Deformation Cone of Pilger Rolling for Forward and Reverse Motion

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Abstract. Two mutually perpendicular pairs of rolls show the distinctive features of the existing pilger rolling processes from the pilger rolling process developed at SUSU. The peripheral velocity vectors of them are placed in different directions from the transition zone formation position from the initial billet to the finished profile (deformation cone). The change in the deformation cone shape with the billet free ends during the pilger rolling process by two mutually perpendicular pairs of rolls, circumferential velocity vectors placed in different directions, are considered. It is accepted that during forward rolling, the billet feed is equal to \( m \), and during reverse rolling it is equal to \( m\lambda \) to ensure equality of displaceable feed volumes when describing the changes sequence in the deformation cone parameters. The gradual supply volumes flattening with a forward and reverse stroke to design values is shown. This was obtained by considering several cycles of pilger rolling by sequentially increasing the feed volumes during reverse rolling and reducing the feed volumes during forward rolling.

1. Introduction
Currently, the pilger rolling process, also called pilgering and periodic rolling, is carried out on pilger mills, mills cold-rolling tube (HPT), roller type cold rolling tube mill (HPTR), planetary, pendulum and rolling-forging mills [1–14]. The pilger rolling process is carried out simultaneously by two, three and four rolls on these mills. In this case, the pilger rolling process at these mills is carried out in direct motion, with the exception of pilger rolling mills with rotating rolls designed at the South Ural State University (SUSU) [5–7] and HPT [8–13] mills that can perform pilger rolling in reverse.

A new pilger rolling process developed at SUSU [15, 16] provides pilger rolling of one pair of rolls in direct motion and the other with a pair of rolls in reverse motion. The vectors of circumferential velocities of mutually perpendicular pairs of rolls are directed in different directions to achieve it.

It is necessary to know the deformation cone geometry (transitional section from the initial billet to the finished profile), which is the initial profile specified in the rolls at each deformation pilger. This is necessary for developing rolls calibration and determining the technological parameters of the instantaneous deformation zone during rolling by two mutually perpendicular roll pairs, one of which it deforms in direct motion, and the other pair of rolls in reverse motion.

2. Methods
Consider the change in the deformation cone shape during the rolling process with the free ends of the billet. We begin the consideration on the condition that the same deformation cones 1, 2 are rolled out on the billet with the same height of the original billet and the resulting profile from both pairs of rolls (Figure 1).
At the same time, we take into account that during direct rolling, the billet feed is equal to \( m \), and during reverse rolling \( m \lambda \) to ensure equality of displaced feed volumes with direct rolling. The total displaced volume in the forward and reverse stroke is \( m H_0 B_0 = m \lambda H_1 B_1 \).

We begin rolling with a pair of rolls that deform by a direct course on the side \( B_0, B_1 \) with feeding \( m \). The deformation cone \( Z \) is rolled out on the billet after rolling with the indicated pair of rolls. Suppose that the front side of the billet from the finished profile receives a linear displacement equal to half the displaced volume minus the feed itself, that is \( \frac{1}{2} m(\lambda - 1) \). The deformation cone on the side \( H_0, H_1 \) will take a position 4.

![Figure 1](image_url)

**Figure 1.** Changing in the shape of the deformation cone.

A pair of rolls, deforming backward along the \( H_0, H_1 \) side, will begin to deform with a rolling section from point \( A \) to point \( B \). Distance between these points are \( m \lambda \). The pair of rolls on the side \( H_0, H_1 \) of the billet roll out the deformation cone 5 after deformation. Let us assume that the back end of the billet will also receive an offset equal to half the displaced volume minus the feed itself \( \frac{m(\lambda - 1)}{2} \). The deformation cone on the side \( B_0, B_1 \) will take position 6.

A pair of rolls, deforming in direct motion, after feeding the billet by a value of \( m \) and rolls out the deformation cone 7 on the side \( B_0, B_1 \). The front end of the billet will receive linear displacement \( \frac{m(\lambda - 1)}{2} \) and the deformation cone on the side \( H_0, H_1 \) will take position 8.

Then a pair of rolls, deforming in reverse, rolls out the deformation cone 9, the back end of the billet will offset by an amount \( \frac{m(\lambda - 1)}{2} \) and the deformation cone on the side \( B_0, B_1 \) will take position 10.

Further rolling is similar to that described above.

Thus, after rolling in reverse (before rolling in direct motion), the deformation cone from the side of the roll deforming inverse will have the form 2 (Figure 2), and the deformation cone from the side of the roll that deforms in direct motion will have the form 4.
Figure 2. The deformation cone of straight pilger rolling.

During deformation by a direct stroke, the metal of the deformation cones will be displaced towards the final product. Instantaneous linear displacement values are $\Delta m_1$. As a result of this, the metal entry lines into the deforming in direct motion rolls will take position 5, and the deformation cone on the side of the roll deforming in reverse motion will take position 1. The position of line 1 determines the width of the instantaneous zone of deformation at the metal entry in the rolls, deforming in direct motion. The deformation cone from the side of the roll, deforming in direct motion, after deformation in direct motion will take position 3.

The deformation cone after rolling in direct motion (before reverse rolling in) from the side of the roll deforming in direct motion will be

have the form 3 (Figure 3), and the deformation cone from the roll side deforming backward will have the form 5.

Figure 3. The deformation cone during reverse pilger rolling.
During the reverse rolling deformation, the deformation cones metal 5 and 3 will be displaced towards the initial billet. The instantaneous inline offset value is denoted by $\Delta m$. The metal entry into the rolls lines, deforming backward, will occupy position 1. The deformation cone from the roll side, deforming in direct motion, will occupy position 4. The position of line 4 determines the instantaneous deformation zone width at the metal entrance in the rolls, deforming backward.

3. Results
The metal forming analysis during the considered pilger rolling process shows that during direct rolling (Figure 2), the LCEN supply volume exceeds the design supply volume $V = mH_0B_0$ per volume limited by the CDE line. AFIC supply volume is less than the design supply volume $V = m\lambda H_1B_1$ per volume limited by the FGI line during reverse rolling (Figure 3).

Then, when rolling in direct motion, the linear displacement of the metal will be greater than the design $\frac{m(\lambda - 1)}{2}$ and point I will move to the side of the finished profile by an amount exceeding $\frac{m(\lambda - 1)}{2}$, increasing the feed volume, which is deformed when rolling in reverse.

The linear offset will be less than the design and point B will move to the side of the original billet by an amount less $\frac{m(\lambda - 1)}{2}$ when rolling backwards. Then the feed volume, deformable during direct rolling, will decrease.

Direct and reverse feed volumes are leveled and equal to the designed feed volumes in subsequent rolling cycles by successively increasing feed volumes during reverse rolling and decreasing feed volumes during direct rolling.

4. Conclusion
1. The distinctive features of the developed method of pilger rolling are shown by two mutually perpendicular pairs of rolls, the peripheral velocity vectors of which are directed in different directions.
2. The patterns of the change in the deformation cones shape during pilger rolling, both direct and reverse, have been established. The use of them is necessary in calculating the rolls calibration and the instantaneous deformation zone parameters.
3. It is shown that the pilger rolling process, carried out sequentially by two pairs of mutually perpendicular rolls, the peripheral velocity vectors of which are directed in different directions, has the ability to equalize the metal supply volumes deformed by each pair of rolls to their design values.

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