Exploring the damping potential of a viscous oil-filled boring bar

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***Abstract*— Machining with high length-to-diameter cantilevered boring bars is prone to vibrations due to the bar's flexibility. To damp machining-induced vibrations, this paper explores the vibration damping potential of a viscous oil-filled boring bar. The central idea is to fill silicone oil in a cavity within the bar and evaluate whether vibrational energy is dissipated through viscous shear within the fluid. We conducted modal tests using two oils with different viscosities. We also checked for potential nonlinearities arising from the presence of oil. The response remained linear, and the higher-viscosity oil reduced the peak response magnitude by a significant 45%. These findings suggest that oil-filled boring bars offer a practical and simple solution for vibration damping. Future work will focus on detailed parametric experimental characterization and on confirming the chatter-free cutting potential of such bars.**

Keywords—Boring bar, Damping, Viscous fluid

I. Introduction

In deep hole machining, boring bars are often designed with high length-to-diameter (L/D) ratios, typically exceeding five, which makes them slender and structurally less rigid. Because of their slender geometry, low stiffness, and limited inherent damping, such tools are highly susceptible to vibrations under cutting forces. Such vibrations can evolve into chatter, a self-excited instability that not only degrades surface finish but also shortens tool life and restricts achievable material removal rates. To overcome these limitations, it is necessary to improve both the stiffness and damping characteristics of slender boring bars [1].

Over the past many decades, a wide range of approaches has been explored to reduce unwanted vibrations in machining processes. These are generally divided into passive and active damping techniques. Passive methods operate by embedding energy-dissipating elements, such as viscoelastic layers, tuned mass dampers, or impact dampers, without the need for external control [2, 3]. Active methods, in contrast, rely on sensors, actuators, and feedback systems to monitor and counteract vibrations in real time, providing adaptability across varying conditions [4]. While passive approaches are typically simpler, robust, and economical, active systems offer greater flexibility and effectiveness but involve higher cost and complexity [5]. As noted in the review by Munoa et al. [6], numerous chatter suppression strategies, both passive and active, have been widely investigated, with the choice of method depending strongly on the specific machining application. Building upon the limitations of conventional methods, recent studies have proposed innovative approaches for improving the damping of slender boring bars.

While most chatter suppression methods require additional attachments or structural modifications, a recent study explored a simpler alternative tailored for milling cutters. Dogan et al. [7-9] investigated the feasibility of filling the internal coolant channels of an indexable milling tool with viscous fluid, specifically silicone oil, which dissipates vibrational energy through viscous shear within the fluid, thereby increasing damping and enhancing stability. Relatedly, Zhang et al. demonstrated that submerging the milling system in viscous fluid improves damping, reduces cutting force coefficients, and enhances thin-wall machining stability by suppressing chatter [10]. Similarly, introducing viscous fluid into a workpiece cavity during turning has been shown to enhance damping and stability, thereby reducing chatter [11]. In the same way, Gürgen and Sofuoğlu demonstrated that integrating shear thickening fluid into cutting tools for turning increases stiffness and stable cutting depth while also improving surface quality [12]. However, all previous studies examined only a single oil viscosity and did not address potential nonlinear behaviors. Moreover, these investigations were limited to turning and milling processes, with no extension of the concept to boring operation.

Since oil-filled boring bars offer a practical and simple solution for vibration damping, the main aim and new technical contribution of this paper is to report the effect of a change in oil viscosity and investigate possible system nonlinearities due to change in excitation amplitudes.

The remainder of the paper is structured as follows. Section II describes the experimental setup and plan. We test a rotating boring bar by filling it with two oils with different viscosities. We also test for repeatability and for potential nonlinearities. Section III presents the results and discusses the damping potential of the viscous fluid. Section IV concludes the study with key findings and future scope.

II. Experimental Setup and Plan

We tested a typical rotating boring bar used to bore deep holes. The bar was made of steel with a total length of 250 mm and a diameter of 25 mm. This boring bar was mounted in a power chuck type milling holder, with the clamping length inside of the boring bar being 50 mm. This made the length-to-diameter ratio 8, i.e., the bar is slender. The bar mounted in a holder was in turn mounted on a 3 axis vertical CNC machining center (model: ACER; make: Ace Manufacturing Systems Ltd.). Though the bar had a cartridge that houses the cutting insert, the bar was tested without the cartridge. Fig. 1 shows the experimental setup.

The boring bar had a cavity that was made to be 40 mm deep with a diameter of 8 mm. Fig. 2(a) shows the cavity. This cavity was separately filled with silicone oils of two different viscosities, namely 1000 cSt and 60,000 cSt. Fig. 2(b) shows the oils we used. The choice of these two oils allowed for a clear comparison between a moderately viscous fluid and a highly viscous one, thereby providing insights into how viscosity potentially influences damping characteristics.

To evaluate the dynamics of this boring bar, we conducted modal tests using standard impact testing procedures [13]. And, since the bar is relatively symmetrical, we tested only the representative Y-direction as shown. And, since the machining stability of the bar is governed by its flexibility in its radial direction [14], the Y-directional measurement is thought to be sufficient to characterize the dynamic behavior of the bar. To measure the response, an accelerometer (model: 3225F1; make: Dytran Instruments Incorporation) was wax mounted directly on the boring bar as shown. Two instrumented modal hammers were used to excite the boring bar to test for its potential nonlinear behavior. A medium hammer (model: 5800B4; make: Dytran Instruments Incorporation) and a large hammer (model: 086D20; make: Dytran Instruments Incorporation) were used. Fig. 1 only shows one hammer as a representative case. Data acquisition was carried out using a multi-channel DAQ system (model: NC-2-379; make: National Instruments) interfaced with MATLAB's data acquisition and analysis module.

Fig. 1: Experimental setup for measuring the boring bar's dynamics.

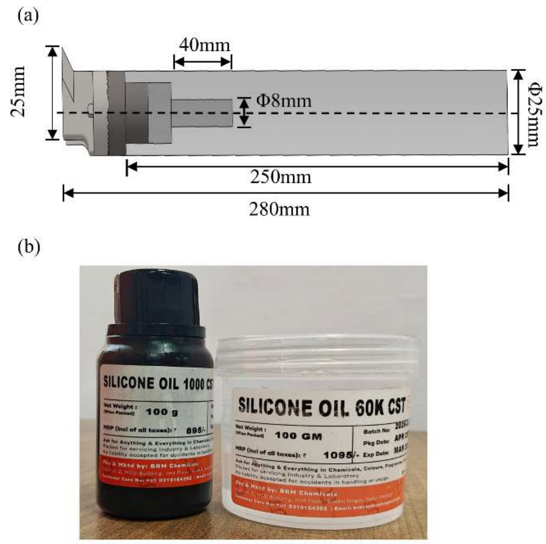

Fig. 2: (a) Schematic of boring bar with internal cavity (b) Silicone oils with viscosity 1000 cST and 60,000 cST respectively

To first establish the benchmark response, we tested the dynamics of the boring bar without there being any oil in its cavity. We then separately filled the two different oils and repeated measurements. The cavity was thoroughly cleaned before filling it with the other oil. Testing for each configuration involved averaging three hits with the two different impact hammers. Each measurement was repeated twice. Additionally, to ensure that the observed trends in behavior were attributable to the influence of the viscous fluid rather than experimental variability, we also tested for repeatability by mounting, testing, removing, re-mounting and re-testing the boring bar in every configuration.

III. RESULT AND DISCUSSION

This section reports on our experimental observations. At first, we discuss repeatability of measurements. That is followed by a discussion on observations from checks for potential nonlinearities. We finally present a comparative analysis of the response of the boring bar with without the two different oils. Results in all cases are shown in terms of frequency response functions (FRFs). The FRFs shown were obtained from the ratio of the Fourier transform of the output response in terms of displacements measured over time to the Fourier transform of the input force also measured over time. The conversion from measured accelerations to displacements shown was done in the frequency domain.

A. Repeatability checks for dynamics

Repeatability of the measurements is discussed herein for the representative case of there being no oil in the cavity. To check for repeatability, we mounted the boring bar, then tested it, then removed it, and then re-mounted it and re-tested it. Results for the representative results obtained with the medium hammer are shown in Fig. 3.

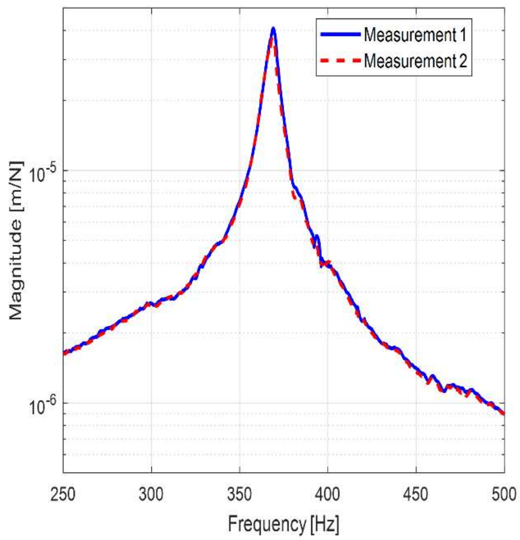

Fig. 3: Repeatability checks of the dynamics of the boring bar without oil in its cavity.

As is evident from the FRFs in Fig. 3, since the response curves overlap, the measurements are repeatable. This suggests that the boundary conditions are repeatable, and, when we add oil in the cavity, any change in response can be attributed to the oil, and not to the boundary condition not being repeatable.

The response characteristics in Fig. 3 also show that there is only one dominant natural frequency of the boring bar in the frequency range of 250 Hz to 500 Hz. This is consistent with how slender cantilevered boring bars respond. The natural frequency of the bar without oil is observed to be 369 Hz. This is the frequency at which the response in the FRF peaks. Prior to discussing how/if the peak response changes when we add oil in the cavity, we discuss response characteristics with different modal hammers.

B. Checks for potential nonlinearities due to changing input forces

Results with changing force levels with the two hammers are shown in Fig. 4. These too are for the representative case of there being no oil in the cavity. The input force with the medium hammer was ~25 N, and with the large hammer it was ~150 N, i.e., a six-fold increase when changing the hammer from medium to large. If the bar exhibited geometric nonlinearity, the output response would change not in proportion to the force. However, as is evident from the FRFs, which normalize output to input, both curves overlap, suggesting that the bar does not exhibhit strong nonlinear characteristics. There is no discernible change in natural frequency. And, though there is a very slight reduction in the peak magnitude with the large hammer, the change is thought to be insignificant and the bar can be assumed to be linear, or at worst, very weakly nonlinear. This observation, along with our measurements being repeatable will help isolate the influence of oil in the cavity.

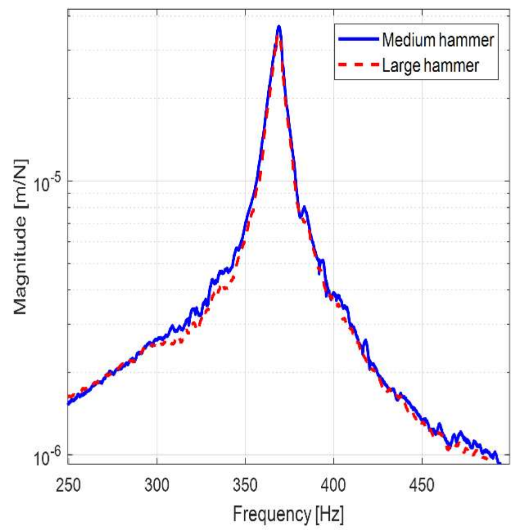

Fig. 4: Response characteristics of the bar without oil when excited by the two different hammers.

C. Influence of different oils in the cavity

To evaluate the influence of viscous fluid on the dynamic response, FRFs were compared under three different conditions: without oil, with 1000 cSt silicone oil, and with 60,000 cSt silicone oil as shown in Fig. 5. The natural frequency of the boring bar without oil was observed at 369 Hz. With the addition of 1000 cSt oil, the natural frequency shifted slightly to 368 Hz, while with the highly viscous 60,000 cSt oil, it further decreased to 365 Hz. Although these frequency shifts are relatively small, they reflect the added mass and damping effect introduced by the fluid. More importantly, the resonance amplitude was significantly reduced in the oil-filled cases compared to the without-oil condition. Specifically, the use of 1000 cSt oil reduced the vibration amplitude by about 15%, while the use of 60,000 cSt oil achieved a much larger reduction of approximately 45%.

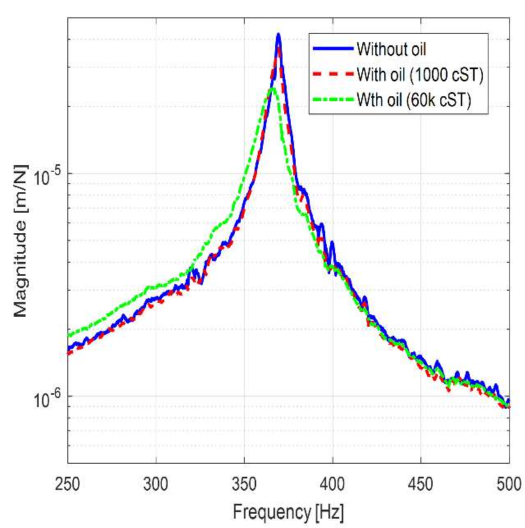

Fig. 5: FRF of the boring bar for with and without silicone oil

These results demonstrate two important outcomes. First, even modest viscosity levels (1000 cSt) can introduce noticeable damping into the system, validating the practical applicability of this method. Second, the strong attenuation observed with 60,000 cSt oil highlights the role of higher viscosity in enhancing damping effectiveness. The overall trend clearly shows that increasing the viscosity of the filling fluid systematically suppresses the dynamic response, confirming that fluid-induced damping can be tuned to achieve desired vibration control levels. This makes viscous oil filling a simple yet powerful method for improving the dynamic stability of boring bars in machining applications.

Results in Fig. 5 for the cases with oil were observed to be repeatable, i.e., like the case for without oil, results for which were shown in Fig. 3, even with the two different oils, when the bar was mounted, tested, removed, re-mounted, and re-tested, the results were repeatable. Furthermore, like the case of results without oil, results for which were shown in Fig. 4, even with oil, the response characteristics were observed to be linear, i.e., when the force amplitude was increased by changing the hammer from medium to large, the FRFs remained the same. This confirmed that, even with oil, the bar exhibited linearity. Since measurements were repeatable and linear, all changes observed in Fig. 5 can be attributed to the role of viscous oil.

IV. CONCLUSION

The paper presented an experimental study on enhancing the damping of a boring bar by filling an internal cavity within it with viscous oil. The results confirmed that damping performance improves with increasing oil viscosity, with the 1000 cSt oil showing a 15% reduction in vibration amplitude and the 60,000 cSt oil achieving a 45% reduction compared to the without-oil condition. Importantly, the natural frequency remained nearly unchanged, shifting only slightly from 369 Hz (without oil) to 368 Hz (1000 cSt) and 365 Hz (60,000 cSt). Linearity checks showed the system to be weakly nonlinear, and repeatability tests verified the robustness of the setup. These outcomes demonstrate that fluid-induced damping is a simple and practical solution to improve the damping potential of slender cantilevered tools.

Future studies could explore a broader range of oils, optimize cavity geometry, and employ controlled excitation using a shaker for more precise characterization. Extending the investigation to chatter suppression under cutting conditions would further validate viscous oil-filled cavities as a cost-effective and adaptable approach for industrial applications.

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REFERENCES

[1] A. Yadav, D. Talaviya, A. Bansal, and M. Law, "Design of chatter-resistant damped boring bars using a receptance coupling approach," *Journal of Manufacturing and Materials Processing*, vol. 4, no. 2, 2020, doi: 10.3390/jmmp4020053.

[2] E. I. Rivin and H. Kang, "Enhancement of dynamic stability of cantilever tooling structures," *International Journal of Machine Tools and Manufacture*, vol. 32, no. 4, pp. 539–561, 1992.

[3] N. D. Sims, "Vibration absorbers for chatter suppression: A new analytical tuning methodology," *Journal of Sound and Vibration*, vol. 301, no. 3–5, 2007, doi: 10.1016/j.jsv.2006.10.020.

[4] A. Preumont, *Vibration Control of Active Structures*, Springer, 2011.

[5] H. C. Yadav, A. Patel, J. Bhoge, P. Wahi, and M. Law, "Experimental analysis of the dynamics of an impact damped boring bar," in *Proc. 13th Int. Conf. on Precision, Micro, Meso and Nano Engineering (COPEN-13)*, 2024.

[6] J. Munoa, et al., "Chatter suppression techniques in metal cutting," *CIRP Annals – Manufacturing Technology*, vol. 65, no. 2, 2016, doi: 10.1016/j.cirp.2016.06.004.

[7] H. Dogan, et al., "Feasibility study of chatter suppression in milling through internal channels," *International Journal of Advanced Manufacturing Technology*, 2025, doi: 10.1007/s00170-025-16594-5.

[8] R. H. Namlu, H. Dogan, and M. Ozsoy, "Effect of tool cavity conditions on damping, chatter mitigation, and surface quality in internally cooled milling tools," in *Proc. 20th CIRP Conf. on Modelling of Machining Operations*, 2025.

[9] M. Ozsoy, "Optimizing coolant channels for improved cutting tool vibration suppression," *Materials and Manufacturing Processes*, 2025, doi: 10.1080/10426914.2025.2507068.

[10] Z. Zhang, H. Li, G. Meng, and S. Ren, "Milling chatter suppression in viscous fluid: A feasibility study," *International Journal of Machine Tools and Manufacture*, vol. 120, pp. 20–26, 2017, doi: 10.1016/j.ijmachtools.2017.02.005.

[11] M. Griskevicius, V. Khaska, and Z. M. Kilic, "Chatter mitigation in turning slender components using viscous fluids," *Journal of Manufacturing and Materials Processing*, 2024, doi: 10.3390/jmmp8040128.

[12] S. Gurgen and M. A. Sofuoglu, "Integration of shear thickening fluid into cutting tools for improved turning operations," *Journal of Manufacturing Processes*, 2020.

[13] D. J. Ewins, *Modal Testing: Theory, Practice, and Application*, 2nd ed., Wiley, Hoboken, USA, 2000.

[14] E. Ozlu and E. Budak, "Analytical modelling of chatter stability in turning and boring operations – Part 1: Model development," *Journal of Manufacturing Science and Engineering*, vol. 129, no. 4, 2007, doi: 10.1115/1.2738118.