The Design of Rollers for Rolling Corrugations in the Ribbon

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Abstract. Corrugated stainless steel ribbon is used as a working element in modern heat exchangers designed for high working temperatures (up to 1000°C). Making corrugations on the ribbon is the most time-consuming operation, which determines the relevance of the study subject. The article offers a method for calculating the tool profile, provided that the centroid is on the outer diameter of the tool. According to the results of calculations and practical studies, this method should be applied. The profile of the rollers was profiled depending on the specified ribbon profile, limits of ribbon profile parameters are determined. The study subject is to determine the grooves profile of the rolling rollers and to determine rational methods for visualizing the rolling process in order to simulate it. To accomplish this aim, the following tasks are to be solved: 1. To determine the rational position of the centroid during the rolling of corrugations on rollers. 2. To determine the parameters of the profiles when the tool centroids are located on the outer diameter of the rollers in the rolling process.

1. Introduction
The article discusses how to design rollers for rolling ribbed ribbon. Ribbons made of steel X18H9T are used in the nozzles of the regenerative heater for wind tunnels, where aircraft components are tested [1]. To ensure the required characteristics there are strict limits on the error profile. The correct calculation of the rollers profile has a significant impact on the accuracy of the ribbon profile [2].

Three design methods are known:
1. Graphic;
2. Graphic-analytical;
3. Analytical [3].

The first method does not fulfill the required conditions for accuracy and can be only an evaluation method for determining approximate parameters of the tool profile [4].

The analytical method, in turn, is absolutely accurate; however, it requires the development of mathematical models [5].

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On this basis, it is possible to identify the main problems encountered when profiling the working part of the rollers:
1. Positioning centroid parts and tools;
2. Definition of the profiles parameters when rolling [7].

2. The problem statement
When designing, it should be taken into account that the rolling diameter must pass through the outer diameter of the tool (Fig. 1a), otherwise the tooth will perform a loop-like movement (Fig. 1b), which negatively affects the tool durability. In addition, with such a movement of the tool, it is impossible to
work out the detail cavity. In the lower part of the tool profile, there is “cropping” of corrugations, thus the limits of the required accuracy are violated (Fig. 1c).

Figure 1. Tool profile: a) at the location of the centroid on the outer diameter of the tool; b) at the location of the centroid on a diameter different from the outer diameter of the tool; c) the difference between the required profile of the tool and the real one.

A tool board is used and it illustrates the operation of the graphic method. The ribbon profile (tool rail) is presented in Figure 2.
Figure 2. Tool Rail Profile: a) at the location of the centroid on the outer diameter of the tool; b) at the location of the centroid on a diameter different from the outer diameter of the tool. With standard use of the slats, the centroids of the part and the tool are in a diameter different from the outer diameter of the part (Fig. 3a). The resulting tool profile is shown in Fig. 1b. In this case, it is possible to roll a ribbon of a given height, but when the roller moves, there will be a “trimming” of the lower forming corrugation.
Figure 3. The position of the rolling diameter: a is different from the outer diameter of the tool; b is coinciding with the outer diameter of the tool; 1 is centroid
When moving the centroids to the outer diameter of the part and maintaining the rail profile (Fig. 3b) the height of the corrugations (Fig. 4) is to be limited. However, when the height requirements are fulfilled, the ribbon is rolled with given accuracy, since the tool does not make movements that can change the profile of the part unplanned (Fig. 2a).

Figure 4. Height adjustment corrugations

3. Theory
To obtain the required profile of the tool, the relative position of the profiles of the part and the required profile of the tool can be determined when rolling their centroid together and that is why two basic points A and B are chosen. Point A should be on the outside diameter of the tool, and point B should be at the intersection of the radius passing through this first point and perpendicular to the radius passing through point C. Point C is located on the profile at the base of the tooth of the tool.
The distance AB is denoted as a (Fig. 5, b). The angle of inclination of the profile is assumed to be equal to $\gamma$, and the rotation angle of the part profile from the initial position is $\varphi$ (Fig. 5a). The initial is considered to be the location where the profiles of the part and the tool pass through the profiling pole P. The condition that the centroids of the part and the tool (initial circle and straight line) roll over each other without sliding follows that when the part is rotated through angle $\varphi$, the rail will move from the initial position along its initial straight line by value $r\varphi$. The relative position of the part and tool profiles is defined in the xOy rectangular coordinate system associated with the tool profile. The x axis of the system coincides with the initial straight line; the origin of coordinates coincides with the intersection point of the tool profile with the initial straight line. To determine the position of the profile, the position of points A and C coordinates is to be determined.

Coordinates of point A are:

$$x_A = r(\varphi -\sin \varphi), \quad y_A = r(1 - \cos \varphi).$$

To calculate the coordinates of point C, an auxiliary set of equations is used, where f1 – f9 (see Fig. 5, b):

Figure 5. Method for determining the tooth profile: a is centroid of part and tool position; b is tool profile position when turning angle $\varphi$; c is tool profile set.
The coordinates of point C are determined with the formulas:

\[ x_C = x_A + f_2 - f_6; \]
\[ y_C = y_A + a \cdot \cos \varphi - f_6; \]

Changing angle \( \varphi \), values \( x_A, y_A, x_C, y_C \) are determined. Sequential position of the straight line AC (Fig. 5, c) is the tool profile.

4. **The results of the experiment**

Under condition of the rolling diameter position along the outer radius of the tool, there were made ribbons nozzles for the cooper heater are made from (Fig. 6). The cylinders that make up the nozzle are made by winding two corrugated ribbons of heat-resistant steel 12X18H9T with thickness \( \delta = 0.4 \) mm onto the core. Corrugations on the ribbon are inclined at an angle 60 degrees. To improve the heat and oil exchange, as well as to improve the folding of the corrugated ribbon, slots are made along them. The width of the slots is not limited (Fig.6).

![Diagram of Cuper Header Head](image-url)

**Figure 6.** Cuper Header Head.
5. The results discussion
At the position of the centroid on the outer diameter, the requirements on the accuracy of the part are met, provided that the height of the corrugations is limited. The calculation of the tool profile is recommended to be performed according to the proposed method, if there are straight profile and the position of the centroids on the outer diameter. The proposed method combines the accuracy of analytical and visualization of graphical methods. In this case, there is relevance of the tool centroids location on the outer diameter.

6. Conclusion
According to the results of the research, a method has been developed to calculate the profile of rolling rollers, taking into account the kinematic features of the process. According to the results of the analysis, it was proved that when rolling a profile on a ribbon, there are technological limitations on the height and angle of inclination of the corrugation.

7. References
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