_2 + 4k_{rvd}(x_1 - x_w) + 4c_{rvd}(\dot{x}_1 - \dot{x}_w) = 0 \quad (4)$$

2.2 Manufacturing of the Workpiece and SRVD

ST-41 steel is used as the workpiece material, and SRVD mass takes the form of a cylindrical rod with a diameter of 38 mm (1.5 inches). The total length is 400 mm with an overhang length of 240 mm. The ratio of SRVD mass to the main system is 1/5 for each axis. Then, each of the four masses is determined to be 250 g in weight. Stainless steel is used as the material of the mainframe of SRVD. All the parts have been designed, being assembled as SRVD in Fig. 4.



(a) (b)

Fig. 4. **a** Manufactured SRVD. **b** Equipment installation during the experiment (1) Spindle and chuck; (2) Workpiece; (3) SRVD; (4) Accelerometer probe; (5) Turret; (6) Boring bar Bode diagram of the main system at L/D ratio

2.3 Data Sampling Instrument and Installation

The experiment is conducted using three different depths of cut, namely 0.25 mm, 0.2 mm, and 0.15 mm. The spindle rotational speed is 720 rpm, and the feed of the tool is 0.1 mm/rev. On each variation, sampling is done using 1 cm of the cutting process.

3 Results and Analysis

3.1 Analysis of Inferential Statistics

The dynamic responses of the main system with and without the SRVD are plotted in an overlaying manner within the same time frame. Judging from the behaviour of the data sample that oscillates around zero in nature, the author decided to use RMS as the comprehensive yet simple statistical tool to analyze the data. It represents the averaged deviation of each amplitude for a given sampling period, which is why it is suitable to determine each parameter's level of "vibration stability". The dynamic response of the main system with and without SRVD are plotted in an overlaying manner within the same time frame as shown in Fig. 5.

The dynamic response of the main system without the SRVD at DoC of 0.25 mm experienced a beating phenomenon that is shown by the large amplitude that builds up and diminishes in a regular pattern. Table 2 represents the vertical RMS value of the workpiece with and without the SRVD and the percentage of reduction of those values after the addition of SRVD. Negative percentage values (highlighted cells) show that the workpiece's dynamic response with the SRVD is greater than that without the SRVD.

All the RMS points of the dynamic response in the vertical and horizontal axis are presented in Table 2 and then plotted to graphs to see whether a trend exists as shown in Fig. 6. This finding shows that, in both vertical and horizontal axes, the addition of SRVD will only effectively reduce vibration that happens at high DoC. In contrast, the addition of SRVD in low DoC will only worsen the vibration of the workpiece (Fig. 6).

3.2 Surface Finish of the Workpiece

This section aims to report the surface finish of the boring process for both with and without the SRVD. Based on the acquired results, the vibration reduction can be seen by comparing the smoothness of the surface finish (Table 3). The smooth surface finish indicates that low vibration had occurred during the cutting process, and the coarse surface finish indicates the high intensity of vibrations or chatter.

4 Conclusion

The data results validate the author's hypothesis that the addition of SRVD does reduce chatter in the boring process. In a detailed manner, this report concludes the following:

1. The addition of SRVD affects the surface finish of the boring process. At DoC 0.2 mm and 0.25 mm, the surface finish from the SRVD-added process exhibit a smoother surface than the surface finish without the SRVD.

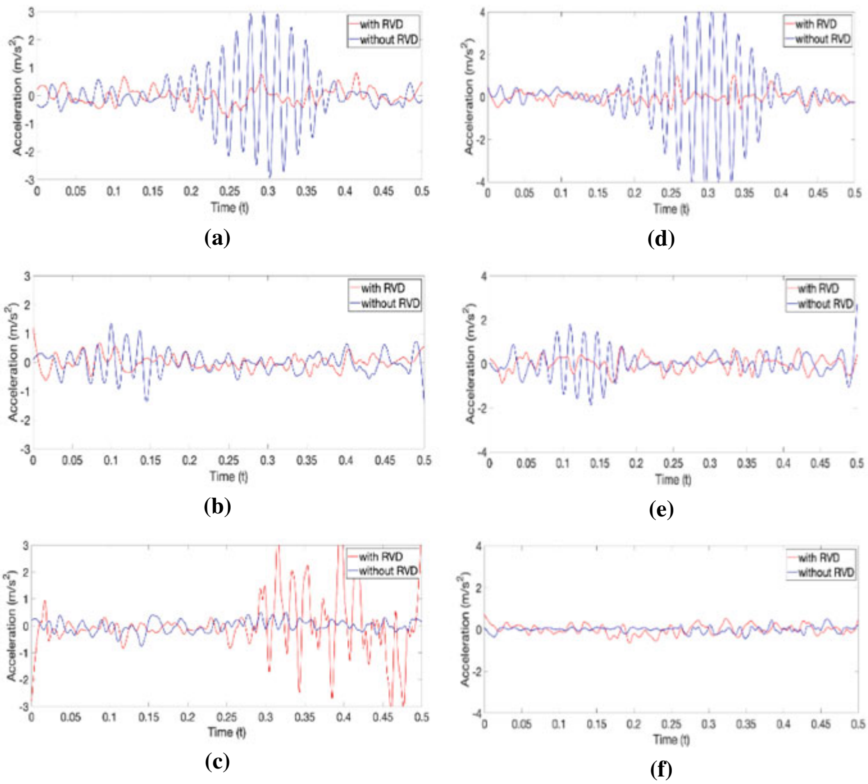
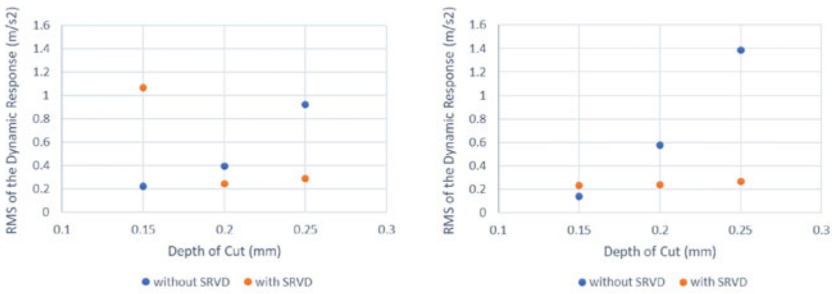


Fig. 5. Dynamic response of the main system with and without the SRVD at the vertical axis **a** DoC of 0.25 mm. **b** DoC of 0.2 mm. **c** DoC of 0.15 mm. Dynamic response of the main system with and without the SRVD at the horizontal axis. **d** DoC of 0.25 mm. **e** DoC of 0.2 mm. **f** DoC of 0.15 mm

Table 2. RMS of the dynamic response

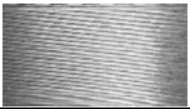
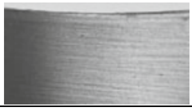
DoC (mm)	RMS of Acceleration (m/s^2)		
	Without SRVD	With SRVD	Percentage of Reduction (%)
Vertical Axis			
0.25	0.9225	0.287	68.89
0.2	0.3942	0.2455	37.72
0.15	0.2212	1.0633	-380.7
Horizontal Axis			
0.25	1.3869	0.2667	80.77
0.2	0.5737	0.24	41.73
0.15	0.138	0.2346	-70



(a) (b)

Fig. 6. RMS of the dynamic response **a** vertical axis, **b** horizontal axis

Table 3. The surface finish of the workpiece at a particular DoC

Without SRVD	With SRVD
DoC of 0.25 mm	
	
DoC of 0.2 mm	
	
DoC of 0.1 mm	
	

2. The addition of SRVD reduces the dynamic response of the boring process.
3. The addition of SRVD is observed to reduce vibration only at the unstable area of the chatter stability lobe. The addition of SRVD appears to worsen the vibration of the boring process when it is operated at a stable area of the chatter stability lobe. Further research needs to be done to validate this finding.
4. The results indicate a positive correlation between the depth of cut to the dynamic response at the boring process without the SRVD. The results indicate a negative correlation between the depth of cut to the dynamic response at the boring process with the SRVD.

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