Study on the Cutting Performance Improvement about Woodworking Forming Cutter that is Assembled by Circular Saw Blades

Bing-tian GAO, Xing-min GAO, Shu-xia MA and Yong-pin YANG

Lanzhou Institute of Technology, Gansu Province Key Laboratory of Green Cutting, Lanzhou, 730050

Keywords: Combined forming tools, Straight blade spiraling, Partitioned cutting, Improvement of cutting performance.

Abstract. For the difficult problem of hard wood milling groove on the mini-type multipurpose woodworking machine tool, a woodworking forming cutter that was assembled by the circular saws, shaft sleeve and flat gaskets was designed. The woodworking forming cutter had a special structure characteristics of the multiple narrow blades combination instead of double wide blades when assembling, it’s saw tooth showed a longitudinal dislocation arrangement, and a whole cutting edge was composed of the corresponding tooth blades on each saw component. The larger rake angle was adopted to improve the cutting performance of saw blade, and saw-tooth was planed after tooth profile optimization to improve the durability and the service life of it. In the milling groove of hard and soft wood, the cutting force was reduced by more than 6 times and the feed speed increased by more than 3 times, because of the special cutter with block straight cutting edges.

Introduction

At present, in order to preserving the ecological environment in our country, the timber supply and the quality of the wood will be reduced hard wood which is machined difficultly and the knotted trunk will be increased[1]. To utilize the wood resource rationally, and improve the quality of wood products and production efficiency, improvement of the wood cutting tool is needed according to processing requirements, which is driven by market demands. It is imperative to research and develop a utility molded cutters with low cost.

The milling grooves(12 mm wide,13 mm deep)of hard wood has always been a technical bottleneck for the mini-type multinational woodworking machine tool (Model MQ431C), for this reason, the woodworking forming cutter that is assembled by circular saw has been researched. By the reform of cutting tool structure and the parameter optimization of cutting tool geometry, not only the mortise of hard wood has been machined, but also the processing efficiency and the processing quality has been improved effectively. In addition, from 5 mm to 13 mm width of arbitrary mortises can be processed, and then equipment function is significantly widened, through the assembling of the number of ranges circular saws and flat gaskets for the cutter.

The Structure Design of Woodworking Forming Cutter that is Assembled by Circular Saw

The Analysis of Disadvantages about Forming Disc Milling Cutters with Double Straight Tooth

The mini-type multipurpose woodworking machine tool, which annual output was more than 40 million sets, is the best-selling product in the Chinese woodworking machinery industry. The demands of majority farmers and emerging woodworking individual operators were been satisfied, because the multipurpose machine tool has the characteristics of small volume, light weight, easy operation and simple utilities.

The forming disc milling cutter with double straight tooth adopts the kind of material of high-speed steel, which working parameters are blade diameter $\Phi$90 mm, blade width 12 mm and speed of main-shaft 2275 r/min. There are two main disadvantages for the shaping cutter: First, because workers need feed wood slowly by hand along positioning board when processing groove, and the intense vibration of machine tool caused by large impact will be produced. Owing to interrupt
cutting of the whole blade was working no matter machining process or machining return, so feed difficult and poor machining quality will be emerged from all of these. For another, due to the characteristics of dense and high hardness for the hardwood, tool tipping and cracking by rift grain what is Produced by squeezing knags or the woods is linked together with knags will be appeared. These will scrapped material, even threaten the personal safety of the workers. From the above analysis, we got a concluded that the structure design of milling groove for hard wood adopting forming disc milling cutters with double straight tooth is unreasonable.

The Structural Design Scheme of Woodworking Forming Cutter What is Packaged by Circular Saw

Based on the German professor Petutschnigg’s “The hierarchical theory of molding milling” [2], the principle of partitioning blade to reduce the cutting force was putted forward; Steward from the United States concluded that cutting blade with large spiral angle continuous working will be reduced the noise effectively [3]; The block structure is used in stepped cylindrical milling cutter as corn, which is imported from Taiwan; There are all kinds of forming cutters with larger rake angle designed and used in Japan, According to the operator’s telling, these forming milling cutters from Japan have good qualities such as brisk cutting, low noise and stable working life [4].

Combining new technology and research results at home and abroad, further study was made in this paper, a new structure of assumed tool was obtained to improve the cutting performance. Following structure decomposition as shown in figure 1, the forming cutter was composed of circular saws, shaft sleeve and flat gasket three parts. The woodworking forming cutter has a special mechanical structure, of the combination by multiple narrow blades replaced double wide blades, spiraling cutting blade with intermittent working replaced straight tooth, and dislocation arrangement for assembling saw-tooth. The structure of woodworking forming cutter assembled by Circular saw as shown in figure 2, circular saw blades, when assembling, was be located by the groove of shaft sleeve. The innovation of forming milling cutters was the block structure was used, which has a fine cutting performance of block cutting blade.

The Determination of Basic Parameters of Woodworking Forming Cutter Assembled by Circular Saw

(1) Determination of the diameter of the cutting edge
The woodworking forming cutter assembled by circular saw was the same diameter as the disc formed cutter: \( D=90 (mm) \), and aperture: \( d=14 (mm) \).

(2) Determination of the width of the cutting edge

The woodworking forming cutter assembled by circular saw was the same width as the disc formed cutter: \( L=12 (mm) \).

(3) The calculation of cutting speed

The motor speed: 2800r/min, the motor and machine tool spindle were driven by pulley, the diameter of drive wheel: \( d_1=64 mm \), the diameter of driven wheel: \( d_2=52 mm \), and learned the speed of driven wheel: \( n=3446 r/min \). From this, the calculated maximum cutting speeds of the tool were being figured out \([5]\):

\[
V = \frac{D \cdot \pi \cdot n}{60 \times 1000} \quad \text{\( (m/s) \)}
\]

\[ V = 16.23 \text{ (m/s)} \]

In the formula: \( D \)- the diameter of the cutting edge, \( D=90 mm \)

The Material Selection of Circular Saw Blade

The machining dynamic stability of circular saw blade is important indicator to measure the processing properties of circular saw blade cutting, because high-speed tool steel that was classed as ultrahigh-strength steels has good harden ability, hardness and rigidity and small thermal deformation, its stable thermoplastic is suitable for manufacturing high-grade thin circular saw blade, therefore, circular saw blade was chooses the material of high speed steel belt(model 100 \( \times \) 1.2, width 100mm, thickness 1.2 mm).

The Parameter Design of Circular Saw Blade

(1) Designing number of teeth of circular saw blade

The structure of circular saw blade as shown in figure 2. Generally, the more was the number of teeth on the circular saw blade, the more saw-tooth blade cutting in unit time, and the better cutting performance there was, but this would reduce the strength of saw-tooth, decrease the chip space between tooth to tooth, and easily cause heat generation of blades; On the contrary, too little number of teeth on the circular saw blade would cause the larger cutting force. The empirical formula of cutter number of teeth \([6]\):

\[
Z = (0.12 \sim 0.32)D
\]

In the formula: \( D \)— the diameter of circular saw, and then \( Z=10.8 \sim 28.8 \)

The small number of saw-dust because of the large chip pocket, this would reduce the cutting noise and prevent dust pollution. Due to low cutting speed of mini-type multipurpose woodworking machine tool and manual feeding, a small value for \( Z \) was chosen, got \( Z=12 \). So the central angle of single saw-tooth was 30°, the corresponding arc length was \( 90 \pi /12=23.562 mm \).

(2) The angle design of circular saw blade \([7]\)

The rake angle of saw-tooth blade would be determined by cutting force test. As shown in figure 3, the main geometrical parameters of saw blade is rake angle \( \gamma \), relief angle \( \alpha \), wedge angle \( \beta \) and cutting edge \( \delta \).

![Figure 3. The schematic diagram of the main cutting geometrical parameters for saw blade.](image)

![Figure 4. The schematic diagram of cutting force experiment for rake angle.](image)
Figure 5. The formation principle of larger tool cutting edge.

In practical processing, the feed speed of work-piece were greater than 10 m/min, so it was known that circular saw blade 3 # had better cutting performance than circular saw blades 2 #. Under constant value of the circumstances of rake angle, wedge angle $\beta$ would decrease with the increase of relief angle $\alpha$, and then the integral rigidity and working life of saw blade would be reduced. The Wear of flank face would be increased by reducing relief angle of saw blade, therefore a reasonable relief angle of $20^\circ$ was chosen. Finally, the main geometric parameters of circular saw blade 3 # were be determined for:

$$\gamma=35^\circ, \alpha=20^\circ, \beta=35^\circ, \delta=55^\circ.$$  

(3) The design for tooth pitch of circular saw blade

The number of teeth on the circular saw blade was 12, the tooth pitch $T$ was:

$$T=360^\circ/12=30^\circ$$

(4) The aperture of circular saw blade

When forming cutter assembled, circular saw blade and plain washer were assembled on shaft sleeve. The aperture of circular saw blade is designed to be 24 mm, and the size of lug boss used to locate was: width of 6mm and height of 1.5mm.

(6) The saw kert of circular saw blade

Using the left, right and center order, the unit saw kert of circular saw blade was composed of three saw-teeth, double stir tooth and one swage setting tooth, the every corresponding tooth of four cutters had the same stir direction, the width of saw kert was 3.6 mm.

The stir value of circular saw blade is minus thickness of circular saw blade from the width of saw kert, and its single stir value:

$$(3.6-1.2)/2=1.2\text{mm}$$

The Plain Washer Design

The plain washer structure as show in figure 2. Plain washer which be placed between two circular saw blade was assembled on shaft sleeve in order to prevent the saw blade lap of between two adjacent of circular saw blades, and make sure the formation of saw kert. The thickness of plain washer was determined by the saw kert of circular saw blade, and the number of plain washer was determined by the width of groove which was processed.

Owing to the 12mm width of groove, the forming cutter was composed of four circular saw blades and three plain washers.

So the single stir value of circular saw blades:

$$(3.6-1.2)/2=1.2\text{mm}$$

To reduce the axial combine error of each block cutting edge, it was required that the two adjacent circular saw blade had 0.8 mm overlap in axial position, so the thickness of plain washer:

$$\left[12 - (1.2 \times 4) - (1.2 \times 2) \right]/3=1.6 \text{ (mm)}$$

The outer diameter of plain washer had the same diameter as flange: $\phi$ 46mm; The aperture diameter of plain washer had the same diameter as flange circular saw blade: $\phi$ 24 mm.
The Shaft Sleeve Design

The shaft sleeve structure as shown in figure 2. To format the reasonable saw kerf, the corresponding tooth blade on each saw blade was been connected a whole cutting edge, the saw-tooth blade of the No.2 (No.4) circular saw blade should placed in the middle of two saw-tooth of No.1(No.3) circular saw blade, the saw-tooth blade of the No.3(No.4) circular saw blade should parallels the No.1(No.2) circular saw blade. Meanwhile, determining the location of slotting on outer cylinder surface was as show in figure 5(a), the five center line of slotting location were marked by angle 0°, 75°, 75°, 75° and 75°, the size of slotting was 6mm of width and 1.5mm of depth. The size design of shaft sleeve was: to guarantee the shaft sleeve after grooving has enough strength, the outer diameter of shaft sleeve has the same as the inner diameter of plain washer or circular saw blade: φ24 mm; For assembled with machine tool spindle, the inner diameter of shaft sleeve was the same as the outer diameter of principal axis: φ18 mm; the length of shaft sleeve was the same as the width of saw-tooth blade: 12mm.

Method to Improve Cutting Performance

The Larger Rake Angle Adopted

The cutting performance of wood cutting tool was impacted greatly by its rake angle. The rake Angle was scoped from 20 to 35 according to references [7], a large value 35° was chosen by cutting force test. Roughness on the surface of the work-piece could be ensured, and also the cracking in advance when the wood cutting could be reduced, because of adopting larger rake angle which has many advantages such as cutting fluid, less power consumption, low noise and small feed resistance.

Larger Tool Cutting Edge Inclination Adopted

The design principle of larger tool cutting edge was as shown in figure 5 (a) : the Arabic numerals at inner circle shows the twelve saw-teeth were lay-out equally on circular saw blade, corresponding with the pitch central angle of 30°. There were four circular saw blades which was be arranged at a specific position by number order D1, D2, D3 and D4 in a unit combination of saw-tooth, and the exact location of origin saw-tooth was confirmed by this way what the boss on internal hole of circular saw blades was located in the groove of shaft sleeve. The corresponding with the new pitch central angle of 45°, which was equivalent to1.5 times for single circular saw blade pitch’s. The distance between two cutting edges had equivalent to 0.5 times for single circular saw blade pitch’s ,the four 75° shows processing position of groove on cylindrical surface of shaft sleeve. According to the formation principle of larger tool cutting edge as show in figure 5 (b) : the distance between two saw-tooth of the same circular saw blade was 15°, a straight line formed from corresponding saw-tooth projection on four circular saw blades, was one oblique lines of cutting edge inclination.

Following above, we can know that the chord length L:

\[ L = 2\sin\frac{T}{2} \times \frac{D}{2} = 2\sin22.5° \times 45 = 34.44 (mm) \]

A right triangle was constituted by the chord length and the width of saw kerf , and the tool cutting edge inclination \( \lambda \):

\[ \lambda = \tan^{-1}L/8.4 = \tan^{-1}34.44/8.4 = 76.29° \]

The Cutting was smoothly at all time, and noise could be fallen from 10db to 15db, because two parallel cutting blades of the new forming cutter were always working gradually in cutting process and return processing as shown in figure 6. In addition, the helical blade with large tool cutting edge inclination had many advantage such as good surface quality, low power consumption, prolonging the service life of cutter and turnings type as C.
Blocking Cutting Edges is Used

The basic principle of the block cutting edges was that the cutting edge with forming curves was be integrated and assembled together as molding layer. For the Saw kert forming of single circular saw blade stir by direction left and right, it was consisted by two parts, the one was double stir tooth cutting in 2/3 times of total stock removal, and the other is one swage setting tooth cutting in 1/3 time s of total stock removal. The Saw kert width of single circular saw blade was 3.6 mm. There were 16 (4×4) pieces of molding layer cut when the new forming cutter worked per circle.

It was informed from previous study, there were four cutting edges parallel working in sections to the width of saw kert. In the longitudinal, the distribution of cutting edges for slot millings shown in figure 6, six cutting edges were working to the slot depth of 13mm. Thus, the cutting force of the former cutter by block cutting edges not only was reduced by more than 8 times ,but also the noise decreased because the length of cutting together for cutting edges was reduced[8].

The Application Effect

The slot millings(12 mm wide,13 mm deep) for woods were respectively tested by forming cutter assembled by circular saw and forming disc milling cutters(Figure 7),and the corresponding experimental data was shown in table 2. It could be seen: for slot millings by forming cutter assembled by circular saw, the average feed speed was 2.1 m/min, the cutting quality were all qualified both on hard wood and soft wood, and the advantages were small vibration of machine tool and cutting steadily; and for slot millings by forming disc milling cutters, the average feed speed was 1/3 times than comparison group. Although the cutting quality were all qualified on soft wood, but 2 non-conforming products on hard wood, so the work-piece was destroyed, and also the disadvantages were large vibration of machine tool and cutting unsteadily.

| Tool Forming disc milling cutters | Forming cutter assembled by circular saw |
|-----------------------------------|------------------------------------------|
| Wood quality | Hard wood | Soft wood | Hard wood | Soft wood |
| Cutting time (s) | 45.3 | 43.5 | 14.4 | 14.3 |
| Cutting time | 45.4 | 42.9 | 14.3 | 14.3 |
|                          |     |     |     |     |
|--------------------------|-----|-----|-----|-----|
| **Cutting time (s)**     | 45.9| 42.3| 14.4| 14.3|
| **Average Cutting time (s)** | 45.53| 42.9| 14.37| 14.3|
| **Average feed (rate/min)** | 0.66| 0.7| 2.1| 2.1|
| **Eligibility**          | All qualified | All qualified | All qualified | All qualified |
| **Machine tool vibration** | large | The larger | Small | Small |

**Conclusion**

The larger rake angle was adopted; saw-tooth was designed after tooth profile optimized to planning saw-tooth; the cutting performance of new circular saw blade with blocking cutting edges was mainly reached the same as the cutting blade with large spiral angle. By assembling the number of ranges circular saws and flat gaskets for the cutter, the arbitrary mortises with the width of from 5 mm to 12 mm and depth of 13 mm could be processed, and the equipment function was significantly widened. The technical bottleneck that grooves of hard wood have been milled on the mini-type multinational woodworking machine tool would be solved, and using efficiency of wood and the processing efficiency had been improved effectively, moreover the technique provided the higher practicability and promotion value.

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