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An Analytical Study of the Effect of Fluid Flow on Damping Characteristics in Deep Drilling

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Abstract

In this study a new method for suppression of chatter vibration in deep drilling based on the model previously provided by authors [Mehrabadi and his colleagues International Journal of Machine Tools and Manufacture 49.12 (2009): 939-946] is discussed. The study showed that the application of the fluid flow would improve the damping characteristic of the drill bit. Some of the advantages of this method are: (i) being simple and low cost in construction, (ii) easy to assemble, and (iii) elimination of the need to adjust damping characteristic of the suppression method. In this research investigation, it is shown that by introducing a Stokes flow around the drill bit contained in a jacket, asymptotic border line of stability could be raised drastically while frequency of the chatter does not vary dramatically.

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

1. Introduction

Chatter vibration in deep drilling and similar operation like boring occurs due to low bending stiffness and damping characteristics of the drill bit [1, 2]. Researchers have developed various methods in order to study chatter vibration in deep hole drilling [3-5]. Moreover, advantageous methods like impact dampers, viscoelastic damper, and magnetorheological fluid have been studied for the suppression of chatter [6-13]. Nevertheless, practical application of most vibration absorbers to the long drilling bit is doubted [14]. A new chatter suppression method and theoretical analysis based on applying a fluid flow in a jacket around the drill bit is introduced. This fluid could be one of conventional industrial fluids which are already used in machining process for lubrication purpose.

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The relative translation of the jacket and the drill bit causes a damping force imposed by the surrounded fluid between the drill bit and the cylinder. The setup is small, simple, and low cost for practical applications relative to usual passive and active procedures.

The configuration could be installed on the drilling head and there would be no requirement to refabricate tool or the machine setup. This procedure could also be applicable to similar machining processes like boring and milling; however, other machining methods are not studied in this paper. Fluid drag force is added to the analytical model which was discussed earlier by the authors [15] and the effect of viscus fluid on deep drilling is studied.

2. Modeling and setup explanation

In order to damp chatter vibration passively, a Stokes fluid flow between drill bit (inner cylinder) and a jacket (outer cylinder) could be inducted.

Different setups shown in Fig. 1 are examples of how fluid could be induced around the drill bit. The configuration could be installed to the drilling head in way that the outer jacket remains non-rotating during the process. If a fluid surrounds the drill bit, drag forces on the drill appears in four main directions (Fig. 2.):

1- Axial direction due to axial movement and vibration of the drill,

2- Rotational direction due to rotating of the tool and rotational vibration,

3 and 4- ξ and η directions in horizontal plane due to whirling of the tool caused by bending vibration.

Since in this study, only bending vibration of the drill is investigated, drag forces in horizontal plane are considered. The tool is assumed as a circular cylinder that is surrounded by fluid; in fact, this assumption is applicable to spade and gun drilling procedures; however, the complicated geometry of conventional drill bits would be studied later.

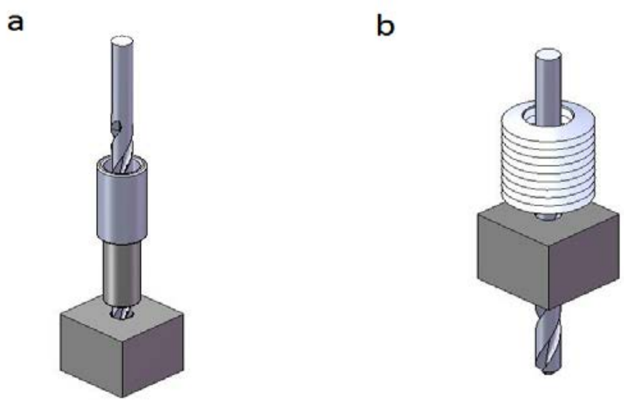

Figure 1: Drill bit and fluid jacket configuration

$$\mathbf{M}\begin{bmatrix}\ddot{\xi}\\ \ddot{\eta}\end{bmatrix}+\mathbf{C}\begin{bmatrix}\dot{\xi}\\ \dot{\eta}\end{bmatrix}+\mathbf{K}\begin{bmatrix}\xi\\ \eta\end{bmatrix}=\vec{\mathbf{F}}+\vec{\mathbf{Q}}+\vec{\mathbf{F}}_D, \quad (1)$$

All parameters except $\mathbf{F_D}$ (N) are discussed previously by the authors. $\mathbf{F_D}$ (N) is the drag force which is caused by the fluid interaction on the drill bit. **F** and **Q** as mentioned previous study are cutting and frictional forces acting on the drill, respectively [15]. On including the gyroscopic effect due to rotating of the tool:

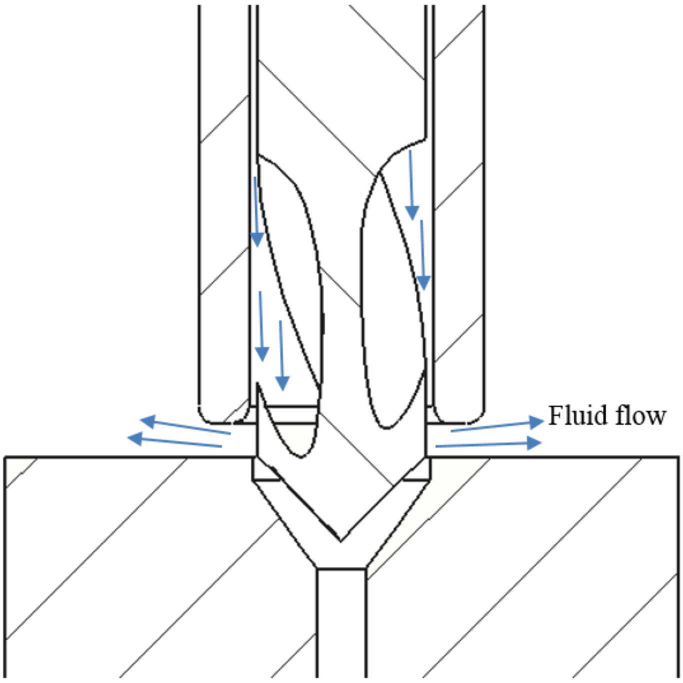

Figure 2: Drill bit surrounded by fluid in a jacket in the early stage of cutting

The equation of motion for drill can be written as

$$\mathbf{M}=\begin{bmatrix}m & 0\\ 0 & m\end{bmatrix},\mathbf{C}=\begin{bmatrix}c & -2m\Omega\\ -2m\Omega & c\end{bmatrix},\mathbf{K}=\begin{bmatrix}k-m\Omega^2 & -c\Omega\\ c\Omega & k-m\Omega^2\end{bmatrix} \quad (2)$$

Where m, c and k are the bending dynamic properties of the drill, and Ω (rad/s) is the drill rotational speed.

The force on the inner cylinder when there is a low-Reynolds-number flow between to concentric cylinder is [16].

$$F_D=-C_{fd}U \quad (3)$$

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

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

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. By considering the whirling vibration and the radial velocity the drag force could be defined as

$$\vec{\mathbf{F}}_D = -C_{fd}\begin{bmatrix}\dot{\xi}-\eta\Omega\\ \dot{\eta}+\xi\Omega\end{bmatrix} \tag{5}$$

By substituting equation (5) into (1), the equation of motion of the drill surrounded by a fluid is formed:

$$\mathbf{M}\begin{bmatrix}\ddot{\xi}\\ \ddot{\eta}\end{bmatrix}+\left(\mathbf{C}+C_{fd}\begin{bmatrix}1&0\\0&1\end{bmatrix}\right)\begin{bmatrix}\dot{\xi}\\ \dot{\eta}\end{bmatrix}+\left(\mathbf{K}+C_{fd}\begin{bmatrix}0&-\Omega\\ \Omega&0\end{bmatrix}\right)\begin{bmatrix}\xi\\ \eta\end{bmatrix}=\vec{\mathbf{F}}+\vec{\mathbf{Q}} \tag{6}$$

To obtain borders of stability, the same method used by authors is applied [15]. Fig**. 3** shows the effect of inducting viscose fluid on stability borders in deep drilling for a specific tool dynamic which is presented in table 1.

Table 1: Tool Dynamics

$f_n = 630Hz$
$k = 0.4\times10^6 N/m$
$\zeta = 0.0080$
$k_{cT} = 13.37\times10^6 N/m^2$
$k_c = 13.37\times10^6 N/m^2$
$r = 4.75mm$
$l = 193mm$

3. Results and Discussion

Results show that adding fluid has a great effect on stability lobes and a very little effect on frequency of chatter. As shown in Fig**. 3** the Asymptotic Border Line of stability (ABL) is raised from 0.9(mm) to 1.4(mm) when C_{fd}

=1 for the tool with specifications given in table 1.

The ABL for various C_{fd} values were calculated for different drills; adding fluid will multiplies ABL by 3-5 when C_{fd} value is 5 comparing with when these is no fluid. ABL is 2 and 1.5 times of its normal value (no fluid) when C_{fd} values is 2 and 1, respectively.

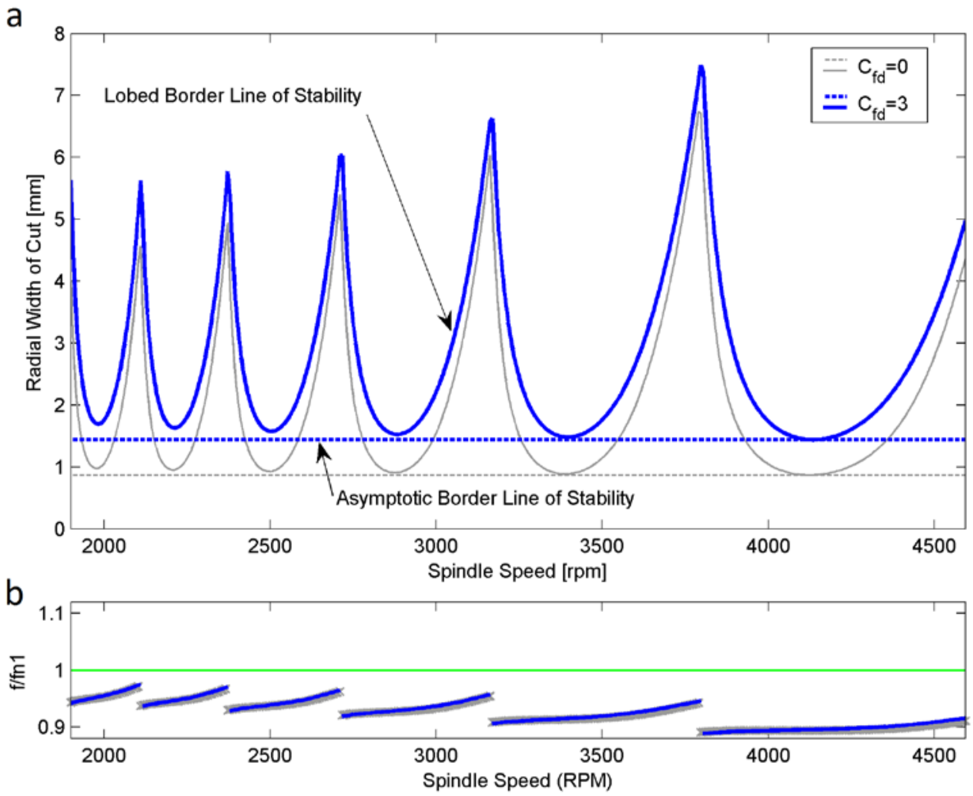

Figure 3: Stability boundaries (a) RWOC. (b) Frequency

4. Conclusions

A new method for suppression of chatter in deep hole machining is theoretically discussed. Studies show that the application of the low-Reynolds-number flow has a great effect in improving damping characteristics of the system. Allowable radial width of cut is increased 1.5 to 5 times of the normal condition (when no fluid is introduced) and the frequency of the chatter does not change much. In this study 1-process damping occurring due to the interference between the drilling flank surface and the workpiece surface, 2-the drag force imposed to the drill bit due to rotating of the tool, and 3-the gyroscopic effect due to the rotation of the tool is considered. However, the gyroscopic effect on the fluid behavior is not considered; also, the drill bit is assumed to be a rounded cylinder without groves. Further investigation is required to calculate these parameters and their effects on the chatter vibration.

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Nomenclature

$\mathbf{C}$	damping matrix of tool (N s m^{-1})
c	tool damping (N m s^{-1})
C_{fd}	drag force coefficient
$\mathbf{F}$	cutting forces matrix (N)
$\mathbf{F_D}$	drag forces matrix (N)
f_n	tool natural frequency (Hz)
$\mathbf{K}$	stiffness matrix of tool (N m^{-1})
k	tool stiffness (k m^{-1})
k_T	specific cutting resistance (N m^{-2})
λ	**ratio of the inner cylinder radius to outer cylinder**
l	**tool length (m)**
$\mathbf{M}$	mass matrix of tool (kg)
m	tool modal mass (kg)
$\mathbf{Q}$	modified frictional forces matrix (N)
r	hole radius (m)
U	relative velocity of fluid and the drill bit (m/s)
Ω	angular spindle speed (rad s^{-1})
ξ,η	tool fixed frame
ζ	tool damping ratio