Effect of Groove-type Chip Breakers in Deep Hole Drilling of 42CrMo

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Abstract. Gun drills have widely been in use in deep-hole drilling of manufacturing in automobiles and models. They could improve straightness and surface roughness of holes. However, with the improvement of material property and the increasing need for drilling holes that have big aspect ratio, problems like breaking and removing chips when drilling deep holes continue to appear, which would break the cutting tool when these problems are severe. All these problems would greatly lower the durability and the ability of machining of gun drills. Additionally, as for drilling holes on crankshaft that’s made of 42CrMo, for example, due to its high fatigue strength and great toughness, it’s not easy to break chips and cutting tools worn down in a fast rate. Aimed at prolonging the lifetime of gun drills when drilling materials that are relatively difficult to drill and improving the manufacturing productivity, this paper presents a kind of gun drill with groove-type chip breaker and describes the geometrical parameters of groove-type chip breaker.

1. Introduction

It’s known that holes of which aspect ratio (Length/Diameter) is bigger than 5 are deep holes [1], which shall be drilled on special machine tools. For that matter, gun drills are widely used for drilling deep holes. They have been used on fields which demand drilling deep holes so far, such as aerospace industries [2].

Gun drills have special structure [3], which ensure that quality of straightness and surface roughness is good. When drilling holes with gun drills, there has to be a guiding hole that is drilled previously or customized guiding sheath to guide cutting tool [4]. Due to restrictions on gun drill material and cutting method, even though solid carbide twist drills that have appeared recently couldn’t drill holes with high accuracy like gun drills [5], thus the application of gun drills on drilling holes is widely used compared to twist drills. With the development of manufacture industries, many kinds of materials that are difficult to be machined are used to be made components, which demands
better function requirements to cutting tools [6]. When machining crankshafts whose material was 42CrMo, there came the phenomenon that cutting tools worn down fast. 42CrMo is a kind of material that is an ultra-high strength steel, which makes chips not easy to break when drilling holes on it. In addition, this very material has high intensity and toughness. Therefore, the productive efficiency of gun drills wasn’t as good as expected when it came to drill deep holes on crankshafts made of 42CrMo. This paper introduces chip-break groove on the face of gun drills in an attempt to solve the difficulties in breaking chips on drilling deep holes, and improves cutting functions and gun drills durability.

2. Mathematical Model of Groove-type chip breaker

2.1 Coordinate Systems

As shown in ‘figure 1’, groove-type chip breaker is decided by these four parameters: groove width $L_w$: The biggest width in the section plane of groove-type chip breaker. Diagonal angle $\lambda$: The angle between intersections of groove-type chip breaker and face of gun drill in horizontal plane and axis. Axial rake angle $\mu$: The angle between groove-type chip breaker in vertical plane and horizontal plane. Radial rake angle $\delta$: The angle between the connection line (drill point and the lowest point of groove-type chip breaker) and the horizontal plan and fillet R.

As shown in ‘figure 2’, the Cartesian coordinate system $\{O:x,y,z\}$ with origin $O$ (drill point) is the global system. There is another movable coordinate system $\{O_m:x_m,y_m,z_m\}$ attached to grinding wheel. Firstly $\{O:x,y,z\}$ and $\{O_m:x_m,y_m,z_m\}$ are at the same position.

The first part of the main cutting lip (OG) is called outside lip, whose direction vector $s (-sinp, 0, -cosp)$, so the equation of $l_{OG}$ goes:
Vector $i_{OA}$ of $l_{OA}$ is obtained by rotating unit vector $i (-1,0,0)$ around axis $y$ clockwise by angle $\lambda$, so we have:

$$
\begin{align*}
\begin{pmatrix}
\cos (-\lambda) & 0 & -\sin (-\lambda)
\end{pmatrix}
\begin{pmatrix}
0 & 1 & 0
\end{pmatrix}
\begin{pmatrix}
-1
\end{pmatrix}
= \begin{pmatrix}
-\cos \lambda \\
0 \\
-\sin \lambda
\end{pmatrix}
\end{align*}
$$

Then we have the equation of $l_{OA}$:

$$
\begin{align*}
\begin{pmatrix}
x \\
y \\
z
\end{pmatrix}
= \begin{pmatrix}
-\cos \lambda \\
0 \\
-\sin \lambda
\end{pmatrix}
\end{align*}
$$

In order to obtain the original position of grinding wheel and make calculating process organized and clear, this paper lays center of grinding wheel at the exact position of origin $O$, and the axis of grinding wheel is paralleled with axis $x$, then operate the grinding wheel as following:

1. Translate it vertically up for $R_w$ (radius of grinding wheel), rotate it around $y$ axis anticlockwise for angle ($\frac{\pi}{2} - \lambda$), then rotate it around $z$ axis anticlockwise for angle($\mu$), finally rotate it around $x$ axis for angle($\delta$).
2. According to what’s mentioned above, the direction vector of the motion track of grinding wheel is the same as the vector of $l_{OA}$. Then we have the equation of the center’s motion track of grinding wheel ($O_w$):

$$
\begin{align*}
\begin{pmatrix}
x + Rw \sin \mu \\
y + Rw \sin \delta \sin \lambda \\
z + Rw \sin \delta \cos \lambda
\end{pmatrix}
\end{align*}
$$

$$
I_w = (I_x, I_y, I_z, 1)^T
$$

Furthermore, we ought to do the same transformation with the center of grinding wheel ($O_w$), and before the transformation, the coordinate of $O_w$ is (0,0,0). So after the transformation, the coordinate becomes: (-$R_w \sin \mu$, $R_w \cos \delta \cos \mu$, -$R_w \sin \delta \cos \mu$). According to what’s mentioned above, the direction vector of the motion track of grinding wheel is the same as the vector of $l_{OA}$. Then we have the equation of the center’s motion track of grinding wheel ($O_w$):

$$
\begin{align*}
\begin{pmatrix}
\frac{x}{\cos \lambda} \\
\frac{y}{\sin \lambda}
\end{pmatrix}
\end{align*}
$$

2.2 The Transformation of Coordinate System on 5-axis CNC Tool Grinder

As shown in ‘figure 2’, when grinding head of gun drill on 5-axis CNC tool grinder, the $B$ axis of grinder only move horizontally, thus we need to transform every element on global coordinate system {$O:x,y,z$} into the grinder coordinate system {$O_m:x_m,y_m,z_m$}. The relationships between those coordinate systems are shown in ‘figure 2’. Therefore, we need to calculate the rotation angles for both $A$ axis and $B$ axis in order to transform the elements on global coordinate system {$O:x,y,z$} into grinder coordinate system {$O_m:x_m,y_m,z_m$}. Vector of grinding wheel axis needs to be rotated around $x$ axis by angle $\varphi_A$, so as the coordinate of center of grinding wheel. We have:

$$
\varphi_A = \cos^{-1} \frac{|l_y|}{\sqrt{l_x^2 + l_y^2}}
$$

Then rotate grinding wheel axis and center of grinding wheel ($O_w$) around $x$ axis for angle $\varphi_A$, we have:
Vector of grinding wheel axis $I_1 = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos \phi_A & -\sin \phi_A \\ 0 & \sin \phi_A & \cos \phi_A \end{pmatrix} \begin{pmatrix} I_x \\ I_y \\ I_z \end{pmatrix} = \begin{pmatrix} I_{x_1} \\ I_{y_1} \\ I_{z_1} \end{pmatrix}$ (8)

Identically, we have the coordinate of grinding wheel center ($O_w$) after the rotation:

$O_w = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos \phi_A & -\sin \phi_A \\ 0 & \sin \phi_A & \cos \phi_A \end{pmatrix} \begin{pmatrix} -R_w \sin \mu \\ R_w \cos \delta \cos \mu \\ -R_w \sin \delta \cos \mu \end{pmatrix} = \begin{pmatrix} R_w \cos \delta \cos \mu \cos \phi_A + R_w \sin \delta \cos \mu \sin \phi_A \\ R_w \cos \delta \cos \mu \sin \phi_A - R_w \sin \delta \cos \mu \cos \phi_A \\ -R_w \sin \mu \end{pmatrix}$ (9)

In order to obtain the rotation angle of $B$ axis, which could be calculated with vector $I_1$, we have:

$\phi_B = \cos^{-1} \frac{|I_{z_1}|}{\sqrt{I_{x_1}^2 + I_{y_1}^2}}$ (10)

3. Experimental Results

Devor and Kapoor [7] had applied groove-type chip breaker into twist drills’ rake face and obtained good improvements in terms of breaking and removing chips. Theoretically, by adding a groove-type chip breaker to gun drill as mentioned above, the axial rake angle and the radial rake angle are changed from $0^\circ$ to a certain angle, thus it makes the cutting lip much sharper, which makes it easier to drill and break chips. Consequently, cutting function would be improved and vibration would be decreased thus axial force would be decreased while operating the experiments.

In terms of torque, similarly, groove-type chip breaker increases the normal rake angle of gun drill, thus cutting lips becomes more sharpen and tangent force during the drilling process would be decreased; simultaneously, smaller chips would reduce the obstacle to gun drill, so torque would
In order to verify that, we did some drilling experiments in terms of workpiece made of 42CrMo (ø160x105), with deep-hole drilling machine tool designed and manufactured by Dalian Jerry Cutting Tool Technology Company. By comparison, we use standard gun drill (without chip-break groove) to do drilling experiments with the same cutting amount as gun drill with groove-type chip breaker, to analyze their axial force value, torque value and the chip form. We used drilling force measurement system which consisted of double component drilling dynamometer to monitor dynamic cutting force and torque while drilling.

As shown in ‘figure 3’ and ‘figure 4’, value of axial force value and torque are present above, STD stands for standard gun drill and CBG stands for gun drill with groove-type chip breaker. Axial forces were decreased by 10.4%, 10.8%, 11.2% and 13.2% respectively under the situation that cutting speed were 64m/min, 80m/min, 96m/min and 112m/min. Similarly, torque value were decreased by 16.3%, 12.6%, 19.0% and 18.0%.

As shown in ‘figure 5’, chips produced by gun drill with groove-type chip breaker are significantly shorter than that produced by standard gun drill when cutting speed is 64m/min and feed rate is 0.025mm/r. Similarly, the length of chips produced by gun drill with groove-type chip breaker are averagely shorter than that produced by standard gun drill when we use other cutting amounts. To be exact, when drilling with standard gun drill with cutting speed is 64m/min-112m/min, feed rate is 0.02mm/r-0.03mm/r, the longest chip is longer than 80mm, though the shortest is longer than 25mm, phenomenon like chip twisting even appeared. However, with the same cutting amounts, gun drill with groove-type chip breaker performed better than standard gun drill: when cutting speed is 64m/min-96m/min, feed rate is 0.02mm/r-0.03mm/r, the length of most chips are shorter than 10mm. When cutting speed is 112m/min, though, the effect of breaking chips wasn’t as apparent as others.
After drilling 36 holes that were 100mm deep with both gun drills, then we observed the signs of wear with geometry parameter measuring instrument of cutting tool [8]. As shown in ‘figure 6’, there appeared some signs of breaking on standard gun drill, whose width was 0.113mm, and its wear value was 0.511mm wide. However, there appeared a certain amount of built-up edge (‘figure 6’) on gun drill with groove-type chip breaker, the wear state of it was normal, and its wear value was 0.248mm, which was almost as half as standard gun drill. Accordingly, gun drill with groove-type chip breaker is better than standard gun drill.

4. Conclusions
Groove-type chip breaker could improve the performances of gun drills while drilling workpiece that’s made of 42CrMo because it increases the normal rake angle of gun drill, thus cutting force while drilling is decreased as well as signs of wear. Gun drill with groove-type chip breaker could accumulate some certain of built-up edge to take place of cutting lip in a certain way and provide a kind of protection for cutting lip, therefore signs of wear on gun drills with groove-type chip breaker were less than that on standard gun drills. In terms of chip state, gun drill with groove-type chip breaker also performed better than standard gun drill, indicated by shorter average chips compared with that produced by standard gun drill.

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