# Experimental Study of the Process of Radial Rotation Profiling of Wheel Rims Resulting in Formation and Technological Flattening of the Corrugations

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**Experimental studies of the wheel rim workpieces with additional technological corrugations have been carried out the results of which showed the ineffectiveness of this technique in profiling to increase thickness of the radial profile junctions of the semi-finished product. The comparison of profiling methods was carried out according to the Cochran's criterion and Student t-test. The additional experiments aimed at the determination of the flexural strain on differently shaped workpieces confirmed the impossibility of creation of the upthrust in the meridional direction during the deformation of the closed shells with straightening of the technological seats (corrugations). It is determined that the seats on the shell unbend in the tangential direction, the bending moments are damped nearthe site of the load application.**

**Keywords:** radial-rotary profiling, profile, rim, process, corrugations.

## 1 Introduction

When designing technological processes, which use profiling, the industrial engineers have to solve many questions, the main of which are: 1) the determination of the dimensions of a workpiece; 2) the determination of the minimum bend radius; 3) the development of measures to eliminate the thinning of the workpiece in the radial passages.

Under these conditions, especially relevant becomes the problem of developing scientific foundations of rational technological processes, their experimental verification, which give the minimum complexity and cost of manufacturing of the specified parts of the best quality [1, 2, 3, 4].

A very promising direction of the intensification of the sheet stamping, profiling of sheet materials and cylindrical workpieces is changing the patterns of application of the external forces [5, 6, 7-11].

## 2 Material and experimental procedure

So, work [4] describes a new method of profiling of the wheel rims, the essence of which is the straightening of the technological corrugations, obtained in the previous passage and thus ensuring an increase in the thickness of the metal in the places of the radius curvature of the finished product (Fig. 1).

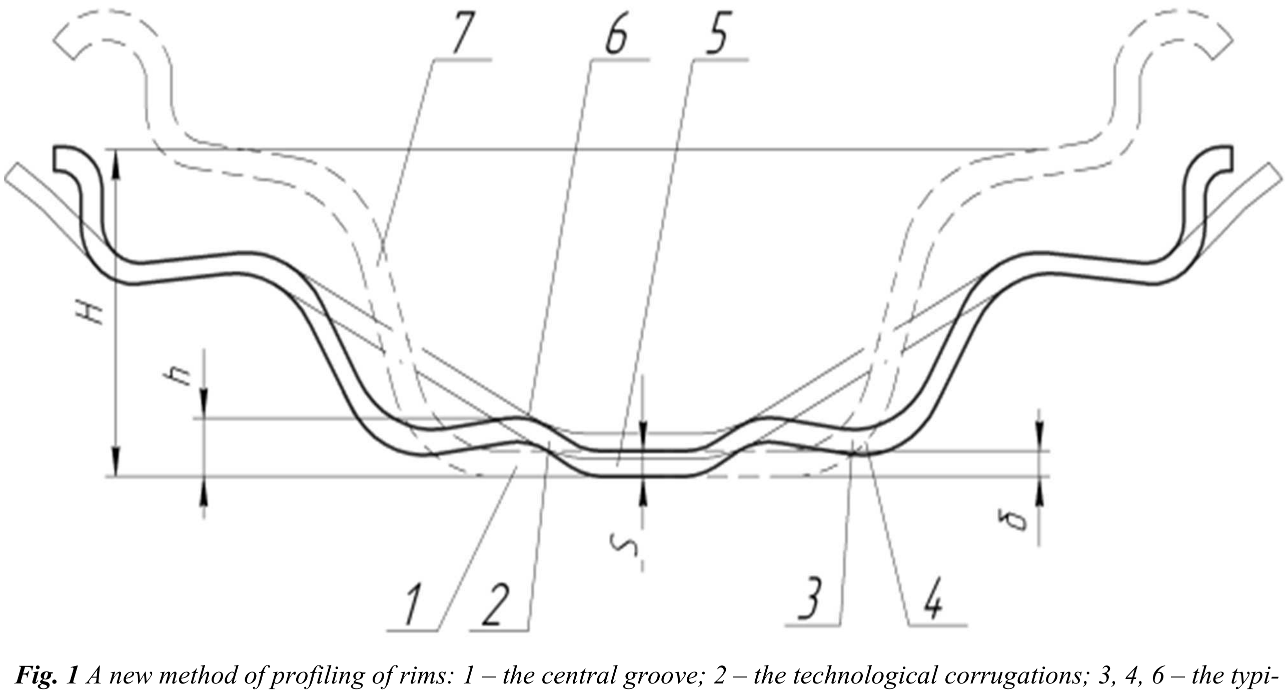


*Fig. 1 A new method of profiling of rims: 1 – the central groove; 2 – the technological corrugations; 3, 4, 6 – the typical profile zones; 5 – the central area of the mounting groove; 7 – the specified profile*

To verify the effectiveness of this method the experimental studies with the wheel rim models were carried out. 30 models of the semi-finished wheel rim W8x16 were subjected to the tests, 10 of which were formed by the conventional techniques, 10 – with the straightening of the direct corrugation and the other 10 – with the straightening of the reverse corrugation (Fig. 2).

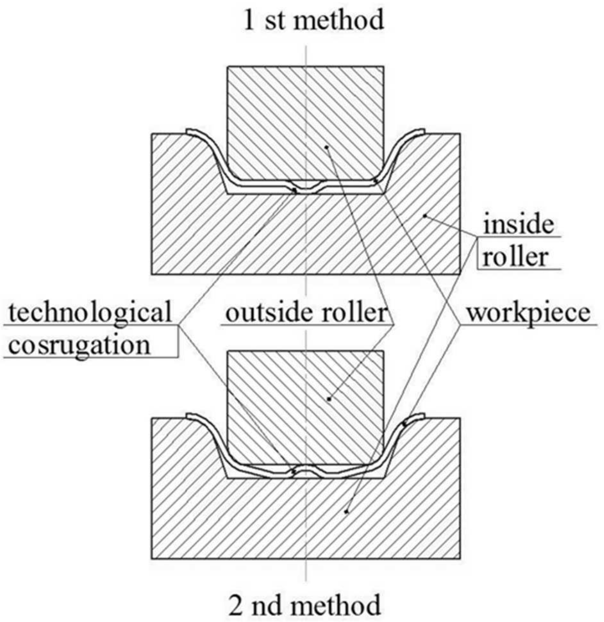


***Fig. 2*** *The straightening of the technological corrugations during the profiling of the wheel rim W8x16*

Fig. 3 (a, b) shows the rollers forming the corrugations and a ready-made semi-finished product. As indicated in studies [6, 7], the straightening of the corrugations causes an additional loading on the workpiece and the displacement of the neutral layer in the zones of bending to the outer surface. The higher the displacement is, the smaller should be the thinning of the semi-finished product in the bending process.

*a)*

*b)*

***Fig. 3*** *Attachments for applying technological corrugations (a), and a semi-finished product with a corrugation*

***Fig. 4*** *The measurement of the thickness of the metal in the curved areas of the profile of the semi-finished product*

The thickness of a workpiece before deformation as well as each semi-finished product after the corresponding passage of the profiling in the corner areas of the profile were measured. The measurements were carried out using a thickness gauge with a measuring range of 0 – 25 mm and least graduation of 0.01 mm (Fig. 4). Further bad measurement errors were eliminated, the arithmetic mean and mean square deviation of the measurement results were calculated, the hypothesis about the normal distribution law was tested, the confidence intervals of the random error, the boundaries of the non-excluded systematic error, and confidence limits of the error of the measurement result were calculated. Some results are summarized in table. 1.

The difference of two new modes of profiling was in a diametrically opposite direction of forming an additional corrugation with respect to the axis of the shell (Fig. 2). From the data given in table. 1 it can be concluded that the thickness of the transition zones of the profile according to the second technology has increased slightly. To estimate the received results of the thickness measurements of the work piece in the transition zones the statistical studies were carried out and the most effective technology was determined.

## 3 Results and discussion

### 3.1 Calculation for the traditional technology and the first profiling method

To address the issue of choosing the best method of profiling, in terms of product quality or reduction of material consumption, thereby reducing the cost of manufactured parts without reducing their performance, there is a need for sample average values of the studied random variables to infer relevant general values of mathematical expectations.

***Tab. 1.*** *The results of measurements of the thickness of the transition zones of the central groove of the semi-finished product*

| No. | The original shell $X_{0,i}$, mm | The original technol. $X_{1,i}$, mm | 1 way $X_{2,i}$, mm | 2 way $X_{3,i}$, mm |
|---|---|---|---|---|
| $X_i$ | 2.0 | 1.96 | 1.98 | 2.02 |
| $\overline{X}$ | 1.995 | 1.975 | 2.005 | 2.03 |
| $S^2$ | 0.0032 | 0.00045 | 0.00125 | 0.0032 |

To address the issue of choosing the best method of profiling, in terms of product quality or reduction of material consumption, thereby reducing the cost of manufactured parts without reducing their performance, there is a need for sample average values of the studied random variables to infer relevant general values of mathematical expectations.

In our case the task is to compare two unknown mathematical expectations M1 and M2, when the studied samples with which the estimates for M1 and M2 are made are independent of each other. Thus, in accordance with the pre-processing of the experimental data, if for two normally distributed general populations with the unknown parameters M1, $\sigma^2_1$ and M2, $\sigma^2_2$ independent samples of the size $n_1$ and $n_2$ respectfully are obtained, then for comparison of sample means the null hypothesis is made (the processing of the results is conducted by method [12]):

1. $H_0 : M_1 = M_2$ – the equality of mathematical expectations.

2. In this task, the alternative hypothesis $H_1^{(1)} = M_1 < M_2$

3. Student t-test used.

4. The form of the t-statistics depends on the equality $\sigma_1^2 = \sigma_2^2 = \sigma^2$, or on their inequality $\sigma_1^2 \neq \sigma_2^2$ (for this purpose the Cochran's criterion is used). When the variances have' no significant differences, the statistics takes the form:

$$t = \frac{X_1 - X_2}{S\sqrt{\frac{1}{n_1} + \frac{1}{n_2}}} \text{ [-]}, \quad (1)$$

where S – is the generalized standard deviation:

$$S = \sqrt{\frac{(n_1 - 1)S_1^2 + (n_2 - 1)S_2^2}{n_1 + n_2 - 2}} \text{ } [mm], \quad (2)$$

where $S_1^2$ $S_2^2$ – sample variances for the two series of observations.

In the second case, when the variances are significantly different from each other, $\sigma_1^2 \neq \sigma_2^2$, the statistics is:

$$t = \frac{\overline{X}_1 - \overline{X}_2}{S\sqrt{\frac{S_1^2}{n_1} + \frac{S_2^2}{n_2}}} \text{ [-]}. \quad (3)$$

5. A desired level of significance α is selected.

6. The limits of the critical area for the tabular values of quantiles of t-distribution in tables [11] are determined. The number of degrees of freedom m is calculated as follows:

– for $\sigma_1^2 = \sigma_2^2 = \sigma$ like $m = n_1 + n_2 - 2$;

– for $\sigma_1^2 \neq \sigma_2^2$ – $\frac{1}{m} = \frac{c^2}{n_1 - 1} + \frac{(1-c)^2}{n_2 - 1}$,

where $c = \frac{\frac{S_1^2}{n_1}}{\frac{S_1^2}{n_1} + \frac{S_2^2}{n_2}}$ [-].

7. The null hypothesis is accepted, i.e. $M_1 = M_2$ if the following inequality is satisfied $|t| \leq t_{2\alpha;m}$.

Regarding the research for the source and the first method of the technological process the obtained data are in (Tabl. 1).

1. We formulate the null hypothesis $H_0 : M_1 = M_2$ .

2. As it is assumed that the new technology by the first method allows to increase the thickness of the semifinished product in the radial junction, which was formed as a result of the introduction of rollers, the alternative hypothesis is chosen in the following form: $H_1 : M_2 > M_1$.

3. To determine the version of the statistics for the t-test we compare the corresponding variances. To do this, the null hypothesis is made: $H_0 - \sigma_1^2 = \sigma_2^2 = \sigma^2$ .

But in our case we have three ways of profiling of the rim, then $H_0 : \sigma_1^2 = \sigma_2^2 = \sigma_3^2 = \sigma^2$.

The alternative hypothesis is $H_0 : {\sigma_{max}}^2 > \sigma^2$.

At the equal volume $n_1 = n_2 = n_3$ of all $k$ samples the Cochran's criterion is used for the analysis:

$$G = \frac{S_{max}^2}{\sum_{i=1}^{k} S_i^2} \text{ [-]}; \quad (4)$$

$$G = \frac{0{,}0032}{0{,}0032 + 0{,}00125 + 0{,}00045} = 0{,}65306.$$

For the selected significance level $\alpha = 0{,}05$, when the number of degrees of freedom is $m = n - 1 = 10 - 1 = 9$ and for the compared variances of $k$ in table [11] we determine the table value $G_{\alpha,m,k.}$, $G_{0{,}05;9;3} = 0{,}9669$. $G < G_{\alpha,m,k}$ – so the hypothesis $H_0 : \sigma_1^2 = \sigma_2^2 = \sigma_3^2 = \sigma^2$ is accepted as working. The variances are homogeneous.

4. Then the *t* test is calculated according to formula (1), for this we determine *S* from (2):

5. $S = \sqrt{\frac{(10-1)0{,}00045 + (10-1)0{,}00125}{10+10-2}} = 0{,}0292$ [*mm*].

$$t = \frac{2{,}005 - 1{,}975}{0{,}0292\sqrt{\frac{1}{10} + \frac{1}{10}}} = \frac{0{,}03}{0{,}013059} \approx 2{,}3$$

6. We choose $\alpha = 0{,}05$ (for technical calculations).

7. We determine the number of degrees of freedom $m = n_1 + n_2 - 2 = 10 + 10 - 2 = 18$.

8. We find the *t*-criterion from [11]: $t_{2\cdot 0{,}05;18} = 2{,}920$.

Conclusion: since $t < t_{2\cdot\alpha;m}$, then the null hypothesis is $H_0 : M_1 = M_2$.

### 3.2 Calculation for the traditional technology and the second method of profiling

For the second scheme:

1. $H_0 : M_1 = M_3$.
2. $H_1 : M_1 < M_3$.
3. The studen *t*-test is used.
4. It follows from the above that the t-criterion is determined by formula (2):
5. $S = \sqrt{\frac{(10-1)0{,}00045 + (10-1)0{,}0032}{10+10-2}} = 0{,}0427$ [*mm*].

$$t = \frac{2{,}03 - 1{,}975}{0{,}019096} = \frac{0{,}055}{0{,}019096} = 2{,}88.$$

6. The level of significance is $\alpha = 0{,}05$.
7. The number of the degrees of freedom is $m = 10 + 10 - 2 = 18$.
8. $t_{2\cdot 0{,}05;18} = 2{,}920$.

Since $t < t_{2\cdot\alpha;m}$, then the null hypothesis $H_0 : M_1 = M_3$ is accepted. We estimate the significance level by the statistical formula MExcel: STUDENT. DIS. Pkh (2,88; 18; 1) = 0,0099. The obtained value in this case indicates that the probability of inequality for the mathematical expectation of the thickness of parts according to new and traditional technologies is very small and makes 0,99 %.

The statistical processing of the results showed the fallibility of the preliminary conclusions: the probability of inequality for the mathematical expectation of the thickness of parts according to new and traditional technologies is very small, less than 1 %, i.e. the technologies are equivalent. The use of profiling technologies with the formation and subsequent flattening of the corrugation did not give a significant economic effect. Along with a slight increase in the thickness of the metal in the transition zone of the central groove, there is a need to introduce an additional transition for the formation of the corrugation, which increased the duration of the production cycle, increasing the number of forming machines in the line, maintenance and adjustment time, reducing production. After the production tests the implementation of this method is suspended.

### 3.3 The comparison of data for the additional loading of variously shaped workpieces

Thus, it is possible to make an intermediate conclusion that the additional loading of a workpiece in the axial direction when the radial-rotary method of manufacturing wheel rims is used is not sufficiently effective for the intensification of this process. In the operations of bending, drawing, reduction, expansion, profiling of bands the upthrust schemes are used that allow to increase both the coefficients of deformation and the wall thickness of the semifinished product in dangerous cross sections. At the same time the additional loading schemes do not lead to positive results in the profiling of the shells.

The above conclusions are confirmed by the following experiment. A method of bending sheet materials with the moment has been developed with the application of the deforming forces to the previously bent seats [13]. In this way the bending of the strip is carried out by the upthrust of the ends and application of the bending moments (Fig. 5).

The emerging flexural deformations testify of the sufficient amount of upthrust of the ends of the workpiece and the possibility of using this method when bending with the upthrust to reduce the thinning in the radial passages. It was expected during unbending of the previously obtained seat expansions in a closed shell to form a bend in the meridional direction similar to the blank sheet. But the experiments conducted with the models of workpieces for rims, showed that straightening of the seats, does not result in deflections in the meridional direction and the horizontal surface of the shell before deformation remains horizontal after it (Fig. 6, 7).

a)

b)

***Fig. 5*** *Bending of the strip: a – initial position of the workpiece; b – final stage of bending*

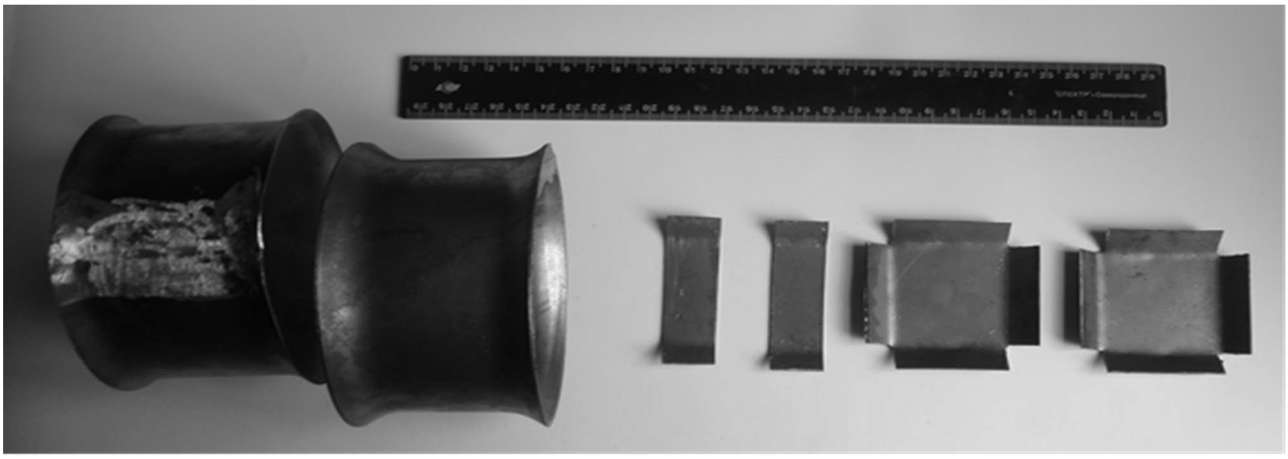

***Fig. 6*** *The workpiece for seat straightening testing*

This fact shows the ineffectiveness of the formation of corrugations on the wheel rim parts and their subsequent straightening in order to distribute metal to the zones of bending. The moments that occur during the deformation of seats are damped in the vicinity of the point of application of the load and are not able to cause bending of the shell in the meridional direction [14, 15]. The shell is bent in the tangential direction, since its stiffness is several times less in the circumferential coordinate.

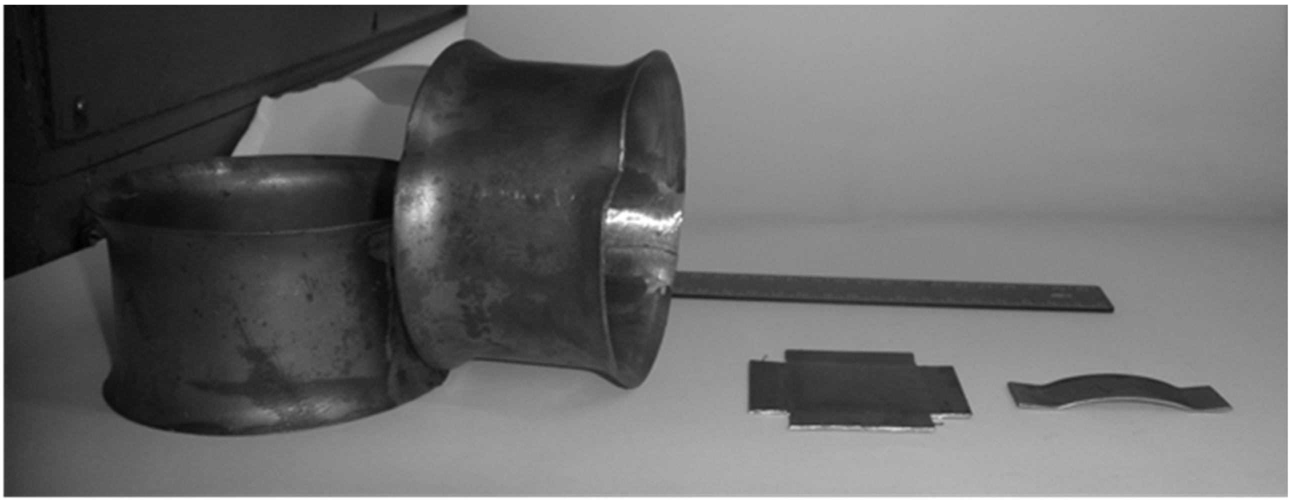

***Fig. 7*** *The workpieces after seat straightening*

## 4 Conclusion

The investigations conducted on the wheel rim workpieces with additional technological corrugations showed the ineffectiveness of this technique in profiling to increase the radial junction thickness of the profile semi-finished product. The comparison of technologies was carried out according to the Cochran's criterion and student t-criterion. The additional experiments aimed at the determination of the flexural deformations of differently shaped workpieces confirmed the impossibility of the creation of the upthrust in the meridional direction during the deformation of the closed shells with the straightening of technological seats (corrugations). It is determined that the seats on the shell are straightened in the tangential direction, and the bending moments are damped near the site of the load application. The experiments scientifically justify locations of the areas of the additional loading at the design stage of the technological processes of profiling and give the possibility to demonstrate the effective techniques aimed at levelling the uneven deformation in the cross section of the wheel rim profile[16].

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