International Journal of Sciences: Basic and Applied Research (IJSBAR)

ISSN 2307-4531
(Print & Online)

http://gssrr.org/index.php?journal=JournalOfBasicAndApplied

Investigating the Effect of Fluid Flow on Chatter Vibration in Drilling

I. Maleki*

Curtin University, Kent Street, Bentley, Perth, Western Australia 6102, School of Mechanical Engineering, Iran University of Science and Technology, Tehran, Iran
Email: mechbrowser@gmail.com

Abstract

In this work the effect of fluid flow on damping characteristics in deep drilling is investigated. Chatter suppression could be performed by both active and passive methods. Generally, passive methods are less costly; however, they require modifications in tool and machine design and structure before the operation; hence, they may not be suitable for currently running equipment. On the other hand, inducting fluid flow as a damping tool does not require any changes in the machine tool structure and could be applied only by adding an extra part (e.g. a cylinder around the drill bit as a fluid container) to the cutting setup. This container could be a flexible cylinder or a multi sliding part cylinder which surrounds the drill bit and the damping fluid and helps to suppress the chatter vibration. In this study, it was shown that conventional cutting fluids could be used as the damping agents; in fact, they could drastically improve damping characteristics of the cutting process. It was also shown that the gap between the drill bit and the cylinder does not have to be precise which lead to even cheaper construction costs. In other words, the asymptotic border of stability (ABL) would drastically rise by adding a cylinder with one to two millimeter gap around the drill bit and forcing the cutting fluid to pass through this gap.

Keywords: drilling; chatter; chatter suppression; fluid; damping.

----

* Corresponding author.

1. Introduction

Regenerative chatter has been the main limitation in cutting operations [1] and also results is poor surface quality[2]; besides, analyzing deep hole drilling vibration, where the ratio of tool length over diameter is higher than 5 [3], is more complex comparing with other procedures [4]. The stiffening properties and damping characteristic of the long drill are very low, which increase the chance of turning the whirling vibration in the early stage of drilling into a regenerative chatter. Thus, many researchers are investigating new methods to overcome this problem [5-7].

However, most of these method emphasis on active suppression methods, which focus on monitoring machine tools dynamic responses and changing cutting conditions to reduce regenerating vibration. Active methods requires many supplementary materials and provision to work; they require sensors, actuators, complicate computer setups, and features that could absorb or supply energy; in other words they require tools that are able to monitor, diagnose and implement changes in machine tools dynamic behavior [8]. Moreover, there are extra cost for maintenance and monitoring of these devices themselves and exceptional staffs that have special knowledge and training are required to work with them, which means the use of these methods more costly and complicated.

On the other hand, passive methods are focused on preventive measures to avoid chatter even before starting. These methods are applied by adding parts or changing the structure of the tool that increases damping characteristics of the machine tool. Kim and his colleagues [9] has introduced mechanical dampers to suppress chatter in long slender mills. Moreover, Plate insertion has been used in cutting tool to enhance damping [10]; impact dampers helped to suppress chatter in boring [11]; carbon fiber epoxy bars are also used in boring [3]; multi-fingered cylindrical insert inside milling clutters has been used [12]; low-density, low-wave-speed media is implemented in aluminum cutting [13]. Recently, application of magnetorheological fluid damper is investigated and shows satisfactory outcomes in damping chatter vibration [14]. Still, these methods require drastic changes in the tool or machine structure. Maleki and his colleagues [15] has theoretically discussed a relatively simple low cost method to suppress chatter that could enhance damping characteristics by induction of fluid flow. It was shown that damping characteristic of the chatter could drastically be changed by using a viscos flow around the drill bit while the flow is sounded by a cylinder. The study suggest that the asymptotic borders of stability will raise, as the viscos flow dampens the vibration passively while the frequency of chatter remains almost the same comparing with when the fluid force term is not applied. This gives the manufacturers the ability to perform the cutting process at higher speeds and bigger radial widths of cut.

In this paper, effect of fluid flow around the drill bit inside a jacket is investigated based on the model introduced earlier [15]. Various parameters that affects the viscos fluid will be discussed; these parameters are related to the characteristics of the fluid and new setup configuration like constant viscosity coefficient and the ratio of inner cylinder radius to the outer cylinder radius. One option to be used as the viscos fluid is the cutting fluid itself; in that case, the economic impact of this method will be much cheaper and will make it extremely conventional. Accordingly, the suitability of the conventional cutting fluids in enhancing damping characteristic at various gaps are investigated.

2. Setup Configuration

As discussed earlier it was suggested that if the drill bit is surrounded by another cylinder and a viscos flows between them as shown in Figure 1 it will increase the damping characteristics of the drilling process. This jacket could be flexible or sliding jacket for conventional drilling bit while for some special drilling process like spade or gun drilling it could be a straight cylinder, as in these procedures the drill shank is very long.

Figure 1: Drill bit surrounded by a jacket

The force on the inner cylinder when there is a low-Reynolds-number flow between to concentric cylinder is

$$F_D = -C_{fd}U \tag{1}$$

Where $\mathbf{C_{fd}}$ (kg/(m.s)) is

$$C_{fd} = \frac{4\pi\mu\left(1+\lambda^2\right)}{\left(1+\lambda^2\right)\times\log_e\left(\frac{1}{\lambda}\right)-\left(1-\lambda^2\right)} \tag{2}$$

Where □ (kg/(m.s)) and □ are the constant viscosity coefficient and the ratio of inner cylinder radius to the outer cylinder radius (r1/r2), respectively, which are demonstrated in Figure 2. A conventional gap (r2-r1) could be between one to two millimeters. The drill bit characteristics are represented in table 1.

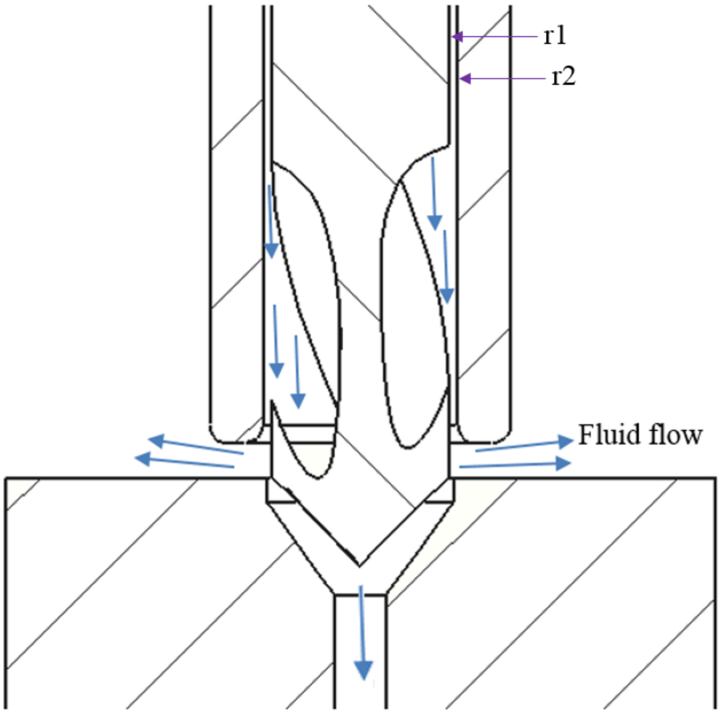

Figure 2: Setup explanation

Dynamic viscosities of conventional fluid cuttings vary from 1 to 2 mPa.s [16, 17], when they are mixed with water with ratios 1:10 or more. This value could raise to 15 mPa.s or more if the cutting fluid is not mixed with water [18].

Table 1: Tool Dynamics

$f_n = 630Hz$
$k = 0.4 \times 10^6 N/m$
$\zeta = 0.0080$
$k_{cT} = 13.37 \times 10^6 N/m^2$
$k_c = 13.37 \times 10^6 N/m^2$
$r = 4.75mm$
$l = 193mm$

3. Results and Discussions

Result are calculated for various fluids and gap distance between drill and the jacket. Effect of viscos fluid on asymptotic border of stability when the dynamic viscosity changes from 1 to 50 mPa.s for three different gap distances between drill bit and jacket is calculated. The gap distances are 1,1.5, and 2 mm.

Effect of dynamic viscosity of fluid on C_{fd} is shown in Figure 3. For the gap distance of 1mm the C_{fd} value changes from 0.1 to 23 Pa.s while it changes from 0.1 to 8 when the gaps is 1.5mm. C_{fd} changes from 0.1 to 4 for the gap distance of 2mm.

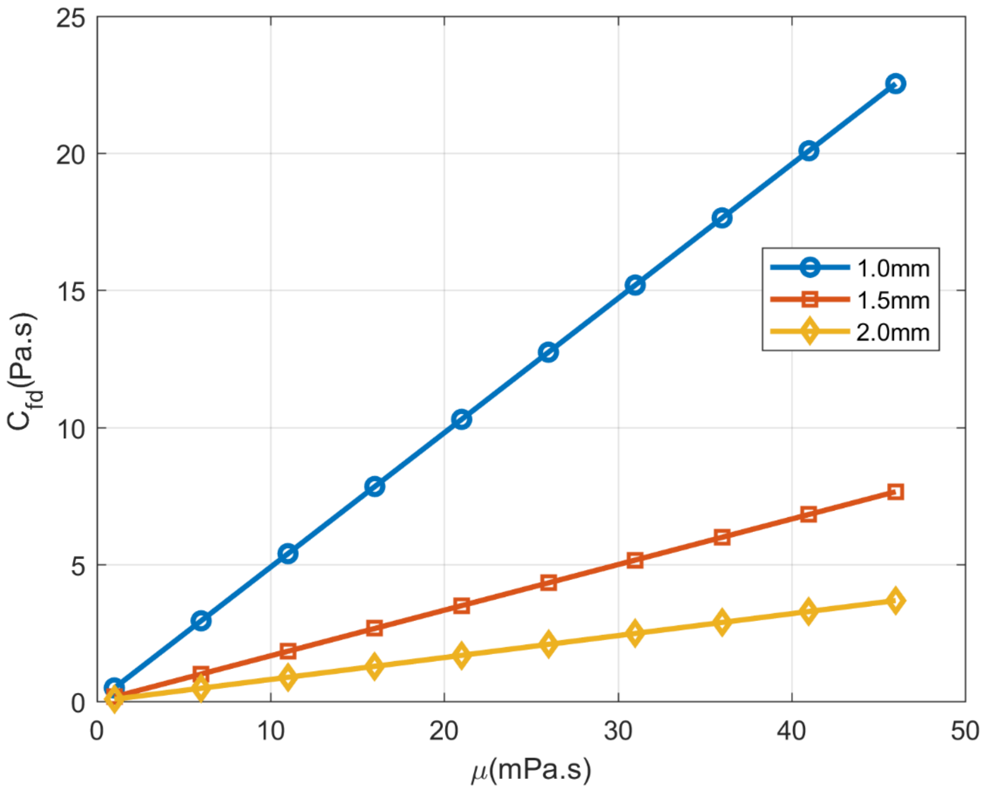

Figure 3: the relation between C_{fd} and for three types of clearance 1mm, 1.5mm, and 2mm gap

The effect of C_{fd} on asymptotic border of stability is shown in Figure 4. The ABL/ABL_0 changes from 1 to 10.2 when the C_{fd} vlue changes from 0.1 to 10 Pa.s. ABL is the value of asymptotic border of stability in the presence of fluid and ABL_0 is the value of asymptotic border of stability when there is no fluid.

By applying the effect of conventional fluid cuttings which vary from 1 to 2 mPa.s, even when the clearance is 2mm, C_{fd} value changes between 0.8-1.7 Pa.s which means ABL/ABL_0 value changes from 1.5 to 2. In other words the cutting procedure is possible at radial width of cut of 1.5 to 2 times bigger than when there is no fluid.

The C_{fd} value changes from 1.6 to 3.2 Pa.s for conventional fluids when the gap is 1.5mm. This mean that the ABL/ABL_0 value changes from 2 to 3.2. For the gap of 1mm to the C_{fd} value changes from 4.7 to 9.4 Pa.s which leads to ABL/ABL0 value changing from 4.5 to 9.5.

The results show that the damping characteristic of the machine tool drastically increase by introducing conventional cutting fluids as viscos fluid.

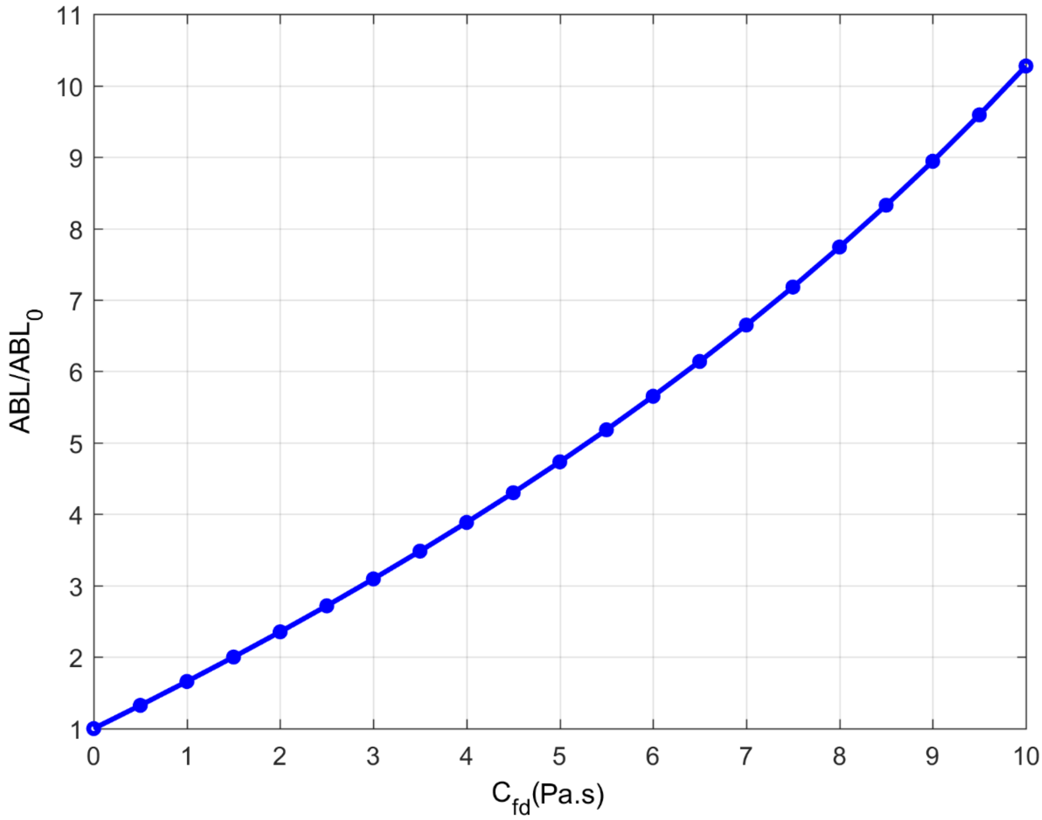

Figure 4: The effect of C_{fd} on ABL/ABL_0.

4. Conclusion

The effect of damping characteristics of the fluid flow was investigated in deep drilling for a long drill. It was shown that the damping characteristics could drastically improve by introducing viscous fluid around the drill bit which is contained in a cylinder. Besides, the possibility to use the conventional cutting fluids as viscos fluid was also discussed; it was shown that with gaps of 1 to 2 mm between jacket and drill bit cutting fluids could raise the asymptotic borders off stability 1.5 to 9.5 times of when there is now fluid depending on the gap size. The result could be better by using fluids with higher viscosity than cutting fluids. However, the effect of cutting fluids themselves seems to be enough to rich the maximum width of cut.

References

[1]. Altintas, Y., and M. Weck. "Chatter stability of metal cutting and grinding." CIRP Annals-Manufacturing Technology 53.2 (2004): 619-642.

[2]. Dias, Tânia, et al. "Milling parameters optimization for surface quality." CONTROLO 2016 (2017): 583-593.

[3]. Hwang, Hui Yun, and Jin Kook Kim. "Design and manufacture of a carbon fiber epoxy rotating boring bar." Composite Structures 60.1 (2003): 115-124.

[4]. Uekita, Masahiro, and Yasuhiro Takaya. "Tool condition monitoring technique for deep-hole drilling

of large components based on chatter identification in time–frequency domain." Measurement 103 (2017): 199-207.

[5]. Qin, Chengjin, et al. "A novel approach for the acquisition of vibration signals of the end effector in robotic drilling." Aircraft Utility Systems (AUS), IEEE International Conference on. IEEE, 2016.

[6]. Siddhpura, M., and R. Paurobally. "A review of chatter vibration research in turning." International Journal of Machine tools and manufacture 61 (2012): 27-47.

[7]. Wan, Min, Zekai Murat Kilic, and Yusuf Altintas. "Mechanics and dynamics of multifunctional tools." Journal of Manufacturing Science and Engineering 137.1 (2015): 011019.

[8]. Quintana, Guillem, and Joaquim Ciurana. "Chatter in machining processes: a review." International Journal of Machine Tools and Manufacture 51.5 (2011): 363-376.

[9]. Kim, Nam H., Dongki Won, and John C. Ziegert. "Numerical analysis and parameter study of a mechanical damper for use in long slender endmills." International Journal of Machine Tools and Manufacture 46.5 (2006): 500-507.

[10]. Marui, Etsuo, et al. "Plate insertion as a means to improve the damping capacity of a cutting tool system." International Journal of Machine Tools and Manufacture 38.10 (1998): 1209-1220.

[11]. Ema, Satoshi, and Etsuo Marui. "Suppression of chatter vibration of boring tools using impact dampers." International Journal of Machine Tools and Manufacture 40.8 (2000): 1141-1156.

[12]. Ziegert, John C., et al. "Enhanced damping in long slender end mills." Journal of Manufacturing Processes 8.1 (2006): 39-46.

[13]. Varanasi, Kripa K., and Samir A. Nayfeh. "Damping of flexural vibration using low-density, low-wave-speed media." Journal of Sound and Vibration 292.1 (2006): 402-414.

[14]. Zhang, Huang, et al. "1992. Research on deep hole drilling vibration suppression based on magnetorheological fluid damper." Journal of Vibroengineering 18.3 (2016).

[15]. I. Maleki, N. M. Nouri, and R. Madoliat. "An Analytical Study of the Effect of Fluid Flow on Damping Characteristics in Deep Drilling." American Scientific Research Journal for Engineering, Technology, and Sciences (ASRJETS) 33.1 (2017): 155-161.

[16]. Sales, Wisley Falco, Anselmo Eduardo Diniz, and Álisson Rocha Machado. "Application of cutting fluids in machining processes." Journal of the Brazilian Society of Mechanical Sciences 23.2 (2001): 227-240.

[17]. Stanciu, Ioana. "A new viscosity-temperature relationship for mineral oil SAE 10W." Analele Universitatii" Ovidius" Constanta-Seria Chimie 23.1 (2012): 27-30.

[18]. Astakhov, Viktor P. "Cutting fluids (coolants) and their application in deep-hole machining." Online URL: http://viktorastakhov. tripod. com/DH/coolant. pdf] accessed on October 23.2015 (2001): 1-17.