

RESEARCH ON FORMING QUALITY OF POLY-WEDGE PULLEY SPINNING

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ABSTRACT

As an important power transmission part, pulleys are widely used in automobile industry, agricultural machinery, pumps and machines. A near-net forming process for six-wedge belt pulleys manufacturing was put forward. For this purpose, the required tooth shape and size can be formed directly by spinning without machining. The whole manufacturing procedures include blanking, drawing and spinning. The spinning procedure includes five processes, performing, drumming, thickening, toothing and finishing. The forming defects occurred during each forming processes of poly-wedge pulley spinning, such as the drumming failure, flanged opening-end, folded side-wall, insufficient bottom size, flashed opening-end, cutting-off bottom, are introduced, and the factors influencing the defects are analyzed. The corresponding preventive measures are put forward.

Keywords: spinning, poly-wedge pulley, forming quality.

1 INTRODUCTION

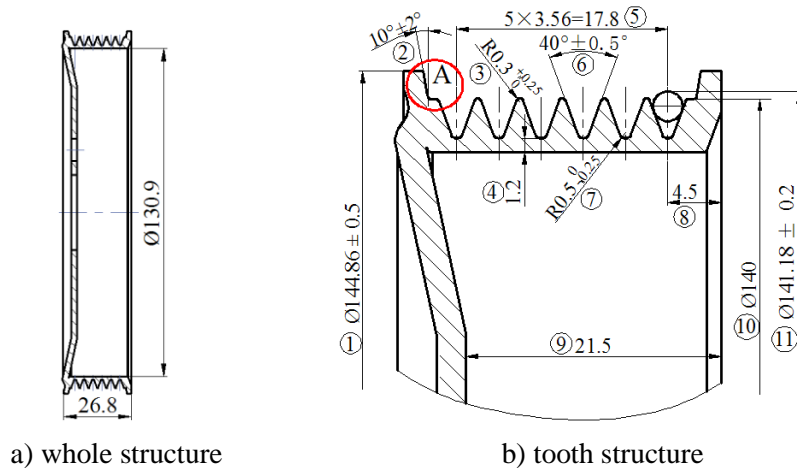
The poly-wedge pulley is an important part of the belt driving system. The strength, rigidity and the service life of the belt, the efficiency and precision of the driving system are influenced directly by the forming quality of the belt (Pan *et al.* 2007). Pulleys are usually produced by machining after casting or forging, which leads to the disadvantages of material wasting, low production efficiency, low product dimensional accuracy, and poor dynamic characteristics (Packham *et al.* 1978). Spun pulley made by metal sheet is now widely applied in various industrial fields with its high accuracy, energy saving, material saving, good dynamic equilibrium and non-pollution, etc. (Wang *et al.* 1999). For the manufacture of V-pulleys, dynamic dampers and automobile wheels, blanks having cup shape on both sides are required (Packham1978). A forming alternative for such shapes is a special process of spinning, the so-called splitting process. This is performed by feeding a tapered roller radially into a rotating disk blank. Initial research findings as to conventional splitting are documented by Keller (1996) and Schmoeckel *et al.* (2000). For poly-wedge pulley spinning, a thicker blank should be adopted to meet the requirement of tooth forming, which results in the increasing of the material waste and the manufacturing cost. This shortage can be overcome well by thickening process. Various factors may influence the forming quality of spinning based on thickening process. The spinning quality of the poly-wedge pulley not only depends on the accuracy of the shape and dimension of blank, the manufacturing and assembling of tools, but also depends on the setting

accuracy of spinning process, processing parameters, and the accuracy of the numerical and hydraulic control system as stated by Sun (2005).

The forming defects during spinning of poly-wedge pulley based on thickening process are analyzed, and the corresponding preventive measures are put forward.

2 PROCESSING ANALYSIS OF POLY-WEDGE PULLEY DEFORMED BY SPINNING

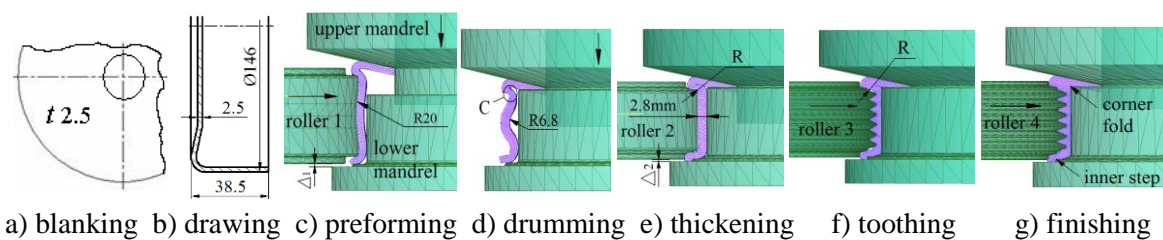
The material used for the poly-wedge pulley is 08Al. The bottom thickness of the pulley is 2.5mm (as shown in Figure 1). According to the condition of constant volume of plastic forming, to form the tooth, the thickness of the side wall should be at least 2.8 mm. To guarantee the requirement of forming the tooth by spinning, there are two methods to prepare the blank. (1) drawing with 2.8 mm thickness circular blank directly; (2) drawing with 2.5 mm thickness circular blank, than thickening its side wall. The redundant material at the bottom of workpiece after spinning should be cut off if 2.8 mm thickness blank was adopted to form the cup-shaped drawing preforming blank based on the first method, which results in the increasing of both the material and manufacturing cost, therefore, the 2.5mm thickness blank is adopted. Thickening process is necessary to thicken the thickness of the side wall of the cup-shaped blank to 2.8mm before tooth forming based on the second method. The whole manufacturing procedures include blanking, drawing and spinning, and the spinning procedure includes five processes, performing, drumming, thickening, tothing and finishing (as shown in Figure 2).



a) whole structure

b) tooth structure

Figure 1: Schematic of six-wedge poly-pulley.



a) blanking

b) drawing

c) preforming

d) drumming

e) thickening

f) tothing

g) finishing

Figure 2: Manufacturing procedures of the poly-wedge pulley.

The five spinning processes are as follows (see Figure 2) (Xia et al. 2009):

(1) Preforming: Feeding the performing roller 1 along the radial direction together with the upper mandrel downward along the axial direction, the side wall of the cup-shaped blank obtained by deep drawing was formed to the shallow drum-shaped workpiece, the radius of the shallow drum-shaped arc was R20 (as shown in Figure 2c);

(2) Drumming: Moving the upper mandrel downward individually until the bottom of the preformed shallow drum-shaped workpiece contacted with the lower mandrel tightly, the side wall of the shallow drum-shaped blank obtained by preforming was further formed as the deep drum-shaped blank, the radius of the deep drum-shaped arc was R6.8 (as shown in Figure 2d);

(3) Thickening: Feeding the thickening roller 2 along the radial direction until the deep drum-shaped side wall was pressed to the flatness, the wall thickness was 2.8 mm after thickening (as shown in Figure 2e).

(4) Tothing: Feeding the tothing roller 3 along the radial direction to form the tooth preliminarily (as shown in Figure 2f).

(5) Finishing: Feeding the finishing roller 4 along the radial direction to shape the tooth accurately (as shown in Figure 2g).

The deformation of the tooth portion of pulley by spinning belongs to the near-net shape forming. The demanded tooth shape and size can be formed directly by spinning without machining. Only slight machining is carried out at the outlines marked by A and B (as shown in Figure 1). Comparing with machining after casting or forging, the material waste was decreased by 50%.

The five processes to form the poly-wedge pulley by spinning complicate the deformation. Different kinds of defects occur during spinning. The main causes and its influencing factors are analyzed and the corresponding preventive measures are put forward.

3 DEFECTS ANALYSIS OF POLY-WEDGE PULLEY DURING DEFORMING STEP BY SPINNING

3.1 Defects during drumming process

The defects occurred during drumming process are mainly diameter expanding at bottom portion, flanging at opening end of workpiece and unsymmetrical drumming (as shown in Figure 3). These defects are actually caused by the previous preforming process. During the preforming process, a desired curvature is obtained by feeding the performing roller 1 along the radial direction together with the upper mandrel downward along the axial direction (as shown in Figure 2c), and the predetermined shallow drum-shaped arc occurs at the side wall of the cup-shaped blank due to the axial pressing of upper mandrel and radial feeding of performing roller 1 (as shown in Figure 2d).

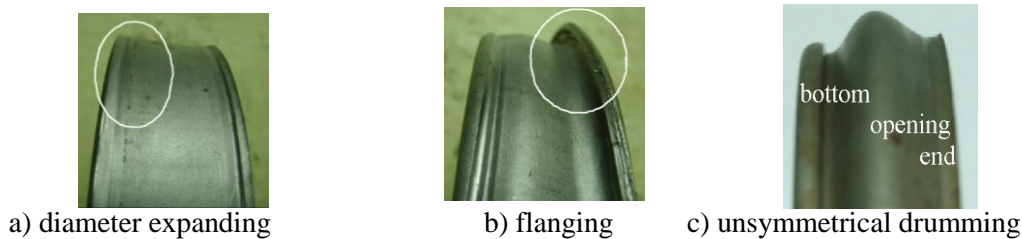


Figure 3: Defects during drumming process

Diameter expanding at workpiece bottom The defect is shown in Figure 3a). The reason for the defect is that the radial feed of roller 1 is too small, the radial feed of roller 1 should be at least 2 times of workpiece thickness, i.e. 4.8~5 mm $((146-2 \times (2.55 \sim 2.75) - 130.9) / 2)$, where the outer diameter of cup-shaped workpiece $\varnothing 146$ is determined by the maximum outer diameter of part $\varnothing 144.86$ plus the machining allowance 2×0.5 ; 2.55~2.75 is variation range of maximum thickness of side wall of cup-shaped workpiece; $\varnothing 130.9$ is the inner diameter of part). If the radial feed of roller 1 is less than 4.8 mm, shallower drum-shaped workpiece will be obtained after performing, drumming deformation at the center portion of cup-shaped workpiece occurs difficultly due to the supporting rigidity of the side wall being strong enough; therefore, diameter expanding occurs at the workpiece bottom because of buckling.

Flanging at opening end The defect is shown in Figure 3b). The reason for the defect is that the setting height of roller 1 is unreasonable. To prevent the metal flowing from the gap Δ_1 between the roller 1 and the surface of the lower mandrel (as shown in Figure 2c), the designed gap Δ_1 should be less than 0.2, the 8% of workpiece thickness. If the gap Δ_1 is greater than the designed one, under the press of the radial feed of roller 1, the material flows easily from the gap Δ_1 , and results in an unstable deformation of opening end and flanging defect when the upper mandrel moves downward during drumming process.

Unsymmetrical drumming The defect is shown in Figure 3c). The reason for the defect is that the distribution of the side wall thickness of the cup-shaped workpiece obtained by deep drawing is

uneven. The thickness reduces gradually from the opening end to the bottom along the side wall of the cup-shaped workpiece (Luo et al. 2010), hence the drum tends to occur at the bottom during drumming.

The main measures to prevent the above defects are as follows: (1) Selecting a reasonable height to set the roller 1, decreasing the gap Δ_1 between the roller 1 and lower mandrel as small as possible on condition that the roller 1 doesn't contact with the lower mandrel, i.e. $\Delta_1=0\sim 0.2\text{mm}$. (2) Controlling the radial feed of roller 1 until the arc surface of roller 1 just contact with the side wall of workpiece, i.e. radial feed=4.8~5mm. (3) Controlling the thickness deviation of the side wall of the cup-shaped workpiece obtained by deep drawing strictly, the maximum thickness deviation should less than 7%.

3.2 Defects during thickening process

The defects occurred during thickening process are mainly side wall folding, insufficient bottom size and flash at opening end (as shown in Figure 4).



(a) side wall folding

(b) insufficient size and flash

Figure 4: defects during thickening

Side wall folding The defect is shown in Figure 4a), a swallowtail annular trough occurs on the side wall of workpiece during thickening. The reason for the defect is the unsymmetrical drum during drumming process (as shown in Figure 3c). Because the drum tends to occur at the workpiece bottom and the wall thickness near the bottom is thinner than another portion, the material flows more easily to the bottom than to the opening end of workpiece. Meanwhile, a large resistance force exists at the bottom arc portion, under the action of the pressing forces from both the bottom and opening end directions, the local accumulated material is extruded, which results in the swallowtail annular folding.

Insufficient bottom size and flash at opening end The defects are shown in Figure 4b). The reason for the defects is that the setting height of thickening roller 2 is unreasonable. The gap Δ_2 between the roller 2 and the lower mandrel is greater than the designed one, Δ_2 should be less than 0.2mm, the 8% of workpiece thickness (as shown in Figure 2e).

The radial extrusion occurs on the corner portion A of workpiece (as shown in Figure 1) under the pressing of roller 2, which results in the material flows towards the workpiece center and results in the insufficient bottom diameter. On the other hand, the material at the opening end flows easily towards the workpiece edge from the gap Δ_2 , which results in the flash at the opening end of workpiece.

To prevent the above defects, a suitable setting height of roller 2 should be guaranteed. The gap Δ_2 between the roller 2 and the lower mandrel should be as smaller as possible under the condition that the roller 2 doesn't contact with the surface of lower mandrel, i.e. $\Delta_2=0\sim 0.2\text{mm}$. Figure 5 shows a qualified thickening workpiece.



Figure 5: Qualified thickening workpiece

3.3 Defects of bottom cutting-off

The defects of bottom cutting-off may occur during both thickening and tothing processes (as shown in Figure 6). The reason for the defect is that the roundness radius R of roller 2 or roller 3 is too small (as shown in Figure 2e and Figure 2f). Because the thickness reduction at the position C (as shown in Figure 2d) is large during preforming, the bottom cutting-off occurs easily during thickening or tothing. The problem could be solved well by increasing the roundness radius R from 1 mm to 2 mm. Experimental results showed that roundness radius R should be greater than 0.8 times of the side wall thickness of cup-shaped drawn workpiece.



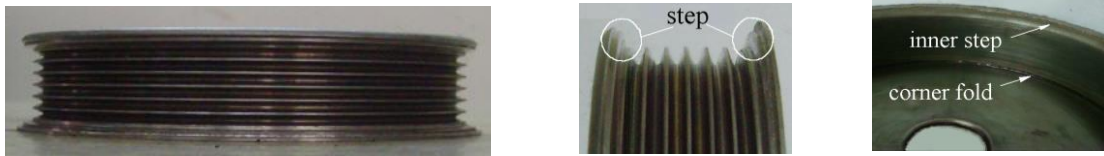
(a) bottom cutting-off during thickening (b) bottom cutting-off during tothing

Figure 6: Bottom cutting-off

4 TRIAL MANUFACTURING OF THE POLY-WEDGE PULLEY

The experiment was carried out in the HGQX-LS45-CNC vertical spinning machine (Xia et al. 2006). The material of blank sheet is 08Al, the gap $\Delta_1=\Delta_2=0.2\text{mm}$, the radial feed of the preforming roller 1 is 4.8mm.

Figure 7 shows the qualified spun poly-wedge pulley. Figure 7a) shows that the spun pulley has the regular contour, distinct outline and good surface quality. Figure 7b) shows the partial enlargement of pulley tooth. It shows that the tooth profile on the side wall is plump and uniform; the steps on both ends are clear, smooth, properly thick. The inner surface of spun workpiece shown in Figure 7c) is smooth, and fits well with the mandrel; the corner fold between the inner bottom and side wall is trim; the inner step at the opening end is clear and complies with the design requirement (as shown in Figure 2g).



(a) complete outline

(b) amplified tooth

(c) inner surface

Figure 7: Qualified spun pulley

Table 1 shows the measuring results of the spun workpiece, the measuring items are shown in Figure 1b). The measuring results indicate that the near-net forming process for six-wedge belt pulleys manufacturing put forward in this paper is reliable and economical.

Table 1: Measuring results of spun workpiece

Measuring items	Dimension	Machining allowance /mm	Measuring results	
			No. 1	No. 2
1	$\Phi 144.86 \pm 0.5\text{mm}$	≥ 0.5	148.4	148.6
2	$10 \pm 1^\circ$	/	$9^\circ 30'$	$9^\circ 30'$
3	$R0.3 + 0.25\text{mm}$	/	0.45	0.45
4	1.2mm	/	1.41	1.22
5	17.8mm	/	17.9	17.85
6	$40 \pm 0.5^\circ$	/	$40^\circ 20'$	$40^\circ 15'$
7	$R0.5 - 0.25\text{mm}$	/	0.46	0.46

8	4.5mm	≥ 0.5	5.3	6.14
9	21.5mm	≥ 0.5	22.6	22.7
10	140mm	+0.5	140.1	140.6
11	141.18 \pm 0.2mm	≥ 0.5	141.45	141.45

5 CONCLUSIONS

The defects occurred during poly-wedge spinning are analyzed. The corresponding preventive measures are put forward. The conclusions are as follows:

(1) The defects occurred during drumming are mainly diameter expanding at bottom, flanging at opening end, and unsymmetrical drumming. The defects can be prevented by setting height and radial feed of preforming roller 1, and setting a small thickness deviation of the side wall of the cup-shaped drawn workpiece. The gap Δ_1 between the roller 1 and the surface of the lower mandrel should be less than 8% of workpiece thickness, the radial feed of preforming roller 1 should be about 2 times of workpiece thickness, the thickness deviation of the side wall of the cup-shaped drawn workpiece should be less than 7% .

(2) The defects occurred during thickening are mainly side wall folding, insufficient bottom size and flash at opening end. The folding defect can be prevented by controlling the thickness deviation of the side wall of the cup-shaped drawn workpiece less than 7%; the insufficient bottom size and flash at opening end can be prevented well by a reasonable setting height of thickening roller 2, and the gap Δ_2 between the roller 2 and the lower mandrel should be less than 8% times of the side wall thickness of cup-shaped drawn workpiece.

(3) The defects of bottom cutting-off may occur during both thickening and tothing. The defects can be prevented by increasing the roundness radius R of thickening and tothing rollers properly, the roundness radius R should be greater than 0.8 times of the side wall thickness of cup-shaped drawn workpiece.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the funding obtained from Production, Teaching & Research Collaborative Project between Guangdong Province and Ministry of Education of China (Project No. 2006D90304021) and National Natural Science Foundation of China (No. 50475097).

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