ANALIZA ELIPSASTOG SAVIJANJA LIMA POMOĆU ČETVEROVALJKASTE MAŠINE

ANALYSIS OF ELLIPTICAL SHEET BENDING USING A FOUR-ROLLERS MACHINE

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REZIME
Savijanje lima predstavlja jedan od najvažnijih postupaka plastične obrade metala. Ovaj proces je široko primjenjivan u različitim industrijskim granama kao što su automobilska, avionska, brodograđevinska i građevinska industrija. Efikasnost i preciznost savijanja značajno utiču na kvalitet konačnog proizvoda, kao i na ekonomičnost proizvodnje.U ovom radu istražuje se proces elipsastog savijanja lima na valjcima. Korištenjem analitičke metode i eksperimentalnih ispitivanja, određeni su optimalni uslovi rada koji omogućavaju postizanje željenog radijusa savijanja uz minimalne deformacije i greške. Poseban fokus stavljen je uticaj K faktora na konačni rezultat. Rezultati istraživanja mogu doprinijeti boljem razumijevanju procesa i unapređenju proizvodnih metoda u industriji obrade metala, posebno kada je u pitanju obrada koja nije uobičajena. U radu je dokazano kako konstrukcija elipse s tri prečnika daje najbolje rezultate savijanja.

Stručni rad

SUMMARY
Sheet metal bending is one of the most important plastic metalworking processes. This process is widely used in various industries such as the automotive, aircraft, shipbuilding and construction industries. The efficiency and precision of bending significantly affect the quality of the final product, as well as the cost-effectiveness of production. This paper investigates the process of elliptical sheet metal bending on rollers. Using analytical methods and experimental tests, optimal operating conditions were determined that allow achieving the desired bending radius with minimal deformation and errors. Special focus was placed on the influence of the K factor on the final result. The research results can contribute to a better understanding of the process and the improvement of production methods in the metalworking industry, especially when it comes to non-standard processing. The paper proves how the construction of an ellipse with three diameters gives the best bending results.

1. INTRODUCTION

Bending of sheet metal is a metalworking process without removing shavings, in which the inner part in the cross-section is shortened and loaded with pressure, while the outer part is elongated and loaded with tension. Sheet metal bending is divided into: circular bending, angle bending and profile bending. Sheet metal bending is the most commonly used procedure for processing sheet metal and metal by plastic deformation. Sheets and metals are usually cold, and if they are characterized by greater thicknesses, they must be heated. Metal alloys designated for cold metal working exhibit much higher strength properties than pure materials due to solid-solution hardening. However, with the increase of mechanical properties its plasticity and workability decreases. [1]

Due to its elasticity, the sheet, or metal, must undergo greater bending in order to obtain the desired angle. During the bending process, the sheet is under the influence of plastic and elastic deformations, which cause the material to take the desired shape or the material expands due to the cessation of the effect of elastic deformations. [1]

In this paper, elliptical bending of sheet metal with a four-roller machine will be considered. In order to compare the methods of conducting the analysis as well as the obtained results, the construction of an ellipse with two and three diameters, the determination of the parameters of the arc length of the ellipse segment was carried out as part of the work. A four-roller FACCIN sheet metal circular bending machine was used.

2. TECHNICAL DATA AND PROBLEM DESCRIPTION

The input data are the diameters of the ellipse R1 and R2. The diameter of R1 is 310 mm, and the diameter of R2 is 220 mm. The given values include the thickness of the sheet metal, which is 3 mm, i.e. the outer diameters are given. The construction of the 3D model and the creation of the drawing for modelling are done in the SolidWorks program. The ellipse function was used for the construction, where the given diameters are directly entered and the desired shape is obtained. The element needs to be bent using the bending radius, but the part in the program is drawn as an ellipse, so the circular bending diameters cannot be automatically generated. A test was performed to bend the given part using the imported CAD model, but the software on the machine is not able to recognize the loaded file. Thus, it is necessary to find a solution that will enable bending and solving the problem.

In order to obtain the optimal solution, the K-factor and the developed length of the element were calculated. Considering that it is metal forming process, the force range during bending was determined analytically. Since it is a larger cross-section, elastic stresses are also present.

3. SOLVING PROBLEM METHODS

During problem solving, there are three options. The first and fastest option is to enter the parameters of the diameter and length of the arc. The program on the machine itself generates the center of the entered diameters and automatically performs the bending. The second option is to transform the ellipse into a shape with two diameters and with two different centers, and the third option is to transform it using three diameters transformation method and with three different centers of circles. [2]

3.1 Arc length

Using the Solidworks program, one quarter of the element was selected to define the parameters, since the element is axisymmetric. The selected part was divided into segments where the arc length and diameter were measured and the values were entered into the machine software what is shown in the Fig. 1 and Fig. 2.

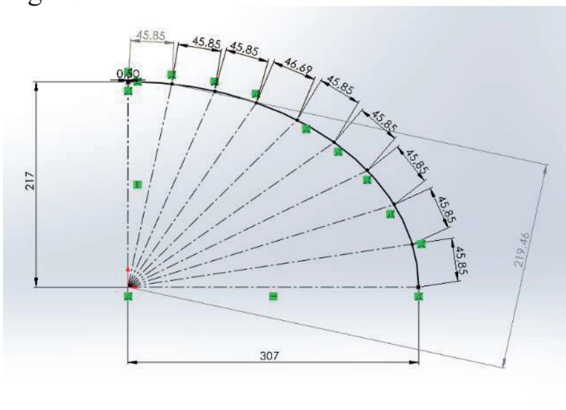

Figure 1 *Arc length distribution*

Figure 2 *Example of entered parameters for arc length*

3.2 Transformation of an ellipse on two diameters

The second way is to transform the ellipse into a shape with two diameters. In this case, there are two diameters that the program will use to perform the bending. In this way, the ellipse is transformed into a shape suitable for “standard” circular bending, but with two different diameters.

This method is shown in the Fig. 3. In the Fig. 5 is obtained shape by entering radius and arc length into the machine software.

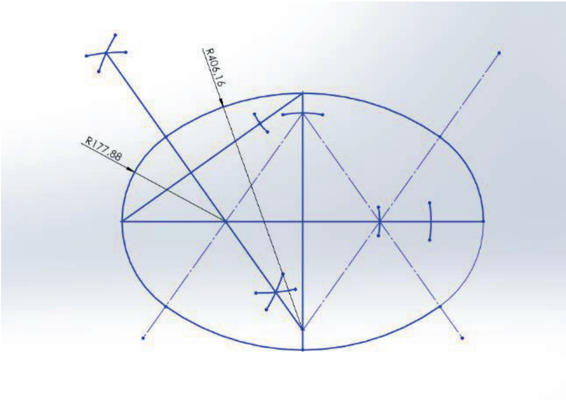

***Figure 3** Transformation of an ellipse to a shape with two diameters*

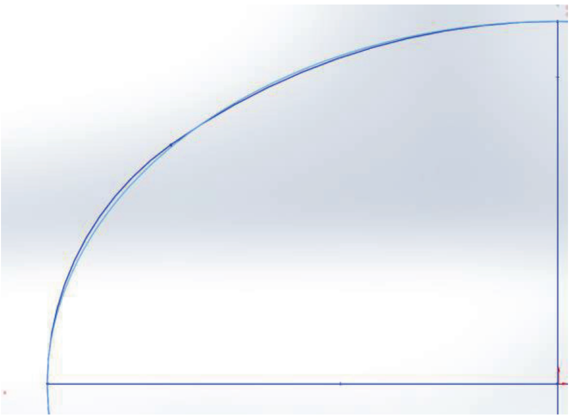

***Figure 4** Display of the deviation of the transformed ellipse from the original one*

***Figure 5** Example of entered parameters for ellipse transformation using two diameters*

3.3 Ellipse transformation using three diameters

The third method is similar to the second, but with one diameter more. Using the elliptical oval method, which is used in construction, mechanical engineering and engineering in general, an ellipse transformation was performed, which is now formed by three different diameters with three different centers. The input parameters for sheet metal bending are the three diameters and bending angles. This is solved in SolidWorks and entire solving method is shown in the Fig. 6. The values were entered into the machine software – Figure 7.

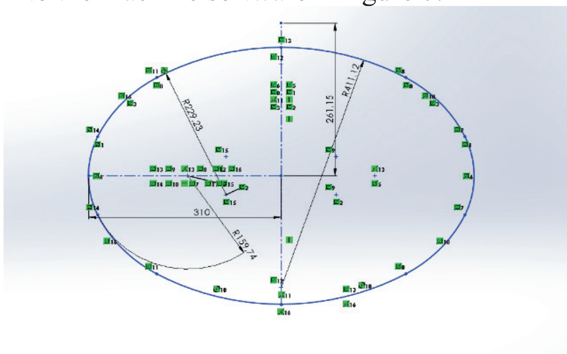

***Figure 6** Ellipse transformation in SolidWorks – 3 diameters*

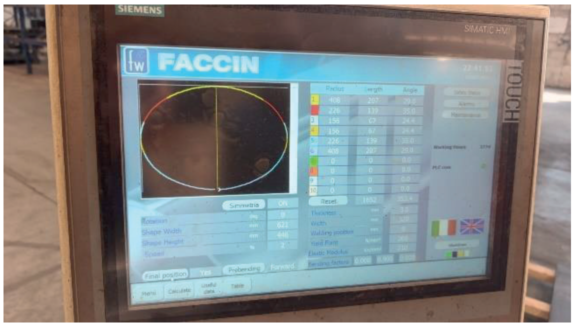

***Figure 7** Example of entering transformation parameters using three diameters*

4. ANALYTICAL CALCULATION

The K-factor is a dimensionless constant that is determined experimentally for each material, sheet thickness and type of bending. Its value usually ranges between 0,33 and 0,5, depending on the bending conditions. For sharp bend angles with a small radius-to-thickness (R/T) ratio, the neutral axis moves toward the inside of the bend, which reduces the K-factor. During bending, the inner surface of the workpiece is loaded in compression, and the outer surface in tension. The neutral line is a line along the workpiece that is not exposed to any of the mentioned loads during the bending process. For the correctness of the production process, it is necessary to calculate the K factor, which is directly related to the developed length of the processed element. [3]

K factor is obtained using mathematical expression [4]:

$$K = \frac{t}{R+t} \quad \ldots[1]$$

4.1 Analytical calculation of K factor for the arc length method

Since this method does not use bending angles and cannot be generated as for standard bending using diameters, the developed length and K factor cannot be related analytically, but rather using the program or experimentally. The K factor is predicted based on the mean of the two factors for given ellipse diameters. [5]

$$K_1 = \frac{t}{t+R_1} = \frac{3mm}{(3+310)mm} = 0{,}0095 \qquad \text{…[2]}$$

$$K_2 = \frac{t}{t+R_2} = \frac{3mm}{(3+220)mm} = 0{,}0134 \qquad \text{…[3]}$$

$$K = K_{sr=} \frac{K_1+K_2}{2} = 0{,}011 \qquad \text{…[4]}$$

4.2 Analytical calculation of K factor for the two-diameter ellipse transformation method

Analytical calculation of the K factor for the two-diameter ellipse transformation method needs to be done for each individual diameter of the part. [4]

$$K_1 = \frac{t}{t+R_1} = \frac{3mm}{(3+177{,}88)mm} = 0{,}016 \qquad \text{…[5]}$$

$$K_2 = \frac{t}{t+R_2} = \frac{3mm}{(3+406{,}16)mm} = 0{,}07 \qquad \text{…[6]}$$

$$K = K_{sr=} \frac{K_1+K_2}{2} = 0{,}04 \qquad \text{…[7]}$$

$$L_n = \theta_n \cdot (R_n + K_n \cdot t) \qquad \text{…[8]}$$

Calculation of developed length: [3]

$$L_1 = \theta_1 \cdot (R_1 + K_1 \cdot t) = 1{,}9073 \cdot (174{,}88 + 0{,}016 \cdot 3) = 333{,}64017\, mm \qquad \text{…[9]}$$

$$L_2 = \theta_2 \cdot (R_2 + K_2 \cdot t) = 1{,}234 \cdot (403{,}16 + 0{,}07 \cdot 3) = 497{,}75858\, mm \qquad \text{…[10]}$$

$$L_{uk} = L_1 \cdot 2 + L_2 \cdot 2 = 1662{,}7975\, mm \text{…[11]}$$

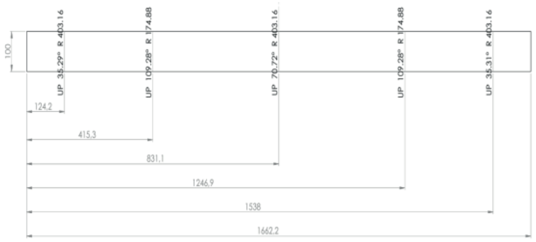

Figure 8 *2D drawing for bending - 2 diameters*

Fig. 8 shows the technological procedure – bending drawing with 2 diameters and in the Fig. 9 bending drawing with 3 diameters. According to the drawing, it can be concluded that the calculation of the developed length for the calculated K factor is correct.

4.3 Analytical calculation of K factor for the three-diameter ellipse transformation method

Since there are three diameters present, it is necessary to determine the K factor for each diameter individually. [4]

$$K_1 = \frac{t}{t+R_1} = \frac{3mm}{(3+156{,}74)mm} = 0{,}0187 \qquad \text{…[12]}$$

$$K_2 = \frac{t}{t+R_2} = \frac{3\, mm}{(3+223{,}23)mm} = 0{,}0133 \qquad \text{…[13]}$$

$$K_3 = \frac{t}{t+R_3} = \frac{3mm}{(3+408{,}12)mm} = 0{,}0073 \qquad \text{…[14]}$$

$$K = K_{sr=} \frac{K_1+K_2+K_3}{3} = 0{,}0131 \qquad \text{…[15]}$$

Calculation of developed length: [3]

$$L_n = \theta_n \cdot (R_n + K_n \cdot t) \qquad \text{…[16]}$$

$$L_1 = \theta_1 \cdot (R_1 + K_1 \cdot t) = 85{,}99 \cdot (159{,}74\, mm + 0{,}0187 \cdot 3\, mm) = 137{,}398 \text{ mm} \qquad \text{…[17]}$$

$$L_2 = \theta_2 \cdot (R_2 + K_2 \cdot t) = 61{,}52 \cdot (229{,}23\, mm + 0{,}0133 \cdot 3\, mm) = 139{,}207 \text{ mm} \qquad \text{…[18]}$$

$$L_3 = \theta_3 \cdot (R_3 + K_3 \cdot t) = 101{,}82 \cdot (411{,}12 + 0{,}0073 \cdot 3) = 415{,}387 \text{ mm} \qquad \text{…[19]}$$

$$L_{uk} = (137{,}398 + 139{,}207 * 2 + 415{,}387) \cdot 2 = 1662{,}398\, mm \qquad \text{…[20]}$$

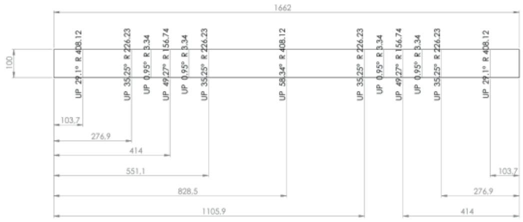

Figure 9 *2D drawing for bending - 3 diameters*

4.4 Analytical stress calculation

In the stress calculation, it is necessary to determine whether the part will be plastically deformed during bending processing, using relations [5]:

$$б = E \cdot \varepsilon = E \cdot \frac{Y}{R} \quad \ldots[21]$$

Y - distance of the most distant intersection point from the neutral axis
R – bending radius
E – modulus of elasticity is 210,000 MPa

$$б = E \cdot \varepsilon = E \cdot \frac{Y}{R} = 210\,000 \cdot \frac{2,94}{411,12} = 1501,7513\ MPa \quad \ldots[22]$$

Since the stress exceeds the yield stress value, the material is in the plastic region. During the analytical calculation, the smallest diameter is included in the analysis. To accurately determine the stress, it is necessary to use expressions that are characteristic of the area of plastic deformation [5]:

$$\sigma = \frac{M_p}{W_p} = \frac{7,93125\ Nm}{3,375 \cdot 10^{-8}\ m^3} \quad \ldots[23]$$

$$\sigma = 2,35 \cdot 10^8\ \frac{N}{m^2} = 235\ MPa \quad \ldots[24]$$

5. RESULTS AND DISCUSSION

For each of the above approaches, test bending was performed on 5 samples.

Table 1 Bending results using the arc length method

Exp. nr.	R1 (mm)	R2 (mm)
1	337	192
2	335	195
3	333	193
4	327	202
5	329	201

In the first bending cycle, it was determined whether the methods would give the required result and which method would have the results closest to the required ones. The bending results are listed in the tables shown below.

Table 2 Bending results using the two-diameter method

Exp. nr.	R1 (mm)	R2 (mm)
1	325	204,5
2	321	209
3	318	212
4	326	204
5	323	206,5

Table 3 Bending results using the three-diameter method – first test

Exp. nr.	R1 (mm)	R2 (mm)
1	315	215
2	312	218
3	317	213
4	312	218
5	315	215

With corrections during bending, manual adjustment of the angle, a program was created that meets the given conditions. In order to confirm the correctness of the program, an additional six samples were bent, on which the correctness of the method was confirmed.

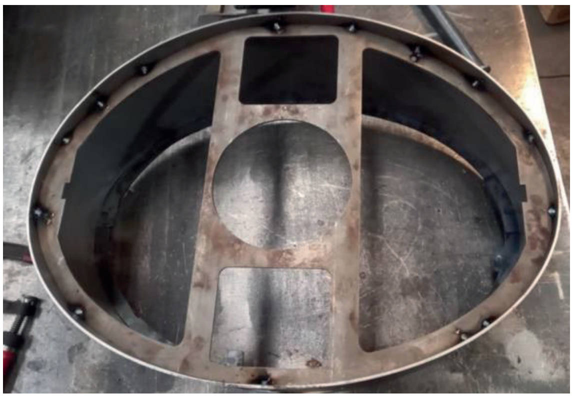

Figure 10 *The final shape obtained by the transformation method using three diameters*

Table 4 Results display for the three-diameter method - optimization and validation of results

Exp. nr.	R1 (mm)	R2 (mm)
1	311	219
2	310	220
3	310	220
4	310	220
5	310	220
6	310	220

6. CONCLUSION

Considering the results for each bending, it was concluded that bending using the arc length did not give desired shape.

The results in the first five samples did not lead to a solution, according to the Table 1. So this method gave negative results for optimization in order to improve the results and obtain the correct function. The results in the Table 2. for bending an ellipse using two diameters, unlike the first approach, gave a better solution, the shape is closer to the ellipse function, but desired results were still not achieved. The transition between the two diameters was overemphasized, and the part that should be connected was separated by up to 50 mm for each sample.

In addition to the above, at the very start when transforming the ellipse into two diameters, a deviation of 2 mm was visible at the Fig. 5, which caused the entire ellipse function to be incorrect. When bending the part using the third method, i.e. using the transformation with three diameters, in the first 5 bending samples it was concluded that the ellipse bent in this way has results that are closest to the required ones and that it is necessary to introduce certain corrections in order to obtain the correct results. The results of the first five samples for the three-diameter bending method are shown in Table 3. After introducing corrections to the resulting piece, in several bending samples, it was possible to achieve desired elliptical shape. The elliptical shape for the given parameters is achieved, and this is shown in Table 4.

After the shape is obtained, the internal stiffening of the part and the part are welded. The bending process was carried out by ThermoFLUX, as well as the calculation, preparation of documentation and measurement, which are presented in chapters 3, 4 and 5.

This paper does not present the calculation of the weld or its definition in a given case. This topic, as well as the stress distribution at the transition between two diameters, would be very useful for analysis, which will be done in one of the following scientific research papers.

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