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Experimental research into the cold-rolling technology of a spiral conveyer vane

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Industrial Summary

In this paper, the forming principle for the cold-rolling of a vane is described. The technological parameters, such as the developed dimensions of the vane, the rolling deformation zone, the blank size, the reduction, and the requirements of the cold-rolling technology in respect of raw materials are discussed and determined. Studies on the cone angle of the working roller and on the structure of the stretch-out-unit of the cold-rolling machine have provided much important information for cold-rolling technology and the structural design of the rolling machine.

Keywords: Vane cold-rolling; conveyer vane; inhomogeneous reduction

1. Introduction

The vane of a spiral conveyer, made of thin steel sheet in the form of a continuous multi-coil spiral, has been applied widely in agricultural machines and in conveying equipment. There are four ways to produce a vane, of which cold-rolling is the most advanced technology. Compared with step-welding, cold-coiling and vibro-stamping, the cold-rolling technology of a vane can produce a vane with the following advantages: (i) greater productivity; (ii) excellent product quality; (iii) less material consumption and lower cost; and (iv) a harder surface and better wear properties.

The results of experimental studies on the cold-rolling technology and the equipment required to produce the vane are presented.

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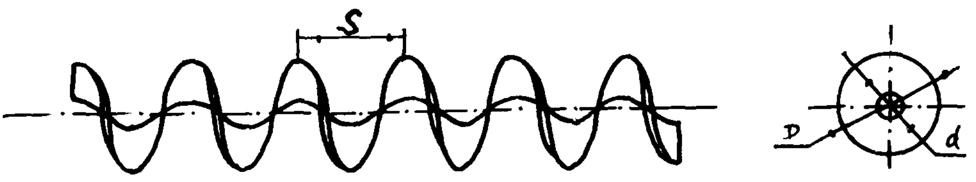

Fig. 1. The contour dimensions of a vane.

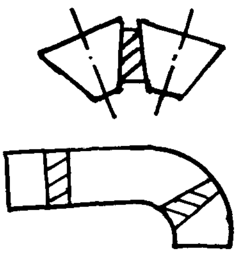

Fig. 2. The deformation of the blank in rolling.

2. Basic principle of vane forming

The vane of a spiral conveyer is determined by its contour dimensions (the inside diameter, the outside diameter and the screw-pitch) and trapezoidal cross-section, as shown in Fig. 1. The forming process is analyzed as follows.

The vane can be formed by means of the inhomogeneous deformation of a metal blank. When various points distributed over the width direction of the strip-blank are pressed unequally, the cross-section of the blank after rolling becomes of trapezoidal shape, as shown in Fig. 2. These points have the same linear velocity as the corresponding contact points on the roller. The linear velocity of each point along the generatrix of the conical roller differs from that of other points so that there are velocity differences between the various points over the width of blank at the outlet of the roller. In addition, unequal reduction along the blank's width given by the conical roller will result in unequal elongation. It can be seen in Fig. 2 that in the zones where there are large reduction and high elongation the linear velocity is also large, the reduction and the elongation changing gradually over the width of blank. Bending deformation of the blank (sickle-bent) will occur naturally after rolling because of the interaction of the deformed zones. Of course, the strip-blank is rolled into a spiral shape when rolled successively. The required vane size is obtained by increasing the pitch through the stretch-out unit.

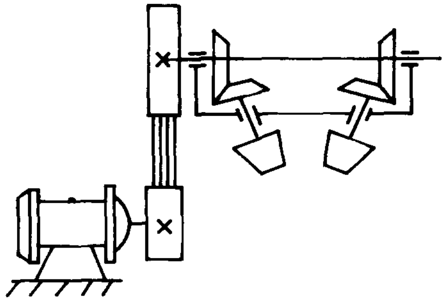

Fig. 3. Schematic diagram of the test machine.

3. Test equipment and materials

3.1. Test equipment

Fig. 3. shows a cold-rolling machine with two conical rollers.

Machine parameters
Cone angle of the roller 60°
Diameter of the roller at the small end ∅20 mm
Diameter of the roller at the large end ∅120 mm
Velocity of the roller rotation 16–18 rpm
Motor power 40 kW

3.2. Test materials

Test materials are SAE 1006, A_3 and commercially pure aluminium (strips).

4. Determination of the technological parameters

4.1. Calculation of the developed shape of the vane [1]

The vane is analysed over one pitch (a complete coil). Before the pitch is stretched through the stretch-out-unit, the developed shape of the vane is a notched plane ring, as shown in Fig. 4.

The developed sizes can be obtained according to the following drawing steps.

(1) Draw two right triangles ABC and ABD, in which AB is equal to the pitch of the spiral vane, BC is equal to πD and BD is equal to πd. The hypotenuses b and a are equal to the actual lengths of the inside edge and the outside edge respectively.

(2) Draw an isosceles trapezium, where the upper side, lower side and height are b, a and $(D - d)/2$, respectively.

(3) Extend two isosceles lines to intersect at point 0.

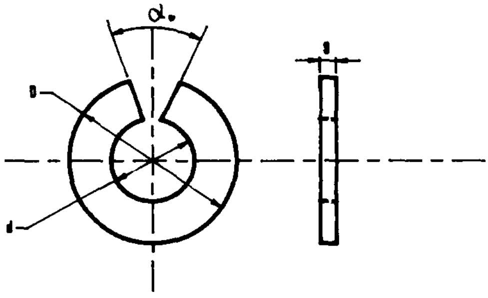

Fig. 4. Developed shape of the vane.

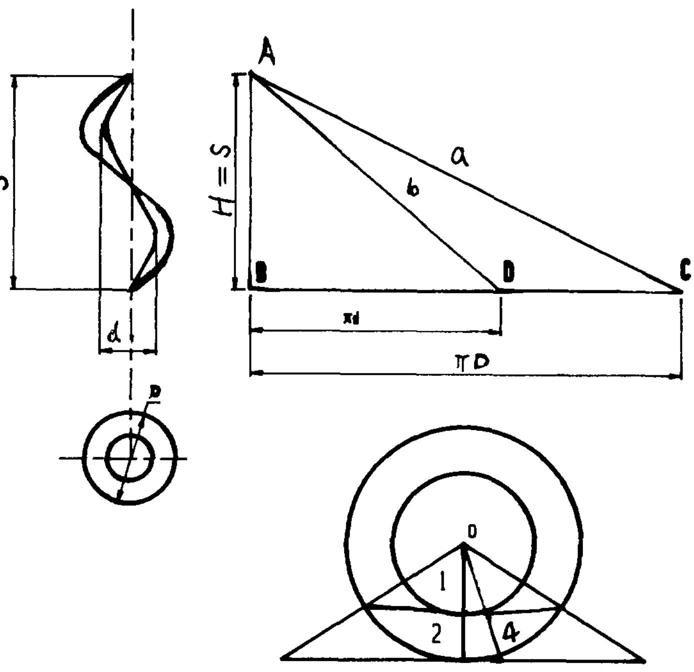

Fig. 5. Spiral unfolded chart.

Draw two circles the centres of which are located at 0 and of radii 01 and 02 respectively, which is the height of the triangle. Take the measurement of the length a in the ex-circle and then obtain point 4. The ring part obtained by linking points 0 and 4 is the developed area, as shown in Fig. 5.

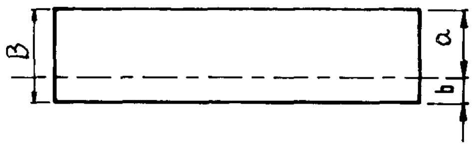

Fig. 6. Boundary between the deforming and the non-deforming region; (a) part having compressive deformation; (b) part not having compressive deformation.

4.2. Determination of the deformation zone in the width direction of the blank

It is very important to rationally determine the boundary between the deforming region and the non-deforming region during the rolling process in order to ensure the vane quality, as shown in Fig. 6.

When a different reduction is given to every point over the blank width during rolling, the large rolling force and the small difference in the forming speed between the top and the bottom of the blank width will be unfavourable for deformation. If a smaller region over blank width is compressed to unequal amounts and no compression deformation occurs in other larger regions, a wave-shape vane will be formed because the metal flow of deforming part is affected by the non-deforming region.

A suitable ratio of deforming part/non-deforming part over the blank width will reduce the rolling force and be good for forming.

Tests and analyses show that a suitable boundary location is at 1/5–1/6 of the blank width (the deforming region occupies 4/5–5/6 of the blank width whilst 1/5–1/6 is the non-deforming region).

4.3. Determining the blank size and the reduction

Consider three kinds of vanes in combine-harvesters, their dimensions being listed in Table 1, where H is the large-end size and h is the small-end size of the cross-section. Strips of SAE 1006 and Al are chosen for the test.

Table 2 provides the blank size. Experimentation is carried out using a 60° cone roller. The gap width between the two rollers is not equi-distant, as it is determined on the basis of the reduction in the blank width, as shown in Fig. 7.

When a strip passes through the rollers, the reduction in the blank width changes gradually from maximum to zero, as listed in Table 3. For products 1 and 2, their boundaries are located at 1/5 of the blank width, whilst the third is located at 1/6. The three kinds of blanks primarily rolled are given in Table 4.

Experimental data show that their widths increase a little, but are within the admissible dimension tolerance.

The blanks are determined to conform to the developed size of vane. The required vane dimension is obtained after the blank-strip has passed through the stretch-out-unit.

Table 1
Product dimension standards

No.	d (mm)	D (mm)	S (mm)	Cross-section dimension
1	26	128 ± 5	$130 \pm {}^{15}_{10}$	$H = 3.5 \pm {}^{0.5}_{0.3}$, $h = 1.5 \pm {}^{0.5}_{0.3}$
2	26	158 ± 5	$160 \pm {}^{12}_{10}$	$H = 3.5 \pm {}^{0.5}_{0.3}$, $h = 1.5 \pm {}^{0.5}_{0.3}$
3	58	245 ± 7	260 ± 15	$H = 5$, $h = 2$

Table 2
Blank dimension

No.	Material	Thickness (mm)	Width (mm)	Length (mm)
1	SAE 1006	3.5	51	500
2	SAE 1006	3.5	66	500
3	Al	5.0	93	400

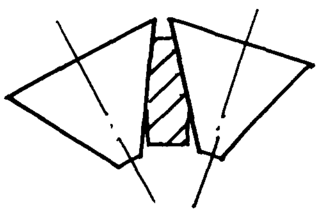

Fig. 7. Diagrammatic sketch of the gap between the working rollers.

4.4. Requirements for materials

It is known from tests and references that the material characteristics have significant effects on the rolling process. High material hardness and poor plasticity make the rolling force increase and the deformability decrease: cracks can appear in the outer edge of the vane as the deformation achieves a fixed value (as shown in Fig. 8). Much less hardness causes the rolling force to decrease, but a wave-shape will appear at the outer edge of the vane as the deformation achieves the fixed value. Some requirements for hardness, plasticity and contour size need to be met in the rolled vane:

(i) The relationship between the hardness and the thickness for general materials is listed in Table 5.

(ii) It is necessary that the elongation of materials should be not less than 25%.

Table 3

No.	Max. compression (mm)	Min. compression (mm)
1	2.1	0
2	2	0
3	3	0

Table 4
Sizes of vane primarily rolled

No.	h (mm)	H (mm)	d (mm)	D (mm)
1	1.4	3.5	65	169
2	1.5	3.5	71	204
3	2.0	5.0	124	315

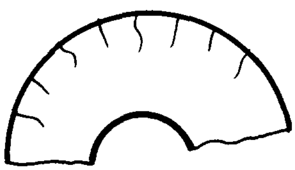

Fig. 8. Cracks at the outer edge of the vane.

(iii) The following condition should be considered in determining the blank size: $B/h \geqslant 6$; where B is width of the blank and h is the thickness of the blank.

5. Structural characteristics of the machine for the cold-rolling of a vane

5.1. Working part [2]

The working part consists of two cantilever conical rollers. Too small a cone angle is unfavourable to deformation because the velocity difference in deformation between the upper end and the lower end of the blank width is small. However, too great a cone angle can make the difference in the forming speed increase between both ends of the blank width, and promote bending deformation. It should be noted that the larger is the cone angle, the larger is the roller diameter, if the working width of the roller is fixed. When the vane is rolled, elastic flattening of the rollers occurs and the gap between the rollers enlarges, so that the required gap width cannot be ensured. Further, increased roller diameter will bring about expansion of the deforming region

Table 5
Hardness and thickness of the material

Hardness (HB)	Thickness H (mm)
120–130	2.5
110–120	3.0
105–115	3.0–3.6
< 105	> 3.6
< 90	4.7

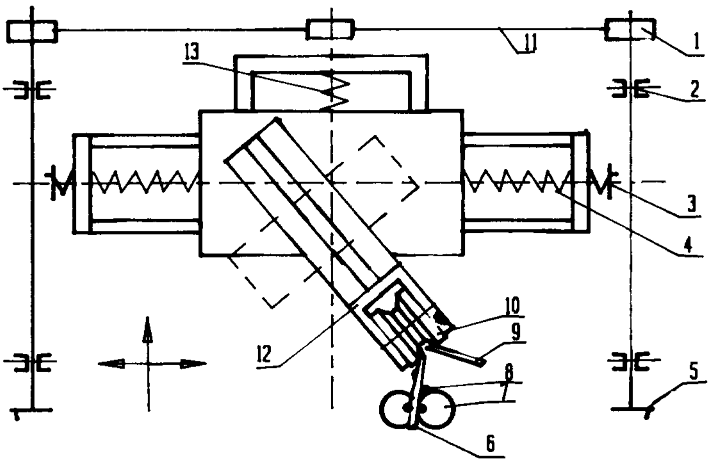

Fig. 9. Diagrammatic sketch of the stretch-out unit: 1.sprocket-wheel; 2.bearing; 3.longitudinal-shift handle4.threaded rod of the longitudinal shift; 5.cross-shift handle; 6.strip-blank; 7.roller; 8.pilot rod; 9.vane; 10.pilot wheel; 11.chain; 12.pilot wheel base; 13.threaded rod of the cross-shift.

(the contact area between the roller and the deformed metal), the unit pressure being diminished in the deforming region, which is disadvantageous to vane forming. Therefore, a suitable roller angle and diameter should be selected to meet the requirements of vane forming. It is known from tests and analyses that the vane can be well formed by choosing a working roller with a 60° cone angle. In rolling, the feed position for a vane with a small inside-diameter should be close to the small-end of the roller.

5.2. Stretch-out unit

The stretch-out unit is used to stretch the pitch of the spiral vane formed naturally by primary rolling, and to reduce the inside diameter in order to obtain the required vane dimensions.

Fig. 9 shows [3] the stretch-out unit. The main working part contains the pilot rod and the pilot wheel. The pilot rod effects the inclination of the vane when the vane is twisted by the pilot wheel. It can also provide reactive force for the vane when it is twisted, so that the vane can obtain the required helical angle.

The pilot wheel is applied to effect twist over the cross-section of the vane. The working positions of the pilot rod and the pilot wheel are adjusted in accordance with the spiral directions of the vane, their positions demanded by right-hand vane being shown in Fig. 9.

6. Conclusions

1. In cold-rolling, it is necessary to calculate the developed dimensions on the basis of the product.
2. The boundary of the deforming region should be at 1/5–1/6 of the blank width to obtain a high-quality vane.
3. Test results show that the hardness and thickness should satisfy the conditions shown in Table 4 in order that rolling process proceeds smoothly.
4. A 60° cone angle should be chosen for the working roller.

The technological parameters selected above will ensure a good-quality product, higher productivity, higher material utilization (more than 95%) and lower cost.

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